Series Editorial: The Third Issue of the Series on Machine Learning in Communications and Networks

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I. Introduction

THE Second Call for Papers of the Series on Machine Learning in Communications and Networks has continued to receive a great number of high-quality papers covering various aspects of intelligent communication systems. In addition to those already published, we include in this issue 27 articles that have been submitted to the call. In the following, we provide a brief review of key contributions of papers in this issue according to their topics.

II. Invited Papers

The invited paper, titled "Interplay between RIS and AI in Wireless Communications: Fundamentals, Architectures, Applications, and Open Research Problems," by Wang *et al.*, comprehensively overviews the state-of-the-art of artificial intelligence (AI)-enhanced reconfigurable intelligent surfaces (RISs), and explores the path to integrating AI with RISs in future wireless networks.

III. Signal Processing

This issue consists of seven papers that address various problems in signal processing using machine learning. The paper, titled "Joint Deep Reinforcement Learning and Unfolding: Beam Selection and Precoding for mmWave Multiuser MIMO with Lens Arrays," by Hu *et al.*, uses deep reinforcement learning (DRL) for the beam selection and deep-unfolding neural network (NN) for the digital precoding optimization. The design outperforms the existing ones in terms of complexity and robustness. In the paper, titled "An Efficient Specific Emitter Identification Method Based on Complex-Valued Neural Networks and Network Compression," by Wang *et al.*, develop a complex-valued NN approach to identifying radio frequency transmitters from their transmitted signal characteristics with reduced model sizes, lower complexity, and less inference time. Experiments results show that the system could reach nearly 100% classification accuracy at high signal-to-noise ratios (SNRs). The paper, titled "Machine Learning for MU-MIMO Receive Processing in OFDM Systems," by Goutay *et al.*, develops a multi-user multiple-input multiple-output (MIMO) receiver that complements a conventional linear receiver with convolutional NNs in order to improve the computation of the channel statistics as well as to propose an alternative demapper that works with all resource elements of the OFDM grid. The results show performance gains over the baseline as well as its scalability. The paper, titled "DeepMux: Deep-Learning-Based Channel Sounding and Resource Allocation for IEEE 802.11ax," by Sangdeh *et al.*, proposes the DeepMux, a deep learning (DL)-based channel detection protocol and a DL-based resource allocation algorithm. The results evaluated by the test platform show that DeepMux has the potential to improve the throughput of the IEEE 802.11ax system. The paper, titled "Deep Active Learning Approach to Adaptive Beamforming for mmWave Initial Alignment," by Sohrabi *et al.*, works on a DL approach to the adaptive and sequential beamforming design problem for the initial access in a millimeter-wave (mmWave) environment with a single-path channel. An NN is adopted to directly map the available information to the sequence of adaptive beamforming. Both the grid-based angle-of-arrival (AoA) estimation and grid-less AoA estimation are discussed. In the paper, titled "Triplet-Based Wireless Channel Charting: Architecture and Experiments," by Ferrand *et al.*, propose a triplet-based channel charting pipeline as well as its extension to improve the standard pipeline. The proposed method is tested with real measurement data, and its efficacy is validated. The paper, titled "Online Downlink Multi-user Channel Estimation using Bayesian Neural Network," by Kumar *et al.*, develops a Bayesian DL framework for model driven online sparse channel estimation in multi user MIMO systems. Tools from Bayesian NN and stochastic variational Bayesian inference are utilized to capture aleatoric and epistemic uncertainty estimates. The proposed framework

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enables marginalizing over penalty parameters and is more suited for online scenario with changing environments.

IV. Learn to Transmit and Semantic Communications

There are three papers in the category of learn to transmit and receive. The paper, titled "Model-Driven Deep Learning Based Channel Estimation and Feedback for Millimeter-Wave Massive Hybrid MIMO Systems," by Ma *et al.*, proposes a model-driven DL (MDDL)-based channel estimation and feedback scheme for wideband mmWave massive hybrid MIMO systems, where the angle-delay domain channels' sparsity is exploited for reducing the overhead. Numerical results show that the proposed MDDL-based channel estimation and feedback scheme outperforms the state-of-the-art approaches. In the paper, titled "Deep-Waveform: A Learned OFDM Receiver Based on Deep Complex-valued Convolutional Networks," by Zhao *et al.*, a deep complex-valued convolutional network (DCCN) has been developed to recover bits from time-domain OFDM signals without relying on any explicit DFT/IDFT. The DCCN can exploit the cyclic prefix (CP) of OFDM waveform for increased SNR by replacing DFT with a learned linear transform. It demonstrates the capability of deep NNs in processing OFDM waveforms and suggests that the FFT processor in OFDM receivers can be replaced by a hardware AI accelerator. The paper, titled "Blind Channel Codes Recognition via Deep Learning," by Shen *et al.*, proposes three channel coding recognizers based on recurrent NNs (RNNs), the attention mechanism, and residual neural networks (ResNet), respectively, to recognize the type and encoding parameters of channel codes from noisy signals.

