Digital Object Identifier 10.1109/OJCOMS.2023.3348029

Guest Editorial: Special Issue on Resource-Efficient Collaborative Deep Learning Over B5G/6G Networks

COLLABORATIVE machine learning is considered as the bedrock of the intelligent B5G networks, where distributed agents collaborate with each other to train learning models in a distributed fashion, without sharing data at a central entity. Despite its broad applicability, the main issue of collaborative learning is the need of local computing to build local learning models as well as iterative information exchange among agents, which may lead to high resource overhead unaffordable in many practical resource-limited systems such as unmanned aerial vehicles (UAVs) and Internet of Things (IoT). To alleviate this resource issue, it is essential to devise resource-efficient collaborative learning techniques, that can optimize the resource overhead in terms of communication, computing, and energy cost, and hence achieve satisfactory optimization/learning performance simultaneously.

Achieving this objective requires synergistic techniques from various fields, including deep learning, optimization, game theory, wireless communications, and graph/network theory. This Special Issue calls for research contributions on resource-efficient collaborative learning from many perspectives, including algorithm design and analysis, fundamental theories, and practical considerations. Through a rigorous review process, eleven papers have been accepted for publication.[1]

In article [A1] by Charatsaris et al., the joint problem of association and uplink transmission power allocation of the users to the edge is formulated and solved as a non-cooperative game in satisfaction form. Different types of equilibria are explored, i.e., the Satisfaction Equilibrium (SE) and Minimum Efficient Satisfaction Equilibrium (MESE) which not only fulfills users' minimum tradeoff but also minimizes the overall network's cost. Algorithms based on Reinforcement Learning (RL) and Best Response Dynamics (BRD) are, then, devised to conclude the SE and MESE points.

The article [A2] by Yeh et al. introduces an intelligent network application (xApp) for network slicing for the open RAN using AI and Deep Learning techniques. The xApp is evaluated with a near Real-Time RAN Intelligent Controller (near-RT RIC) and showed the network slicing functionality in an automated and intelligent fashion.

In [A3], Said et al. propose to equip buses by Intelligent Reflective Surface (IRS) allowing them to act as mobile IRS. These buses will become a relay for the surrounding moving vehicles. Practically speaking, not all buses have to be IRS equipped. Then, the authors design an optimization approach for selecting the best buses equipped with IRS. They use a Multi Integer Linear Programming (MILP) which gives optimal results but with a very long processing time. Furthermore, they propose a neural-network to learn the result of the MILP.

In [A4], Abbas et al. propose an automated Artificial Intelligence (AI) and Multi-Access Edge Computing (MEC)-enabled solution for provisioning and managing network slice resources across multiple domains, specifically tailored for IoT services. This solution provides an abstraction layer that generates slice templates for each domain and automates the deployment of resources based on the specified QoS requirements.

The article [A5] by Diamanti et al. investigates the optimization of energy-efficient power and rate allocation for both common and private messages transmitted in the downlink of a single-cell single-antenna network. To address this, they reframe the problem of maximizing energy efficiency as a multi-agent Deep Reinforcement Learning (DRL) problem. In this context, each transmitted private message serves as a distinct DRL agent. These agents individually explore their respective state-action spaces, with a fixed size that remains independent of the total number of agents. Furthermore, they share their accumulated experience through exploration with a shared neural network.

In [A6], Selvarajan et al. explore the feasibility of allocating finite resources beyond fifth generation networks for extended reality applications through the implementation of enhanced security measures via offloading analysis (RLIS). The proposed method involves the integration of deep learning algorithms, specifically multilayer perceptron and long short-term memory, along with their corresponding activation functions. A comparative study has been designed to investigate the outcomes of extended reality applications beyond fifth generation functions, with a focus on proximity limits and the avoidance of data queues.

In [A7], Serhani et al. address the issue of data sample selection and scheduling of federated learning at the edge computing level. They present a dynamic sample selection optimization scheme that aims to optimize resources usage and address data heterogeneity. The extensive results of the experiment demonstrate that the designed scheme outperforms the resource efficiency of conventional training methods, with a lower convergence time and improved resource efficiency.

[1]The articles in this special issue were published across volumes 4 (2023) and 5 (2024).

In article [A8] by Moudoud et al., a novel approach to enhance IoT security in the 5G and beyond era by leveraging a distributed Q-learning algorithm within a deep reinforcement learning framework is presented. Recognizing the heightened connectivity and speed of such networks, the paper addresses security threats by proposing a self-learning intrusion detection system. This system observes the behavior of connected devices, predicting anomalies and overcoming challenges of limited IoT data and bandwidth constraints.

In [A9], Gururaj et al. propose a collaborative energy-efficient routing protocol (CEERP), which is based on usage of multi-objective improved seagull algorithm (MOISA) as an optimization technique to enhance the system's performance.

