Guest Editorial Special Issue on Machine Learning in Wireless Communication—Part 2

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I. Introduction

MACHINE learning and data driven approaches have recently received much attention as a key enabler for future 5G and beyond wireless networks. Yet, the evolution towards learning-based data driven networks is still in its infancy, and much of the realization of the promised benefits requires thorough research and development. Fundamental questions remain as to where and how ML can really complement the well-established, well-tested communication systems designed over the last four decades. Moreover, adaptation of machine learning methods is likely needed to realize their full potential in the wireless context. This is particularly challenging for the lower layers of the protocol stack, where the constraints, problem formulation, and even the objectives may fundamentally differ from the typical scenarios to which machine learning has been successfully applied in recent years. In addition, a thorough understanding of the fundamental performance limits is also essential in order to establish quality-of-service guarantees that are common in communication system design. Such challenges, which lie at the core of the special issue, can be categorized into a number of research topics ranging from the optization of neural networks architectures that are suited to wireless communication links (inclusing autoencoders, generative adversarial networks, reinforcement based networks etc) to performance analysis, to the acceleration of data-driven training, and possibly in distributed settings. The application domains within the wireless realm are also quite diverse in nature with promising preliminary results in the area of physical layer design and resource allocation as well as for network service orchestrations. Testbeds and experimental evaluations are also begining to be reported.

It is interesting to note that the call for papers received an especially strong response from the community, with no less than 31 original contribution papers being eventually accepted in a double-issue, further attesting of the rapid development of this scientific area. In this guest editorial paper for Part 2 of the special issue, we briefly review the key contributions and map them to the key research themes emerging from the domain of research. The readers are referred to Part 1 of the special issue for an overview paper by the team of guest editors where some of the major promises and challenges of ML in wireless communication systems were reviewed. The special issue (Part 2) contributions are categorized as below:

II. RF and Channel Prediction

In the paper "Proactive received power prediction using machine learning and depth images for mmWave networks," the authors demonstrate the feasibility of proactive received power prediction by leveraging spatiotemporal visual sensing information in the context of reliable millimeter-wave (mmWave) networks. Their mechanism predicts the time series of received power to as many as several hundred milliseconds ahead, by leveraging a combination of camera imagery and machine learning.

In the paper "Sparsely self-supervised generative adversarial nets for radio frequency estimation," the authors consider the problem of Radio frequency (RF) estimation. RF prediction plays a significant role in cellular networks planning. In that paper they propose the use of sparsely self-supervised generative adversarial nets (SSGAN), a novel data-driven model to generate the RF maps of an area from irregularly distributed measurement samples, thereby achieving highers accuracy and finer granularity reconstruction.

In "Decision directed channel estimation based on deep neural network k-step predictor for MIMO communications

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in 5G," the authors employ a deep neural network (DNN) channel predictor to develop a decision-directed (DD)-channel estimation algorithm for MIMO-space-time block coded systems in highly dynamic vehicular environments. The show that the use of the DNN for channel prediction alleviates the need for fast Doppler estimation, which is a serious challenge in vehicular communications.

III. Localization and Positioning

In the paper "A particle filter-based reinforcement learning approach for reliable wireless indoor positioning," wireless indoor positioning is studied and a particle filter-based reinforcement learning (PFRL) approach is proposed. By integrating a reinforcement learning-based resampling method, the robustness against localization failure is improved. The proposed method is validated through experimental results.

In "Active learning and CSI acquisition for mmWave initial alignment," the authors consider the problem of learning the angle of arrival (AoA) from a user to a base station equipped with an antenna array. They propose a sequential active learning algorithm, and derive an upper bound on the expected search time of the proposed algorithm via the Extrinsic Jensen Shannon Divergence. The bound shows that the algorithm asymptotically matches noiseless bisection search, and the error probability decays exponentially in the search time.

In the paper "Machine learning for in-region location verification in wireless networks," the authors consider the problem of verifying whether a user is inside a region of interest (ROI). They show that, for finite data, ML solutions are more accurate than Neyman-Pearson and GLRT tests based on estimated channel statistics.

IV. Physical Layer Design

The paper "Model-free training of end-to-end communication systems" looks at end-to-end learning of communication systems through neural network (NN)-based autoencoders while avoiding the classical issues of requiring a differentiable channel model. The authors present a novel learning algorithm which enables training of communication systems with an unknown channel model or with non-differentiable components.

The paper "A regression approach to certain information transmission problems" investigates a general information transmission model, under independent and identically distributed Gaussian codebook and nearest neighbor decoding rule with processed channel output, using the performance metric of generalized mutual information.

In the paper "Deep learning-based decoding of constrained sequence codes", the authors propose using deep learning approaches to decode fixed-length and variable-length CS codes. They introduce fixed-length constrained sequence decoding based on multiple layer perception (MLP) networks and convolutional neural networks (CNNs), and demonstrate that the new techniques are able to achieve low bit error rates that are close to maximum a posteriori probability (MAP) decoding.

