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Guest Editorial Special Issue on Emerging Technologies Enhanced Cooperative Integrated Sensing and Communication in 6G Era

SIXTH Generation (6G) will turn the vision of everything sensing, everything interconnecting, and everything intelligent into reality. That is, the 6G network will have native sensing capability, thus making itself a huge sensor to perceive the physical world ubiquitously. Leveraging radio sensing capability, the integrated sensing and communication (ISAC) technology will utilize wireless signals to realize perception functions such as positioning, detection, imaging, and identification of targets, acquire information about the surrounding physical environment, tap communication capabilities, and enhance user experience. Through endogenous integration of spectrum resource allocation, hardware architecture design, multi-point collaboration, and all-around interaction of information, it can realize green energy saving while realizing communication and sensing capabilities, improve spectrum efficiency and detection accuracy, and ultimately realize the performance enhancement of the whole network.

By combining the advancements of other emerging technologies in the 6G era, such as artificial intelligence (AI), terahertz (THz), intelligent reflecting surface (RIS), Cell-Free, etc., cooperative ISAC relying on multiple base stations (BSs) is driven to become a reality. For instance, AI can analyze and process the perceived environmental information in real-time through methods such as machine learning and deep learning, which can realize adaptive adjustment and intelligent decision-making of multiple BSs, thus enabling efficient cooperative ISAC. Besides, the very narrow beamwidth available at the THz frequency band and Massive MIMO system can facilitate the realization of high-definition sensing and localization. In addition, RIS can provide a virtual line-of-sight (LOS) path to conquer the blockage problem and introduce additional degrees of freedom to improve both the communication and sensing ability, thus allowing multiple distributed BSs to collaborate when the direct link is blocked. To this end, this special section focuses on the emerging technologies enhanced cooperative ISAC in 6G Era that have just begun to attract extensive attention from both academia and industry.

In the first article by Zhang et al. [A1], a photonics-aided terahertz ISAC system based on a subcarrier-chirp inter-embedded (SCIE) waveform is proposed. The method efficiently embeds communication subcarriers into the idle time-frequency resources of a linear frequency-modulated continuous wave (LFMCW), thereby enhancing time-frequency utilization without compromising its inherent large time-bandwidth product. The scheme supports flexible modulation formats and exhibits good frequency tunability, offering a viable waveform design for high-performance ISAC in future 6G networks.

The second article by Sun et al. [A2] introduces a uncrewed aerial vehicle (UAV)-based intelligent sensing system operating over a cell-free massive MIMO network. The method integrates the high-speed maneuverability of UAVs with the distributed, user-centric architecture of cell-free massive multiple-input multiple-output (CF-mMIMO) to enhance sensing accuracy and communication reliability in dynamic environments. Specifically, a fine-tuned YOLOv5s model accelerated by TensorRT is employed for real-time target recognition from aerial imagery, while an improved tracking algorithm combining intersection-over-union (IOU) matching and Kalman filtering is introduced for robust trajectory prediction. The system offloads computation-intensive sensing tasks to a central server via the CF-mMIMO fronthaul, ensuring low-latency control feedback to the UAV. A prototype system validates the framework, demonstrating its effectiveness in supporting bandwidth-intensive tasks and reliable target tracking in real-world scenarios.

By exploiting commercial long-term evolution (LTE) downlink signals as illuminators, the third article [A3] proposes a passive UAV tracking system. The method employs two digital uniform linear arrays to capture both the line-of-sight reference signal from the base station and the scattered surveillance signal from the target UAV. Through the cross ambiguity function computed from these signals, key parameters including bistatic range, Doppler shift, and angle-of-arrival (AoA) are estimated. To address challenges of missed detections and false alarms, a multi-target tracking framework is introduced, incorporating track initialization, prediction via state transition models, and correction using Kalman filtering. The system demonstrates meter-level tracking accuracy in real-world experiments, validating its feasibility for passive UAV monitoring with existing cellular infrastructure.

