IEEE JOURNAL ON
**SELECTED AREAS IN COMMUNICATIONS**

IEEE Xplore® Digital Library
http://ieeexplore.ieee.org/Xplore

# 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 (SGCN) as three issues of the IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS (JSAC). The first issue of JSAC SGCN was published in December 2015 with 39 papers. The second issue was published in May 2016 with 52 papers. This third and last issue has a total of 71 papers, covering a wide selection of topics. These topics can be characterized in six categories, with one subcategory appearing in one of the six main categories.

The first category in this issue is energy efficiency in wireless communications and networking. There are 15 papers in this category. The first paper by Cheng *et al.* concentrates on Fifth Generation (5G) cellular networks and proposes an optimization approach based on statistical Quality-of-Service (QoS). Zarakovitis *et al.* consider the nonideal case of imperfect Channel State Information (CSI) and data outage and present an energy-efficient system proposal. Che *et al.* jointly design the optimal Base Station (BS) on/off operation policy and the on-grid energy purchase policy from a network-level perspective in a large-scale network. Souza *et al.* consider the uplink connection in Orthogonal Frequency Division Multiple Access (OFDMA) networks and describe power and subcarrier allocation strategies for energy efficiency. Zhao and Wang study a Cloud Radio Access Network (C-RAN) and attempt to achieve a power consumption tradeoff between the transport network and the Remote Radio Heads (RRHs). They formulate an RRH selection problem, which takes the traffic density of the service area into consideration and falls into a generalized form of classical capacitated facility location problem. The optimization task is to select a subset of the RRHs to minimize the total power consumption of the C-RAN while satisfying a series of network constraints, including power and bandwidth budgets, traffic demand, and spectral efficiency requirement. To that end, they develop an efficient local search algorithm. Yan *et al.* compare energy consumption of conventional mobile services against those of newer and popular services such as instant messaging. Kim and Wentzloff study ultra low-power (ULP) devices and propose the concept of embedded back-channel communication through Orthogonal Frequency Division Multiplexing (OFDM) frames. Even if the ULP devices are incapable of demodulating OFDM, they can decode the embedded messages. Liu considers secondary users in cooperative cognitive radio networks and develops an energy-efficient strategy for them. Yang *et al.* study the recently popular concept of Device-to-Device (D2D) communications and develop an energy-efficient power control strategy for them. The authors investigate the energy-efficient power control for D2D communications underlaying cellular networks, where uplink resource blocks allocated to one cellular user equipment are reused by multiple D2D pairs and co-channel interference caused by resource sharing becomes a significant challenge. Due to the unaffordable complexity of the global optimal solution, the authors propose suboptimal schemes through adding constraints on the interferences to convert the non-concave problems into concave ones and to give sub-optimal solutions with reasonable complexity. Simulation results are presented to demonstrate the effectiveness of the proposed schemes. Ortin *et al.* study IEEE 802.11 wireless local area networks and develop resource-on-demand schemes for them for energy efficiency. Five papers in this category concentrate on small cells or heterogeneous networks. The first paper in this subcategory is by Sun *et al.* It concentrates on time division duplex and studies energy efficiency through traffic adaptation in small cell networks. Wu *et al.* concentrate on unlicensed spectra and propose a secrecy-based approach for data offloading for energy efficiency. Liu and Fong investigate coverage probability, link and network energy efficiencies in the downlink of a heterogeneous cellular network consisting of $K$ independent Poisson point processes of BSs. They propose a simple and feasible energy-efficient channel-aware cell association scheme, together with the maximum received power association and nearest base station association schemes. Gabry *et al.* consider edge-caching in heterogeneous networks from an energy efficiency point of view. Finally, Kashef *et al.* introduce dynamic planning which has been used by network operators for energy saving by switching BSs on-off according to the traffic load conditions while providing QoS guarantees for mobile users.

