Artificial Intelligence for Cognitive Wireless Communications


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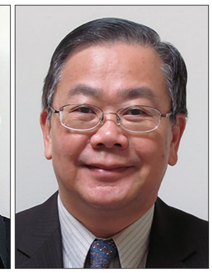
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With the rapid development of wireless communication and networking technologies, novel information services and applications are booming globally. Advanced communications and networks greatly enhance users' experience and have had a significant impact on all aspects of people's lives, including at home, at work, in social exchanges, and economically. Although these advanced techniques have extensively improved users' quality of experience (QoE), they are not adequate to meet the various requirements of seamless wide area coverage, high-capacity hotspot, low-power massive connections, low latency and high reliability, and other scenarios.

Therefore, in order to satisfy the requirements of optimized management, dynamic configuration, and fast service composition, it is a great challenge to develop smart wireless communication and networking technologies. In this case, cognitive computing was put forward to meet the above challenges. Derived from cognitive science and data analytics, cognitive computing can mimic or augment human intelligence, and exhibits great potential to power smart wireless communication networks.

Under the new service paradigm, artificial intelligence (AI) is significant for cognitive wireless communications to meet various technical challenges. The application potential includes complicated decision making, wireless network management, resource optimization, and in-depth knowledge discovery in complex wireless networking environments. At the same time wireless communication and network ecosystems have to be upgraded with new capabilities, including provisioning personalized and smart 5G network services assisted by data cognitive intelligence, advanced wireless signal processing based on deep learning, optimized wireless communication physical layer design based on reinforcement learning, adaptive wireless resource management based on cognitive power, and so on.

This Special Issue presents a comprehensive view of research challenges and opportunities regarding AI for cognitive wireless communications in order to cope with the extreme demands of user experience, efficiency, and performance in a complex wireless networking environment. In response to the Call for Papers, we received over 50 paper submissions. After a careful review process, 13 outstanding articles have been collected for this Special Issue.

In the first article, "Artificial Intelligence Empowered Edge Computing and Caching for Internet of Vehicles," the authors create an innovative AI-empowered vehicular network architecture that can intelligently orchestrate edge computing and caching to enable cross-layer offloading and cooperative multi-point caching. Leveraging advanced deep reinforcement learning (DRL), the proposed architecture and solutions can significantly improve system utility by jointly optimizing edge computing and caching resources. This article is the first work in the literature that integrates AI into edge computing and caching to significantly enhance the intelligence and performance of vehicular networks. The DRL empowered edge resource management and optimization mechanism is an elegant breakthrough to deal with the conflict between heterogeneous requirements of on-vehicle applications and the complexity of the vehicular environment. The work is a leading study to provide intelligence for the future generation autonomous driving.

In the second article, "When RFID Meets Deep Learning: Exploring the Cognitive Intelligence for Activity Identification," the authors introduce an advanced RFID activity identification framework, DeepTag, in which a deep learning based approach is used for activity identification in multipath-rich environments. DeepTag gathers massive phase information from multiple tags, and preprocesses them to extract such key features as pseudospectrum and periodogram. Then the preprocessed signal power and angle information is fed into a deep learning architecture that combines a convolutional neural network (CNN) and a long short-term memory (LSTM) network. The proposed DeepTag framework can well adapt to both tag-attached and tag-free activity identification scenarios.

To address the limitations of conventional D2D communications and caching strategies, the third article, "COCME: Content-Oriented Caching on the Mobile Edge for Wireless Communications," proposes content-oriented caching on the mobile edge for wireless communications, which is caching adequate popular content on the mobile edge. The case study demonstrates that the proposed approaches can effectively decrease the traffic load by consuming an acceptable volume of storage resources on mobile edges.

The fourth article, "Deep Learning Based Energy Efficiency Optimization for Distributed Cooperative Spectrum Sensing," investigates the application of deep learning techniques for wireless communication systems with a focus on energy efficiency optimization for distributed cooperative spectrum sensing. A combinatorial optimization problem is constructed by formulating the energy efficiency of distributed cooperative sensing. Based on this formulation, the authors develop a deep learning framework by means of integrating a graph neural network and reinforcement learning to improve the overall system energy efficiency. Simulation results under different network scales demonstrate the effectiveness of the proposed approach.

