Guest Editorial: Special Issue on Enabling Massive IoT With 6G: Applications, Architectures, Challenges, and Research Directions

DRIVEN by the Internet-of-Things (IoT)-enabled massively data-intensive applications, such as virtual-augmented-reality-based gaming, ultramassive machine-type communications, holographic rendering and high-precision communications, multiway teleconferencing, etc., there is a need for technological advancements and evolutions for wireless communications beyond the fifth-generation (5G) networks. The wireless data traffic is estimated to reach 4394 EB by 2030 (Source: ITU), and 5G will be unable to provide support to most of these advanced applications. Here, 6G is expected to extend the 5G capabilities to very high levels where millions of connected devices and applications could operate seamlessly with high data rates and low latency.

Research in Massive IoT enabled with 6G has begun and is expected to gain momentum in the coming years. Investigations have been particularly focussed on requirements, key technologies, interoperability issues, system architectures, energy efficiency, intelligence, spectral efficiency, secrecy and privacy, affordability, and customization for 6G-enabled massive IoT networks. This special issue aims to provide the scientific community with a comprehensive overview of innovative technologies, advanced architectures, and potential challenges for 6G-enabled massive IoT.

The response to our call for this special issue was overwhelming, as we received in total 133 submissions from around the world. During the review process, each article was assigned to and reviewed by at least three experts in the field, with a rigorous multiround review process. Thanks to the great support from the former Editor-in-Chief, Prof. Xuemin (Sherman) Shen, and the current Editor-in-Chief, Prof. Honggang Wang, and the dedicated work of numerous reviewers, we were able to accept 31 excellent articles covering various topics in Massive IoT with 6G. In the following, we will introduce these articles and highlight their main contributions.

In the article "Energy-efficient random access for LEO satellite-assisted 6G Internet of Remote Things" Zhen *et al.* discuss the reliable design and detection of random access (RA) preamble to effectively enhance the access efficiency in high-dynamic low-earth-orbit (LEO) scenarios.

The article "Large intelligent surface-assisted nonorthogonal multiple access for 6G networks: Performance analysis" investigates the error rate performance of large intelligent surface (LIS)-assisted nonorthogonal multiple-access (NOMA) networks.

The article "Toward 6G architecture for energy-efficient communication in IoT-enabled smart automation systems" discusses how the energy-efficient communication and user's QoE level can be captured through UT device during multimedia transmission.

In the article "Spatially coupled protograph LDPC-coded hierarchical modulated BICM-ID systems: A promising transmission technique for 6G-enabled Internet of Things," Yang *et al.* discuss a spatially coupled (SC) protograph low-density parity-check (P-LDPC)-coded M-ary quadrature amplitude modulation (QAM) HM-BICM-ID systems.

In "IoT-based big data secure management in the fog over a 6G wireless network," Stergiou *et al.* discuss an innovative and secure infrastructure for managing big data on smart buildings that operates in a 6G network.

The article "Information-centric massive-IoT-based ubiquitous connected VR/AR in 6G: A proposed caching consensus approach" presents a blockchain mechanism for information-centric massive Internet of Things (IC-mIoT) nodes and discusses a new consensus mechanism Proof-of-Cache-Offloading (PoCO).

The article "Stackelberg game for service deployment of IoT-enabled applications in 6G-aware fog network" presents a 6G-aware fog federation model for utilizing maximum fog resources and providing demand specific services across the network while maximizing the revenue of fog service providers and guaranteeing the minimum service delay and price for IoT users.

The article "Energy-efficient resource allocation strategy in massive IoT for industrial 6G applications" investigates the energy consumption problem with a massive IoT system model and clustering using a multiagent system (MAS) for industrial 6G applications.

In the article "Energy-efficient drone trajectory planning for the localization of 6G-enabled IoT devices," Kouroshnezhad *et al.* investigate a novel approach called SEmi-Dynamic Mobile Anchor Guiding (SEDMAG) for drones which aims at energy-conservative trajectory planning and localization of massive IoT devices.

The article "Practical network coding technologies and softwarization in wireless networks" investigates practical network

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coding technologies and summarizes complexity-optimized methods and explains the interaction effect of coding opportunities and decoding overhead.

In "Anomaly detection based on multidimensional data processing for protecting vital devices in 6G-enabled massive IIoT," Han *et al.* investigate the methodologies used to quantify the obtained information and to protect the high priority IIoT nodes with assistance from sixth-generation (6G) networks.

The article "Base station wakeup strategy in cellular networks with hybrid energy supplies for 6G networks in an IoT environment" discusses a fuzzy logic-based wakeup technique which comprehensively considers the energy wakeup level and the available network resource ratio.

In the article "Socially aware joint resource allocation and computation offloading in NOMA-aided energy-harvesting massive IoT," Pei *et al.* discuss a mobile edge computing offloading scheme for cellular IoT networks with massive NOMA-aided energy-harvesting (EH) machine-type communication device (MTCD) and several roadside units with edge servers randomly distributed in a macrocell.

