IEEE TCCN Special Section Editorial: Intelligent Resource Management for 5G and Beyond

LEARNING from massive network data to produce cognitive knowledge for efficient resource management in 5G and beyond 5G (B5G) is still challenging. We are delighted to introduce the readers to this special section of the IEEE TRANSACTIONS ON COGNITIVE COMMUNICATIONS AND NETWORKING (TCCN), which aims at exploring recent advances and addressing practical challenges in the intelligent resource management in 5G/B5G. We have received a total number of 30 submissions, and after a rigorous review process, 15 articles have been selected for publication, which are briefly discussed as follows.

With the broad deployment of IoT and mobile devices, 5G provides more sufficient services but is hard to control all the resources efficiently. The first article, entitled "Fine-Grained Management in 5G: DQN Based Intelligent Resource Allocation for Network Function Virtualization in C-RAN," authored by Zhang, Dong, and Ota, introduced a DQL (Deep Q-learning Network) based intelligent resource management method to improve the quality-of-service (QoS) under limited network resources. The simulation shows that the proposed MSIO improves 3.12% with the maximum communication quality and the ARODQ algorithm improves 4.05% compared with other classical solutions. Through the above network slicing based resource management, they explore the efficient spectrum usage for 5G and B5G.

In the second article, entitled "Human-Behavior and QoE-Aware Dynamic Channel Allocation for 5G Networks: A Latent Contextual Bandit Learning Approach," Zhou *et al.* studied an innovative idea of using the human behavioral data and channel condition information in 5G networks by using state-of-the-art machine learning tools to improve the quality-of-experience (QoE) of end users. It considers the individual users' contexts to improve their QoE as well as exploring the user mobility data to make intelligent channel resource allocations. It is the first time to figure out that the "latent" information of the underlying clusters of users' locations can be learned by the proposed low-complexity contextual bandits algorithms to improve the communication performance. Experiments demonstrate an about 30% QoE improvement than classic bandits algorithms and an about 45% QoE improvement than the case without implementing machine learning algorithms.

A 5G network is the key driving factor in the development of vehicle-to-vehicle (V2V) communication technology. Considering the fast channel variations and the continuous-valued state in a high mobility vehicular environment, in the third article, entitled "A Reinforcement Learning Method for Joint Mode Selection and Power Adaptation in the V2V Communication Network in 5G," Zhao *et al.* proposed a reinforcement learning (RL) framework based on V2V communication mode selection and power adaptation. The simulation results show that the proposed method can significantly optimize the total capacity of the vehicle-to-infrastructure (V2I) links and ensure the latency and reliability requirements of the V2V links. The solution proposed in this paper can further enhance the intelligent management of 5G networks.

In traditional cognitive radio networks, the limited spectrum aggregation capacity of cognitive users makes full-band perception inefficient and unnecessary. The fourth article, entitled "Deep Reinforcement Learning for Dynamic Spectrum Sensing and Aggregation in Multichannel Wireless Networks," by Li *et al.*, presented the use of a deep reinforcement learning method to help a user to learn spectrum sensing and aggregation strategies independently. The proposed solution uses partial perception and is based on the user's own bandwidth demand and aggregation capacity in unknown dynamic spectrum environments. Simulation results show that the proposed method can achieve near-optimal decision accuracy in most scenarios with stable temporal and spatial complexity. This work provides an example on the combination of deep reinforcement learning and intelligent spectrum resource utilization for 5G and B5G.

Traditional spectrum availability detection approaches rely on spectrum sensing techniques, which, however, consume considerable energy and time, and require complex prior information from primary users (PUs). In the fifth article, entitled "Spectrum Availability Prediction for Cognitive Radio Communications: A DCG Approach," Yu *et al.* leveraged fine-tuned CNN (Convolutional Neural Network) and GRU (Gated Recurrent Unit) models to develop a hierarchical spectrum learning model called DCG to perform local spectrum availability prediction for each secondary user (SU). Moreover, it designs an enhanced DCG model to enable two SUs to find the same channel to communicate with each other through channel selection prediction. This paper conducts thorough simulations to show that the designed models achieve high prediction accuracy with limited training overhead.

The sixth article, entitled "A GRU-Based Prediction Framework for Intelligent Resource Management at Cloud Data Centres in the Age of 5G," by Lu *et al.*, introduced an

Digital Object Identifier 10.1109/TCCN.2020.2993976

intelligent prediction framework called IGRU-SD (Improved Gated Recurrent Unit with Stragglers Detection), to predict the anticipated level of resource requests. Experimental results demonstrate that the proposed IGRU-SD prediction framework outperforms the existing predicting models based on ARIMA (Auto Regressive Integrated Moving Average), RNN (Recurrent Neural Network) and LSTM (Long Short Term Memory) in terms of the achieved prediction accuracy.

In the seventh article, entitled "Intelligent Traffic Adaptive Resource Allocation for Edge Computing-Based 5G Networks," Chen *et al.* focused on artificial intelligence for controlling mobile traffic flow. They developed traffic flow prediction algorithms for both single-site mode and multi-site cases. Experiments show the effectiveness of the proposed scheme in reducing communication latency and its impact on lowering packet loss ratio.

The integrated terrestrial-satellite network is an important direction for future communications, in which efficient resource allocation is crucial due to the integrated architecture. The eighth article, entitled "Two-Layer Game Based Resource Allocation in Cloud Based Integrated Terrestrial-Satellite Networks," authored by Zhu *et al.*, proposed a two-layer game based resource allocation scheme in the cloud based integrated terrestrial-satellite network. The optimal pricing strategy is obtained to maximize the utility of the operator while satisfying QoS constraints of users. Simulation results show that the proposed integrated network can make full use of the power and computation resources, and also reduce the energy consumption. This paper provides possible solutions for intelligent resource management in integrated networks B5G.

