Guest Editorial
Special Issue on Collaborative Intelligence for Green Internet of Things in the 6G Era

IN THE 6G era, with the hyper-connectivity among humans and everything, we are anticipating Internet of Things (IoT) applications in various fields, including smart city, smart factory, smart home, smart grid, e-health, and smart transportation, accompanied by new services with rich experiences, such as truly immersive VR/AR/MR (XR), high-fidelity mobile hologram, and digital twins. However, in order to facilitate these emerging IoT applications, we have to investigate the collaboration among different network entities to achieve joint optimization under heterogeneous communication, caching, and computing resources. Recently, artificial intelligence (AI) based approaches have been attracting great interest in empowering computer systems. Since the centralized learning approaches face many challenges in terms of scalability, some collaborative learning approaches, such as federated learning and multi-agent systems, have been investigated recently to reduce networking overhead and improve learning efficiency. Based on refined AI technologies, collaborative intelligence can achieve better decisions by aggregating knowledge and enabling efficient coordination among multiple agents with a light communication overhead. It is envisioned that the collaborative intelligence is the enabler for collaborative IoT systems.

The objective of this special issue is to present the latest results, insights, and perspectives in the new area of enabling collaborative intelligence in IoT systems toward a greener and smarter society. We were successful in attracting 73 submissions. All of the submitted papers were rigorously evaluated according to the standard reviewing process of the IEEE TRANSACTIONS ON GREEN COMMUNICATIONS AND NETWORKING. Following a rigorous peer review process, 20 papers were accepted in this special issue. The accepted papers cover a wide range of topics for enabling collaborative intelligence for Green IoT in the 6G Era. We hope this special issue will shed light on collaborative intelligence for IoT, and open up many exciting and critical future research activities in related fields.

The first group of articles focuses on collaborative learning approaches for IoT. The article by Zhang et al. [A1] develops a federated learning paradigm for non-intrusive load monitoring (NILM) applications towards the green home vision. The article by Huang et al. [A2] discusses the model allocation problem for federated learning in mobile edge computing environments. The article by Qi et al. [A3] proposes a federated incremental learning (FIL) method to address the problem of heterogeneous local datasets in modulation classification. The article by Liu et al. [A4] studies federated graph learning under a cross-silo setting.

The second group focuses on communication resource optimization technologies. The article by Liu et al. [A5] proposes a nonorthogonal multiple access (NOMA) based green multi-UAV assisted approach to increase user capacity while improving the energy utilization of each UAV. The article by Wang et al. [A6] proposes a green spectrum sharing framework by exploiting crowdsensing. The article by Zhou et al. [A7] investigates the network resource scheduling and route management for Multi-Mode Green IoT. The article by Liu et al. [A8] discusses the radio frequency fingerprint identification (RFFI) technology that identifies an emitter by extracting one or more unintentional features of signals.

The third group of articles focuses on collaborative computing and control technologies. The article by Zhou et al. [A9] discusses a joint optimization of computation offloading, service caching, and resource allocation in a collaborative edge computing system with multi-users. The article by Lei and Fan [A10] discusses the problem of how to switch between positive and negative controllers to minimize the hybrid cost function for asymmetrical processes. The article by Wang et al. [A11] introduces a hierarchical network-assisted task offloading architecture for Green IoT. The article by Liu et al. [A12] considers the diversity of computing tasks and the heterogeneity of computing power resources in Internet of Vehicles (IoV). The article by Lyu et al. [A13] studies resource allocation for computation offloading to minimize the latency and energy consumption in low earth orbit (LEO) satellite-based IoT.

The fourth group of articles focuses on collaborative green IoT protocols and systems. The article by Liu et al. [A14] proposes a collaborative routing protocol considering spatial-temporal features of vehicle trajectories for urban vehicular cyber physical systems. The article by Guo et al. [A15] proposes a deep collaborative intelligence-driven traffic forecasting model in green IoV. The article by Qian et al. [A16] presents a novel pipeline for facilitating the green IoT-oriented blockchains. The article by Li et al. [A17] discusses about multi-UAV cooperative trajectory planning targeting for emergency rescue scenarios. The article by Tang et al. [A18] discusses the issue of improving resource

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efficiency and extending network lifetime in IoT. The article by Liu et al. [A19] proposes a distributed joint path planning and charging-discharging decision algorithm to maximize the overall profit of electric vehicles (EVs) in vehicle-to-grid. The article by Wu et al. [A20] proposes an efficient edge-terminal collaboration scheme to handle diverse task requirements of IoV applications.

