# IEEE TCCN Special Section Editorial: Machine Learning and Artificial Intelligence for the Physical Layer

WE ARE delighted to introduce 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 applications of machine learning (ML) and artificial intelligence (AI) for physical layer design and optimization. We have received a total number of 36 submissions, and after a rigorous review process, 12 articles have been selected for publication, which are briefly discussed as follows.

The first article, titled "DeepReceiver: A Deep Learning-Based Intelligent Receiver for Wireless Communications in the Physical Layer," authored by Zheng *et al.* proposes a novel receiver model, namely DeepReceiver, to recover the original information from the distorted signal by means of a deep neural network. In the receiver model, a one-dimensional convolution DenseNet (1D-Conv-DenseNet) structure is used to improve the adaptability of the network to different input signal lengths. At the output layer, multiple binary classifiers are used to achieve multi-bit information stream recovery. Simulation results show that the proposed DeepReceiver is capable of achieving better bit error rate (BER) performance under the influence of various factors, such as noise, RF impairments, multipath fading, cochannel interference, dynamic environments, and unified reception of multiple modulation and coding schemes (MCSs).

The second article, titled "Automatic Modulation Classification Based on Deep Residual Networks With Multimodal Information," authored by Qi *et al.* exploits a waveform-spectrum multimodal fusion (WSMF) method to realize automatic modulation classification (AMC) based on deep residual networks (Resnet). Different from most existing AMC methods, the proposed WSMF method obtains the processing gain by fusing multimodal information from multiple transformation domains together. Simulation results demonstrate performance advantages of the proposed WSMF method, which is capable of distinguishing among sixteen modulation signals and exhibits good performance even for higher-order digital modulation types.

The third article, titled "Contour Stella Image and Deep Learning for Signal Recognition for the Physical Layer," authored by Lin *et al.* develops a framework to transform complex valued signal waveforms into images with statistical significance, namely contour stellar image (CSI). The proposed framework can convey deep statistical information from raw wireless signal waveforms and bridge the gap between signal waveforms to deep learning (DL) amenable data formats. Furthermore, several potential application scenarios and effective CSI-based solutions to address signal recognition challenges are presented. The investigation validates that CSI can help bridge the gap improving signal recognition with DL.

The fourth article, titled "Visualizing Deep Learning-Based Radio Modulation Classifier," authored by Huang *et al.* visualizes different deep learning-based radio modulation classifiers by introducing a class activation vector. Both convolutional neural network (CNN) based classifiers and long short-term memory (LSTM) based classifiers are investigated by exploring different hyperparameter settings via extensive numerical evaluations. The numerical results indicate that, both the CNN-based classifier and LSTM-based classifiers extract similar radio features relating to modulation reference points, and that the radio features extracted by deep learning-based classifiers can be dependent on the contents carried by radio signals.

The fifth article, titled "Open Set Wireless Transmitter Authorization: Deep Learning Approaches and Dataset Considerations," authored by Hanna *et al.* investigates the problem of recognizing authorized transmitters and rejecting others. This problem is formulated as open set recognition and anomaly detection. Some methods based on one or more binary classifiers, multiclass classifiers and signal reconstruction are studied in transmitter authorization. The authorization method's robustness against temporal changes in fingerprints is also evaluated as a function of the approach and the dataset structure. Simulation results show that the method can achieve an outlier detection accuracy of 98% on a same day test set and of 80% on a different day test set.

The sixth article, titled "Multi-Agent Deep Reinforcement Learning-Based Trajectory Planning for Multi-UAV Assisted Mobile Edge Computing," authored by Wang *et al.* proposes a multi-agent deep reinforcement learning algorithm to independently manage the trajectory of each UAV, with the final goal of jointly optimizing the geographical fairness among all user equipment (UEs), the fairness of each UAV's UE-load and the overall energy consumption of UEs. Simulation results show that the proposed method can achieve better performance than other traditional algorithms in terms of fairness for serving UEs, fairness of UE-load at each UAV and energy consumption for all the UEs.

