DATA SCIENCE AND ARTIFICIAL INTELLIGENCE

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Future communication systems will be increasingly complex and heterogeneous, involving multiple networking technologies with different capabilities and characteristics and heterogeneous nodes with diverse features. All constituent elements will effectively interwork with the aim of advanced, high-quality service provisioning in a cost efficient manner, any time, any place in a seamless and transparent way, maintaining consistency, robustness/availability and service continuity. Diverse requirements should be satisfied, stringent performance metrics should be guaranteed, while systems should be enabled to adapt and efficiently evolve to ever changing conditions in a quick pace.

Lately, the unprecedented amount of data availability in conjunction with the advancement in data analytics algorithms and computing processing have acted as a catalyst, allowing for the incorporation of artificial intelligence (AI) and machine learning (ML) capabilities into networks. In this way, knowledge acquisition and intelligent decision making support is enabled, considered to be a viable solution toward efficient network management, handling effectively increasing complexity, heterogeneity and highly dynamic networks' nature. AI/ML empowered future networks are enabled to sense their context of operation, analyze, reason and plan, make a decision, and act in accordance with the decision reached, while they learn from previous experience, thus optimizing their operation. Future networks are expected to have the ability to autonomously think, learn, remember, and adapt to changing conditions in order to achieve end-to-end goals and objectives.

This Series is dedicated to the application of AI, ML, and data analytics to address different problems of communication systems, presenting new trends, approaches, methods, frameworks, systems for efficiently managing and optimizing networks related operations. Even though AI/ML is considered a key technology for next generation networks, still many research challenges need to be solved before it could reach its full potential. This Series has been increasingly popular, steadily receiving a greater number of submissions, despite its short lifetime. For this issue, only three months after the most recent one, eight articles were accepted following a rigorous review process by experts in the area in order to ensure the best possible papers were selected. The first six articles fall within future wireless systems (5G and beyond) design, while the last two apply AI/ML to promote security related solutions to defense mechanisms and end-to-end congestion control.

The first article, "When Machine Learning Meets Wireless Cellular Networks: Deployment, Challenges, and Applications" by Ursula Challita, Henrik Ryden, Hugo Tullberg, provides an overview of the main requirements and key factors identified for efficiently deploying and integrating AI functionalities in 5G and beyond networks. To this respect, authors discuss the distribution of network intelligence, introducing three main types, as well as the challenges posed by a ML-based air interface supporting efficient data transmission, reducing energy consumption, while also satisfying latency requirements of different applications. Data acquisition, data security and integrity, and AI implementation are highlighted as key areas to be further investigated for a successful integration of AI in future wireless networks, while specific properties necessitated for AI-based systems include robustness and efficiency, AI goal alignment, active learning and explainable AI techniques. A diverse set of use case applications of AI to different networking problems are presented, including mobility management, wireless security, localization and physical layer, while the benefits that such techniques can bring to the network are highlighted. The authors conclude that an ML-based architecture for end-to-end communication system design along with an ML-based air interface are open research problems to be further investigated for initial deployments of AI-enabled wireless networks.

In light of the aforementioned, the second article, "A Machine Learning-based Framework for Optimizing the Operation of Future Networks" by Claudio Fiandrino, Chaoyun Zhang, Paul Patras, Albert Banchs, and Joerg Widmer, proposes a general machine learning-based framework that leverages AI and ML tools to efficiently manage and optimize the performance of highly dynamic wireless networks. The proposed framework is modular and can instantiate and orchestrate multiple ML pipelines across different network segments for achieving different objectives. Machine intelligence is enabled into new as well as existing network functions, while reuse of existing control mechanisms with minimal or no modifications is succeeded. The authors use ML to forecast future traffic demands and characterize traffic features, advancing more intelligent decisions in critical network control mechanisms, such as load balancing, routing and scheduling. Their focus is on deep learning algorithms, while they additionally discuss the integration of their proposed solution in the 5G architecture. The proposed framework is validated, considering the proactive routing mechanism, and is shown to significantly reduce packet delay.

In a similar line of work, identifying the importance of traffic prediction to the optimization of network resource management in future wireless systems, the third article, "Assisting for Intelligent Wireless Networks with Traffic Prediction: Exploring and Exploiting Predictive Causality in Wireless Traffic" by Juan Wen, Min Sheng, Jiandong Li, and Kaibin Huang, endeavors to improve traffic prediction accuracy by exploiting predictable causality which arises between occurrences of special events and triggered traffic variations. Traditional temporal and spatial correlation based prediction techniques mainly predict the regular component in traffic, constituting them ineffective for large-scale varying traffic. Therefore, in order to tackle this limitation, the authors propose a novel framework of Correlation and Causality based Prediction (Coca-Predict) that integrates correlation and causality based prediction to exploit their complementary strengths, predicting regular component and variation tendency, hence maximizing the prediction accuracy. Experimental results based on the realistic dataset demonstrate that Coca-Predict provides a significant improvement on prediction accuracy over the state-of-the-art techniques by exploiting traffic causality.

