Editorial: Introduction to the Issue on Joint Communication and Radar Sensing for Emerging Applications

I. Introduction

THE integration of Radar and Communication systems has recently attracted a lot of research and commercial interest. The emergence of spectrum-hungry applications have necessitated the exploitation of the permanently allocated, but potentially under-utilized spectral resources, and sharing the frequency bands between radar and communication systems has attracted substantial attention. Below 10 GHz, a large portion of spectral resources are primarily allocated to radar systems, which have seen increasing cohabitation with wireless communication systems. At the higher frequencies such as the millimeter-wave bands, the communication and radar platforms are also expected to coexist harmoniously. Nevertheless, with the allocation of the available frequency bands to the above wireless technologies, the interference in the radar bands is on the rise, and has raised concerns both from governmental and military organizations for the safeguarding of critical radar operations. With achieving spectral coexistence as one of its goals, research effort is well underway to address the issue of the spectral coexistence of communication and radar. Recognising the opportunities arising beyond coexistence, there has been a recent surge in research in designing joint communication and radar (JCR) systems, that go beyond managing interference between the two transmissions, to designing multi-functional transmissions that simultaneously serve the sensing and the communications functionalities.

This special issue has been motivated by the recent increasing interest in the exploitation of the radar spectrum for use of commercial wireless communication, as well as emerging applications requiring joint communication and sensing designs. Accordingly, the aim of this Special Issue (SI) has been to gather the relevant contributions in the area of joint radar and communication system design.

Our guest editorial team would like to thank the Authors of all published and unpublished papers who contributed their works towards this Special Issue. Our sincere gratitude also goes to our expert Reviewers for their timely and thorough reviews that have significantly contributed to the quality of the Special Issue.

We wish to keep this editorial short and refer to the overview article, titled "An Overview of Signal Processing Techniques for Joint Communication and Radar Sensing" by A. Zhang *et al.* [A1] that follows, for a recent overview of state-of-the-art JCR signal processing and a comprehensive list of references. Below we summarise the papers that comprise the present Special Issue.

II. Summary of the SI

The contributions to the present SI broadly fall under the following thematic areas.

A. Transmitter/Receiver Designs for JCR

In their paper "Dual-Functional Radar-Communication Waveform Design: A Symbol-Level Precoding Approach," Li *et al.* [A2] present a symbol level precoding approach to radar-communications signalling. They develop two efficient algorithms that solve the non-convex symbol level precoding problem. The first algorithm converts the original optimization problem into two sub-problems, and iteratively solves them using efficient algorithms. The second algorithm provides a much faster solution at the price of a slight performance loss, using an efficient algorithm. Extensive simulations verify the distinct advantages of the proposed symbol-level precoding designs in both radar target detection and multi-user communications.

C. Xu *et al.* [A3] consider a rate splitting approach to the design of joint radar and communications. In their paper "Rate-Splitting Multiple Access for Multi-Antenna Joint Radar and Communications" they design the message splits as well as the precoders of the communication streams and radar sequence to jointly maximize the radar and communication performance. They conclude that rate splitting multiple access is a powerful interference management strategy for dual functional radar and communication systems.

In the scheme titled "FRaC: FMCW-Based Joint Radar-Communications System via Index Modulation," D. Ma *et al.* [A4] the authors propose and index modulation based FMCW-based radar-communications system that operates with a reduced number of radio frequency modules. Their performance analysis and numerical results show that the proposed radar scheme achieves similar resolution performance compared with a wideband radar system operating with a large receive aperture, while requiring less hardware overhead. For the communications subsystem, FRaC achieves higher rates and improved error rates compared to dual-function signalling based on conventional phase modulation.

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The work by C. Shan *et al.* [A5] "Power Loss Suppression for Time-Modulated Arrays in Radar-Communication Integration," treats the problem of Power Losses in Radar-Communications transmission implemented with Time-Modulated Arrays. They derive the closed-form expression of the power losses for the radar-communications integration scenario and use that to optimize the sideband radiation. The effectiveness of their theoretical derivation is verified by simulations.

Tsinos *et al.* [A6] present a joint transmit and receive design for Radar-Communication systems. Their proposed approach in "Joint Transmit Waveform and Receive Filter Design for Dual-Function Radar-Communication Systems" does not require the knowledge of a predetermined radar beampattern in order to optimize the performance of the radar part through its approximation. Instead, a beampattern is generated by maximizing the radar receive signal-to-interference ratio (SINR) thus, enabling a more flexible design. Moreover, the radar receive filter processing and its optimization is considered. The effectiveness of the proposed solutions is verified via numerical results.

