Guest Editorial Special Issue on Green IoT for Future Space–Air–Ground–Ocean-Integrated Networks and Applications

THE Internet of Things (IoT) plays a critical role in enabling the seamless integration of disparate devices. Future IoT will rapidly expand its coverage to offer future worldwide omnipresent applications and services by merging communications in diverse spatial domains to build the space–air–ground–ocean-integrated network (SAGOI-Net). SAGOI-Net will include a significant number of battery-powered network nodes, such as satellites, unmanned vehicles, and underwater devices, due to the extremely vast geographic reach and dynamics in free space. Given the battery limitations, high-energy-efficiency communications and networking will be critical to the future system. Green SAGOI-Net seeks to not only bring ubiquitous connectivity to every corner of the globe but also to deliver more data with the same amount of energy.

There are already research and development activities on holistic green solutions for the SAGOI-Net that is ultra-dynamic, autonomous, and decentralized. Recent technological breakthroughs include radio frequency (RF) energy harvesting, simultaneous wireless and information transfer (SWIT), ambient backscatter communications (AmBC), and so on. The integration of numerous SAGOI networks, on the other hand, provides a new possibility for energy savings by coordinating the operation of diverse networks and shifting energy-consuming tasks to power-rich or power-efficient nodes.

However, there is still an urgent need in both industry and the research community to better understand the technical details and recent progress of green IoT and SAGOI-Net. We planned this feature topic to help address that need and wanted to focus on recent advances as well as survey articles on green IoT and future SAGOI-Net, such as novel visions, concepts, theories, protocols, and architectures for SAGOI-Net green IoT. In addition, novel solutions combining real-time data with new technologies, such as 6G, blockchain, RIS, federal learning, and cutting-edge promising models, were offered. As the research is still in its infancy, we hope that this feature topic will serve as a useful resource and inspire more specialists to contribute to this field.

The response to our Call for Papers on this feature topic was overwhelming, with 52 papers submitted from around the globe. During the review process, each paper was assigned to and reviewed by at least three experts in the relevant area, with a rigorous two-round review process. Due to the lack of space, we can only accommodate 15 excellent papers covering various aspects of green IoT for future space–air–ground–ocean-integrated networks and applications.

Article [A1] proposes an EKFFL approach to help sensor node trajectory creation. This approach extends the widely used flocking control algorithm and fully utilizes multimodal data by using tools from the control system and signal processing.

Article [A2] develops an antenna with three parasitic elements coupling with higher order modes via slot-hole excitation of a higher order mode dielectric resonator antenna with a dielectric constant of ten. Radiation variation in many directions can be produced by altering the distance between the three parasitic elements and modifying the capacitor at their terminals.

Article [A3] makes use of reconfigurable intelligent surfaces (RIS) to improve upon the existing SAGIN infrastructure with a realistic channel estimation scheme.

Article [A4] recommends to use collaborative LEO satellites to allow the deployment of secure and green IoRT in order to overcome issues, such as limited energy supply, high mobility, and security vulnerabilities.

Article [A5] proposes a cooperative resource allocation approach to optimize the joint optimization problem under the constraints of resource and communication latency, which can migrate more computation-intensive tasks to the edge clouds.

Article [A6] presents a service provision method based on service function chaining (SFC) to address the issue of traditional network architectures being unable to support resource allocation in large-scale complex network environments.

Article [A7] describes how to use a convolutional neural network to fuse input communication data and SAR images into a combined representation that can then be transmitted to other nodes in space–air–ground–ocean-integrated IoT networks.

Article [A8] proposes a novel scheme for establishing an energy-efficient autonomous and decentralized SAGOI-Net by using an intelligent autonomous underwater glider (AUG) to serve marine applications.

Article [A9] investigates how blockchain and 6G technology may be used to improve spectrum sharing among UIoT devices.

Article [A10] proposes a model of wireless computing power networks (WCPNs) by jointly unifying computing resources from both end devices and MEC servers and formulates a new task transfer problem to optimize the allocation of computation and communication resources in WCPN.

Digital Object Identifier 10.1109/JIOT.2023.3246846

The synchronous downlink system is theoretically analyzed by using the Nakagami-m fading model in [A11]. This work also derives the statistical characteristics of multiple access interference (MAI) and MAI plus noise.

Article [A12] designs a reconfigurable intelligent surface (RIS)-assisted AmBC system to increase the achievable sum rate (ASR).

The cluster-based HetNets energy-efficient resource allocation mechanism (CHERA) has been proposed in [A13] to assure the energy-efficient operation of space–air–ground networks for smart IoT applications.