The article "Learning-based queue-aware task offloading and resource allocation for space–air–ground-integrated power IoT" investigates the challenges faced by the joint optimization of task offloading and computational resource allocation and discusses a learning-based QUeue-AwaRe Task offloading and rEsouRce allocation algorithm (QUARTER).

The article "AI-driven collaborative resource allocation for task execution in 6G-enabled massive IoT" discusses a 6G-enabled massive IoT architecture that supports dynamic resource allocation. Further, the article presents a discussion on a dynamic nested neural network which adjusts nested learning model structure online to meet training requirements of dynamic resource allocation.

The article "An integrated deep learning algorithm for detecting lung nodules with low-dose CT and its application in 6G-enabled Internet of Medical Things" discusses the integration of a novel deep learning algorithm into 6G-enabled IoMT to provide and share medical records and monitoring results online and realize an online diagnosis.

The article "An efficient and lightweight predictive channel assignment scheme for multiband B5G-enabled massive IoT: A deep learning approach" discusses a deep-learning-based predictive channel selection method to unravel the potential challenges associated with the dynamic channel conditions in the multiband relay networks.

In "Distributed probabilistic offloading in edge computing for 6G-enabled massive Internet of Things," Liao *et al.* investigate the challenges for edge computing in 6G, especially on making offloading decisions facing densified servers considering both channel interference and queuing and discuss a distributed two-stage offloading (DTSO) strategy to give tradeoff solutions.

The article "Contention resolution in Wi-Fi 6-enabled Internet of Things based on deep learning" presents a contention window (CW) control strategy for Wi-Fi 6 systems that leverages deep learning to search for optimal configuration of CW under different network conditions.

The article "6G-enabled short-term forecasting for large-scale traffic flow in massive IoT based on time-aware locality-sensitive hashing" discusses a big-data-driven and nonparametric model aided by 6G to extract similar traffic patterns over time for accurate and efficient short-term traffic flow prediction in massive IoT, mainly based on time-aware locality-sensitive hashing (LSH).

In the article "Neural architecture search for robust networks in 6G-enabled massive IoT domain," Wang *et al.* discuss techniques on automatically searching for robust and efficient neural network structures for artificial-intelligence-enabled Internet-of-Things (AIoT) systems.

In "Privacy-preserving multiobjective sanitization model in 6G IoT environments," Lin *et al.* investigate the need to secure 6G IoT networks and discuss an ant colony optimization (ACO) approach by adopting multiple objectives as well as using transaction deletion to secure confidential and sensitive information

The article "Big data analytics for 6G-enabled massive Internet of Things" investigates the influence of the 6G-based big data analysis technology with large-scale IoT devices with various parameters such as energy consumption, success rate, etc.

In "Coded stochastic ADMM for decentralized consensus optimization with edge computing," Chen *et al.* discuss the strategies to overcome the issues with communication bottleneck and straggler node in distributed learning systems using error-control-coding-based stochastic incremental ADMM.

The article "Data-driven trajectory quality improvement for promoting intelligent vessel traffic services in 6G-enabled maritime IoT systems" investigates a two-phase data-driven machine learning framework for vessel trajectory reconstruction.

In "BTMPP: Balancing trust management and privacy preservation for emergency message dissemination in vehicular networks," Liu *et al.* investigate providing a satisfactory solution to balancing the trust management and privacy preservation in vehicular networks using a novel method named BTMPP, which is able to provide both the precise trust management and strong conditional privacy preservation simultaneously.

The article "Toward green communication in 6G-enabled massive Internet of Things" discusses the opportunities with green communication in 6G-enabled massive IoT devices by following the cluster-based data dissemination in the network.

The article "Blockchain-envisioned UAV communication using 6G networks: Open issues, use cases, and future directions" presents a broad survey on the architecture, requirements, and use cases of 6G technology.

The article "6G-enabled IoT home environment control using fuzzy rules" discusses electronic modules, infrastructure, and fuzzy rules control model with implemented software for new generation home environment supported by 6G network communication standards.

The article "Cooperative wireless-powered NOMA relaying for B5G IoT networks with hardware impairments and channel estimation errors" discusses the performance of cooperative simultaneous wireless information and power transfer

(SWIPT) nonorthogonal multiple access (NOMA) for massive IoT systems.

In "Vulnerability assessment of 6G-enabled smart grid cyber-physical systems," Tariq *et al.* discuss a graphical-processing-unit-enabled adaptive robust state estimator that comprises deep learning algorithm, long short-term memory, and a nonlinear extended Kalman filter to improve security in massively connected CPSs.

We would like to express our sincere thanks to all the authors for submitting their articles and to the reviewers for their valuable comments and suggestions that significantly enhanced the quality of these articles. We are also grateful to Prof. X. Shen, the former Editor-in-Chief, and Prof. H. Wang, the current Editor-in-Chief of IEEE INTERNET OF THINGS JOURNAL, for their 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 massive IoT with 6G.

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