Conventional ISAC designs typically prioritize either sensing or communication, or achieve limited integration, which restricts spatial degrees of freedom, coverage, and performance balance in dynamic environments. To overcome these limitations, the fourth paper by Osorio et al. [A4] proposes a comprehensive networked ISAC framework that exploits cooperative distributed nodes to deeply integrate sensing and communication functionalities. The methodology is built on a multi-layer architecture spanning from the physical to the network layer. Furthermore, the architecture incorporates a mutual information-based privacy-preserving scheme to limit information leakage from sensing signals and introduces a general resilience model with quantifiable metrics to ensure sustained operation under failures, interference, or attacks. This holistic approach, supported by protocol extensions and coordinated waveform design, advances ISAC towards a networked, resilient, and secure paradigm for 6G systems.

This fifth paper by Ye et al. [A5] addresses the challenge of high pilot overhead for beamforming in highly dynamic vehicular networks, where a two-step radar-LiDAR fusion framework is proposed to predict optimal RF beams without pilot-based channel estimation. In this first step, the relevant features are extracted from sensing data to identify effective radio reflectors from dense point clouds. In the second step, processed radar images and LiDAR images of selected reflectors are fused via a specially designed multimodal transformer (MMT), which employs image stitching or merging at its input layer to integrate multi-source data. Additionally, beam pruning is introduced to leverage historical beam-direction statistics, narrowing the candidate beam set and improving prediction efficiency. Evaluated on the DeepSense 6G dataset, this fusion-based approach demonstrates superior beam prediction accuracy and robustness over single-modality or CNN-based methods, significantly reducing pilot overhead while maintaining low latency.

To address the joint optimization of resource efficiency and perceptual quality from the perspective of network operators, the sixth paper [A6] proposes a communication-aware, game-theoretic bandwidth allocation framework for multi-user visual data transmission over cell-free networks. The method models the operator-user interaction as a non-cooperative game, where the operator sets a spectrum unit price and users compete for bandwidth. More specifically, a fair and adaptive utility function is proposed, which can accommodate the diverse characteristics of visual data. By deriving the operator's revenue function and users' aggregate utility, supply and demand functions are obtained. The equilibrium spectrum price is then determined via market supply-demand equilibrium theory, ensuring a unique Nash equilibrium. A lightweight cross-layer feedback mechanism enables dynamic price adjustment. Simulations confirm the framework improves Quality of Service (QoS) fairness and overall perceptual quality compared to conventional schemes.

To adapt to the dynamic maritime networks, the seventh article [A7] proposes a Subarea-based Collaborative Deep Q-Network (Subarea_CDQN) enhanced with online learning. The paper employs a multi-agent system to detect neighboring node positions and manage queue statuses, while utilizing ISAC technology to ensure safe operational distances and alleviate communication constraints. To address large-scale network challenges, the maritime topology is modeled as a graph and partitioned into multiple subareas. Within each subarea, multi-point collaboration adopts the CDQN method to intelligently select next-hop transmission paths, thereby reducing global computational load. Furthermore, to cope with dynamic topology changes caused by node mobility, global and subarea online learning strategies are designed, enabling the network to dynamically adjust routing policies and optimize forwarding paths. The proposed approach demonstrates enhanced performance in packet arrival rate, retransmission rate, and packet loss rate while maintaining efficient delivery time.

The last article by Otani et al. [A8] poposes an open-source software-defined radio (SDR) device-free sensing platform for ISAC. The platform leverages an open database to identify available frequencies in the target sensing area, selects frequencies for sensing based on the measured channel state information (CSI), and utilizes them for analysis. This approach employs the broadcast signal from the base station, ensuring no interference with the communication system's efficiency. It can be implemented at a low cost by utilizing OpenAirInterface (OAI) as an open-source software (OSS) platform for capturing cellular signals, and its feasibility is demonstrated in an outdoor human detection scenario.

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APPENDIX: RELATED ARTICLES

[A1] J. Zhang et al., "Photonics-aided THz integrated sensing and communication system based on a subcarrier-chirp inter-embedded waveform," *IEEE Open J. Commun. Soc.*, vol. 6, pp. 2993–3003, 2025, doi: 10.1109/OJCOMS.2025.3545896.