In "Lightweight machine learning for efficient frequency-offset-aware demodulation," the authors explore machine learning techniques to counter the phase error introduced due to residual carrier frequency offset (CFO) and noise. Specifically, they use a support vector machine (SVM) to determine the optimal detection boundaries and perform real-time demodulation. The authors corroborate the analytical results and demonstrate the efficacy of the approach via implementation on software-defined radios.

In "Supervised-learning for multi-hop MU-MIMO communications with one-bit transceivers," the authors consider the problem of effective communication over a nonlinear multi-hop multi-user multiple-input multiple-output relay channel, in which multiple users send information symbols to a multi-antenna base station (BS) with one-bit analog-to-digital converters via intermediate relays, each with one-bit transceiver. Since the optimal maximum-likelihood detector cannot be realized in practice given the unrealistic assumption of having perfect and global channel state information at the BS, a novel detection framework based on supervised-learning is proposed and its performance characterized.

In Enhanced Machine Learning Techniques for Early HARQ Feedback Prediction in 5GâŁž the authors investigate a form of preemptive hybrid automatic request request (HARQ) scheme. They use machine learning tools, namely, extraction of features from the first few iterations of the decoding process and its use as inputs to a classifier, to predict the outcome of the decoding process ahead of time. In turn, this allows the receiver initiate the early transmission of the acknowledgment message, thereby reducing latency without compromising on reliability. The utility of early HARQ is demonstrated in the context of ultra-low latency and high reliability (URLLC) communications.

V. Wireless Security

In the paper "Power control identification: A novel Sybil attack detection scheme in VANETs using RSSI," the RSSI-based Sybil node detection is proposed as an efficient scheme to identify Sybil nodes. After discussing different types of Sybil attacks, a Power Control Identification Sybil Attack Detection (PCISAD) scheme to find anomalous variations in RSSI time series is proposed. Using a linear SVM classifier, the proposed scheme is able to efficiently detect Sybil nodes, and its performance is verified through extensive simulations and real-world experiments.

In the paper "Jam me if you can: Defeating jammer with deep dueling neural network architecture and ambient backscattering augmented communications," an anti-jamming solution is proposed in which the wireless node learns to adapt to the jamming strategy of the jammer. To improve the learning rate, using a new dueling neural network architecture for deep reinforcement learning is proposed. Through extensive simulation results, it is shown that the proposed algorithm learns faster and outperforms other state-of-the-art methods.

VI. Routing and Higher-Layer Protocols

In the paper "SmartCC: A reinforcement learning approach for multipath TCP congestion control in heterogeneous networks," the authors address the challenges created the diverse

QoS characteristics of heterogeneous links when applying congestion control mechanisms, as these suffer from a number of performance problems such as bufferbloat, suboptimal bandwidth usage, etc. In turn they we propose a learning-based multipath congestion control approach capable of dealing with the diversities of multiple communication path in heterogeneous networks.

In "CARMA: Channel-aware reinforcement learning-based multi-path adaptive routing for underwater wireless sensor networks," the authors propose a new adaptive routing protocol for underwater sensor networks. The new protocol adaptively switches between single-path and multi-path routing guided by a distributed reinforcement learning framework that jointly optimizes route-long energy consumption and packet delivery ratio. The protocol is compared to several baselines using actual experiments at sea – which is a highlight of this paper.

David Gesbert (F'11) received the Ph.D. degree from the École Nationale Supérieure des Télécommunications, France, in 1997. From 1997 to 1999, he was with the Information Systems Laboratory, Stanford University. He was a Founding Engineer with Iospan Wireless, Inc., a Stanford spin-off pioneering MIMO-OFDM (now Intel). Before joining EURECOM in 2004, he was an Adjunct Professor with the Department of Informatics, University of Oslo. Since 2017, he has been a Visiting Academic Master within the Program 111 at the Beijing University of Posts and Telecommunications and a member with the Joint BUPT-EURECOM Open5G Lab. Since 2019, he has been heading the Huawei-funded Chair on Adwanced Wireless Systems Towards 6G Networks. He is currently a Professor and the Head of the Communication Systems Department, EURECOM. He has published about 300 papers and 25 patents. He was a recipient of the 2019 ICC Best Paper Award, the 2015 IEEE Best Tutorial Paper Award (Communications Society), the 2012 SPS Signal Processing Magazine Best Paper Award, the 2004 IEEE Best Tutorial Paper Award (Communications Society), the 2005 Young Author Best Paper Award for Signal Processing Society Journals, and paper awards at conferences 2011 IEEE SPAWC and 2004 ACM MSWiM. He is also a Board Member for the OpenAirInterface (OAI) Software Alliance. He was named the Thomson-Reuters Highly Cited Researcher in Computer Science. He was the Technical Program Co-Chair for ICC 2017. Since 2015, he has held the ERC Advanced grant "PERFUME" on the topic of smart device communications in future wireless networks.

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