In the fifth article, "A Data-Centric Cognitive Gateway with Distributed MIMO for Future Smart Homes," the authors first research the-state-of-the-art techniques and solutions for smart home infrastructure, and discuss both their advantages and disadvantages. Then they propose a data-centric cognitive gateway that is simple, efficient, and secure for smart homes. In addition, the article investigates the trade-off among deployment cost, routine maintenance overhead, and system security.

The sixth article, "Fog Computing for Smart Grid Systems in 5G Environment: Challenges and Solutions," focuses on handling the latency issue during the data analytics in smart grid using fog computing, which acts as a bridge between SG and cloud computing to fill the gap between processing power of remote data centers and smart devices in SG systems. The authors discuss the architecture of SG in the context of fog computing for making the decision about energy requirement by the smart devices at the fog layer. Moreover, the communication and computing aspects are also explored in the context of 5G network infrastructure.

AI provides intelligent computing and optimized design methods for cognitive wireless network and attempts to effectively utilize deep learning and reinforcement learning to meet the resource allocation demands in wireless networks. In the seventh article, "Intelligent Cognitive Radio in 5G: AI-Based Hierarchical Cognitive Cellular Networks," the authors propose a novel paradigm for 5G cellular communication networks, a distributed cognitive cellular network that integrates AI and CR technologies into a sophisticated multi-agent system. Based on multi-agent reinforcement learning, the article makes the dynamic resource allocation balance among PUs, SUs, and BSs. The results show that the method could improve the utilization of spectrum resources in a cognitive cellular network.

In the eighth article, "An Audio-Visual Emotion Recognition System Using Deep Learning Fusion for Cognitive Wireless Framework," the authors propose an automatic audio-visual emotion recognition system in a connected healthcare framework. A 2D CNN model and a 3D CNN model are utilized to obtain the speech modality and visual modality, respectively. The proposed system is evaluated on three databases, and the experiments prove the great performance of the system. In the healthcare framework, edge computing is the basis of the intensive processing cloud computing. In the edge computing, the article realizes edge caching that can store the CNN model parameters. Therefore, it is also demonstrated that the method could achieve high performance in the test.

The ninth article, "Fusion of Cognitive Wireless Networks and Edge Computing," addresses the computing resource waste issue in the context of the large-sized IoT. The authors propose a novel method for achieving a cost-efficiency goal, which emphasizes the cognitive wireless communications in which edge computing techniques and reinforcement learning algorithms are combined. The experimental evaluations show that the proposed paradigm could dramatically reduce computing costs, such as energy consumption

The 10th article, "Toward Intelligent Network Optimization in Wireless Networking: An Auto-Learning Framework," pays attention to using machine learning (ML) techniques to deal with the network optimization problems (NOPs) in wireless communication systems (WCSs). The authors propose an auto-learning framework (ALF) to achieve intelligent and automatic network optimization, and further list six ML-models in ALF, including automatic model construction, experience replay, efficient trial and error, RL-driven gaming, complexity reduction, and solution recommendation. These ML-based proposals provide new insights and motivations for dealing with the NOPs in WCSs.

The 11th article, "Artificial Intelligence Based Data Analytics for Cognitive Communication in Heterogeneous Wireless Networks," focuses on constructing intelligent and effective cognitive communication with the assistance of AI-based data analytics. The authors propose a novel AI-driven data analytics based spectrum allocation algorithm, which enables the adaptive adjustment of the allocation parameters according to the network environmental status during allocating spectrum to users. Deep learning technology is also used to adaptively adjust parameters on the basis of network status during the spectrum allocation process. The proposed algorithm can improve the spectrum utilization rate in heterogeneous wireless networks.

The 12th article, "CONet: A Cognitive Ocean Network," attempts to apply cognitive intelligence to ocean network applications. The authors propose an AI-aware perception sensor layer, an AI-empowered fog layer, and a smart cloud layer applied to future cognitive ocean networks. Meanwhile, the authors also point out the future trends and some issues of the CONet. From testbed experiments, the proposed architecture can improve the experience of exploring the ocean in the future.