Article [A14] presents a method for recognizing human continuity activity characteristics from sensor data streams in multiview IoT network situations.

To address the restricted load capability of tiny UAVs, [A15] develops a system model for assembly UAVs that may jointly optimize resource management, particularly the energy resource.

In closing, we would like to thank all the authors for their contributions, and all the reviewers for their dedication in reviewing the papers and providing valuable comments and suggestions for refining the quality of the papers. In addition, we appreciate the advice and support from Dr. Honggang Wang and Dr. Nei Kato, the previous and the current Editor-in-Chief of IEEE INTERNET OF THINGS JOURNAL, and the IEEE publication staff for their help in the publication process. Finally, we hope that the readership will find this feature topic interesting and stay tuned for new developments in this research area.

APPENDIX: RELATED ARTICLES

[A1] X. Huang, J. Liang, X. Shen, and Q. Liang, "A multimodal data harness approach of mobile sensors trajectory planning for target tracking," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9252–9261, Jun. 1, 2023.

[A2] C. Li, Y. Duan, B. Du, and X. Tao, "Adjustable dielectric resonator antenna with parasitic elements for 5G SAGOI-IoT applications," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9262–9272, Jun. 1, 2023.

[A3] X. Meng, N. Zhang, M. Jian, M. Kadoch, and D. Yang, "Channel modeling and estimation for reconfigurable-intelligent-surface-based 6G SAGIN IoT," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9273–9282, Jun. 1, 2023.

[A4] P. Yue, J. Du, R. Zhang, H. Ding, S. Wang, and J. An, "Collaborative LEO satellites for secure and green Internet of Remote Things," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9283–9294, Jun. 1, 2023.

[A5] J. Liu, G. Li, Q. Huang, M. Bilal, X. Xu, and H. Song, "Cooperative resource allocation for computation-intensive IIoT applications in aerial computing," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9295–9307, Jun. 1, 2023.

[A6] P. Zhang, Y. Zhang, N. Kumar, and M. Guizani, "Dynamic SFC embedding algorithm assisted by federated learning in space–air–ground-integrated network resource allocation scenario," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9308–9318, Jun. 1, 2023.

[A7] Z. Jing, J. Mu, X. Li, Q. Zhou, and Q. Tian, "Efficient fusion and reconstruction for communication and sensing signals in green IoT networks," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9319–9328, Jun. 1, 2023.

[A8] Z. Li, J. Wen, J. Yang, J. He, T. Ni, and Y. Li, "Energy-efficient space–air–ground–ocean-integrated network based on intelligent autonomous underwater glider," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9329–9341, Jun. 1, 2023.

[A9] Z. Sun, F. Qi, L. Liu, Y. Xing, and W. Xie, "Energy-efficient spectrum sharing for 6G ubiquitous IoT networks through blockchain," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9342–9352, Jun. 1, 2023.

[A10] Y. Lu, B. Ai, Z. Zhong, and Y. Zhang, "Energy-efficient task transfer in wireless computing power networks," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9353–9365, Jun. 1, 2023.

[A11] Z. Li, S. Chen, and S. Han, "Performance analysis of downlink multi-satellite joint service system toward SAGOI-Net," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9366–9374, Jun. 1, 2023.

[A12] Q. Liu, M. Fu, W. Li, J. Xie, and M. Kadoch, "RIS-assisted ambient backscatter communication for SAGIN IoT," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9375–9384, Jun. 1, 2023.

[A13] P. Yu et al., "Self-organized and distributed green resource allocation for space–air–ground IoT networks," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9385–9397, Jun. 1, 2023.

[A14] R. Yuan and J. Wang, "The human continuity activity semisupervised recognizing model for multiview IoT network," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9398–9410, Jun. 1, 2023.

[A15] J. Xiong, L. Guo, M. Shan, B. Liu, P. Yu, and L. Guo, "Wireless resources cooperation of assembled small UAVs for data collections of IoT," *IEEE Internet Things J.*, vol. 10, no. 11, pp. 9411–9422, Jun. 1, 2023.

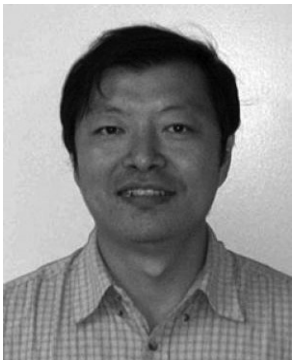
BO RONG
Communications Research Centre Canada
Ottawa, ON, Canada

MOHAMED CHERIET
Systems Engineering Department
École de Technologie Supérieure
University of Quebec
Montreal, QC H3C 3P8, Canada

JON MONTALBAN
Department of Electronic Technology
University of the Basque Country
48940 Leioa, Spain

LEI SHI
South East Technological University
Carlow, Ireland

YI QIAN
Department of Electrical and Computer Engineering
University of Nebraska–Lincoln
Lincoln, NE 68588 USA



Bo Rong received the Ph.D. degree from Beijing University of Posts and Telecommunications, Beijing, China, in 2001.