The second category is optimization and resource allocation for energy efficiency. There are 13 papers in this category. The first paper in this category is by Guan *et al.* It introduces sleep scheduling for communication networks based on cooperation between the network and the users. In order to accomplish this, the authors exploit the selfishness of both users and the network to cooperatively schedule the idle links and nodes into sleep to save energy. The paper by Luo *et al.* considers green cognitive communications and develops an integrated spectrum and information market for it. Li *et al.* consider a joint optimization problem with the

The author is with the Center for Pervasive Communications and Computing, Department of Electrical Engineering and Computer Science, University of California, Irvine. This work is partially supported by NSF under Grant No. 1307551.

Digital Object Identifier: 10.1109/JSAC.2016.2626106

simultaneous satisfaction of four objectives: BS operation, user association, subcarrier assignment, and power allocation. Wang *et al.* discuss dynamic resource allocation for smart-grid powered Multi-Input Multi-Output (MIMO) downlink transmissions. Wei investigates multiuser full-duplex decode-and-forward indoor relay systems at 60 GHz and proposes a cross-layer resource allocation algorithm for energy efficiency. Bi and Zhang discuss distributed charging control in broadband wireless power transfer networks. Wu proposes an energy-efficient small cell operation algorithm with spectrum-power trading. Lahoud *et al.* examine energy-efficient joint scheduling and power control in multi-cell wireless networks. Li and Zang study energy-efficient communications in wireless body area networks and introduce an accelerometer-assisted transmission power control solution for them. Chang *et al.* investigate collaborative mobile clouds which are enabled by wireless power transfer and develop an energy-efficient resource allocation algorithm for them. Zappone *et al.* introduce a distributed resource allocation algorithm for energy efficiency in MIMO OFDMA wireless networks. This work deals with the problem of distributed resource allocation in MIMO multi-carrier multiple-access channel networks. The assignment between users and subcarriers is allocated together with the transmit powers of the users for energy efficiency maximization, by means of an approach which merges the popular Dinkelbach's algorithm within the framework of distributed auction theory and stable matching. Employing this new model, it is shown that the proposed distributed algorithms can even outperform centralized resource allocations which require a larger feedback energy consumption. Ozcan *et al.* describe an energy-efficient power allocation technique for cognitive radio systems in the case of imperfect spectrum sensing. Finally, Yigitel *et al.* present an urban case study for dynamic BS topology management for energy efficiency in heterogeneous networks. In particular, the authors derive a pico BS deployment methodology on top of the existing network infrastructure to accommodate peak traffic conditions and propose an offline-centralized and an online-distributed dynamic BS operation algorithm for power savings.