In their paper "MIMO-OFDM Joint Radar-Communications: Is ICI Friend or Foe?," Keskin *et al.* [A7] study the effect of intercarrier interference (ICI) onto the performance of joint radar-communications. They propose a novel ICI-aware sensing algorithm for MIMO-OFDM systems to detect the presence of multiple targets and estimate their delay-Doppler-angle parameters. Importantly, the proposed algorithm can further exploit the ICI effect to enable resolving targets located at the same delay-Doppler-angle cell. Simulation results illustrate the ICI exploitation capability of the proposed approach and showcase its superior detection and estimation performance in high-mobility scenarios over conventional methods.

In the paper "Joint Multi-User Communication and Sensing Exploiting Both Signal and Environment Sparsity" Zhang *et al.* [A8] introduce a method to exploit signal and environment sparsity for joint radar-communications. They propose an iterative and incremental joint multi-user communication and environment sensing scheme, and analyze The trade-off relationship between the key system parameters. The simulation results validate the convergence and effectiveness of their algorithm.

In their paper "Emergency Semantic Feature Vector Extraction from WiFi Signals for In-Home Monitoring of Elderly" Lu *et al.* [A9] try to detect mobility events from the ubiquitous WiFi signals in indoor environments. Common emergencies of the elderly are described as a combination of the Position, Behavior and Respiration of the elderly. They design a neural network to extract such events using ambient WiFi signals Their experimental results show the effectiveness of their approaches for in-home monitoring and emergency notification.

B. *Millimeter-Wave JCR Designs*

Kwon *et al.* [A10] in their article "Joint Communication and Localization in Millimeter Wave Networks" investigate a joint communication and localization approach for millimeter wave networks. The authors introduce a cooperative beamforming and power allocation scheme with multiple base stations to maximize the weighted sum rate of mobile stations while guaranteeing position and orientation estimation error bounds. Their numerical results show that the proposed scheme achieves a larger rate-accuracy region compared to conventional schemes.

In the paper titled "Hybrid Beamforming Design for OFDM Dual-Function Radar-Communication System," the authors led by Z. Cheng [A11] take an optimization approach and design a hybrid beamforming for an OFDM-DFRC system that jointly optimizes the achievable sum-rate of communication and squared error of space-frequency spectrum of radar. Their numerical simulations demonstrate the effectiveness of the proposed scheme.

In the paper titled "Terahertz-Band Joint Ultra-Massive MIMO Radar-Communications: Model-Based and Model-Free Hybrid Beamforming," A. M. Elbir *et al.* [A12] focus on the issue of hybrid beamforming for Terahertz MIMO Radar and Communications. They propose a beamformer that provides a trade-off between communications and radar performance. They further implement deep learning solutions to the proposed model-based hybrid beamformers. Their results demonstrate a high spectral efficiency while exhibiting limited hardware cost and computation time.

C. *JCR in Vehicular Applications*

Tang *et al.* [A13] contribute their work "Self-Interference-Resistant IEEE 802.11ad-Based Joint Communication and Automotive Radar Design," where they study a communication-standards based approach to the design of joint radar and communication systems. They exploit the preamble signalling to combat self-interference for short-range sensing, and the pilot signal and a few self-interference-free OFDM symbols at the end of the data frame to combat self-interference. They present a number of Simulation results that show accurate velocity and range estimation can be achieved for up to 200-meter radar sensing, with the communication signalling.

Zhang *et al.* [A14] focus on the connected car scenario. In their paper "Design and Performance Evaluation of Joint Sensing and Communication Integrated System for 5G MmWave Enabled CAVs," they present a joint sensing and communication integrated system based on the 5G New Radio protocol to achieve low latency and high data rates. They further prove the feasibility and existence of pure strategy Nash equilibrium (NE) for their approach, and propose a resource allocation algorithm. Their simulation and experimental results show that the proposed algorithm can improve the radar total mutual information by 26%, and the feasibility of the proposed JSCIS is achieved with an acceptable radar ranging accuracy within ± 0.25 m, as well as a stable data rate of 2.8 Gbps using the 28 GHz mmWave frequency band.

Yuan *et al.* [A15] in their paper "Integrated Radar Sensing and Communication-assisted Orthogonal Time Frequency Space Transmission for Vehicular Networks" introduce a radar-communications method based on Orthogonal Time Frequency Space Transmission. They concentrate on the vehicular scenario and present a beamsteering approach that exploits the sensing functionality and beam prediction. They further design an efficient uplink detector by taking into account the channel estimation uncertainty. Through numerical simulations, they demonstrate the benefits of the proposed sensing-assisted transmission scheme.

