Guest Editorial
Green Communications and Networking Series

Ender Ayanoglu, *Fellow, IEEE*

A SUBSTANTIAL amount of research exists in the area of energy efficiency in communications and networking. In recognition of this fact, the IEEE Communications Society has decided to publish a SERIES ON GREEN COMMUNICATIONS AND NETWORKING as three issues of the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS. The first issue of the Series was published in December 2015 with 39 papers. This second issue of the Series has 52 papers, covering a wide selection of topics. These topics can be characterized in five categories. The first category in this issue is cellular networks. There are 15 papers in this category.

The first paper by C.-H. Liu and L.-C. Wang introduces a green approach for small-cell networks and calculates the optimal cell load and throughput when cell associations of users are made in a generalized manner. X. Guo *et al.* propose a base station sleeping mode in an energy-optimal and delay-constrained manner. O. Arouk *et al.* consider machine-type communications in cellular networks. They provide energy savings based on group paging. S. Cai *et al.* study dynamic small-cell operation in heterogeneous networks and provide methods to increase energy efficiency in them. S. Zhang *et al.* also study green heterogeneous networks but provide energy savings by means of traffic offloading. The paper by X. Wang *et al.* discusses cloud-based radio access networks with optical access and provide energy efficiency via virtual base station formation. D. Li *et al.* study the backhaul problem in millimeter-wave cellular networks. They provide energy efficiency by means of decentralized and renewable energy pricing and allocation. J. Wu *et al.* describe an energy-efficient way of multipath video transport to mobile devices in heterogeneous networks. The paper by C. Jeong and W.-Y. Shin studies the capacity of large-scale hybrid networks with cost-effective infrastructure, called Greeninfra. In addition, the authors discuss the effects of their cost-reduction approach on energy efficiency. W. Nie *et al.* study user-centric and cross-tier base station clustering and co-operation in heterogeneous networks with the goals of increasing user rate and energy efficiency. Another study of cloud-based radio access networks is provided in the paper by Z. Zhao *et al.*, where the authors use cluster content caching for improving energy efficiency. Another content caching approach is provided in the paper by M. Gregori *et al.*, where the authors discuss their approach for small-cell and device-to-device networks. The delay-energy tradeoff in multicast scheduling is studied in the paper by C. Huang *et al.* to generate green cellular networks. P. Cao *et al.* advocate the use of group sparse power control for semidynamic resource management in downlink heterogeneous networks. The final paper in this category is by S. Samarakoon *et al.*, where the authors discuss turning density into energy efficiency by means of ultra-dense small-cell networks.

The second category consists of papers that propose various optimization, resource allocation, and scheduling algorithms. This category has 12 papers. V. Eramo *et al.* observe that virtual router migration allows for resource consolidation with the consequence to reduce the power consumption in low traffic periods. However, they note that the migration technique should be applied judiciously to avoid an excessive quality-of-service (QoS) degradation. The paper studies virtual network embedding problems aware of both operation and reconfiguration costs that are characterized by the energy consumption and the revenue loss due to QoS degradation. L. Xu and A. Nallanathan model an energy-efficient resource allocation problem as a chance-constrained programming for multicast cognitive orthogonal frequency division multiplexing (OFDM) networks. The resource allocation is subject to constraints in service quality requirements, total power constraint, and probabilistic interference. The paper by R. Deng *et al.* studies the network utility maximization problem in static-routing rechargeable sensor networks with the link and battery capacity constraints. For this, the authors decouple the original problem equivalently into separable subproblems by means of dual decomposition and propose a distributed algorithm in the context of joint rate and battery control, which can converge to the globally optimal solution. L. Zhang *et al.* investigate energy efficiency in cognitive radio networks, where cognitive users are allowed to access a licensed frequency band opportunistically, provided that the licensed band is vacant. Specifically, they study the impact of imperfect spectrum sensing and formulate the energy efficiency maximization problem as a joint optimization problem of the spectrum sensing duration and the transmit power of the cognitive users. The paper by M. Costa and A. Ephremides discusses performance tradeoffs related to energy efficiency in cognitive networks, providing results on the relationship of system parameters. A noncooperative model is analyzed and tradeoffs among system parameters are studied. The authors also propose a cooperative model and again study tradeoffs among system parameters. The paper by X. Wang *et al.* studies dynamic energy management for smart-grid powered coordinated multipoint transmissions. With the goal of minimizing the expected energy transaction cost while guaranteeing the QoS of the worst-case users, an

This work was partially supported by the NSF under Grant 1307551.