The third category is energy harvesting and wireless power transfer, two subjects that have become very active research topics. This is evidenced by the fact that we have 23 papers in this category. The first paper in the category is by Fong *et al.* It calculates achievable rates for the save-and-transmit option in energy harvesting. Ahmed *et al.* investigate optimal stochastic power control for energy harvesting systems with delay constraints. Zou *et al.* study energy harvesting with limited energy arrival knowledge not at the baseband but at radio frequencies (RF). Fong and Tan consider binary-input energy-harvesting channels and evaluate the scaling exponent when polar codes are used with them. Zhang *et al.* study energy-harvesting cognitive radio sensor networks and develop a utility-optimal resource management and allocation algorithm for them. Zhu and Huang examine the near-far problem in communication with wireless power and introduce analog spatial cancellation to attack it. They consider a scenario where ultra-dense small-cell BSs are deployed and simultaneous-wireless-information-and-power-transfer (SWIPT) is feasible over short ranges. They address the challenge for designing a wireless powered communication system which is manifested by the severe near-far problem where a user attempts to decode an information-transfer signal in the presence of extremely strong SWIPT signals. They design a framework for analog spatial cancellation in a multi-antenna system. Sunny investigates joint scheduling and sensing allocation in energy-harvesting sensor networks with fusion centers. Mao *et al.* discuss the case of dynamic computation offloading for mobile edge computing in the case of energy-harvesting devices. Margolies *et al.* examine a neighbor discovery algorithm for energy-harvesting devices. Shaviv and Ozgur introduce a universally near-optimal online power control technique for energy-harvesting nodes. The authors propose a simple online power control policy that requires minimal information regarding the distribution of the energy arrivals and prove that it is universally near-optimal for all parameter values. In particular, the policy depends on the distribution of the energy arrival process only through its mean and it achieves the optimal long-term average throughput of the channel within both constant additive and multiplicative gaps. This result also enables approximation of the long-term average throughput of the system with a simple formula, which sheds some light on the qualitative behavior of the throughput, namely how it depends on the distribution of the energy arrivals and the size of the battery. Tang *et al.* investigate wireless information and energy transfer in fading relay channels. Sharma and Murthy evaluate packet drop probability for dual energy-harvesting links in the case of possibility of retransmission. Deshmukh and Vaze study the case of both energy harvesting and no energy harvesting for online energy-efficient packet scheduling with a common deadline. In this problem, the total number of packets arriving within the deadline is known, but the packet arrival times are unknown, and can be arbitrary. The proposed algorithm tries to finish the transmission of each packet assuming all future packets are going to arrive at equal time intervals within the leftover time. The proposed algorithm is shown to be competitive in that it is logarithmic in the number of packet arrivals. Benkhelifa *et al.* examine the multiuser MIMO decode-and-forward relay broadcasting channel with energy-harvesting relays and propose a method for sum-rate enhancement with it. Calvo-Fullana *et al.* develop sensor selection and power allocation strategies for energy-harvesting wireless sensor networks. The authors investigate the problem of jointly selecting a predefined number of energy-harvesting sensors and computing the optimal power allocation. Their goal is to minimize the reconstruction distortion at the fusion center. This optimization problem is non-convex. The authors propose two suboptimal strategies. Performance is assessed by means of computer simulations. Baknina and Ulukus consider energy-harvesting broadcast channels and propose optimal and near-optimal online power scheduling strategies for them. The authors consider an energy-harvesting broadcast channel where a transmitter powered by energy harvested from the environment serves data to two receivers on the downlink. They focus on online transmission schemes where the transmitter knows the energy arrivals only causally as they happen. The authors show that their proposed policy is near-optimal in that it yields rates

that are within a constant gap from the developed upper bound, and therefore, from the actual capacity region, for all system parameters. Chen *et al.* investigate energy-harvesting small-cell networks with massive MIMO and develop an energy-efficient full-duplex self-backhaul system for them. Miridakis *et al.* develop opportunistic switching techniques between data transmission and energy harvesting in cognitive relaying under energy efficiency considerations. Rezaee *et al.* study energy-harvesting systems with continuous energy and data arrivals and suggest optimal offline and heuristic online algorithms. Qian *et al.* introduce optimal transmission policies for relay communication networks with ambient energy-harvesting relays. Kong *et al.* employ the Ginibre point process model for an exact performance analysis of ambient RF energy-harvesting wireless sensor networks. Wang *et al.* discuss energy harvesting to aid a super Wi-Fi network relying on solar activity, in particular its network association strategies. The last paper in this category is by Dong *et al.* which discusses a distance-and-energy-aware routing algorithm with energy reservation for energy-harvesting wireless sensor networks.

The fourth category is energy-efficient networking and protocols. There are six papers in this category. The first paper in the category is by Song *et al.* It studies a router with traffic-aware properties for energy efficiency. Han *et al.* study a multiple-access scheme called Orthogonal Power Division Multiplexing from a green networking viewpoint. The authors propose a power division multiplexing scheme, analogous to the time division multiplexing and frequency division multiplexing. They show that their proposed scheme not only has low computational complexity but also has better energy efficiency than the conventional protocols. Sivaraman *et al.* describe a method to make router line cards energy-efficient by means of dynamic management of packet memory. This work studies the role of packet buffer memory on the power consumption of backbone routers. This study shows the feasibility of, and energy savings from, dynamic management of packet buffer memory in core routers. Shen *et al.* propose a non-stochastic online learning approach without any assumption on the statistical behavior of the small BS activities. Yang *et al.* study energy efficient routing in satellite networks. Finally, Pu *et al.* propose D2D Fogging, a novel mobile task offloading framework based on network-assisted D2D collaboration, where mobile users can dynamically and beneficially share the computation and communication resources among each other. The purpose of this framework is to achieve energy-efficient task executions for network-wide users. To that end, the authors propose an optimization problem formulation that aims to minimize the time-average energy consumption for task executions of all users, meanwhile taking into account the incentive constraints of preventing the over-exploiting and free-riding behaviors that may harm the user's motivation for collaboration. Simulation results demonstrate that the proposed online algorithm not only achieves superior performance (i.e., it reduces 30%-40% energy consumption compared with user local execution), but also adapts to various situations in terms of task type, user amount, and task frequency.

