Foreword to the Special Section on Innovations in Radar Spectrum

WHERE large swaths of the radio frequency (RF) spectrum were once the sole provenance of radar, today there is unceasing competition for this vital resource. Indeed, the sheer volume and complexity of the numerous users is mind-boggling, especially to those who must contend with regulatory structures that cannot possibly keep pace with the rate of innovation in this domain.

As evidenced by the immense number of recent surveys on the topic of spectrum sharing [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], this large and rapidly growing body of research makes the phrase "hot topic" a rather absurd understatement. From methods to perform dual-function radar/communications by the same system, to cognitive radar approaches that seek to minimize the interference imposed upon other spectrum users, to addressing the proliferation of in-band interference the radar itself must face, there is a wide variety of emerging research focused on radar's multifunction usage, deconfliction, containment, and sharing of spectrum explored in this second special section of the recently launched IEEE TRANSACTIONS ON RADAR SYSTEMS. Following a strong response, the topics investigated in these selected eight papers span much of the breadth of the radar spectrum research community.

The notion of cognitive radar can take on many forms, from traditional automation of frequency selection to modern on-the-fly waveform design and more, though the common theme tends to be the leveraging of some form of perception–action cycle whereby the radar modifies its behavior according to the observed environment based on some prescribed metric(s) of goodness. Within the spectrum context, cognitive radar has often been associated with maximizing spectrum usage while simultaneously minimizing the amount of interference that the radar causes to other users. In [A1], Kovarskiy et al. examine a higher level cognition framework whereby different existing "restless bandit" strategies are selected depending on the perceived spectral conditions. A real-time implementation of this framework is demonstrated with emulated interference using software-defined radio (SDR) hardware.

Machine learning is then leveraged by Flendermeyer et al. [A2] through the use of a reinforcement learning approach to dynamically adapt a cognitive radar trade-space comprised of collision avoidance with other users, bandwidth utilization, and distortion losses incurred by waveform-agile behavior. Open-air experimental measurements demonstrate performance.

Rounding out the cognitive radar papers, in [A3], Hussain et al. illustrate the utility of the ultrawideband (UWB) throb signal comprised of an aggregate of generalized Gaussian pulses separated in time. An analytical expression for the spectrum of this signal is derived and in turn, used to formulate an optimization algorithm to enable radar spectrum notching on transmit for operation in congested RF environments.

Next, a pair of papers investigate the enormous potential design space for combined radar and communication operations. In [A4], Bekkali et al. pose a power allocation problem that seeks to maximize the weighted sum of communication and radar information rates, where the latter is in the context of the impulse response of hypothesized extended targets. Two waveform design strategies are then developed and demonstrated to permit a tradeoff between radar and communication performance.

In [A5], Correas-Serrano et al. present a nonuniform variant of the orthogonal time–frequency space (OTFS) modulation scheme as a means to achieve separability for multiuser joint radar/communication applications. Sparse reconstruction via compressed sensing is then employed to reduce self-interference and enhance radar parameter estimation.

The impact of tuning hardware requirements for spectrum sensing over multiple distinct bands is addressed by Kulmon et al. [A6]. A scheduling model is posed to balance between target tracking and spectrum survey, in turn leading to a multicriteria nonlinear optimization problem involving the expected track information gained by a new measurement and the Kullback–Liebler divergence of the sampled sequence of tuned bands.

Finally, a pair of papers take aim at the difficult task of radar receive processing in complex spectral environments. In [A7], Bondre et al. consider how to design receive processing techniques for radar detection in the context of cooperative spectrum coexistence with communications. A generalized likelihood ratio test (GLRT) detector is derived to facilitate the prediction of receiver operating characteristics (ROC) performance, which is demonstrated via Monte Carlo simulation.

Then, Mattingly et al. [A8] address the nonstationary effect known as range sidelobe modulation (RSM) that arises from waveform-agile operation, which can introduce a higher sensitivity floor. A modified backprojection technique is proposed in conjunction with mismatched filtering to mitigate the particularly deleterious RSM that occurs when a cognitive radar changes bandwidth and/or intermediate frequency during the coherent processing interval. Performance is demonstrated using open-air measurements collected by an SDR-based radar testbed.

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APPENDIX: RELATED ARTICLES

[A1] J. A. Kovarskiy, A. F. Martone, R. M. Narayanan, and K. D. Sherbondy, "Restless bandits for metacognitive spectrum sharing with software defined radar," *IEEE Trans. Radar Syst.*, vol. 1, pp. 401–412, Aug. 2023.

[A2] S. A. Flandermeyer, R. G. Mattingly, and J. G. Metcalf, "Deep reinforcement learning for cognitive radar spectrum sharing: A continuous control approach," *IEEE Trans. Radar Syst.*, vol. 2, pp. 125–137, Jan. 2024.

[A3] M. G. M. Hussain and M. A. R. Koura, "Optimization algorithm for spectral notching based on analytical frequency spectrum of ultrawideband throb signal represented by chirp-Fourier series," *IEEE Trans. Radar Syst.*, vol. 1, pp. 740–752, 2023.

[A4] N. Bekkali, S. Bidon, M. Benammar, and D. Roque, "Mutual information-driven power allocation in OFDM dual-function radar-communication systems," *IEEE Trans. Radar Syst.*, vol. 1, pp. 605–622, 2023.

[A5] A. Correas-Serrano, N. Petrov, M. Gonzalez-Huici, and A. Yarovoy, "MIMO OTFS with arbitrary time-frequency allocation for joint radar and communications," *IEEE Trans. Radar Syst.*, vol. 1, pp. 707–718, 2023.

[A6] P. Kulmon, J. Suja, and M. Benko, "Scheduling of multi-function sensor," *IEEE Trans. Radar Syst.*, vol. 1, pp. 729–739, Nov. 2023.

[A7] A. S. Bondre and C. D. Richmond, "ROC performance prediction for cooperative radar-communications via Wilks' theorem," *IEEE Trans. Radar Syst.*, vol. 1, pp. 632–645, 2023.

[A8] R. G. Mattingly, A. F. Martone, and J. G. Metcalf, "Techniques for mitigating the impact of intra-CPI waveform agility," *IEEE Trans. Radar Syst.*, vol. 2, pp. 24–40, 2024.

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[7] Y. Cui, F. Liu, X. Jing, and J. Mu, "Integrating sensing and communications for ubiquitous IoT: Applications, trends, and challenges," *IEEE Netw.*, vol. 35, no. 5, pp. 158–167, Sep. 2021.

[8] 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. 1295–1315, Nov. 2021.

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[11] A. Liu et al., "A survey on fundamental limits of integrated sensing and communication," *IEEE Commun. Surveys Tuts.*, vol. 24, no. 2, pp. 994–1034, 2nd Quart., 2022.

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