The seventh article, titled "UAV-Assisted Wireless Energy and Data Transfer With Deep Reinforcement Learning," authored by Xiong *et al.* investigates the energy and data

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transfer optimization problem in unmanned aerial vehicle (UAV)-assisted communications. By means of the value iteration algorithm, the Markov decision process (MDP) model can be solved to obtain optimal strategies of the UAV to collect data, deliver data, and receive transferred energy to replenish on-device battery energy storage, which maximizes the long-term utility of the UAV effectively. Simulations and numerical results validate that, the deep reinforcement learning (DRL) based MDP model is capable of achieving better wireless energy and data transfer strategies in terms of higher long-term utility of the UAV.

The eighth article, titled "Coordinated Beamforming for UAV-Aided Millimeter-Wave Communications Using GPML-Based Channel Estimation," authored by Wang *et al.* proposes an UAV-aided communication scheme to enhance the quality of service (QoS) of edge users in the 5th generation (5G) networks. In the proposed scheme, the UAV only feeds back the channel state information (CSI) to the primary base station (BS). Therefore, a machine learning based channel estimation scheme is studied to reduce the performance loss caused by the CSI feedback delay. Moreover, a maximize signal to interference-plus-noise ratio (Max-SINR) based beamforming compensation scheme is also proposed to reduce inter-BS interference, which helps coordinated BSs perform hybrid beamforming. The simulation results show that the proposed scheme improves the BER and sum rate performance.

The ninth article, titled "Q-Learning Based Spectrum Access for Multimedia Transmission Over Cognitive Radio Networks," authored by Huang *et al.* proposes a novel Q-learning based spectrum access scheme to improve the spectrum efficiency of cognitive radio. In the proposed Q-learning algorithm, the reward function is redefined by two indicators, i.e., the rigorous delay and throughput performance requirements of multimedia applications, to adaptively allocate multimedia data over multiple idle spectrum holes. The experiments demonstrate that the proposed scheme can quickly converge to a stable state in terms of throughput, power efficiency, and collision probability. Moreover, the proposed learning rate adjustment strategy saves 22% time to achieve the targeted collision probability.

The tenth article, titled "Learning-Based Hybrid Beamforming Design for Full-Duplex Millimeter Wave Systems," authored by Huang *et al.* proposes two learning schemes to design hybrid beamforming (HBF) for full-duplex (FD) millimeter wave systems, i.e., extreme learning machine based HBF (ELM-HBF) and convolutional neural network based HBF (CNN-HBF). In the proposed framework, an alternating direction method of multipliers (ADMM) based algorithm and a majorization-minimization (MM) based algorithm are used to achieve self-interference (SI) cancellation beamforming and joint optimization of transmitting and receiving HBF. Compared with orthogonal matching pursuit (OMP) algorithms, the proposed learning-based schemes can achieve at least 22.1% higher spectral efficiency and reduce the online prediction time by almost 20 times.

The eleventh article, titled "Measuring Sparsity of Wireless Channels," authored by Zhang *et al.* investigates several measures for wireless channel sparsity from the propagation view. The potential measures of channel sparsity considered are the number of multipath components (MPCs), channel degrees of freedom (DoF), the Gini index, and the Ricean $K$ factor. Meanwhile, in order to show the inter-dependency between different measures and channel sparsity, the channel diversity measure is selected as an indicator. Based on realistic channel measurements and data mining methods, the analysis shows that DoF and Gini index provide the best sensitivity and accuracy for measuring channel sparsity, and the widely used channel parameter of Rician $K$ factor has fairly good sensitivity to channel sparsity.

Finally, in the last article, titled "Channel Estimation Enhancement With Generative Adversarial Networks," authored by Hu *et al.*, introduces a generative adversarial network (GAN) based channel estimation enhancement algorithm. A conditional GAN with an improved Wasserstein GAN is integrated in the novel framework to improve the training stability and the learning ability of GANs. In addition, in order to alleviate overfitting that may occur during the training of GANs, a strategy based on a lookup table is also proposed. Numerical results verify that, benefiting from GANs, the proposed GAN-based channel estimation enhancement algorithm improves the accuracy of channel estimation without increasing the training data requirements, and yields lower relative error performance, especially in the low SNR regions.

Our Guest Editor team is pleased with the technical depth and span of this Special Section in IEEE TCCN. We also recognize that it is hard to cover all emerging issues of machine learning and artificial intelligence for the physical layer. 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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