In the fifth category of devices for energy efficiency and green optical communications, we have two papers. The first one is by Liu *et al.* and is on a power amplifier linearization technique with limited analog-to-digital dynamic range. The authors propose a digital predistortion technique to compensate for the power amplifier nonlinearity with limited analog-to-digital converter dynamic range. By accurately estimating the loop delay and attenuation of the cancellation chain, the baseband replica of the RF cancelling signal is recovered, and the original power amplifier output signal is rebuilt to estimate the digital predistortion coefficients. The experiments show significant gains against similar results from the literature. The second paper is by Natalino *et al.* and has to do with green optical backbone networks. The paper targets the lifetime-aware management of a set of optical line amplifiers in an optical network exploiting sleep mode in order to save energy. The authors first present a simple model to predict the optical line amplifier lifetime. They then provide different mixed integer linear programming formulations which jointly consider energy saving and lifetime. The proposed approaches can achieve a good lifetime performance without consuming significantly more energy than purely energy-aware strategies.

Our sixth and final category is energy efficiency in data storage and sensors, including smart grid applications. We have 12 papers in this category. The first paper in this category is by Anastasopoulos *et al.* It has to do with deploying renewable energy sources for an energy-efficient cloud service. The authors propose a service provisioning scheme based on stochastic linear programming. Based on measurements from the National Solar Radiation Data Base, traffic statistics from the Internet2 measurement archive, and experimentations with real network configurations, the authors show that the proposed scheme is stable and achieves fast convergence to the optimal solution, while at the same time reduces the overall $CO_2$ emissions by up to 60% for different levels of demand requests. Tran *et al.* propose an incentive mechanism for economic demand-response in colocated datacenters. Rana *et al.* study renewable generations in smart grids and propose a dynamic state estimation technique. Chen *et al.* consider Internet-of-Things (IoT) sensor nodes employing millimeter waves and study energy-autonomous wireless communication for them. Sun *et al.* study colocation demand response and propose joint online mechanisms for individual utility and social welfare maximization. The main proposal of the authors is an incentive auction that provides tenants monetary remuneration for emergency demand response energy reduction, minimizing social cost, which combines with an online primal-dual framework for each tenant to schedule their delay-tolerant workloads. The online optimization at each tenant targets its utility maximization, concurrently reporting valuation functions for the tenant to participate in the auction. The authors validate the efficiency of their algorithms through theoretical analysis and trace-driven simulations. Zhou *et al.* study bilateral electricity trade between smart grids and green datacenters and introduce new pricing models and performance evaluation. Fu *et al.* study processor-sharing server farms and propose an asymptotically optimal job assignment for energy efficiency for them. Specifically, the authors study the problem of job assignment in a large-scale realistically-dimensioned server farm comprising multiple processor-sharing servers

