Guest Editorial: Green Industrial Internet of Things

INTERNET of things (IoT), which supports ubiquitous information exchange and content sharing among smart devices with little or no human intervention, is a key enabler for various applications such as smart city, smart grid, smart health, and intelligent transportation systems. Within the paradigm, the industrial Internet of things (IIoT) is a new ecosystem that combines intelligent and autonomous machines, advanced predictive analytics, and machine–human collaboration to improve productivity, efficiency, and reliability. IIoT connects billions of mobile digital devices, manufacturing machines, industrial equipment, etc., and generates an unprecedented volume of industrial data. The gap between the rapidly growing demands of data rate and existing bandwidth-limited network infrastructures has become ever prominent. Moreover, the interaction and connection of things in IIoT will consume substantial energy in contrast with limited energy storage of the things. Therefore, the greenness of IIoT is crucial for the success of IIoT. In particular, with the prevalence of mobile devices, electronic devices, cameras, social networks, social media, etc., our world is generating big data and multimedia big data, which further aggregate the energy demand in terms of the data transmission and processing of IIoT.

This Special Section aims to consolidate the current state of the art in terms of fundamental research ideas and network engineering, geared toward exploiting greenness of IIoT. Eight technical articles have been selected from the rigorous peer-review process. These articles cover topics on routing, security, resource allocation, machine learning, etc., which are crucial for implementing the green IIoT paradigm.

Energy harvesting-based device-to-device (D2D) communication is considered as one of the efficient transmission schemes for realizing the IIoT. In the first article, “Online energy scheduling policies in energy harvesting enabled D2D communications,” Ning *et al*. study the implications of the peak power constraints and processing cost on the energy-scheduling policy for energy-harvesting-enabled D2D communications. From this work, it can be found that the peak power should be used around the time slots of each energy arrival, and the only time slot in which the intermittent communication may occur is the last time slot. A new optimal energy-scheduling algorithm is devised based on these observations. The simulation results demonstrate the effectiveness of the proposed energy-scheduling algorithm and the validity of the mathematical analyses.

In the second article authored by Liu *et al*., “Energy-efficient resource allocation for cognitive Industrial Internet of Things with wireless energy harvesting,” a cognitive Industrial Internet of Things (CIIoT) with wireless energy-harvesting (WEH) framework is proposed to harvest the radio frequency (RF) energy of the primary user (PU)’s signal, and energy-efficient resource allocations in different spectrum access modes are presented to maximize the average transmission rate of CIIoT while guaranteeing the energy saving requirements. Simulation results show that the CIIoT with WEH can consume less power to achieve a larger transmission rate, and the hybrid mode outperforms the underlay and overlay modes in the aspects of transmission rate and energy saving.

In many IIoT applications, WPT and autonomous vehicle technologies, in combination, have the potential to solve a number of residual problems concerning the maintenance of, and data collection from embedded devices. The third article, “Optimal dynamic recharge scheduling for two stage wireless power transfer” by Pandiyan *et al.*, proposes a two-stage wireless power network approach, in which a large network of devices may be grouped into small clusters, where packets of energy are inductively delivered to each cluster by the mobile power-delivery vehicle (PDV). A novel dynamic recharge-scheduling algorithm is presented to jointly minimize PDV travel distance and WPT losses. The efficacy and performance of the algorithm are evaluated in simulation and the algorithm is shown to achieve better throughput for large, dense networks.

The fourth article, “Energy-efficient content placement with coded transmission in cache-enabled hierarchical Industrial IoT Networks” authored by Gu *et al.*, studies the energy-efficiency problem in a cache-enabled hierarchical IIoT network. This article proposes a content-placement strategy with coded transmission to reduce backhaul load, and derives a closed-form expression of energy consumption. A joint content-placement matrix and the cache-size allocation optimization problem is established to minimize the total energy consumption. Simulation results indicate the superior energy-efficiency performance of the proposed content-placement strategy.

Developing the energy-efficient security mechanism is also important for the IIoT application. In the fifth article, “Energy-Efficient end-to-end security for software defined vehicular networks,” Raja *et al*. propose an energy-efficient end-to-end security solution for software-defined vehicular networks (SDVN). The proposed SDVN provides lightweight end-to-end security and detects the potential intrusions inside the VANET architecture using collaborative learning, which guarantees privacy through a fusion of differential privacy and homomorphic encryption schemes. The simulation results provide higher energy efficiency through reduced end-to-end security communication cost.

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In the sixth article, "SDN-enabled energy-efficient routing optimization framework for Industrial Internet of Things," Tariq *et al*. propose an SDN-based analytical parallel routing framework by using the massive processing power of the graphics processing unit (GPU) for dynamically optimizing multiconstrained QoS parameters in IIoT. A QoS-enabled routing-optimization problem is formulated as a max-flow-min-cost problem and a greedy heuristic scheme is proposed, which dispatches the path-calculation task concurrently to GPU for calculating optimal forwarding paths considering the QoS requirement of each flow. Comparative analysis of simulation results with the shortest path delay, Lagrangian relaxation-based aggregated cost, and sway schemes indicates a reduced violation in the service level agreement.

The seventh article, "Communication-efficient federated learning for digital twin edge networks in Industrial IoT," Zhang *et al*. present the digital twin edge networks (DITEN) by incorporating digital twin into edge networks to fill the gap between physical systems and digital spaces. The federated learning is leveraged to construct digital twin models of IoT devices based on their running data. Moreover, an asynchronous model-update scheme is proposed to mitigate the communication overhead. Numerical results show that the proposed federated learning scheme for DITEN improves the communication efficiency and reduces the transmission energy cost.

Nonorthogonal multiple access (NOMA) is considered as an efficient access scheme for providing better throughput performance for IIoT. In the eighth article, "NOMA assisted multi-task multi-access mobile edge computing via deep reinforcement learning for Industrial Internet of Things," Wu *et al*. exploited NOMA for the computation offloading in multiaccess mobile edge computing (MA-MEC) and proposed a joint optimization of the multiaccess multitask computation offloading, NOMA transmission, and computation-resource allocation, with the objective of minimizing the total energy consumption of IoT device to complete its tasks subject to the required latency limit. Both static and dynamic channel scenarios are considered and different algorithms are proposed to solve the joint optimization problem by utilizing both convex optimization and deep reinforcement learning (DRL) schemes respectively. The advantage of the NOMA-assisted multitask MA-MEC against the conventional orthogonal multiple access scheme under both static and dynamic channels are demonstrated through the simulation study.

In the end, the editors would like to thank all the authors for their excellent contributions and all the reviewers for their rigorous reviews and valuable comments on the submitted manuscripts. The editors are also grateful for the strong support from Prof. Ren Luo, Editor-in-Chief of the IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS and the Secretary Office.

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