Guest Editorial Special Issue on Green Internet of Things: Challenges and Future Opportunities—Part II

INTERNET of Things (IoT) is a key enabler for many modernized applications from marine monitoring to outer space exploration. However, the complicated operations (such as device interconnection, data transmission, and service optimization) will consume substantial energy in contrast with limited energy storage of IoT devices. To improve architectural sustainability and ultimately reduce systemic cost, the greenness design of IoT has become ever prominent. Particularly, with the continuous penetration of advanced information and communications (ICT) technologies (such as VR/AR, UAVs, and automobiles), our smart world is being surrounded by big IoT data that extremely craves for energy-efficient caching, computing, networking and securing.

Some emerging techniques (e.g., edge computing, SDN/ICN, artificial intelligence) are envisioned to have promising ability to bring novel approaches to overcome the sustainability limitations of current IoT systems and specifically to improve the energy efficiency. This second part of our editorial provides short description of eighteen high quality research papers with novel contributions on Green IoT. In the following, we will introduce these articles and highlight their main contributions.

Jaiswal *et al.* "Quantum Learning-Enabled Green Communication for Next-Generation Wireless Systems" discusses on a framework for joint optimal Relay and transmit Power Selection (QRL-RPS) towards harnessing the benefits of Quantum Reinforcement Leaning (QRL) in the design of next generation wireless systems, In QRL-RPS, each sensor node learns using its present and past local state's knowledge to take optimal decision in relay and transmit power selection.

Mahmoud *et al.* "Intelligent Reflecting Surfaces Assisted UAV Communications for IoT Networks: Performance Analysis" investigates the use of intelligent reflecting surface (IRS) concept in unmanned aerial vehicles (UAV) enabled communications aiming to extend the network coverage and improve the communication reliability as well as spectral efficiency of Internet of Things (IoT) networks. In particular the work derives tractable analytic expressions for the achievable symbol error rate (SER), ergodic capacity, and outage probability of the considered set up.

Zhu *et al.* "Synthesized Corpora to Evaluate Fuzzing for Green Internet of Things Programs" discusses a framework to generate a corpora that provide with the contexts of bugs for more comprehensive fuzzing evaluation.

Yang *et al.* "Protograph LDPC-Coded BICM-ID With Irregular Mapping: An Emerging Transmission Technique for Massive Internet of Things" presents a study on the adaptive irregular-mapping (AIM)-aided BICM-ID systems with the use of protograph low-density parity-check (PLDPC) codes. The work further discusses a three-step design strategy to generate a type of adaptive constellations, which can be combined with their corresponding initial constellations to formulate an AIM scheme for improving the BICM-ID performance.

Li *et al.* "Physical Layer Security of Cognitive Ambient Backscatter Communications for Green Internet-of-Things" discusses on cognitive ambient backscatter communication (C-AmBC) as a new spectrum paradigm for the green Internet-of-Things (IoT) with stringent energy and spectrum constraints, in which the backscatter device (BD) can achieve communications by simultaneously sharing both spectrum and radio-frequency (RF) sources. The paper further discusses on a framework of C-AmBC networks in the presence of an unlicensed eavesdropper.

Xu *et al.* "Multi-Energy Scheduling of an Industrial Integrated Energy System by Reinforcement Learning-Based Differential Evolution" discusses on an industrial multi-energy scheduling framework (IMSF) proposed with the aim of optimizing the usage of renewable energy and reducing the energy costs. The technique addresses the management of multi-energy flows in industrial integrated energy systems – incorporating multi-energy storage, renewable energy generation, energy conversion, and energy trading in a synchronous manner.

Bany Salameh *et al.* "Energy-Efficient Cross-Layer Spectrum Sharing in CR Green IoT Networks" presents a discussion on an efficient cross-layer design consisting of joint optimization of the modulation order as a physical-layer parameter and the backoff probability as a MAC-layer parameter with the objective of minimizing the energy consumption in the CR-based green IoT networks subject to IoT delay guarantees, licensed primary radio (PR) channel availability and PR user activities.

Yu *et al.* "Multi-Timescale Multi-Dimension Resource Allocation for NOMA-Edge Computing-Based Power IoT With Massive Connectivity" discusses on a multi-timescale multi-dimEnsion Resource allocatIon and Task Splitting algorithm, namely MERITS, for NOMA-edge computing-based PIoT. Here a Lyapunov optimization is exploited to decompose the long-term stochastic optimization problem into three short-term deterministic subproblems, i.e., RB allocation in

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a large timescale, task splitting and computation resource allocation in a small timescale.