In the last article, "Intelligence at the Edge of Complex Networks: The Case of Cognitive Transmission Power Control," the authors explore the latest development path in the field of AI and, particularly, ML may help solve the complex requirements of IoT communications, especially acting in the crucial role of "predictive" communications. The authors illustrate the software architectures and the fundamental mechanisms based on AI in communications. Finally, the article introduces an exemplary case study where ML is successfully employed to find the delicate balance between spectrum and energy efficiency in wireless sensor networks. The emerging panorama for cognitive communications is one in which intelligent processes must start at the very edge and need to transfer meta-learned information in a peer-to-peer fashion.

In closing, we would like to thank all the authors who submitted their research work to this Special Issue. We would also like to acknowledge the contribution of many experts in the field who have participated in the review process, and provided helpful suggestions to the authors to improve the contents and presentations of the articles. We would in particular like to thank Prof. Yi Qian, the Editor-in-Chief, and the publishing team for their support and very helpful suggestions and comments during the delicate stages of concluding the special issue.

Biographies

Kai Hwang [LF] is presently a Presidential Chair Professor in Computer Science and Engineering at the Chinese University of Hong Kong, Shenzhen. He also serves as a chief scientist at the Cloud Computing Center, Chinese Academy of Sciences. He has taught at the University of Southern California and Purdue University for 46 years prior joining CUHK in 2018. He received his Ph.D. in electrical engineering and computer science from the University of California, Berkeley. He has published extensively in the fields of computer architecture, parallel processing, cloud computing, the Internet of Things, and network security.

Min Chen [SM'09] is a professor in the School of Computer Science and Technology at Huazhong University of Science and Technology. He has more than 300 paper publications, including 200+ SCI papers, 80+ IEEE transactions/journal papers, 28 ESI highly cited papers, and 9 ESI hot papers. His Google Scholar Citations reached 16,500+ with an h-index of 64 and i10-index of 204. His top paper was cited 1950+ times. He received the IEEE Communications Society Fred W. Ellersick Prize in 2017. He was selected as a Highly Cited Researcher in 2018.

Hamid Gharavi received his Ph.D. degree from Loughborough University, United Kingdom, in 1980. He joined the Visual Communication Research Department at AT&T Bell Laboratories, Holmdel, New Jersey, in 1982. He was then transferred to Bell Communications Research (Bellcore), where he became a Distinguished Member of Research Staff. In 1993, he joined Loughborough University as a professor and chair of communication engineering. Since September 1998 he has been with the National Institute of Standards and Technology (NIST), U.S. Department of Commerce, Gaithersburg, Maryland. He was the recipient of the Washington Academy of Science (WAS) Distinguished Career in Science Award for 2017. He served as a member of the Editorial Board of the *Proceedings of the IEEE* from January 2003 to December 2008. He has been the Editor-in-Chief of *IEEE Transactions on CAS for Video Technology* and *IEEE Wireless Communications*.

Victor C. M. Leung [F] is currently a Distinguished Professor of Computer Science and Software Engineering at Shenzhen University, China. Prior to his retirement from the Department of Electrical and Computer Engineering at the University of British Columbia (UBC) at the end of 2018, he was a professor and holder of the TELUS Mobility Research Chair. He has contributed more than 1200 peer-reviewed journal/conference papers, 43 book chapters, and 14 books in the areas of wireless networks and mobile systems. He was a winner of the 2012 UBC Killam Research Prize, the IEEE Vancouver Section Centennial Award, and the 2017 Canadian Award for Telecommunications Research. He co-authored papers that won the 2017 ComSoc Fred W. Ellersick Prize, the 2017 *IEEE Systems Journal* Best Paper Award, and the 2018 IEEE CSIM Best Journal Paper Award. He is a Clarivate Analytics "Highly Cited Researcher." He is a Fellow of the Royal Society of Canada, the Canadian Academy of Engineering, and the Engineering Institute of Canada.