Guest Editorial Special Issue on Selected Papers From IEEE Globecom 2020

ENERGY consumption in communication systems and networks has been a critical problem for network operators and equipment vendors, particularly since the past decade when energy price has been increasing. Many researchers began investigating this problem and made substantial scientific contributions to reduce energy consumption or to improve energy efficiency in communication networks. Noticing this trend, the Green Communication Systems and Network track was first launched in *IEEE Globecom* 2011 within the Selected Areas in Communications Symposium, and became its own symposium since *IEEE Globecom* 2016.

Over the years numerous high-quality papers were published in these tracks and symposiums (as well as those in the *IEEE ICC* counterparts). Many of them were subsequently extended and published as a journal article. In order to speed up the dissemination process and enhance the scientific impact, this special issue invited authors from accepted papers in this symposium of *IEEE Globecom* 2020 to extend their work for a fast-tracked review process and publication route. In addition, accepted papers relating to green communication and networking from other symposiums were also invited. Out of the invited 51 papers, there were 26 submissions, with 14 high quality papers accepted after vigorous peer review. These papers are grouped into three categories and their contributions are summarized in the following.

Green Communication Networks: Enhancing energy efficiency or minimizing energy consumption of a communication network is fundamental to green communication research. In [A1], Javad-Kalbasi and Valaee investigated the user association problem in small cell networks that employs millimeter wave backhauls to maximize energy efficiency. They proposed centralized and distributed user association algorithms that meet certain spectral efficiency targets, and show that the proposed algorithms achieve higher energy efficiency comparing to existing schemes.

From operators' perspective, the key driver for energy efficiency in their networks is to maximize revenue while maintaining a certain quality of service. Balakrishnan *et al.* investigated a revenue maximization problem in [A2]. The considered cellular network is powered by both solar and power-grid, and the proposed cooperative coverage adjustment model dynamically adjusts the coverage area based on traffic load and energy availability. Simulation results show that the proposed method increases the revenue gain and traffic skewness.

Future networks will have higher capability but also higher complexity in terms of topology and operation. Machine learning is highly promising for these networks, and particularly decentralized learning can guarantee data security. In [A3], Kuo *et al.* studied the use of decentralized learning for edge computing, and proposed the Green Transmission Power Level Allocation Problem for Decentralized Learning (GreenDL) that jointly optimizes link cardinality, transmission power consumption, and transmission collision. Two algorithms are then proposed with results showing a reduced power consumption.

It has been widely reported that data centers consume a significant amount of electricity and hence numerous research works investigated the reduction of the energy consumption in data centers. Amongst them, the Low Energy Monitoring Network (LEMoNet) can effectively reduce excessive use of electricity by monitoring the environment in data centers. In [A4], Jafarizadeh and Zheng solved a multi-objective optimization problem to determine the optimal number of gateways, optimal location, and optimal transition power in LEMoNET. The proposed model reduces a significant amount of power consumption while maintaining a high packet reception rate.

Green Internet of Things (IoT): The world is ever more connected and is in the dawn of the IoT era. Having numerous connected devices will inevitably increase energy consumption, as such improving energy efficiency in IoT is crucial for a sustainable connected future. Ramanna *et al.* [A5] studied the cost of association, periodic beacon reception, maintaining association, and station wake up. Experimental results were obtained from a testbed, which provided further insights into enhance energy efficiency of WiFi-based IoT system.

Another prominent IoT system is Long-Range (LoRa), which makes use of Chirp Spread Spectrum (CSS). In [A6], Bizon Franco de Almeida *et al.* studied the performance of CSS and proposed two modulation techniques to increase both spectral and energy efficiency. The maximum likelihood estimation for CSS is also derived, and a low complexity channel estimation scheme is also proposed. The improvements of the proposed schemes are detailed in the paper.

Besides energy efficiency improvement in the physical layer, the MAC layer can also be enhanced. In [A7], Peper *et al.* proposed a MAC sublayer protocol that encodes information using the silent intervals between pulses. Theoretical analysis

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and experiments were conducted and demonstrated that the proposed protocol is suitable for high density IoT systems with limited energy resources.

