Guest Editorial: AI Empowered Communication and Computing Systems for Industrial Internet of Things

I. Introduction

INTERNET of Things (IoT) expects to incorporate massive machine-type communication (MTC) devices, such as sensors, controllers, and actuators, and allows them to interact with each other for data acquisition and analysis. As one of the most important applications of IoT in industry sector, industrial Internet of Things (IIoT) connects industrial assets to collect and process data in industrial environments to enable intelligent operation, such as industrial monitoring, automation, and control. In IIoT, data collected from various devices need to be collected and processed in a timely, reliable, and efficient manner. To meet the stringent requirements of IIoT, advanced communication and computing technologies expect to play significant roles. For data collection, heterogeneous communication and networking technologies such as dynamic spectrum access, LoRa, Zigbee, and 5G can be employed. For data processing, edge/fog computing, and cloud computing can provision computing and storage resources for IIoT. With fog/edge computing in proximity of data sources, data can be preprocessed and computational tasks can be executed locally, which can promote context-awareness and achieve low-latency. Cloud computing with abundant resources can facilitate computation-intensive tasks and support decision making for a relative large scale.

In such a heterogeneous system incorporating communication and computing, there are many technical challenges to address. The industrial environment itself exhibits high randomness and dynamics, due to factors such as time-varying wireless channels, node mobility, and stochastic data, and task arrival. In addition, vast amounts of data are collected in IIoT, which are complex in terms of scale, structure, and content, need to be processed in real-time for fast response. Last but not least, incorporating storage and computation resources in IIoT, it is very challenging to manage heterogeneous resources in an efficient way to meet diverse service requirements. In such a complex and dynamic system, artificial intelligence (AI) holds great potential to address the aforementioned challenges. AI can help analyze massive industrial data to provide insights and predictive analyses in real-time, and facilitate efficient decision-making through learning to intelligently manage and control the system for IIoT.

This special section aims at soliciting original research and practical contributions from both industry and academia to advance the IIoT, including network modeling and architecture, AI algorithms for various layers, intelligent resource management, big data driven edge systems, orchestration of edge, and cloud servers. Through a rigorous peer-review process, nine articles have been accepted. In the following, we summarize the accepted articles in this editorial.

The first article entitled "An Efficient Clustering Framework for Massive Sensor Networking in Industrial IoT" focuses on the energy consumption issue in massive machine type IoT communication (mMTIC). As mMTIC is usually used to cover a relatively large area, multihop communication is necessary which, however, can cause energy hole problems. In this article, an AI-based clustering routing framework is developed, which can not only optimize the energy consumption but also improve the performance of communication and data collection.

As IIoT devices are typically resource constrained, their computation-intensive tasks can be offloaded to mobile edge computing (MEC) servers in proximity for processing. To efficiently process those computational tasks and address the dynamics in task arrivals in IIoT, the second article entitled "Deep Reinforcement Learning based Dynamic Resource Management for Mobile Edge Computing in Industrial Internet of Things" jointly allocates computing resources and optimizes power control in MEC for IIoT. To deal with the dynamics and continuity of task generation, a deep reinforcement learning (DRL) based algorithm is proposed to reduce the long-term average delay.

In IIoT, a mix of different types signals can cause complicated interference and dramatically degrade the classification rate of signals. As a result, the training time for extracting features can be prolonged. To deal with this issue, the third article entitled "Intelligent Signal Classification in Industrial Distributed Wireless Sensor Networks-Based IIoT" proposes a scheme for signal classification using feature fusion. With the proposed scheme, the received signals are processed by frequency reduction and sampling pretreatment. Deep learning is used for signal classification by each sensor while recognition results are then aggregated for a final classification.

The fourth article entitled "Reinforcement Learning Enabled Dynamic Resource Allocation in Internet of Vehicles" investigates communication and computing resources management for connected vehicles. The resource allocation problem is formulated as a semi-Markov decision process and a reinforcement learning algorithm is employed to solve it. Through simulation results, it is demonstrated that the proposed learning algorithm can effectively improve resource utilization and service experience.

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Digital twin can enable digital transformation of IIoT to facilitate efficient system management. The fifth article entitled "Deep Reinforcement Learning for Stochastic Computation Offloading in Digital Twin Networks" studies computation offloading with the objective of minimizing the energy consumption and improving efficiency of data processing in digital twin networks. Asynchronous actor-critic algorithm is utilized to optimize the computation offloading policy to minimize the long-term energy efficiency in IIoT.

The sixth article entitled "A Reinforcement Learning Empowered Cooperative Control Approach for IIoT-based Virtually Coupled Train Sets" introduces an IIoT-based virtually coupled train sets (VCTS) to improve the capacity of the transportation system and the flexibility of the railway organization. To achieve cooperative control of VCTS, reinforcement learning algorithms are adopted to find the optimal policy, wherein artificial potential field is used to reduce the computation complexity.

The seventh article entitled "Deep Reinforcement Learning Based Computation Offloading in Fog Enabled Industrial Internet of Things" studies computation offloading to reduce the service latency and energy consumption of IIoT devices, where computation-intensive tasks are offloaded to fog access points (F-APs). A multiagent DRL approach is proposed to select F-AP for minimizing the long-term energy consumption. In addition, offline training is performed in the cloud and decisions are made in an online manner, which helps accelerate F-AP selection using trained DRL models.

To support computation-intensive deep neural network (DNN) inference services, collaboration among IIoT devices, and edge networks plays an important role in achieving low delay and high accuracy. The eighth article entitled "Accuracy-Guaranteed Collaborative DNN Inference in Industrial IoT via Deep Reinforcement Learning" investigates the joint optimization of edge computing resource allocation, inference task offloading, and sampling rate adaption, by means of constrained Markov decision process (CMDP). A DRL algorithm is developed to solve this CMDP problem for achieving the minimum average service delay and guaranteing accuracy requirements.

The ninth article entitled "Cooperative Jamming Secure Scheme for IWNs Random Mobile Users Aided by Edge Computing Intelligent Node Selection" investigates the security aspect in industrial wireless networks (IWNs). Cooperative physical layer security scheme is devised to enhance the communication security, where optimal cooperative jamming (CJ) nodes are efficiently selected to broadcast jamming signals to affect the adversaries.

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