Guest Editorial
Special issue on green internet of things: Challenges and future opportunities - Part II

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Special Issue on Green Internet of Things: Challenges and Future Opportunities

AFFORDABLE and clean energy is one of the critical sustainability goals of the U.N. charter. The sufficiency in energy does have a profound influence on the quality of life of people in that society. The development of society and/or countries heavily depends on generating and sustaining the population's energy needs. One of the critical aspects of energy sustainability is avoiding wastage. On average, 35% of energy is wasted in homes, and around 30% is wasted in the industries! However, the humongous development in electronics, communications, embedded systems, and intelligence at the edge is spearheading the innovations to make the world smarted and efficient.

This revolution has been powered by the Internet of Things (IoT), which is a crucial enabler. The energy sector is gaining a lot to minimize losses, making the environment intelligent and comfortable for people while energy-efficient. IoT is modernizing applications from marine monitoring to outer space exploration even. However, the complicated operations, such as device interconnection, data transmission, and service optimization, will consume substantial energy. Thus the IoT being a tool to reduce waste and increase efficiency, should be significantly energy efficient.

While IoT contributes to all other aspects of human lives and the environment, the massive growth in the IoT domain needs to be sustainable. Thus making IoT greener is an essential aspect that researchers need to work on. Further, the limited energy storage of IoT devices is also a big challenge. To improve architectural sustainability and ultimately reduce systemic cost, the greenness in IoT design has become much more prominent. 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 craves significantly for energy-efficient caching, computing, networking, and security.

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. However, how to fully utilize these techniques from communication, data processing, and computing, etc., to improve the energy efficiency of IoT still faces many fundamental challenges. Some open issues require immediate studies: How can we achieve much higher energy efficiency of the IoT network with limited bandwidth provisioning and low transmit power? How can we utilize advanced capabilities of IoT, such as in-network storage and caching, offload the IoT data to release the traffic scale in the cellular networks and provide low-latency IoT services in an energy-efficient manner?

Can we leverage recent advances in computing to design an energy-efficient computing platform for IoT? How can we create lightweight security schemes such as encryption to reduce the energy consumption of a secure IoT network?

We took off with many more questions, and our focus in bringing this special issue was to challenge the researchers in the community. We received many original to quality submissions with novel contributions on Green IoT, from energy efficiency and reducing energy consumption. Contributions by the applications of emerging technologies (e.g., social computing, big data computing, fog computing, edge computing, emotional computing, SDN) to address the greenness issues of IoT. There were many contributions, and it was tedious to select only some of them. We are eventually publishing two special issues on the Green IoT topic. We are here with the first edition of the special issue. The selected papers under various categories have been grouped, and their contributions are summarized here to benefit the readers.

Physical Layer & MAC: Physical layer and MAC are the basic communication layers, and making it efficient is an important task. Backscatter communication has been one of the most scalable and almost maintenance-free IoT systems. It finds a lot of use in massively deployed IoT sensors. Ahsan *et al.*, "BER Analysis of a Backscatter Communication System With Non-Orthogonal Multiple Access," have looked into the BER analysis of such a system with non-Orthogonal multiple access in backscatter communication systems. The BER expressions have been considered under various scenarios.

Syed Waqas *et al.*, "Energy-Efficient MAC for Cellular IoT: State-of-the-Art, Challenges, and Standardization," have thrown light on the important domain of energy-efficient MAC for cellular IoT, and have studied standardization till now and the challenges. This article looks at the big canvas of Low Power WANs and provides their advantages, disadvantages and compares them. Miaowen *et al.*, "Cyclic Delay Diversity With Index Modulation for Green Internet of Things," have contributed cyclic delay diversity (CDD) with index modulation for green IoT. Specifically, the authors have looked into increasing spectral efficiency. The potential of CDD has been exploited in the IoT domain making it computationally less complex.

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Networking: The networking layer is the most studied part of IoT systems and applications. Several research directions have emerged and this is one of the most interesting areas under IoT. Stable election protocol which is distance aware as well as energy-efficient has been looked into by Afia Naeem *et al.* "DARE-SEP: A Hybrid Approach of Distance Aware Residual Energy-Efficient SEP for WSN." IoT devices are often energy-constrained and thus the residual battery aware management of the network is an important task. Energy efficiency in WSNs has been studied for the last two decades, but still, many issues are prevailing. Cluster head selection is one of the crucial aspects but making the selection more stable is also important. Diya *et al.*, "SEC2: A Secure and Energy Efficient Barrier Coverage Scheduling for WSN-Based IoT Applications," looked into secure and energy-efficient scheduling for WSNs. A cluster ensemble scheme is proposed to secure a barrier from malicious attacks while preventing QoS degradations. Though clustering is a means to solve the energy efficiency issue and thereby increasing the lifetime, one of the meta problems is to define the optimal radius of the clusters. Kapal Dev *et al.*, "Optimal Radius for Enhanced Lifetime in IoT Using Hybridization of Rider and Grey Wolf Optimization," have proposed optimal clustering with hybridization of rider and Grey Wolf optimization. A hierarchical energy-efficient service selection has been studied by Endong *et al.,* "A Hierarchical Energy Efficient Service Selection Approach With QoS Constraints for Internet of Things." The service-oriented architecture is most apt for selections of services when the IoT devices are deployed in large numbers. An IoT device can indeed be used for multiple services and thus a proper selection and faster convergence at yet energy efficient is the requirement of the day. The authors also consider the service selection under QoS constraints.