The author is with the Center for Pervasive Communications and Computing, Department of Electrical Engineering and Computer Science, University of California, Irvine, Irvine, CA, USA (e-mail: ayanoglu@uci.edu).

Digital Object Identifier 10.1109/JSAC.2016.2551620

infinite-horizon optimization problem is formulated to obtain the optimal downlink transmit beamformers that are robust to channel uncertainties. Z. Asad *et al.* study big data applications that put pressure on data center networks. This paper proposes use of the mixing technique, spate coding, working in tandem with software-defined network control as a means of dynamically controlled reduction in volume of communication. V. Hatzi *et al.* introduce the problem of green Web crawling from a set of remote Web servers, where the goal is to reduce the carbon footprint incurred by a large-scale Web crawler. They devise a page refresh policy that minimizes the total staleness of pages subject to a constraint on the amount of carbon emissions due to Web page processing and download at the distant servers. The paper by R. Atawia *et al.* makes the observation that predictive resource allocation techniques that exploit knowledge of the future signal strength along roads can be promising approaches to save base station energy and improve user QoS. This paper addresses energy-efficient predictive resource allocation applied to stored video streaming using chance-constrained programming. The proposed framework achieves the desired QoS level under imperfect channel predictions without compromising the energy efficiency compared to opportunistic schedulers. I. A. Ouédraogo and E. Oki present an algorithm for networks with traffic uncertainty. Simulation results show that their approach, while being robust to traffic uncertainty, achieves energy efficiency comparable to the models where the knowledge of the traffic information is required. M. Mahzoon *et al.* consider the problem of communicating data from energy-constrained distributed sensors. To reduce energy requirements, the authors focus on the problem where the recipient wants to perform supervised learning and classification on the data received from the sensors. The authors study supervised learning and classification under total energy limitations. The paper by K. Xiong *et al.* investigates energy efficiency in a multiple relay-aided OFDM system, where decode-and-forward relay beamforming is employed to help information transmission. The authors state simulation results demonstrate the effectiveness of the algorithm they developed.

The active topic of energy harvesting makes up the third category with 12 papers. The paper by Z. Chen *et al.* studies a two-way relay network with three nodes and discusses the performance optimization of digital network coding and physical network coding schemes under the energy harvesting constraints and peak power constraints. It also considers the energy transfer between nodes, which is referred to as energy cooperation. S. Avallone and A. Banchs develop a channel assignment and routing algorithm for energy harvesting multiradio wireless mesh networks. The authors assume mesh nodes operate by harvesting ambient energy and hence they can count on a limited and time-varying amount of power to accomplish their functions. The problem addressed is a joint channel assignment and routing problem with additional constraints on the node power consumption. A. Ibrahim *et al.* analyze the stability of slotted Aloha with opportunistic RF energy harvesting by utilizing the ambient RF energy, particularly interference from neighboring transmissions, to replenish the batteries of the energy harvesting enabled nodes. A. Sunny and J. Kuri propose a unified framework that can be leveraged to efficiently design and deploy large-scale multihop energy harvesting sensor networks. A. Biason *et al.* investigate the achievable secrecy rates in an energy harvesting communication system composed of a transmitter, a receiver, and a malicious eavesdropper. The authors show that high secrecy rates can be obtained only with power and coding rate adaptation. The paper by X. Lu *et al.* adopts a stochastic geometry framework based on the Ginibre model to analyze the performance of self-sustainable communications over cellular networks with general fading channels. The paper by E. A. Kadir is on the development of hardware for energy harvesting. Specifically, it presents a new approach of designing an indoor Wi-Fi energy harvester with a bridgeless converter that operates at low incident power. B. Varan and A. Yener study energy harvesting networks with limited energy and data storage as well as delay constraints in the single user channel, the two-way channel, and the two-way relay channel with block fading. Z. Wang *et al.* develop energy-bandwidth allocation algorithms in fading channels for multiple energy harvesting transmitters. J. Yang *et al.* study the optimal sensing scheduling problem for an energy harvesting sensor. The objective is to strategically select the sensing time such that the long-term time-average sensing performance is optimized. A. Ibrahim *et al.* consider a distributed storage system where data storage nodes are equipped with energy harvesting transmitters. The main operations of the distributed storage system are serving the file requests of data collectors and, additionally, repairing the content of storage nodes that fail or leave the system. B. Gurakan and S. Ulukus consider the energy harvesting diamond channel, where the source and two relays harvest energy from nature and the physical layer is modeled as a concatenation of a broadcast and a multiple access channel. The authors use a dual decomposition method to solve the overall problem efficiently.