D. JCR Overview

Finally, the Special Issue culminates in the overview from the Guest Editors titled "An Overview of Signal Processing Techniques for Joint Communication and Radar Sensing" led by A. Zhang [A1], that introduces the key opportunities and challenges in the area, and presents a comprehensive overview of key approaches to dual-functional communications and sensing and the state-of-the art in the area. This completes our Special Issue.

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APPENDIX
RELATED WORKS

[A1] J. A. Zhang *et al.*, "An overview of signal processing techniques for joint communication and radar sensing," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1294–1314, Nov. 2021, doi: 10.1109/JSTSP.2021.3113120.

[A2] R. Liu, M. Li, Q. Liu, and A. L. Swindlehurst, "Dual-functional radar-communication waveform design: A symbol-level precoding approach," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1315–1330, Nov. 2021, doi: 10.1109/JSTSP.2021.3111438.

[A3] C. Xu, B. Clerckx, S. Chen, Y. Mao, and J. Zhang, "Rate-splitting multiple access for multi-antenna joint radar and communications," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1331–1346, Nov. 2021, doi: 10.1109/JSTSP.2021.3110312.

[A4] D. Ma, N. Shlezinger, T. Huang, Y. Liu, and Y. C. Eldar, "FRaC: FMCW-based joint radar-communications system via index modulation," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1347–1363, Nov. 2021, doi: 10.1109/JSTSP.2021.3118219.

[A5] C. Shan *et al.*, "Power loss suppression for time-modulated arrays in radar-communication integration," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1364–1376, Nov. 2021, doi: 10.1109/JSTSP.2021.3118896.

[A6] C. G. Tsinos, A. Arora, S. Chatzinotas, and B. Ottersten, "Joint transmit waveform and receive filter design for dual-function radar-communication systems," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1377–1391, Nov. 2021, doi: 10.1109/JSTSP.2021.3112295.

[A7] M. F. Keskin, H. Wymeersch, and V. Koivunen, "MIMO-OFDM joint radar-communications: Is ICI friend or FOE?," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1392–1407, Nov. 2021, doi: 10.1109/JSTSP.2021.3109431.

[A8] X. Tong, Z. Zhang, J. Wang, C. Huang, and M. Debbah, "Joint multi-user communication and sensing exploiting both signal and environment sparsity," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1408–1421, Nov. 2021, doi: 10.1109/JSTSP.2021.3111432.

[A9] L. Guo, Z. Lu, S. Zhou, X. Wen, and Z. He, "Emergency semantic feature vector extraction from WiFi signals for in-home monitoring of elderly," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1422–1437, Nov. 2021, doi: 10.1109/JSTSP.2021.3109429.

[A10] G. Kwon, A. Conti, H. Park, and M. Z. Win, "Joint communication and localization in millimeter wave networks," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1438–1454, Nov. 2021, doi: 10.1109/JSTSP.2021.3113115.

[A11] Z. Cheng, Z. He, and B. Liao, "Hybrid beamforming design for OFDM dual-function radar-communication system," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1455–1467, Nov. 2021, doi: 10.1109/JSTSP.2021.3118276.

[A12] A. M. Elbir, K. V. Mishra, and S. Chatzinotas, "Terahertz-band joint ultra-massive MIMO radar-communications: Model-based and model-free hybrid beamforming," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1468–1483, Nov. 2021, doi: 10.1109/JSTSP.2021.3117410.

[A13] A. Tang, S. Li, and X. Wang, "Self-interference-resistant IEEE 802.11ad-based joint communication and automotive radar design," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1484–1499, Nov. 2021, doi: 10.1109/JSTSP.2021.3118888.

[A14] Q. Zhang, X. Wang, Z. Li, and Z. Wei, "Design and performance evaluation of joint sensing and communication integrated system for 5G mmWave enabled CAVs," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1500–1514, Nov. 2021, doi: 10.1109/JSTSP.2021.3109666.

[A15] W. Yuan, Z. Wei, S. Li, J. Yuan, and D. W. K. Ng, "Integrated sensing and communication-assisted orthogonal time frequency space transmission for vehicular networks," *IEEE J. Sel. Topics Signal Process.*, vol. 15, no. 6, pp. 1515–1528, Nov. 2021, doi: 10.1109/JSTSP.2021.3117404.

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