For time-sensitive IoT applications, mission-critical IoT (MC-IoT) can provide ultra-reliable and low-latency communication (URLLC) to satisfy the stringent requirements. Cao *et al.* investigated the physical layer security of a relay-based MC-IoT in [A8]. In addition to the obtained closed form expressions for secrecy throughput, this paper jointly optimized the block length and transmit power, and proposed a hybrid duplex relay selection scheme. It has shown that the proposed scheme can achieve a higher secrecy throughput and energy efficiency for MC-IoT.

For ultra-high data rate connectivity, Light Fidelity (LiFi) is a promising candidate that can be used to connect LiFi-enabled IoT devices. In [A9], Nguyen *et al.* proposed a novel dimming method called indexed dimming (iDim) to reduce the optical power while achieving a wide brightness range and maintaining a high signal-to-noise ratio (SNR) and data transmission rate. Simulation and experiment show that iDim achieves these requirements at an extremely low optical power.

Green Unmanned Aerial Vehicles (UAV)-Enabled Network: Recently, UAV-enabled communication network has drawn much attention as an effective approach to provide enhanced coverage, especially to hard-to-reach areas. However, energy consumption is a critical issue for UAV, and hence improving energy efficiency is crucial. In [A10], Zhang *et al.* studied energy efficient secure video streaming delivered by a rotary-wing UAV-enabled networks. The video level selection, power allocation and UAV trajectory are jointly optimized under a secrecy timeout probability constraint to maximize the long-term energy efficiency. A safe deep Q-learning network (DQN) is used to solve the problem and the results show an improved energy efficiency and secrecy rate.

In addition to delivering data to information receivers, researchers have been investigating the use of UAV-enabled network to also deliver power wirelessly to energy receivers. Najmeddin *et al.* explored such a scenario by using NOMA in [A11]. The overall energy efficiency is optimized by decomposing the problem into a UAV positioning problem and a resource allocation problem. Both single and multiple UAV scenarios are considered, and results show an enhanced energy efficiency over OMA-based scheme.

Apart from using UAV to deliver data, it can also be used to gather data in IoT networks. This application scenario has been investigated for time-sensitive and energy-limited IoT network in [A12] by Ghdiri *et al.* In particular, the UAVs collect data from cluster heads, which aggregate data from the sensor nodes. An optimization problem has been formulated by minimizing the deployment cost and operating energy, subject to several performance constraints. A two-step solution was proposed to first optimize the cluster head number and location, followed by optimizing the number of UAVs and their trajectories. Simulation results show that the energy consumption is minimized while maximizing the amount of data collection.

A similar application scenario of using UAV to collect data from IoT devices is also investigated in [A13] by Kuo *et al.* Unlike the previous paper, this work considered multiple fixed-wing UAVs with circular flight trajectories. The optimization problem is formulated on maximizing the total energy savings by device association, and the centers and radii of the UAV circular trajectories. The first problem is solved by a two-stage maximum energy-saving device association policy, and the latter is optimized by an iterative load-balancing algorithm. Simulation results show that the proposed solutions outperform other schemes in terms of total energy savings.

The final paper in this category is not restricted to UAV-enabled networks but can be applied to any networks with mobile vehicles equipped with sensors and communication modules. Kang *et al.* explored the energy efficiency problem for mobile-vehicle-assisted mobile crowd sensing (MCS) in [A14]. A joint task selection and route planning problem was investigated, and a multi-population Mean-Field Game problem was proposed, which is then solved efficiently by a proposed G-prox primal-dual hybrid gradient method.

The guest editorial team hope you will enjoy these selected high-quality papers in this special issue, and that they will inspire further work and research in the field of green communication and networking.

Finally, we would like to thank all the authors who submitted their papers, and all the reviewers who provided their timely expert comments to improve the quality of this special issue. More importantly, we would like to show our deep appreciation to the Editor-in-Chief of this journal, Prof. Zhisheng Niu, who initiated the concept of this special issue and provided immense support throughout the publication process.