[A2] J. Sun, W. Shi, J. Yao, W. Xu, D. Wang, and Y. Cao, "UAV-based intelligent sensing over CF-mMIMO communications: System design and experimental results," *IEEE Open J. Commun. Soc.*, vol. 6, pp. 3211–3221, 2025, doi: 10.1109/OJCOMS.2025.3550975.

[A3] Y. Sun et al., "An experimental study of passive UAV tracking with digital arrays and cellular downlink signals," *IEEE Open J. Commun. Soc.*, vol. 6, pp. 3779–3794, 2025, doi: 10.1109/OJCOMS.2025.3558430.

[A4] D. P. M. Osorio, B. Barua, K.-L. Besser, H. Blue, P. Dass, and P. Porambage, "The rise of networked ISAC: Emerging aspects and challenges," *IEEE Open J. Commun. Soc.*, vol. 6, pp. 5072–5091, 2025, doi: 10.1109/OJCOMS.2025.3575729.

[A5] Z. Ye, Y. He, G. Yu, and P. Loskot, "Radar-LiDAR fusion-aided RF beams prediction for vehicular communications," *IEEE Open J. Commun. Soc.*, vol. 6, pp. 5121–5134, 2025, doi: 10.1109/OJCOMS.2025.3577193.

[A6] C. Liu, L. Yu, L. Sha, C. Zhang, and D. Wang, "Resource allocation algorithm for sensing video transmission over cell-free radio access networks," *IEEE Open J. Commun. Soc.*, vol. 6, pp. 5319–5327, 2025, doi: 10.1109/OJCOMS.2025.3577170.

[A7] X. Sun, T. Yang, C. Han, G. C. F. Lee, and S. Sun, "Subarea collaborative deep Q-network with online learning: Advanced multi-agent routing strategies for dynamic maritime networks," *IEEE Open J. Commun. Soc.*, vol. 6, pp. 7200–7214, 2025, doi: 10.1109/OJCOMS.2025.3599122.

[A8] H. Otani, T. Murakami, K. Ohara, S. Otsuki, Y. Takatori, and T. Ogawa, "An open-source SDR-based device-free sensing platform for integrated sensing and communication (ISAC)," *IEEE Open J. Commun. Soc.*, vol. 6, pp. 9982–9990, 2025, doi: 10.1109/OJCOMS.2025.3623613. .

YONGMING HUANG
National Mobile Communications Research Laboratory
Southeast University
Nanjing 210096, China

Pervasive Communication Center
Purple Mountain Laboratories
Nanjing 211111, China

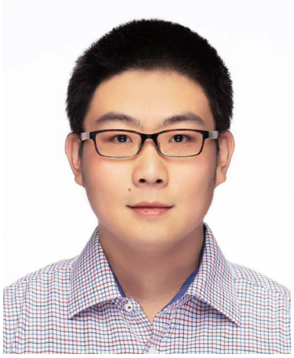
HUAZHOU HOU
Pervasive Communication Center
Purple Mountain Laboratories
Nanjing 211111, China

DONGXUAN HE
School of Information and Electronics
Beijing Institute of Technology
Beijing 100081, China

GUNES KARABULUT KURT
Department of Electrical Engineering
Polytechnique Montréal
Montreal, QC H3T 1J4, Canada

TONY Q. S. QUEK
Information System Technology and Design Pillar
Singapore University of Technology and Design
Singapore 487372

YONGMING HUANG (Fellow, IEEE) received the B.S. and M.S. degrees from Nanjing University, Nanjing, China, in 2000 and 2003, respectively, and the Ph.D. degree in electrical engineering from Southeast University, Nanjing, in 2007. Since March 2007, he has been a Faculty with the School of Information Science and Engineering, Southeast University, where he is currently a Full Professor. He has also been the Director of the Pervasive Communication Research Center, Purple Mountain Laboratories since 2019. From 2008 to 2009, he visited the Signal Processing Lab, Royal Institute of Technology (KTH), Stockholm, Sweden. He has published over 200 peer-reviewed papers, hold over 80 invention patents. His current research interests include intelligent 5G/6G mobile communications and millimeter wave wireless communications. He submitted around 20 technical contributions to IEEE standards, and was awarded a certificate of appreciation for outstanding contribution to the development of IEEE standard 802.11aj. He has served as an Associate Editor for the IEEE TRANSACTIONS ON SIGNAL PROCESSING, the IEEE WIRELESS COMMUNICATIONS LETTERS and a Guest Editor for the IEEE JOURNAL SELECTED AREAS IN COMMUNICATIONS, is serving as an Editor-at-Large for the IEEE OPEN JOURNAL OF THE COMMUNICATIONS SOCIETY, an Area Editor for the Chinese Journal of Electronics, and an Editor for the SCIENCE CHINA INFORMATION SCIENCES.