There is one paper on semantic communications in this issue. In the paper, titled "Semantic Communication Systems for Speech Transmission," by Weng *et al.*, attempt to recover the semantic content inside speech signals, minimizing errors at the semantic rather than the bit or symbol level. A DL-enabled semantic communication system for the transmission of speech signals, named DeepSC-S, has been developed based on an attention mechanism by utilizing a squeeze-and-excitation network, which shows desirable performance and is robust to channel variations, especially in low SNR regime.

V. Resource Management and Network Optimization

We have seven papers in this issue that deal with resource management and network optimization using machine learning techniques. In the paper, titled "Incentive-driven Deep Reinforcement Learning for Content Caching and D2D Offloading," by Zhou *et al.*, a novel incentive-driven deep Q-network-based method, named IDQNM, is proposed to encourage device-to-device (D2D) offloading and content caching, in which the reverse auction is employed as the incentive mechanism. To solve the formulated integer non-linear programming (INLP) maximizing the saving cost of the content service provider (CSP), the content caching method based on DRL is proposed to get the approximate optimal solution, and a standard Vickrey–Clarke–Groves (VCG)-based payment rule is proposed to compensate for mobile nodes' cost. The paper, titled "TCP-NeuRoc: Neural Adaptive TCP Congestion Control with Online Changepoint Detection," by Li *et al.*, develops a novel congestion control mechanism called NeuRoc that uses online changepoint detection and the DRL technique to generate the optimal congestion control policy, which allows TCP operating at Kleinrock's optimal operation point to achieve full bandwidth usage and low latency. The paper further proposes a cold-started training and deployment framework to reduce the cost of bootstrap in deployment. The paper, titled "PnP-DRL: A Plug-and-Play Deep Reinforcement Learning approach for Experience-Driven Networking," by Xu *et al.*, proposes PnP-DRL, an offline-trained solution, to address the unexpected performance degradation or even system crash due to random exploration and half-trained policies when deploying DRL in the real world. The proposed method leverages batch reinforcement learning to learn the best control policy from pre-collected transition samples without interacting with the environment.

The paper, titled "Age of Information Aware VNF Scheduling in Industrial IoT Using Deep Reinforcement Learning," by Akbari *et al.*, utilizes the single agent low-complexity compound action actor-critic RL to cover both discrete and continuous actions and jointly minimize virtual network functions (VNFs) cost and the age of information (AoI) in terms of network resources under end-to-end quality-of-service constraints. To surmount the single-agent capacity limitation for learning, the proposed solution is further extended to a multiagent deep RL scheme in which agents collaborate with each other. The paper, titled "Fuzzy Logic-Based Resource Allocation Algorithm for V2X Communications in 5G Cellular Networks," by Zhang *et al.*, develops a self-adaptive fuzzy logic-based strategy to intelligently allocate resources for vehicle-to-everything (V2X) communications in 5G cellular networks. Simulation results reveal that the proposed fuzzy logic-based algorithm improves resource utilization and satisfy V2X requirements. The paper, titled "Buffer-Aided Relay Selection for Cooperative Hybrid NOMA/OMA Networks with Asynchronous Deep Reinforcement Learning," by Huang *et al.*, considers a two-hop relay selection problem over hybrid NOMA/OMA transmission with the buffer length and delays constraints. Two asynchronous reinforcement learning-based schemes are proposed to solve the problem. Simulation results demonstrate the effectiveness of the proposed algorithms. The paper, titled "A Deep Reinforcement Learning Framework for Contention-Based Spectrum Sharing," by Doshi *et al.*, considers decentralized contention-based medium access for base stations (BSs) operating on unlicensed shared spectrum, where each BS autonomously decides whether to transmit on a given resource. The developed distributed reinforcement learning framework provides decentralized inference, online adaptability and also caters to partial observability of the environment through recurrent Q-learning. Empirically, the maximization of the proportional fairness metric is competitive with a genie-aided adaptive energy detection threshold,

while being robust to channel fading and small contention windows.

