Guest Editorial: Special Issue on Computational Intelligence in the Internet of Things

The Internet of Things (IoT) has undoubtedly paved a new surge of research and development on connecting objects, streamlining processes, and enabling intelligence on top of sensor networks that collect data from cyber, physical, and human worlds. The next generation of sensor networks should provide the infrastructure and services to embrace novel concepts, computing models, techniques, and applications for the effective management, retrieval, evaluation, and decision making of the massive, heterogeneous IoT data. This further calls for better designing the IoT network and communications, optimizing cloud-edge collations, and advocating intelligent and energy-efficient applications in the broad context of IoT. New challenges and opportunities lie in the way of enabling machine intelligence in the broad contexts of IoT, creating a fertile ground for research and innovation. This requires novel methodological, algorithmic, mathematical, and computational methods that incorporate the most recent advances in communications, sensor networks, data analytics, and artificial intelligence to solve the theoretical and practical problems in IoT systems and IoT-enabled services. On the one hand, the existing architectures, models, and techniques should be carefully reexamined based on the emerging advanced analytics and intelligent approaches; on the other hand, newly emerging technologies such as edge/fog computing, blockchain, and deep neural networks should be exploited to address the challenges in existing computing frameworks and techniques and to advance the state-of-the-art knowledge in this area.

There have been enormous responses to the preceding theme, with about 70 papers submitted under this Call for Papers around the world. During the review process, each paper went through a rigorous review process and was reviewed by at least three experts in the relevant areas. Thanks to the courtesy of the Editor-in-Chief, Professor Yunhao Liu, we were able to accept 13 excellent papers covering various aspects of "Computational Intelligence in the Internet of Things."In the following, we will briefly introduce these papers in four groups and highlight their main contributions.

1 TOPOLOGY, COMMUNICATION, DATA QUALITY

In "Robust Networking: Dynamic Topology Evolution Learning for Internet of Things," the authors focus on improving communication capacity under possible network failures for applications that require high quality of services. They propose an approach called *ROEL* to optimize the topology of IoT networks and to intelligently prospect the robust degree in the process of evolutionary optimization. ROEL is based on a neural network and can resist cyber-attacks induced by some failed nodes.

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In "LeaD: Learn to Decode Vibration-Based Communication for Intelligent Internet of Things," the authors present a new vibration-based communication protocol named *LeaD* that can learn unique vibration patterns to decode short messages transmitted to smart IoTs devices. LeaD transmits and decodes vibration signals in bits groups, which are considered as reproducible patterns of vibration, to convert decoding into a pattern classification problem solvable by machine learning models. The authors find that the convolutional neural network achieves excellent performance and is robust to poses, distances, and types of devices. LeaD is tested to be lightweight and suitable for use on various smart IoT devices.

In "Intelligent Data Collaboration in Heterogeneous-Device IoT Platforms," the authors introduce an intelligent data collaboration solution to fight the low quality of data, which hinders the development of high-quality applications on diverse IoT platforms, especially those comprised of heterogeneous devices. The solution provides IoT with a adaptive collaboration ability that enables filtering noise out of temperature readings in an IoT network based on deep learning (more specifically, a denoising autoencoder LSTM).

2 CLOUD, EDGE, AND END-USER DEVICE COLLABORATION

In "Scalable Estimator for Multi-Task Gaussian Graphical Models Based in an IoT Network," the authors propose a cloud-based approach called *Multi-FST* to integrate and process heterogeneity and large-scale IoT data efficiently. In particular, they use a graphical model to depict variable dependencies in data collected from different edge devices and jointly estimate multiple, high-dimensional, and sparse Gaussian graphical models for related tasks in distributed edge devices. The approach is tested to be less computationally expensive and support smooth optimizations.

In "Edge Content Caching with Deep Spatiotemporal Residual Network for IoV in Smart City," the authors propose an edge content caching method with service requirement prediction, named *E-Cache*, to improve the deliver efficiency of content and the reuse efficiency of resources in edge servers in the context of smart cities. Based on numerous requests issued by in-vehicle applications for the same or different content to distributed edge servers, the authors address the optimization challenge by first predicting future requirements based on the deep spatiotemporal residual network (ST-ResNet) and then elaborating the content caching schemes based on the predicted requirements, which can be further adjusted by a many-objective optimization to minimize the execution time and the energy consumption of vehicular services.