Resource Allocation: Energy efficiency needs to be in every domain as we have seen above. The data centers account for 2% of the world's energy and each data center uses at least 100MW of energy. Thus it is important to make data centers efficient. Zhou *et al.*, "AFED-EF: An Energy-Efficient VM Allocation Algorithm for IoT Applications in a Cloud Data Center," look into the Virtual Machine (V.M.) allocation in Data Centres. Yuzhe *et al.*, "SSUR: An Approach to Optimizing Virtual Machine Allocation Strategy Based on User Requirements for Cloud Data Center," have also proposed an optimization strategy to allocate V.M.s considering the user requirements. This is one of the hard problems since QoS should be considered while energy spent needs to be reduced. Abdulhamid *et al.* proposed privacy-aware R.F. spectrum reservation for virtualization of IoT "Energy-Efficient Multivariate Privacy-Aware RF Spectrum Reservation in Wireless Virtualization for Wireless Internet of Things." This work directly relates to QoS expected from deployed large-scale IoT devices.

Monitoring Applications: IoTs are mainly used for data gathering and many associated applications. Efficient data storage and transmission is an important role in green IoT. IoT is being used in various scenarios. An interesting application of monitoring river water pollution is presented in "An Energy-Efficient River Water Pollution Monitoring System in Internet of Things" by Swathi *et al.* We know that one of the biggest and holy rivers of India was polluted heavily and technology interventions have been used to slowly get the glory of the almost lost river by proposing an energy-efficient monitoring system applying deep neural network and long-range communication technology. Cache management in an energy harvesting Device to device communication in a cellular network is studied by Yue *et al.* "Cache- and Energy Harvesting-Enabled D2D Cellular Network: Modeling, Analysis and Optimization." Cache hit probability and successful transmission probability were studied under three modes using stochastic geometry. The authors show an increase in the caching efficiency using their two probabilistic caching strategies. Caching saves energy by avoiding repetitive transmissions by the base stations. Xuemei *et al.*, "An Integral Data Gathering Framework for Supervisory Control and Data Acquisition Systems in Green IoT," propose a data gathering framework for supervisory control in SCADA networks. Interestingly the authors look into both optimizing the selection of the node with the least energy consumption as an aggregator and then UAVs for data collection from the SCADA networks. Radar/optical visual sensing has been one of the interesting topics that are bringing multidisciplinary aspects of IoT. Visual data reconstruction when many UAVs are involved is studied by Mohammad *et al.* "BL-ALM: A Blind Scalable Edge-Guided Reconstruction Filter for Smart Environmental Monitoring Through Green IoMT-UAV Networks." The authors propose a newer version of a non-linear blind edge-guided spatial filter based on linear minimum mean square error estimation (LMMSE).

Learning and Edge Computing: Machine Learning (ML) has been one of the recent and popular research topics. Further, edge computing is very close to the area of IoT. For various applications and scenarios where large-scale IoT devices are deployed, ML at the edge is very useful but it also throws a lot of challenges. Energy-efficient intelligent edge computing has been the focus of many leading researchers currently. Tan *et al.*, "Latent Discriminative Low-Rank Projection for Visual Dimension Reduction in Green Internet of Things," proposed a latent discriminative low-rank projection (LDLRP) method for visual dimension reduction. Data self-expressiveness model is developed using low-rank and discriminative similarity relations of data. Reducing the data dimension directly helps in reducing the energy. The Industrial Internet of Things (IIoT) is one of the main pillars of the Industry 4.0 revolution. Reduction in energy consumption is usually done by optimizing task scheduling without taking into account a load of computing and energy for data transmission. Ning *et al.*, "Deep-Green: A Dispersed Energy-Efficiency Computing Paradigm for Green Industrial IoT," have proposed Deep-Green a distributed energy-efficient computing paradigm for the IIoT. The authors propose joint optimization of computing and network resources by merging data transmission and data processing at the edge. A computation reuse architecture at the edge called CoxNet has been proposed by Zouhir *et al.* "CoxNet: A Computation Reuse Architecture at the Edge." Authors propose to reuse the output of the past computations when the inputs are similar and show that 66% execution time can be reduced with CoxNet. Lastly, Laisen *et al.*, "Intrusion Detection in Green Internet of Things: A Deep Deterministic Policy Gradient-Based Algorithm," propose an algorithm for intrusion detection by analyzing the behavior of the attackers before they invade the network. Finding these behaviors and learning them before can indeed protect the IoT network and the privacy of the users. The authors propose deep reinforcement learning to analyze the network traffic before an attack.

We feel that this special issue will trigger more focused research on various aspects of IoT that were hitherto not looked into. We do hope that the articles also induce more collaborative work during the situation caused by COVID-19. Finally, we wish every one of our IEEE family very good health and safety during this pandemic. Together we can bring innovation in various domains of Communication and Networking with an eye on energy.

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