Nine papers constitute the category of networking and protocols, our fourth category. The paper by G. Sankaran and K. M. Svalingam concentrates on traffic grooming for data centers using energy-efficient optical and hybrid optical systems instead of packet switching. The authors state their algorithm achieves any-to-any route reachability without using fast optical switches with substantially reduced power requirements as compared to competitive techniques. K. Ohsugi *et al.* discuss an energy-efficient way of achieving caching in named data network routers. The prefix-matching and per-packet caching employed by named data networking are known to consume large amounts of energy. The authors develop a power consumption model and provide an analysis for improved energy efficiency in software routers. D. P. Van *et al.* concentrate on sensor-enhanced fiber-wireless access networks. They design an energy efficiency scheme for such networks and to understand its performance, they analyze and emulate its operation in hardware. M. Abdelhakim and T. Li concentrate on a wireless sensor network with cooperation by mobiles and develop an energy-efficient scheme for real-time transmissions. Bolla *et al.* investigate the idea of proxying network connectivity to maintain network presence on behalf of idle devices, so that they can "sleep." Their paper provides and analysis which covers a broad range of alternatives, taking into consideration both implementations already available in the market and prototypes built for

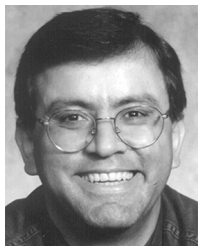
research purposes. R. Sanchez-Iborra and M.-D. Cano observe multimedia services require energy efficiency in addition to other requirements due to limited battery time. The paper introduces an opportunistic routing protocol, JOKER, which is intended to increase the performance of the network supporting multimedia traffic as well as enhancing the energy efficiency of the nodes. The paper by H. Moon introduces channel-adaptive random access to reduce the required transmission power for random access in wireless systems based on time division duplex. With channel-adaptive random access, transmission of a random access packet is delayed until the channel satisfies the transmission condition. The paper proposes a discontinuous channel measurement scheme for channel-adaptive random access to reduce the power consumption. B. Zhou *et al.* observe the increased energy consumption in wired networks and target the network-wide energy-saving problem by leveraging speed scaling as the energy-saving strategy. They propose a distributed routing scheme, HDEER, to improve network energy efficiency in a distributed manner without significantly compromising traffic delay. F. Jalali *et al.* study tiny computers located in end-user premises as local servers for Internet-of-Things and fog computing services, called nano servers. To study energy consumption of nano servers, the authors propose and use flow-based and time-based energy consumption models for shared and unshared network equipment. The authors show that nano servers in fog computing can complement centralized data centers to serve certain applications, and lead to energy saving.

The fifth category is on the new and active concept of wireless energy transfer. There are four papers in this category. The authors of the first paper Q. Liu *et al.* propose and experimentally evaluate two protocols for the control plane of the static charger/mobile receiver wireless power transfer networks (WPTN) to optimize the charger workflow and make the WPTN reduce the idle time of its transmitters. C. You *et al.* propose a mobile cloud system powered by wireless energy transfer. In this system, a set of policies are employed to have the mobile unit efficiently transmit its data by being powered with wireless transmission from the base station. S. Timotheou *et al.* discuss a multi-input single-output downlink system by exploiting the constructive interference at the receiver for both information and energy transfer. This is achieved under the constraints of user QoS and energy transfer constraints. The final paper in the category by Z. Wang *et al.* discusses a large-scale distributed sensor network. The energy transfer is achieved by adaptively changing the directionality or the radius of the transmission when some sensor nodes are inactive. They show that the use of this scheme results in more efficient energy transfer as compared to the nonadaptive case.