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APPENDIX: RELATED ARTICLES

[A1] M. Javad-Kalbasi and S. Valaee, "Centralized and distributed algorithms for energy and spectrum efficient user association in small cell networks," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1781–1790, Dec. 2021, doi: 10.1109/TGCN.2021.3100358.

[A2] A. Balakrishnan, S. De, and L.-C. Wang, "Network operator revenue maximization in dual powered green cellular networks," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1791–1805, Dec. 2021, doi: 10.1109/TGCN.2021.3094164.

[A3] J.-J. Kuo, C.-W. Ching, H.-S. Huang, and Y.-C. Liu, "Energy-efficient topology construction via power allocation for decentralized learning via smart devices with edge computing," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1806–1819, Dec. 2021, doi: 10.1109/TGCN.2021.3096884.

[A4] M. Jafarizadeh and R. Zheng, "Optimal design of LEMoNet for environmental monitoring of data centers," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1820–1832, Dec. 2021, doi: 10.1109/TGCN.2021.3100592.

[A5] V. K. Ramanna, J. Sheth, S. Liu, and B. Dezfouli, "Towards understanding and enhancing association and long sleep in low-power WiFi IoT systems," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1833–1845, Dec. 2021, doi: 10.1109/TGCN.2021.3085908.

[A6] I. B. F. de Almeida, M. Chafii, A. Nimr, and G. Fettweis, "Alternative chirp spread spectrum techniques for LPWANs," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1846–1855, Dec. 2021, doi: 10.1109/TGCN.2021.3085477.
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[A7] F. Peper *et al.*, "High-density resource-restricted pulse-based IoT networks," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1856–1868, Dec. 2021, doi: 10.1109/TGCN.2021.3090044.

[A8] J. Cao, J. Zhao, X. Zhu, X. Zhu, Y. Jiang, and Z. Wei, "Toward a green secure relay system for mission-critical IoT: Hybrid duplex relay selection and resource allocation in the finite block length regime," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1869–1879, Dec. 2021, doi: 10.1109/TGCN.2021.3093206.

[A9] T. Nguyen, M. S. Islim, C. Chen, and H. Haas, "iDim: Practical implementation of index modulation for LiFi dimming," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1880–1891, Dec. 2021, doi: 10.1109/TGCN.2021.3089758.

[A10] Z. Zhang *et al.*, "Energy-efficient secure video streaming in UAV-enabled wireless networks: A safe-DQN approach," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1892–1905, Dec. 2021, doi: 10.1109/TGCN.2021.3095315.

[A11] S. Najmeddin, S. Aïssa, and S. Tahar, "Energy-efficient resource allocation in multi-UAV networks with NOMA," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1906–1917, Dec. 2021, doi: 10.1109/TGCN.2021.3101200.

[A12] O. Ghdiri, W. Jaafar, S. Alfattani, J. B. Abderrazak, and H. Yanikomeroglu, "Offline and online UAV-enabled data collection in time-constrained IoT networks," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1918–1933, Dec. 2021, doi: 10.1109/TGCN.2021.3104801.

[A13] Y.-C. Kuo, J.-H. Chiu, J.-P. Sheu, and Y.-W. P. Hong, "UAV deployment and IoT device association for energy-efficient data-gathering in fixed-wing multi-UAV networks," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1934–1946, Dec. 2021, doi: 10.1109/TGCN.2021.3093453.

[A14] Y. Kang, S. Liu, H. Zhang, Z. Han, S. Osher, and H. V. Poor, "Task selection and collision-free route planning for mobile crowd sensing using multi-population mean-field games," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1947–1960, Dec. 2021, doi: 10.1109/TGCN.2021.3086001.

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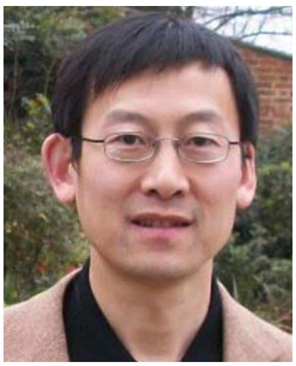

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