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APPENDIX: RELATED ARTICLES

[A1] Y. Zhang et al., "FedNILM: Applying federated learning to NILM applications at the edge," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 857–868, Jun. 2023.

[A2] H. Huang, Y. Yang, Z. Jiang, and Z. Zheng, "Worker-centric model allocation for federated learning in mobile edge computing," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 869–880, Jun. 2023.

[A3] P. Qi, X. Zhou, Y. Ding, S. Zheng, T. Jiang, and Z. Li, "Collaborative and incremental learning for modulation classification with heterogeneous local dataset in cognitive IoT," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 881–893, Jun. 2023.

[A4] T. Liu, P. Li, Y. Gu, and Z. Su, "S-Glint: Secure federated graph learning with traffic throttling and flow scheduling," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 894–903, Jun. 2023.

[A5] X. Liu, Z. Liu, and M. Zhou, "Fair energy-efficient resource optimization for green multi-NOMA-UAV assisted Internet of Things," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 904–915, Jun. 2023.

[A6] X. Wang, M. Umehira, M. Akimoto, B. Han, and H. Zhou, "Green spectrum sharing framework in B5G era by exploiting crowdsensing," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 916–927, Jun. 2023.

[A7] Z. Zhou et al., "Collaborative learning-based network resource scheduling and route management for multi-mode green IoT," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 928–939, Jun. 2023.

[A8] M. Liu, C. Liu, Y. Chen, Z. Yan, and N. Zhao, "Radio frequency fingerprint collaborative intelligent blind identification for green radios," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 940–949, Jun. 2023.

[A9] H. Zhou, Z. Zhang, Y. Wu, M. Dong, and V. C. M. Leung, "Energy efficient joint computation offloading and service caching for mobile edge computing: A deep reinforcement learning approach," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 950–961, Jun. 2023.

[A10] X. Lei and Y. Fan, "Optimal control of asymmetrical multi-agent switching systems for IoT," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 962–971, Jun. 2023.

[A11] C. Wang, X. Yu, L. Xu, and W. Wang, "Energy efficient task scheduling based on traffic mapping in heterogeneous mobile edge computing: A green IoT perspective," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 972–982, Jun. 2023.

[A12] Y. Liu, D. Wang, B. Song, and X. Du, "Green heterogeneous computing powers allocation using reinforcement learning in SDN-IoV," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 983–995, Jun. 2023.

[A13] Y. Lyu, Z. Liu, R. Fan, C. Zhan, H. Hu, and J. An, "Optimal computation offloading in collaborative LEO-IoT enabled MEC: A multi-agent deep reinforcement learning approach," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 996–1011, Jun. 2023.

[A14] B. Liu et al., "Collaborative intelligence enabled routing in green IoV: A grid and vehicle density prediction based protocol," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 1012–1022, Jun. 2023.

[A15] Z. Guo et al., "Deep collaborative intelligence-driven traffic forecasting in green Internet of Vehicles," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 1023–1035, Jun. 2023.

[A16] K. Qian, Y. Liu, C. Shu, Y. Sun, and K. Wang, "Fine-grained benchmarking and targeted optimization: Enabling green IoT-oriented blockchain in the 6G era," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 1036–1051, Jun. 2023.

[A17] J. Li, X. Liu, G. Han, S. Cao, and X. Wang, "TaskPOI priority based energy balanced multi-UAVs cooperative trajectory planning algorithm in 6G networks," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 1052–1065, Jun. 2023.

[A18] Y. Tang, X. Deng, L. Yi, Y. Xia, L. T. Yang, and X. Tang, "Collaborative intelligent confident information coverage node sleep scheduling for 6G-empowered green IoT," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 1066–1077, Jun. 2023.

[A19] P. Liu, Z. Liu, N. Zhang, and F. Lin, "Cooperative game-based charging-discharging efficiency optimization of electric vehicles in 6G-enabled V2G," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 1078–1089, Jun. 2023.

[A20] D. Wu, T. Liu, Z. Li, T. Tang, and R. Wang, "Delay-aware edge-terminal collaboration in green Internet of Vehicles: A multi-agent soft actor-critic approach," *IEEE Trans. Green Commun. Netw.*, vol. 7, no. 2, pp. 1090–1102, Jun. 2023.

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