Article [A10] by Yang et al. presents a study on the network resource management of beyond 5G massive Internet of Things, with a focus on the analysis of the large-scale network conflict caused by IoT devices' dense deployment. In this paper, a hypergraph-based resource-efficient collaborative reinforcement learning method was proposed to handle network conflict and then improve resource efficiency.

In [A11], Pandey et al. introduce a breakthrough in evaluating 5G networks and MEC systems, providing customizable, on-demand datasets for optimal testing under various conditions, crucial in scenarios where real-world data usage is limited. Furthermore, the paper presents a sustainable, cost-effective synthetic data generator, showcasing its vital role in the progressive landscape of mobile computing and energy efficiency.

Our Guest Editorial team members sincerely thank the authors and reviewers for their contributions to this Special Issue. We also would like to thank Prof. Sinem Coleri, Editor-in-Chief of the IEEE OJ-COMS, and Chang Cai, Editorial Assistant, for their great guidance and assistance.

APPENDIX: RELATED ARTICLES

[A1] P. Charatsaris, M. Diamanti, and S. Papavassiliou, "Joint user association and resource allocation for hierarchical federated learning based on games in satisfaction form," *IEEE Open J. Commun. Soc.*, vol. 5, pp. 457–471, 2024, doi: 10.1109/OJCOMS.2023.3347354.

[A2] S.-P. Yeh, S. Bhattacharya, R. Sharma, and H. Moustafa, "Deep learning for intelligent and automated network slicing in 5G Open RAN (ORAN) deployment," *IEEE Open J. Commun. Soc.*, vol. 5, pp. 64–70, 2024, doi: 10.1109/OJCOMS.2023.3337854.

[A3] A. M. Said, M. Marot, H. Afifi, and H. Moungla "Optimal mobile IRS deployment for empowered 6G networks," *IEEE Open J. Commun. Soc.*, vol. 5, pp. 540–552, 2024, doi: 10.1109/OJCOMS.2023.3331102.

[A4] K. Abbas, Y. Cho, A. Nauman, P. W. Khan, T. A. Khan, and K. Kondepu, "Convergence of AI and MEC for autonomous IoT service provisioning and assurance in B5G," *IEEE Open J. Commun. Soc.*, vol. 4, pp. 2913–2929, 2023, doi: 10.1109/OJCOMS.2023.3329420.

[A5] M. Diamanti, G. Kapsalis, E. E. Tsiropoulou, and S. Papavassiliou, "Energy-efficient rate-splitting multiple access: A deep reinforcement learning-based framework," *IEEE Open J. Commun. Soc.*, vol. 4, pp. 2397–2409, 2023, doi: 10.1109/OJCOMS.2023.3322047.

[A6] S. Selvarajan, H. Manoharan, A. O. Khadidos, A. Shankar, M. S. Mekala, and A. O. Khadidos, "RLIS: Resource limited improved security beyond fifth-generation networks using deep learning algorithms," *IEEE Open J. Commun. Soc.*, vol. 4, pp. 2383–2396, 2023, doi: 10.1109/OJCOMS.2023.3318860.

[A7] M. A. Serhani, H. G. Abreha, A. Tariq, M. Hayajneh, Y. Xu, and K. Hayawi "Dynamic data sample selection and scheduling in edge federated learning," *IEEE Open J. Commun. Soc.*, vol. 4, pp. 2133–2149, 2023, doi: 10.1109/OJCOMS.2023.3313257.

[A8] H. Moudoud and S. Cherkaoui, "Empowering security and trust in 5G and beyond: A deep reinforcement learning approach," *IEEE Open J. Commun. Soc.*, vol. 4, pp. 2410–2420, 2023, doi: 10.1109/OJCOMS.2023.3313352.

[A9] H. L. Gururaj, R. Natarajan, N. A. Almujally, F. Flammini, S. Krishna, and S. K. Gupta, "Collaborative energy-efficient routing protocol for sustainable communication in 5G/6G wireless sensor networks," *IEEE Open J. Commun. Soc.*, vol. 4, pp. 2050–2061, 2023, doi: 10.1109/OJCOMS.2023.3312155.

[A10] F. Yang, C. Yang, J. Huang, K. Yu, S. Garg, and M. Alrashoud, "Hypergraph based resource-efficient collaborative reinforcement learning for B5G massive IoT," *IEEE Open J. Commun. Soc.*, vol. 4, pp. 2439–2450, 2023, doi: 10.1109/OJCOMS.2023.3321310.

