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Editorial: Machine learning-based spectrum occupancy prediction and resource allocation/management for wireless communication systems

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Editorial on the Research Topic
Machine learning-based spectrum occupancy prediction and resource allocation/management for wireless communication systems

Over the past 2 decades, wireless communication systems have undergone a rapid transformation, marked by the transition from fourth generation (4G) to fifth generation (5G) and the ongoing development of sixth generation (6G). This evolution has been driven by the exponential growth of connected devices, the proliferation of the Internet of Things (IoT), and the increasing demand for high data rates, ultra-reliable low-latency communications, and massive machine-type connectivity. These trends inevitably exert unprecedented pressure on spectrum resources, which are inherently scarce and limited. Hence, efficient spectrum management has become one of the most pressing challenges in the design of next-generation wireless networks.

Conventional static allocation strategies are no longer adequate to cope with the highly dynamic nature of modern wireless environments. The coexistence of heterogeneous services, fluctuating traffic patterns, and diverse quality-of-service requirements necessitates more flexible and intelligent approaches to spectrum occupancy prediction (SOP) and resource allocation. In this context, machine learning (ML) has emerged as a transformative tool. By leveraging vast amounts of data and advanced learning architectures, ML can capture hidden patterns in spectrum usage, predict occupancy trends across multiple domains, and enable adaptive allocation decisions in real time. This paradigm shift aligns closely with the vision of cognitive and self-organizing networks, where intelligence is embedded into every layer of the system to enhance efficiency, adaptability, and resilience.

Against this backdrop, the Guest Editors proposed this Research Topic to collect original and high-quality contributions addressing the opportunities and challenges of ML-based SOP and resource allocation/management. The aim is to explore both theoretical

foundations and practical applications, bridging the gap between emerging ML methodologies and real-world wireless systems. In total, four papers have been accepted, each providing unique insights and advancing the state of the art.

The first paper, titled *"Machine Learning-Based Spectrum Occupancy Prediction: A Comprehensive Survey"* by Aygül et al., presents a broad and detailed overview of ML techniques for SOP. The authors systematically review statistical models, classical ML methods, and modern deep learning (DL) frameworks applied to SOP. Special emphasis is given to the role of multidimensional correlations across time, frequency, and space, which are critical for capturing the dynamics of wireless environments. The paper also addresses key challenges such as dataset availability, transferability of models across environments, interpretability of learning outcomes, and vulnerabilities to adversarial manipulation. By synthesizing existing work and outlining unresolved questions, the survey serves as a valuable reference for researchers and practitioners seeking to advance SOP research.

The second contribution, *"Optimizing 5G Resource Allocation with Attention-Based CNN-BiLSTM and Squeeze-and-excitation Architecture"* by Rayyis et al., introduces a hybrid DL framework designed for efficient resource allocation in 5G networks. The proposed model integrates convolutional neural networks (CNNs) for feature extraction, squeeze-and-excitation blocks for adaptive feature recalibration, bidirectional long short-term memory (BiLSTM) networks for temporal sequence modeling, and an attention mechanism for enhanced context awareness. To address the problem of data imbalance, a weighted loss function is employed, while Bayesian optimization is used to fine-tune hyperparameters. Extensive simulations demonstrate that this architecture achieves remarkable accuracy and robustness, outperforming baseline methods in terms of both efficiency and reliability. This work underscores the potential of advanced DL architectures for practical deployment in next-generation wireless systems.

The third accepted paper, *"Graph-Theoretic Approach to Mobility-Aware Frequency Assignment via Deep Q-Learning"* by Kim et al., explores the use of reinforcement learning (RL) for dynamic spectrum allocation in mobile environments. The authors formulate frequency assignment as a graph-theoretic problem, where interference relationships are represented as edges between nodes. By integrating this framework with deep Q-learning, the system is able to adapt frequency assignments as users move, mitigating interference while maintaining efficiency. The paper also discusses the importance of interference span minimization and techniques such as net filter discrimination (NFD) in improving system performance. Simulation results validate the effectiveness of the proposed approach, showing clear improvements in adaptability and interference management compared to conventional assignment schemes.

The fourth and final paper, *"Spatio-Temporal Beam-Level Traffic Forecasting in 5G Wireless Systems Using Multi-Task Learning"* by Tommy et al., addresses the critical challenge of forecasting traffic at the granularity of beams in 5G systems. Unlike traditional traffic prediction approaches, this work employs a multi-task learning framework that captures both spatial and temporal dependencies across beams. By jointly learning related forecasting tasks, the model improves prediction accuracy and generalization. The authors demonstrate that beam-level forecasts enable networks to proactively adjust resources with finer granularity, leading to improved efficiency and reduced congestion. This paper highlights the importance of spatio-temporal learning for traffic-aware resource management, a direction that is highly relevant for dense 5G deployments and future 6G networks.

Collectively, these four contributions showcase the transformative potential of ML in SOP and resource allocation. They span survey work, novel DL architectures, RL frameworks, and multi-task traffic forecasting, thereby providing a multifaceted perspective on the field. At the same time, the papers highlight open challenges such as scalability, interpretability, dataset generation, and robustness, which remain important avenues for future exploration.

Before concluding this editorial, the Guest Editors would like to thank all the authors who submitted their manuscripts to this Research Topic and shared their latest research results. We also extend our sincere gratitude to the reviewers for their constructive feedback and timely evaluations, which greatly enhanced the quality of the published works. Finally, we acknowledge the support of the *Frontiers in Communications and Networks* editorial office for their professional assistance throughout the process.

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