HUAZHOU HOU (Member, IEEE) received the B.S. degree from Beijing Institute of Technology (BIT) in 2013, and the M.S. and Ph.D. degrees from Northeast University in 2015 and 2020, respectively. From 2017 to 2019, he was a Joint Ph.D. student with RMIT University, Melbourne, Australia. From 2020 to 2023, he was a Postdoctoral with Southeast University. He is currently an Associate Professor with Purple Mountain Laborites, Nanjing, China. His research interests include Unmanned systems, integrated sensing and communication, and signal processing.

DONGXUAN HE (Member, IEEE) received the B.S. degree in automation and the Ph.D. degree in information and communication systems from the Beijing Institute of Technology (BIT) in 2013 and 2019, respectively. From 2017 to 2018, he was a visiting student with the Singapore University of Technology and Design. From 2019 to 2022, he was a Postdoctoral Researcher with the Department of Electronic Engineering, Tsinghua University. He is currently an Assistant Professor with the School of Information and Electronics, BIT. His current interests include Integrated sensing and communication, terahertz communication, and AI empowered wireless communications. He was a recipient of the Best Paper Award from 2024 IEEE ICSIDP and 2025 IEEE IWCMC. He is currently serving as a Guest Editor for the IEEE OPEN JOURNAL OF THE COMMUNICATIONS SOCIETY, the *Electronics*, and the *Space: Science and Technology*. He is a TPC Member of various flagship IEEE conferences, such as IEEE ICC and IEEE GLOBECOM. He was also an Exemplary Reviewer of IEEE WIRELESS COMMUNICATIONS LETTERS.

GUNES KARABULUT KURT (Fellow, IEEE) received the B.S. degree (with Highest Hons.) in electronics and electrical engineering from Bogaziçi University, Istanbul, Türkiye, in 2000, and the M.A.Sc. and Ph.D. degrees in electrical engineering from the University of Ottawa, Ottawa, ON, Canada, in 2002 and 2006, respectively. She is a Canada Research Chair (Tier 1) in New Frontiers in Space Communications and a Professor with Polytechnique Montréal, Montreal, QC, Canada. She is the Director of Poly-Grames Research Center, and the Co-Founder and the Director of Education and Training of ASTROLITH, Transdisciplinary Research Unit of Space Resource and Infrastructure Engineering, Polytechnique Montréal. She is also an Adjunct Research Professor with Carleton University, Canada. She worked in different technology companies in Canada and Türkiye from 2005 to 2010. From 2010 to 2021, she was a Professor with Istanbul Technical University. She has received the Turkish Academy of Sciences Outstanding Young Scientist (TÜBA-GEBIP) Award in 2019. She is a Marie Curie Fellow.

TONY Q. S. QUEK (Fellow, IEEE) received the B.S. degree in mechanical engineering from National Chung Cheng University, Chiayi, Taiwan, in 2004, and the M.S. degree in mechanical engineering from National Tsing Hua University, Hsinchu, Taiwan, in 2006. He is currently pursuing the Ph.D. degree in mechanical engineering with Texas A&M University at College Station, College Station, TX, USA.

From 2008 to 2009, he was a Research Assistant with the Institute of Physics, Academia Sinica, Tapei, Taiwan. His research interest includes the development of surface processing and biological/medical treatment techniques using nonthermal atmospheric pressure plasmas, fundamental study of plasma sources, and fabrication of micro- or nanostructured surfaces.

Dr. Quek's awards and honors include the Frew Fellowship (Australian Academy of Science), the I. I. Rabi Prize (APS), the European Frequency and Time Forum Award, the Carl Zeiss Research Award, the William F. Meggers Award, and the Adolph Lomb Medal (OSA).