VI. Distributed/Federated Learning and Communications

Four papers in this issue study distributed or federated learning in communications and networks. The paper, titled "LOSP: Overlap Synchronization Parallel with Local Compensation for Fast Distributed Training," by Wang *et al.*, proposes a new synchronization mechanism for fast distributed learning, named LOSP, which overlaps computation and communication procedures and introduces local compensation to mitigate adverse effects caused by non-strict synchronization. It is theoretically proved that LOSP preserves the same convergence rate as the sequential stochastic gradient descent for non-convex problems, and exhibits good scalability. Evaluations show that LOSP significantly improves convergence accuracy and communication costs. In the paper, titled "Scalable Orchestration of Service Function Chains in NFV-enabled Networks: A Federated Reinforcement Learning Approach," by Huang *et al.*, a novel scalable service function chain (SFC) orchestration (SSCO) scheme is proposed for network function virtualization (NFV)-enabled networks. A federated-learning-based framework is designed to train a global learning model, with time-variant local model explorations while avoiding data sharing. Simulation results demonstrate that SSCO significantly reduces placement errors, improves resource utilization ratios, and achieves desirable scalability. The paper, titled "Slashing Communication Traffic in Federated Learning by Transmitting Clustered Model Updates," by Cui *et al.*, proposes the model update compression by soft clustering (MUCSC) algorithm to compress model updates transmitted between clients and the parameter server in federated learning. It is proved that the compressed model updates are unbiased estimates of their original values and MUCSC can minimize influence of the compression error on the model accuracy. The boosted MUCSC algorithm is further developed to achieve a high compression rate by grouping insignificant model updates into a super cluster. The paper, titled "A Joint Learning and Communication Framework for Multi-Agent Reinforcement Learning over Noisy Channels," by Tung *et al.*, proposes a novel formulation of the "effectiveness problem" in communications by considering multiple agents communicating over a noisy channel under the multi-agent reinforcement learning (MARL) framework. It generalizes both the traditional communication problem, where the main goal is to convey a message reliably over a noisy channel, and the "learning to communicate" framework in MARL, where the underlying communication channels are assumed to be error-free.

VII. Selected Topics

We have one paper in this issue using DL for radio frequency fingerprint identification. The paper, titled "Radio Frequency Fingerprint Identification for LoRa Using Deep Learning," by Shen *et al.*, develops a DL-based radio frequency fingerprint identification (RFFI) scheme for LoRa systems with DL. Theoretical and experimental results show the proposed LoRa identification scheme effectively addresses the carrier frequency offset drift, and the proposed hybrid classifier with three DL architectures can significantly improve the accuracy and stability of RFFI.

We have three papers addressing robustness against malicious attacks in machine learning. Robust backdoor attacks have been developed in "Defense-Resistant Backdoor Attacks against Deep Neural Networks in Outsourced Cloud Environment," by Gong *et al.*, that can evade existing defense strategies from the standpoint of malicious cloud providers. They have refined the trigger generation algorithm by selecting the neurons with large weights and activations and then computing the triggers via gradient descent to maximize the value of the selected neurons. Furthermore, they have extended the attack space by proposing multi-trigger backdoor attacks that can misclassify inputs with different triggers into the same or different target labels. The paper, titled "Evaluating and Improving Adversarial Robustness of Machine Learning-Based Network Intrusion Detectors," by Han *et al.*, studies the gray/black-box traffic-space adversarial attacks to evaluate the robustness of ML-based intrusion detection systems (NIDSs). The proposed attack can automatically mutate original traffic with limited knowledge and affordable overhead while preserving its functionality. It is effective for evaluating the robustness of various NIDSs using diverse ML/DL models and non-payload-based features, and includes an explanation method for the fragile robustness of ML-based NIDSs. In the paper, titled "Robust Online Learning against Malicious Manipulation and Feedback Delay with Application to Network Flow Classification," by Li *et al.*, investigate robust online learning using delayed feedback to address malicious data generators that attempt to gain favorable outcomes by manipulating data features. Four algorithms have been proposed considering whether the feedback delay is static or dynamic and whether the malicious data generators are clairvoyant or not. The article derives regret bounds for the four algorithms, show that they are sub-linear under mild conditions, and further evaluate the algorithms in network flow classification via experiments using real-world data traces.

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Finally, we wish the contents of our Series will inspire the readers to investigate the challenging and open problems in the field of machine learning in communications.