In "eDeepSave: Saving DNN Inference Using Early Exit During Handovers in Mobile Edge Environment," the authors introduce an early exit technique to maximally maintain services during handovers when partitioning the DNN to a mobile device and its connected edge server to accelerate DNN inference. The proposed solution, called *eDeepSave*, can automatically determine the frames to be saved during a handover to maximize the number of saved frames, including the partially completed frames. It also re-partitions the last arriving frame before the end of the handover with a provable performance bound so the frames after the handover can be processed without experiencing congestion.

In "GPFS: A Graph-Based Human Pose Forecasting System for Smart Home with Online Learning," the authors present a a hybrid cloud-edge system called *GPFS*, a graph convolutional neural network–based sequence-to-sequence learning method, to implement a computer vision–based human pose forecasting based on a sequence of historical pose frames in edge environments. GPFS enhances the sequence encoder by representing both the spatial and temporal connections of the human joints using graphs and capturing both motion patterns of joints and the correlations among human joints. The system has been extended to cope with online data for adapting the cloud-trained model.

3 QUALITY OF EXPERIENCE, PRIVACY PRESERVATION

"Queec: QoE-Aware Edge Computing for IoT Devices Under Dynamic Workloads" presents a QoE-aware edge computing system for complex IoT event processing that can be hardly supported by low-end IoT devices due to limited resources. This system deals with dynamic workloads by offloading computation-intensive tasks from low-end IoT devices to nearby edge nodes in a fast and transparent manner. An optimization of scheduling multi-user tasks to multiple edge nodes ensures that the offloading latency is minimized automatically.

In "Privacy-Preserving Data Aggregation Against Malicious Data Mining Attack for IoT-Enabled Smart Grid,"the authors propose a privacy-preserving data aggregation scheme called *PDAM* to support efficient data source authentication, integrity checking, and secure user participation in IoT-enabled smart grids. PDAM is resilient to malicious data mining attacks launched by internal or external attackers; it also achieves data confidentiality against both a malicious aggregator and a curious control center for an authorized user.

In "Clustering-Based Efficient Privacy-Preserving Face Recognition Scheme Without Compromising Accuracy," the authors focus on reducing the computational cost of preserving a query face image and propose an efficient privacy-preserving face recognition scheme based on clustering. The scheme matches an encrypted face query against clustered faces in the repository to save the computational cost while preserving the identification accuracy via a multi-matching scheme. They achieve a sub-linear time complexity, which is important for time-critical face identification applications based on the IoT.

4 ENERGY MONITORING AND CONSUMPTION OPTIMIZATION

In "Deep Reinforcement Learning for Tropical Air Free-Cooled Data Center Control," the authors target at controlling the supply air temperature and relative humidity adaptively to maintain the computing performance and reliability of servers in air free-cooled data centers in tropical zones. They model the problem as Markov decision processes and apply deep reinforcement learning to learn the policy that can minimize the energy consumption under the temperature and relative humidity constraints on the air supply.

In "Semi-Supervised Intrusive Appliance Load Monitoring in Smart Energy Monitoring System," the authors introduce a semi-supervised learning method that leverages labeled and unlabeled datasets to classify appliances in an IoT-based energy monitoring system in a smart home environment. The samples are generated by a transformation built upon weighted versions of the DTW Barycenter Averaging algorithm and are fitted into consistency learning to solve the practical case that labeled data are often insufficient to support accurate supervised learning.

In "Energy-Efficient Collaborative Sensing: Learning the Latent Correlations of Heterogeneous Sensors," the authors present a novel energy-efficient collaborative sensing framework to optimize the energy consumption of IoT devices to enable energy-efficient sensing and rich-sensor inference tasks on resource-constrained IoT devices. The framework discovers latent correlations among heterogeneous sensors via an attention mechanism in a temporal convolutional network. It then applies multi-task learning to predict the statuses of energy-intensive sensors based on the low-power sensors, which make it possible to decrease the sampling frequency of energy-intensive sensors to save energy.

5 CONCLUSION

We would like extend our appreciation to all of the authors from both academic and industry backgrounds for their support and excellent contributions to the vibrant area of machine intelligence for the IoT. Their results undoubtedly help researchers and practitioners to leverage the full potential and opportunities brought by the massive and ubiquitous IoT data. We would also like to thank the reviewers for their efforts in reviewing, as well as their invaluable comments and constructive suggestions that helped improve the quality of these papers. Finally, we appreciate the advice and support of the Editor-in-Chief of this journal, Professor Yunhao Liu, for his help in the whole publication process.

Yunhao Liu

Editor-in-Chief