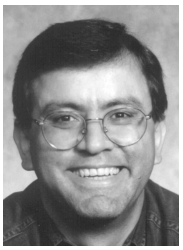
with different service rates, energy consumption rates, and buffer sizes. Their aim is to optimize the energy efficiency of such a server farm by effectively controlling carried load on networked servers. To this end, the authors propose a job assignment policy which is both scalable and near optimal. Through numerical simulations, the authors demonstrate the effectiveness of their proposed policy and its robustness to different job-size distributions, and observe that significant improvement in energy efficiency can be achieved by using the knowledge of power consumption of idle servers. Wu *et al.* propose a novel physical layer scheme that achieves simultaneous transmission and air computation in wireless data center networks. With the proposed scheme, multiple sources transmit in the same time slot with appropriately chosen parameters, such that the superimposed signal can be directly transformed to the desired summation at the receiver. The authors state theoretical analysis and simulation results show that their scheme can significantly improve both bandwidth and energy efficiency. Peng *et al.* study large-scale wireless sensor networks and propose an energy-efficient and robust implementation. The authors propose two self-organizing schemes for large-scale wireless sensor networks. Both schemes generate clustering-based and scale-free-inspired large-scale wireless sensor networks, which are energy-efficient and robust. Wu *et al.* investigate participatory sensing systems and propose an energy-efficient transmission technique for them. Guo *et al.* consider C-RANs and suggest the use of hybrid clustering and computation provisioning for energy efficiency. Finally, Barcelo *et al.* propose a service optimization technique for IoT-Cloud combination. The authors formulate the service distribution problem in IoT-Cloud networks as a minimum cost mixed-cast flow problem that can be efficiently solved via linear programming. The results show that with the right optimization tools, the flexibility of IoT-Cloud networks can be exploited to efficiently deliver a wide range of IoT services in the context of next-generation smart environments, while significantly reducing overall power consumption.

The three issues of JSAC SGCN were intended as an incubator for a new journal covering the same subject area. Based on the success of these issues, the IEEE Communications Society decided to complete its submission to IEEE for this new journal. These decisions are made by the Periodicals Committee of the IEEE Technical Activities Board (TAB). This committee convened in June 2016 to discuss several proposals made by a number of IEEE societies for new journals and magazines, including our proposal for the IEEE TRANSACTIONS ON GREEN COMMUNICATIONS AND NETWORKING. I am very glad to report that after our presentation, a closed session discussion, and an open vote, TAB granted our request. IEEE TRANSACTIONS ON GREEN COMMUNICATIONS AND NETWORKING is a quarterly online-only journal whose first issue is scheduled to be published March 2017. The new journal has the Web site `www.comsoc.org/tgcn` and paper submissions can be made using `mc.manuscriptcentral.com/tgcn`. It is cosponsored by the IEEE Communications, Signal Processing, and Vehicular Technology Societies.

The papers submitted to the JSAC SGCN were reviewed by an Editorial Board. At the time of this writing, the Editorial Board consisted of the following highly capable and hard-working individuals, listed in alphabetical order. I would like offer my strongest appreciation and thanks to them and to hundreds of anonymous, as much capable and hard-working, reviewers for putting together this Series, 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), 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), Luca Sanguinetti (University of Pisa), Himal Suraweera (University of Peradeniya), 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 his Ph.D. degree from Stanford University, Stanford, CA in 1986 in electrical engineering. He was with the Communications Systems Research Laboratory, Holmdel, NJ, part of AT&T Bell Laboratories until 1996, and Bell Laboratories, Lucent Technologies from 1996 until 1999. During 1999-2002, he was a Systems Architect at Cisco Systems, Inc., San Jose, CA. Since 2002, he has been a Professor in the Department of Electrical Engineering and Computer Science, University of California, Irvine, Irvine, CA, where he served as the Director of the Center for Pervasive Communications and Computing and held the Conexant-Broadcom Endowed Chair during 2002-2010.

His past accomplishments include invention of the 56K modems, characterization of wavelength conversion gain in wavelength division multiplexed systems, and diversity coding. During 2000-2001, Dr. Ayanoglu served as the founding chair of the IEEE-ISTO Broadband Wireless Internet Forum, an industry standards organization.

From 1990 to 2002, Dr. Ayanoglu served on the Executive Committee of the IEEE Communications Society Communication Theory Committee, and from 1999 to 2002, was its Chair. From 1993 until 2014 he was an Editor, and since January 2014 is 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. He served as the Editor-in-Chief of IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS – SERIES ON GREEN COMMUNICATIONS AND NETWORKING from December 2014 to December 2016. Since June 2016, he is serving as the founding Editor-in-Chief of IEEE TRANSACTIONS ON GREEN COMMUNICATIONS AND NETWORKING.

Dr. Ayanoglu is 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 received the IEEE Communications Society Communication Theory Technical Committee Outstanding Service Award in 2014.