[A11] C. Pandey, V. Tiwari, R. S. Rathore, R. H. Jhaveri, D. S. Roy, and S. Selvarajan, "Resource-efficient synthetic data generation for performance evaluation in mobile edge computing over 5G networks," *IEEE Open J. Commun. Soc.*, vol. 4, pp. 1866–1878, 2023, doi: 10.1109/OJCOMS.2023.3306039.

BOUZIANE BRIK
Computer Science Department
College of Computing and Informatics
Sharjah University
Sharjah, UAE

MEHDI BENNIS
Faculty of Information Technology and Electrical Engineering
Centre for Wireless Communications
University of Oulu
90570 Oulu, Finland

XIANBIN WANG
Innovation Centre for Information Engineering
Western University
Ontario, ON N6A 3K7, Canada

MOHSEN GUIZANI
Machine Learning Department
Mohamed Bin Zayed University of Artificial Intelligence (MBZUAI)
Abu Dhabi, UAE

BOUZIANE BRIK received the engineer degree (Ranked First) in computer science and the M.Sc. and Ph.D. degrees from Laghouat University, Algeria, in 2010, 2013, and 2017, respectively.

He is currently working as an Assistant Professor with the Computer Science Department, Computing and Informatics College, Sharjah University, UAE. Before joining Sharjah University, he worked as an Assistant Professor with the DRIVE Department, Bourgogne University, France. He also worked as Postdoctoral Fellow with the University of Troyes, CESI School, and Eurecom Research Institute, in France. He has been working on resources management and security challenges of 5G network slicing in the context of H2020 European Projects, including MonB5G, 5GDrones, InDiD, and 5G-INSIGHT. He is an active member in many conferences' organizing committees, such as Globecom, WCNC, ICC, GIIS, EAI, and EAI CICom. He organized different special issues in prestigious journals as well as conference workshops. He also has been a Reviewer of many IFIP, ACM, and IEEE conferences (ICC, Globecom, WCNC, IWCMC, and LCN) and journals, such as IEEE transactions, magazines, and letters.

MEHDI BENNIS (Fellow, IEEE) is a Full (Tenured) Professor with the Centre for Wireless Communications, University of Oulu, Finland, and the Head of the Intelligent Connectivity and Networks/Systems Group. He has published more than 200 research papers in international conferences, journals and book chapters. His main research interests are in radio resource management, game theory, and distributed AI in 5G/6G networks. He has been the recipient of several prestigious awards, including the 2015 Fred W. Ellersick Prize from the IEEE Communications Society, the 2016 Best Tutorial Prize from the IEEE Communications Society, the 2017 EURASIP Best Paper Award for the *Journal of Wireless Communications and Networks*, the all-University of Oulu award for research, the 2019 IEEE ComSoc Radio Communications Committee Early Achievement Award, and the 2020 Clarviate Highly Cited Researcher by the Web of Science. He is an Editor of IEEE TRANSACTIONS ON COMMUNICATIONS and Specialty Chief Editor for Data Science for Communications in *Frontiers in Communications and Networks*.

XIANBIN WANG received the Ph.D. degree in electrical and computer engineering from the National University of Singapore in 2001.

He is a Full Professor and the Tier-1 Canada Research Chair of 5G and Wireless IoT Communications with Western University, Canada. Prior to joining Western, he was with Communications Research Centre Canada as a Research Scientist/Senior Research Scientist from July 2002 to December 2007. From January 2001 to July 2002, he was a System Designer with STMicroelectronics. His research activities have led to more than 400 highly cited publications and over 30 patents. His ground-breaking research, innovation, and technical contributions, further bolstered by his tireless efforts in technology transfer and research training, have directly improved the operational outcome of interconnected consumer, industry and defence systems and further accelerated the transformation of our industry and society.

MOHSEN GUIZANI (Fellow, IEEE) received the Ph.D. degree from Syracuse University, USA. He is a Professor with MBZUAI, UAE. He is the author of ten books, 800+ publications (with 56,000+ citations) and five U.S. patents. He received two Best Journal Paper Awards (CSIM 2021 and COMST 2018). He received the IEEE Distinguished Service Award from EMEA in 2021; and three Recognition Awards (CISTC 2020, AHSN 2018, and WTC 2017). He received six IEEE Conference Paper Awards (GLOBECOM 2022, 2018, 2016, and ICC 2020 and 2014). He is listed as a Clarivate Highly Cited Researcher during the last 4 years from 2019 to 2022. He served as the Editor-in-Chief for IEEE NETWORK from 2018 to 2020. He has been serving as an Advisory Editor of IEEE INTERNET OF THINGS JOURNAL since 2015, a Senior Editor of IEEE NETWORK since 2020, and *IEEE Standard Magazine* Series Editor since 2020. He was the Chair of the WTC from 2009 to 2010 and the Chair of TAOS from 2006 to 2007.