Network slicing is an emerging paradigm in mobile networks in order to meet the highly stringent and diverse user requirements for service provisioning. Network slicing leverages Network Function Virtualization (NFV) to enable the instantiation of multiple virtual networks, i.e. slices, over the same physical network infrastructure. Optimizing managing functions and resource usage under network slicing is a challenging task that necessitates efficient decision making at all network levels, in some cases even in real-time. In light of the aforementioned, in the fourth article, "Network Slicing Meets Artificial Intelligence: An AI-based Framework for Slice Management" by Dario Bega, Marco Gramaglia, Andres Garcia-Saavedra, Marco Fiore, Albert Banchs, and Xavier Costa-Perez, a general framework for AI-based network slice management is outlined, introducing AI into three different key functions of the system, namely, admission control of new slices, radio resource scheduling of slice traffic, and resource allocation to slices in the network core. Practical deep learning architectures are provided for three case studies, illustrating the high typical gain that could be achieved from integrating AI in network slicing. The authors conclude that AI has great potential to optimize next generation mobile network performance, assuming that present AI architecture limitations are properly addressed.

One of the most important open challenges to be addressed in AI/ML based architectures is building and quantifying trust between human end-users and enabling AI algorithms. This is the problem addressed in the fifth article, "Explainable Artificial Intelligence (XAI) for 6G: Improving Trust between Human and Machine" by Weisi Guo. Specifically, the author proposes adoption of Explainable AI that can quantify uncertainty in wireless networks and explain decisions taken in a way humans could understand in order to address the lack of transparency and trust challenge introduced by Deep Neural Networks (DNN). The author outlines core concepts of XAI for future wireless systems including public and legal motivations in AI, definitions of explainability, performance of deep learning techniques in the PHY and MAC layers vs explainability trade off, XAI algorithms and technical methods to improve explainability in deep learning, including symbolic representation, feature visualization techniques, local and global machine learning model reduction, and physics informed design. Finally, open research areas are highlighted.

Privacy preservation and communication limitations are another great challenge to be adequately addressed by AI empowered wireless network architectures. In the sixth article, "Federated Learning for Wireless Communications: Motivation, Opportunities and Challenges" by Solmaz Niknam, Harpreet S. Dhillon, and Jeffery H. Reed, the adoption of federated machine learning in the context of 5G networks and beyond is proposed, satisfying decentralization, privacy preservation, scalability, and efficiency requirements, taking into consideration energy, bandwidth, delay and data privacy concerns in wireless communications. After introducing federated learning, the authors discuss several possible applications in 5G networks, including edge computing and caching, spectrum management, and 5G core network functions. The authors also discuss open critical challenges concerning applications of federated learning and related considerations, including security and privacy, algorithm convergence under communication and computation limitations and wireless setting, referring mostly to wireless channel conditions/quality. To demonstrate the applicability of federated learning to content popularity prediction in a cache-enabled network for augmented reality (AR) applications, simulations were performed and the results indicate that federated learning could approach the performance of a centralized scheme.

As future networks are becoming more and more complex, conventional rule-based congestion control approaches tend to become inefficient. Therefore, ML techniques are embraced to design effective congestion control algorithms. This is the problem addressed in the seventh article, "Machine Learning for End-to-end Congestion Control" by Ticao Zhang and Shiwen Mao, in which a selected review of the recent advances on ML-based end-to-end congestion control is provided and open problems that need to be further investigated from both networking and ML perspectives are discussed, also offering insights on potential future research directions.

The last article falls within the realm of security, exploiting AI to improve the endogenous security and the defense mechanisms of the active defense systems themselves. Specifically, existing static defense measures adopted for online service systems can be fragile and costly. To this respect, learning-enhanced active defense (LAD) is considered to be a promising technology. However, the security of the defense mechanism itself is neglected, focusing on fortifying the protected target. Thus, developing new defense technologies with self-protection capability is of outmost importance. This problem is addressed in the eighth article, "Endogenous Security Defense against Deductive Attack: When Artificial Intelligence Meets Active Defense for Online Service" by Zan Zhou, Xiaohui Kuang, Limin Sun, Lujie Zhong and Changqiao Xu. The authors, after classifying LAD technologies and discussing their merits and shortcomings while analyzing relevant threats, propose a new endogenous security defense mechanism named Learning-enhanced Spatio-temporal Strategy Mutation (LSSM). This mechanism innovatively designs bidimensional strategy mutation against threats from deductive attacks, and thus ensures the endogenous security of the defense mechanism itself. The experimental results highlight the performance of the proposed mechanism.

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