He is a Research Scientist with Communications Research Centre Canada, Ottawa, ON, Canada. He has authored or coauthored over 100 technical papers in major journals and conferences on the topic of wireless networking and communications. Many of these publications have theoretical and practical significance to the research community and industry. His research interests include the space–air–ground integrated network, deep machine learning, intelligent RRM in 5G/6G, and smart IoT.

Dr. Rong serves as an Associate Editor for *IEEE Network Magazine*, as well as a Column Editor for *IEEE Wireless Communications Magazine*. He is a member of the IEEE Communications Society and the IEEE Broadcasting Society.

Mohamed Cheriet (Senior Member, IEEE) received the State Engineering degree in computer science from USTHB, Bab Ezzouar, Algeria, in 1984, and the M.Sc. and Ph.D. degrees in computer science from the University of Pierre and Marie Curie (Paris 6), Paris, France, in 1985 and 1988, respectively.

Since 1992, he has been a Professor with the Systems Engineering Department, École de Technologie Supérieure, University of Quebec, Montreal, QC, Canada, where he was appointed as a Full Professor in 1998. He was the Co-Founder and the Director of the LIVIA Laboratory for Vision and Artificial Intelligence from 2000 to 2006, and has been the Founder and the Director of the Synchromedia Laboratory for Multimedia Communication in Telepresence Applications since 1998.

Prof. Cheriet is the Founder and the former Chair of the IEEE Montreal Chapter of Computational Intelligent Systems, a Steering Committee Member of the IEEE Sustainable ICT Initiative, and the Chair of ICT Emissions Working Group.

Jon Montalban received the M.S. degree and the Ph.D. degree in telecommunications engineering from the University of the Basque Country, Leioa, Spain, in 2009 and 2014, respectively.

He is part of the TSR (Radiocommunications and Signal Processing) Research Group, University of the Basque Country, where he is an Assistant Professor with the Department of Electronic Technology. He has held visiting research appointments with Communications Research Centre Canada, Ottawa, ON, Canada, and Dublin City University, Dublin, Ireland. His main research interest is in the area of network architectures for wireless communications. He is currently involved in research activities related to broadcasting in 5G environments and wireless systems for reliable industrial communications.

Dr. Montalban is the co-recipient of the Scott Helt Memorial Award to recognize the best paper published in IEEE TRANSACTIONS ON BROADCASTING in 2019. He has served as a reviewer for several renowned international journals and conferences in the area of wireless communications and currently serves as an Associate Editor for IEEE ACCESS and IEEE TRANSACTIONS ON BROADCASTING.

Lei Shi received the master's degree in computer science from Uppsala University, Uppsala, Sweden, in 2006, and the Ph.D. degree from the University of Göttingen, Göttingen, Germany, in 2010.

He is a Lecturer with South East Technological University, Carlow, Ireland. He worked for companies, including Dell-EMC, Beijing, China, and Huawei Technologies, Beijing. He was a Researcher with the University of Massachusetts at Amherst, Amherst, MA, USA, and a Visiting Professor with Technion, Haifa, Israel. His research interests include network management and cloud computing.

Dr. Shi is an EU Marie Curie Fellow.

Yi Qian (Fellow, IEEE) received the Ph.D. degree in electrical engineering from Clemson University, Clemson, SC, USA, in 1996.

He is currently a Professor with the Department of Electrical and Computer Engineering, University of Nebraska–Lincoln, Lincoln, NE, USA. He has research and industry experience in information and communication network security, wireless communications and networks, wireless sensor networks, vehicular communication networks, smart grid communications, broadband satellite communications, optical communications, high-speed communications and networks, and Internet of Things. His research interests include cyber security and communication network security, and computer and communication networks.

Prof. Qian was the Chair of the IEEE Technical Committee for Communications and Information Security. He was the Technical Program Chair for IEEE International Conference on Communications 2018. He serves or has served on the editorial boards of several international journals and magazines, including as the Editor-in-Chief for IEEE WIRELESS COMMUNICATIONS from July 2018 to June 2022. He was a Distinguished Lecturer for IEEE Vehicular Technology Society and a Distinguished Lecturer for IEEE Communications Society.