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MIMO Signal Processing for Over-the-Horizon Radar: Experimental Results

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The Networked Over-the-Horizon Radar (NOTHR) is a flexible and scalable high-frequency (HF) radar system for wide-area surveillance and target detection over oceans and remote regions. It is based on a bistatic configuration with a large transmitter and multiple small, mobile receivers, offering a cost-effective and easily deployable solution [1]. The system employs Multiple-Input Multiple-Output (MIMO) radar signal processing techniques to enhance signal detection, angular estimation, and clutter rejection [2]. Designing a large MIMO radar transmitter presents several engineering challenges, such as selecting waveforms for a high number of transmitted signals while preserving their orthogonality.

This paper focuses on evaluating the performance of multiple waveforms in a real-world Over-the-Horizon Radar (OTHR) system and analyses their scalability for a large transmitting array. A measurement campaign was conducted using a five-element HF transmitter array and a single receiver. Note that this equates to the Multiple-Input Single-Output (MISO) radar configuration. The experimental setup and processing chain were designed to evaluate various MIMO radar waveforms, including Doppler, Time, and Code Division Multiple Access (DDMA, TDMA, and CDMA) [3]. These techniques were employed to calibrate the system and assess its performance under both surface wave and skywave propagation conditions.

Initial results demonstrated the system's ability to accurately estimate range, Doppler, and direction-of-departure (DOD) within the radar cube obtained via MISO processing. Matched filter and beamformer outputs were analysed to assess the separability and overall performance of different waveforms. The calibration process proved crucial for achieving effective transmit beamforming during processing, significantly improving signal-to-noise ratio (SNR) and waveform separability. Additionally, the system successfully received and processed signals reflected by the ionosphere. Radar processing results revealed variations in signal amplitude and phase, attributed to dynamic ionospheric conditions. These observations provided valuable insights into skywave signal behaviour over time. Waveform performance examples under skywave conditions further demonstrated the system's effectiveness in challenging propagation environments.

Tests conducted with CDMA signals, both in fast and slow time, produced outputs with sidelobe levels too high for practical scalability. In contrast, the best results were obtained with Time and Doppler Division schemes. However, those that use phase encoding across signals transmitted by different elements to resolve TDMA signal ambiguity showed higher degradation due to residual phase errors after calibration in skywave scenarios. This emphasizes the importance of a robust calibration process for achieving accurate and reliable results in OTHR systems. Furthermore, incorporating real ionospheric data is essential for improving skywave propagation models and refining MIMO radar signal processing algorithms. These results contribute to the ongoing development of NOTHR as a novel wide-area surveillance system.

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