Guest Editorial

Foreword to the Special Section on Spectrum Sharing

It has been over 50 years since Nobel Laureate Bob Dylan told us that "the times they are a changin'," but that statement is as true today as it was then, particularly in the context of radio frequency (RF) spectrum usage. For example, it has long been an "established fact" that a radar requires *dedicated* spectrum for its *sole use* in order to meet the tremendous sensitivity that is required of it. However, recent years have witnessed the growth of dynamic frequency selection capabilities that have already been deployed to facilitate the use of radar spectrum by other devices on an opportunistic basis. Moreover, the prospect of dual/multifunction systems is eliciting a plethora of new capabilities in which distinctly different modes may potentially work together to make the whole truly greater than the sum of its parts. And of course, there is the underlying driver of increasing spectral congestion due to our own voracious appetites for wireless data access that is providing a major push for so much of this rapid innovation.

Given the relatively recent massive uptick in research devoted to spectrum sharing, the purpose of this special section is to cast the spotlight on a cross-section of these efforts. The IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS is an ideal venue for consideration of this emerging topic because the interaction between these hitherto disparate modes of operation truly requires a broader *systems perspective* that transcends and encompasses the individual disciplines of signal processing, microwave circuits, RF engineering, and electromagnetics, as well as the various operating paradigms of individual modalities such as radar, communications, navigation, and electronic warfare.

Following an excellent response to the Call for Papers and after a careful review process, we have selected 14 papers for inclusion in this T-AES special section on spectrum sharing. These papers represent a diverse set of applications, approaches, and technical disciplines, which is rather appropriate given the context. Specifically, the first grouping of four papers considers the impact of interference on incumbent systems, followed by a pair of papers that develop filtering strategies to address in-band interference. The next set of three papers subsequently examine methods to design one's own signal structure with other spectrum users in mind. The last group of five papers then explore emission strategies whereby different functions can be realized simultaneously. The following introduces these papers in a bit more detail.

When different systems are required to cohabitate spectrum, particularly if one of them is an incumbent system for which the cost to replace or modify is excessively high, it stands to reason that the newer entrant would employ some means to sense the spectrum to avoid the occurrence of mutual interference. In "Sequential sensor selection and access decision for spectrum sharing" by Lee and Ekici, a multiarmed bandit problem formulation is used to develop an algorithm that selects a subset of spectrum sensing nodes so that the energy usage for this task in each secondary mobile unit is kept to a minimum, thereby extending battery life while ensuring sufficient coverage to avoid interfering with the primary radar. Likewise in "Spatial spectrum sharing for satellite and terrestrial communication networks" by Zhang *et al.*, the interference effects that future fifth-generation (5G) communications in millimeter-wave bands will have on geostationary satellite systems are assessed so that suitable protection regions can be determined.

A cognitive radar operating mode is proposed and experimentally evaluated in "Avoidance of time-varying RF interference with software-defined cognitive radar" by Kirk *et al.*, whereby the radar frequency band is adapted according to sensed interference from other users sharing the same band. The paper "New spectrum efficient reconfigurable filtered-OFDM based *L*-band digital aeronautical communication system" by Agrawal *et al.*, then proposes a reconfigurable protocol and orthogonal frequency division multiplexing (OFDM) waveform to permit bandwidth adaptation in the presence of dynamic interference for air traffic management systems.

When in-band interference from another spectrum user cannot be avoided, it becomes necessary to employ appropriate receive filtering that addresses the particular characteristics of the other user. In "Optimal linear detection of signals in cyclostationary, linearly modulated, digital communications interference" by Zilz and Bell, a radar receiver whitening filter is derived that suppresses interference from in-band communication systems based on linear modulation schemes such as OFDM and code division multiple access. Conversely, the paper "Mitigating linear frequency modulated pulsed radar interference to OFDM" by Carrick *et al.*, develops a time-varying frequency shift filter that suppresses interference in OFDM communication receivers caused by radars employing linear FM waveforms.

Beyond receive interference suppression is the notion of designing one's own emitted signals in a manner that accounts for other in-band users according to a *good spectral neighbor* policy that benefits all users. In "Novel radar waveform optimization for a cooperative radar-communications system" by Chiriyath *et al.*, a radar waveform design technique is proposed that relies on a joint estimation rate encompassing both radar and communication performance. A cognitive radar formulation is then considered in "Efficient algorithms for synthesizing probing waveforms with desired spectral shapes" by Tang and Liang, whereby coded waveforms are designed according to a weighted least squares approach to realize in-band spectral avoidance regions in which spectrum sharing can occur. Given the high transmit power requirements of most radars "Joint radar amplifier circuit and waveform optimization for ambiguity function, power-added efficiency, and spectral compliance" by Latham *et al.*, subsequently examines the design of physical radar emissions within the context of an adaptive and reconfigurable transmitter circuit to address dynamic spectrum environments.

Finally, a rapidly emerging subgenre of spectrum sharing is the concept of dual/multifunction modes in which two (or possibly more) capabilities are realized concurrently by the same system (as opposed to alternating functions that are time-shared). In "Study of the target self-interference in a low-complexity OFDM-based radar receiver" by Mercier *et al.*, the efficacy of information-bearing OFDM is evaluated in terms of the radar detection performance that could be achieved by using the same signal for sensing and communications. Spatial degrees of freedom are exploited in "Dual-function MIMO radar communications system design via sparse array optimization" by Wang *et al.*, where a communication attribute is incorporated into a MIMO radar signal according to various antenna selection strategies.

In the paper "Joint radar-communications co-use waveform design using optimized phase perturbation" by Zhou *et al.*, a dual-function radar/communication signal structure is proposed in which a phase-shift keying information sequence is used to modify a radar phase code. Dokhanchi, Mysore, Mishra, and Ottersten likewise consider OFDM and phase-modulated continuous-wave instantiations of these signals in "An mm-wave automotive joint radar-communications system" as a means to enhance vehicle safety. This broader waveform diversity based class of signals is then evaluated in "High-SNR channel capacity for communication over radar waveforms" by Weiner using information theory to determine the possible data rates that can feasibly be achieved for radar-embedded communications.

It is hoped that the reader finds this collection of spectrum sharing papers to be of great value in setting the stage as this topic continues to evolve. It has been said that the only completely accurate prediction one can make about spectral congestion is that it will continue to get worse. However, as these papers abundantly illustrate, our ability to creatively innovate will most certainly continue as well.

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