The papers submitted to the JSAC SERIES ON GREEN COMMUNICATIONS AND NETWORKING are handled by an Editorial Board. At the time of this writing, the Editorial Board consists of the following highly capable and hard-working individuals, listed in alphabetical order. I would like to offer my strongest appreciation and thanks to them and to hundreds of anonymous, as much capable and hard-working, reviewers for putting together this first issue and the upcoming issues, on behalf of our community.

Editorial Board: Albert Banchs (Universidad Carlos III de Madrid), Emil Bjornson (Linkoping University), Roberto Bruschi (University of Genoa), Claude Chaudet (Telecom ParisTech), Shuguang Cui (Texas A&M University), Jaafar Elmirghani (University of Leeds), Fabrizio Granelli (University of Trento), Pulkit Grover (Carnegie Mellon University), Deniz Gunduz (Imperial College London), M. Cenk Gursoy (Syracuse University), Kaibin Huang (University of Hong Kong), Daniel Kilper (University of Arizona), Bhaskar Krishnamachari (University of Southern California), Victor Leung (University of British Columbia), Vincenzo Mancuso (IMDEA), Michela Meo (Politecnico di Torino), Paolo Monti (KTH), Zhisheng Niu (Tsinghua University), Raghu Raghavendra (University of Southern California), Dario Rossi (Telecom ParisTech), Luca Sanguinetti (University of Pisa), Nirmala Shenoy (Rochester Institute of Technology), Himal Suraweera (University of Peradeniya), Antonia Tulino (Bell Labs), Sennur Ulukus (University of Maryland), Rahul Vaze (TIFR Mumbai), Jinsong Wu (Universidad de Chile), Guanding Yu (Zhejiang University), Richard Yu (Carleton University), Rui Zhang (National University of Singapore).

I would also like to thank Ting Qiang, Tammy Hung, and Laurel Greenidge with the IEEE Communications Society, and Lauren Briede and Sharon T. Nutter with IEEE Publishing Operations.



Ender Ayanoglu (S'82–M'85–SM'90–F'98) received the Ph.D. degree in electrical engineering from Stanford University, Stanford, CA, USA, in 1986. He was with the Communications Systems Research Laboratory, Holmdel, NJ, USA, part of AT&T Bell Laboratories until 1996, and Bell Laboratories, Lucent Technologies from 1996 to 1999. From 1999 to 2002, he was a Systems Architect with Cisco Systems, Inc., San Jose, CA, USA. Since 2002, he has been a Professor with the Department of Electrical Engineering and Computer Science, University of California, Irvine, Irvine, CA, USA, where he served as the Director of the Center for Pervasive Communications and Computing and held the Conexant-Broadcom Endowed Chair from 2002 to 2010.

His past accomplishments include invention of the 56K modems, characterization of wavelength conversion gain in wavelength division multiplexed systems, and diversity coding. From 2000 to 2001, he served as the Founding Chair of the IEEE-ISTO Broadband Wireless Internet Forum, an industry standards organization.

From 1993 to 2014, he was an Editor, and since January 2014, has been a Senior Editor of the IEEE TRANSACTIONS ON COMMUNICATIONS. He served as the Editor-in-Chief of the IEEE TRANSACTIONS ON COMMUNICATIONS from 2004 to 2008. As of December 2014, he is serving as the Editor-in-Chief of IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS—SERIES ON GREEN COMMUNICATIONS AND NETWORKING. From 1990 to 2002, he served on the Executive Committee of the IEEE Communications Society Communication Theory Committee, and from 1999 to 2002, was its Chair.

Dr. Ayanoglu was the recipient of the IEEE Communications Society Stephen O. Rice Prize Paper Award in 1995 and the IEEE Communications Society Best Tutorial Paper Award in 1997. He was also the recipient of the IEEE Communications Society Communication Theory Technical Committee Outstanding Service Award in 2014.