Sacco *et al.* "Resource Inference for Sustainable and Responsive Task Offloading in Challenged Edge Networks" presents a discussion on the challenges faced in optimally and rapidly (re)assigning tasks to IoT agents in varying network conditions and presents RITMO, a distributed and adaptive task offloading algorithm aimed to overcome this challenge. RITMO exploits a simple yet effective regressor to dynamically predict the length of future UAV task queues. Such prediction is then used to anticipate the node overloading and avoid agents that are likely to exhaust their battery or their computational resources.

Rajavel *et al.* "QoS-Aware Sensor Virtualization for Provisioning Green Sensors-as-a-Service" works around the problem of efficient virtual sensor formation in sensor-cloud for provisioning green Internet of Things (IoT)-based services. Authors discuss that the sustainability of sensor-cloud primarily depends on its quality of service (QoS), resource utilization efficiency, and the revenue earned by its stakeholders. As sensor nodes are resource-constrained, it is important to minimize the overall energy consumption at these devices and for the overall network, thereby reducing the cost-of-service provisioning.

Timilsina *et al.* "A Reinforcement Learning Approach for User Preference-Aware Energy Sharing Systems" discusses on an Energy Sharing System (ESS) that takes into account the consumers' preference, engagement, and bounded rationality. The problem of maximizing the energy exchange while considering such user modelling is formulated and shown to be NP-Hard.

Chen *et al.* "Leveraging Graph Convolutional-LSTM for Energy-Efficient Caching in Blockchain-Based Green IoT" discusses on a Request Graph Convolutional-LSTM to capture the spatio-temporal request patterns in Blockchain-based IoT networks and make predictions. Further, a heuristic algorithm based on the predictions is presented to develop pre-caching strategy, which determines the data and location to be cached to minimize the mean data retrieval latency restricted by the cache space of IoT network entities and the freshness of IoT content.

Bhattacharjee *et al.* "Energy Efficient Data Gathering in IoT Networks With Heterogeneous Traffic for Remote Area Surveillance Applications: A Cross Layer Approach" addresses the problem of energy-efficient data gathering in an Internet of Things (IoT) based remote area surveillance application by designing a suitable MAC layer uplink solution.

Feng *et al.* "Energy-Efficient Offloading for Mission-Critical IoT Services Using EVT-Embedded Intelligent Learning" discusses on a priority-differentiated offloading strategy that takes into account the stringent quality of service (QoS) requirements of mission-critical services and green resource allocation. Particularly, Lyapunov optimization is first introduced to derive an upper-bound queue minimization problem with the consideration of energy consumption and task priority.

Tazrin *et al.* "UV-CDS: An Energy-Efficient Scheduling of UAVs for Premises Sterilization" address the challenges faced by off-the-shelf drones such as limited flight-time and payload-carrying capacity. Further, the authors formulate an optimization problem to minimize the energy consumed by drones equipped with ultraviolet-C band (UV-C) panels.

Jan *et al.* "LightIoT: Lightweight and Secure Communication for Energy-Efficient IoT in Health Informatics" discusses a lightweight and secure communication approach for data exchanged among the devices of a healthcare infrastructure. Further the proposed framework operates in three phases: initialization, pairing, and authentication. These phases ensure the reliable transmission of data by establishing secure sessions among the communicating entities (wearables, gateways and a remote server).

Li *et al.* "Energy-Efficient Scans by Weaving Indexes Into the Storage Layout in Computing Platforms for Internet of Things" discusses on a storage layout DIFusion that integrates the data and the index in a unified structure. DIFusion enables an energy-efficient scan because it inherits the early-stopping capability from ByteSlice and possesses the data-skipping ability at the same time.

Kaur *et al.* "Secure and Energy Efficient-Based E-Health Care Framework for Green Internet of Things" presents and discusses a secure and energy-efficient Internet of Things (IoT) model for e-health. The main objective is to secure the transmission and retrieval of biomedical images over IoT networks. To achieve this, the compressive sensing and five-dimensional hyper-chaotic map (FDHC) are utilized to encrypt the biomedical images.

We would like to express our sincere thanks to all the authors for submitting their papers and to the reviewers for their valuable comments and suggestions that significantly enhanced the quality of these articles. We are also grateful to Prof. Zhisheng Niu, the Editor-in-Chief of the IEEE TRANSACTIONS ON GREEN COMMUNICATIONS AND NETWORKING, for the great support throughout the whole review and publication process of this special issue, and, of course, all the editorial staff. We hope that this special issue will serve as a useful reference for researchers, scientists, engineers, and academics in the field of Green IoT.

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