Introduction to the Issue on Adaptive Waveform Design for Agile Sensing and Communication

WAVEFORM-agile sensing, the ability to adapt and diversify the waveform at each time instant, is fast becoming one of the most important methods by which systems can be dynamically adapted to their environment to achieve performance gains over non-adaptive systems. Such adaptation can lead to great benefits including improved performance and reduced sensor usage leading to greater system efficiency. For example, waveform diversity can allow one or more sensors on-board a platform to automatically change operating parameters such as frequency, gain pattern and pulse repetition frequency to meet the varying environment. As another example, modern agile beam radar systems can provide high resolution images, detect fast moving objects, and change waveforms from pulse to pulse. Continuing development of new sensor modalities and sensor waveform agility, advances in fabrication, miniaturization, and integration of sensors into complex systems, and developments in ad-hoc networks all contribute to the rapid escalation of sensor system capabilities. Until recently, sensor hardware was not capable of changing the transmitted waveform in real time. With the emergence of new flexible digital waveform generators and highly advanced sensor electronics, real-time waveform design can successfully be integrated into a sensor system.

Early attempts toward waveform-agile sensing treated the sensor and sub-system as completely separate entities. Instead, the aim was to improve the matched filter response of the receiver in order to maximize resolution, minimize the effects of mismatching, optimally design the signal for reverberation-limited environments, or for clutter rejection or noise cancellation. Currently, in many applications, sensing systems are designed with capabilities of configuring the transmit waveforms and processing them at each time step. For example, in target tracking, being able to shape the transmitted waveform on a pulse-to-pulse basis results in obtaining information that can optimally improve the tracker’s estimate of the target state. In target detection applications, especially in challenging scenarios such as detecting a low grazing angle target in heavy sea clutter, waveform-adaptation can be exploited to mitigate the effect of the environment and thus improve detection performance. In wireless communications, waveform diversity techniques allow adaptation of the waveform to match the distortion caused by the environment to optimize the communication performance instead of distorting it.

Thus, increasingly complex operational scenarios call for sophisticated techniques like waveform diversity to enable effective integrated command, control, communications, computers, and intelligence operation from diverse platforms to maintain an asymmetrical technological edge. With the available EM spectrum becoming increasingly scarce, a crucial need in many applications such as sensing, communications, countermeasures and network centric warfare, is one of multiple sensing, multi-modal sensor operation, and multi-function processing from diverse platforms. End-to-end optimization for sensor, communication or intelligence gathering systems using diverse waveforms includes selection of waveforms in real-time using all available information. Waveform-diverse systems must exploit information pertaining to the propagation environment, transmit and receive antennas and their motion, targets and clutter, and communication signals. Several aspects of this information evolve with time. Therefore, waveform generation resources have to be optimally and adaptively integrated with electromagnetic phenomenology and other available knowledge sources using physical, experimental, and data-dependent approaches. Sensor fusion has a potential for enhanced performance in difficult operational scenarios. However, this potential has not been fully realized in the past. In this context, it becomes imperative to associate data from multiple sensors with suitable models. The association problem becomes especially difficult when multiple platforms are used and when strong clutter precludes the detection of targets by individual sensors. Concurrent detection and tracking, or concurrent detection, tracking, and fusion have to be employed. Commercial applications of this technology include wireless networks and optimal resource allocation for enhancing channel capacity. These problems are the focus of a number of supported research efforts worldwide.

In the near future, advanced intelligent radar systems will use knowledge-based techniques to perform signal and data processing. This will be achieved in a cooperative manner within and between platforms of sensors and communication systems while exercising waveform diversity as well as reconnaissance, surveillance, imaging and communications within the same sensor system. Thus, changing appropriately the waveforms and sensor processing algorithms can enhance the system performance in the presence of changes in the environment; this is the basic concept of adaptive waveform design.

The waveform agility provided by modern sensor technologies promises significant improvements in active sensor system performance as waveforms are tailored to match the target, its environment, and information to be extracted. However, full realization of this promise requires significant advances in waveform design and scheduling, environmental modeling, and sensor configuration and control. The goal of this special issue is to feature recent advances in the area of adaptive waveform design for agile sensing and communication as well as remaining challenges. The advances can include novel
physical, mathematical, and computational methods to combat important signal processing challenges arising on account of large system dimensionality and stressful conditions of sample support and onerous computational requirements. This special issue integrates a number of different areas in the field of waveform-agile sensing. Specifically, our 18 papers encompass the areas of: 1) Waveform Design; 2) Adaptive Waveform Design and Detection; 3) Surveillance and Classification in Radar; 4) Multiple-Input Multiple-Output (MIMO) Radar Systems; and 5) Wireless Communications.

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