Efficient spectrum scheduling is challenging for 5G-satellite integrated networks due to the limited amount of spectrum. In the ninth article, entitled "Intelligent Spectrum Assignment Based on Dynamical Cooperation for 5G-Satellite Integrated Networks," Tang *et al.* proposed the cooperative transmission ability model and formulate the intelligent spectrum assignment problem. Based on dynamical cooperation among PUs and cognitive users (CUs), the authors presented a stable matching-based cooperative transmission algorithm. Simulation results demonstrate significant improvements in spectrum utilization and system performance.

The tenth article, entitled "End-to-End Performance-Based Autonomous VNF Placement With Adopted Reinforcement Learning," by Bunyakitanon *et al.*, introduced an Adapted REinforcement Learning VNF Performance Prediction module for autonomous VNF placement that enhances MANagement and Orchestration framework (MANO) decisions, particularly for end-to-end delay-sensitive applications. It contributes to this special issue, which focuses on the end-to-end intelligent resource management, by leveraging end-to-end service-level performance predictions for placing VNFs based on an adapted reinforcement learning model. This makes VNF placement decisions (i) more resilient to dynamic conditions, as well as (ii) portable to other network nodes and (iii) able to generalize in heterogeneous network environments. Experimental results verify an increased accuracy of VNF performance predictions by 40%–45% and an overall improved VNF placement efficiency over supervised learning models in 23 out of a total of 27 investigated scenarios.

The mobile edge computing as the core technology of the 5G resource management can be empowered by the micro-services architectures. In order to maintain healthy and robust micro-services systems, in the eleventh article, entitled "An Intelligent Anomaly Detection Scheme for Micro-Services Architectures With Temporal and Spatial Analysis," Zuo *et al.* aimed at efficient fault management through adaptive temporal and spatial analysis. They proposed an intelligent anomaly detection framework, which jointly digests functioning log data by template extraction and representation learning, and services dependency relations by embedded tracing matrix. The empirical experiments visualize the integrated numerical features indicating the latent distribution of normal samples, and successfully segment abnormal samples based on outlier detection. The proposed anomaly detection scheme can improve the performance of intelligent resource management.

Network data collection plays a fundamental role in network management and network intrusion detection. However, existing literature lacks an economic data collection method, especially in Software Defined Networks (SDNs). In the twelfth article, entitled "An Adaptive Network Data Collection System in SDN," Zhou *et al.* proposed an adaptive network data collection system in SDN by making use of centralized control and programming. It selects collection nodes based on network performance status and decides traffic sampling probability according to traffic flow characteristics in order to reduce the volume of collected data and ensure data analysis accuracy simultaneously. Experimental results show the system outperforms existing works in terms of CPU (Central Processing Unit) and memory consumption, flow recovery and network threat perception ability. This work contributes to this special issue by providing a practical and intelligent method of network data collection that can save network node resources and facilitate resource management in the context of 5G and B5G.

As the densification of 5G networks, managing the performance in such a complex network will be challenging. Particularly, ultra-dense networks pose inter-call interference that challenges scheduling of transmissions. The thirteenth article, entitled "Dynamic Scheduler Management Using Deep Learning," by Hall *et al.*, explored deep reinforcement learning approach that can dynamically adjust the choice of schedulers for each cell to jointly deliver the best user experiences. Three training methods were studied in the approach including batch-based, NeuralBandit-based, and experience replay training. The paper shows that the approach can achieve an increase of up to 77% of user quality of service satisfaction compared to that of the static homogeneous scheduler deployment.

In the fourteenth article, entitled "Intelligent Trajectory Inference Through Cellular Signaling Data," Qi, Shen, and Yin proposed a novel localization algorithm using signaling data in cellular networks. The proposed approach incorporates novel filtering techniques to identify the most accurate Timing Advance (TA) data, and then runs a map-matching algorithm to locate a user. Evaluations on real world traces show that it achieves a high trajectory matching accuracy in metropolitan area. This paper provides a solution on intelligent use of signaling data for cellular systems.

Finally, in the last article, entitled "Lightweight Batch AKA Scheme for User-Centric Ultra-Dense Networks,"

Yao *et al.* focused on an important challenge of emerging 5G networks with ultra-dense deployment of access points: namely, reliable and secure authentication and authorization. Rigorous security analysis, supported by extensive performance evaluation, demonstrates that the proposed lightweight batch authentication and key agreement (LBAKA) scheme can maintain the privacy of identity information under a variety of attacks with less computation and communication overhead than other existing solutions. The proposed scheme thus provides a viable solution to one of the crucial problems posed by end-to-end resource management for 5G networks.

The Guest Editor team is pleased with the technical depth and span of this Special Section in IEEE TCCN. We also recognize that it cannot cover all emerging issues on intelligent resource management for 5G and beyond. We sincerely thank all the authors and reviewers for their efforts, and the Editor-in-Chief and Staff Members for their gracious support. We hope that the readers will enjoy this special section.

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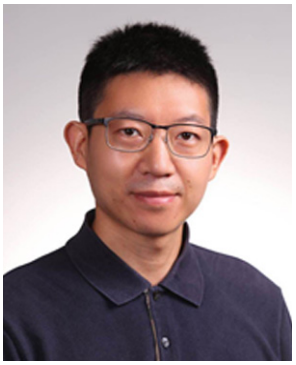

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