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Artificial Neural Network for DOA Estimation via Programmable Metasurfaces

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In recent years, digital programmable metasurfaces have become a powerful and versatile platform for implementing various functions. Especially, the combination of machine learning algorithms and metasurfaces is gaining wide attention and has been widely applied. On the other hand, direction of arrival (DOA) estimation has long been an attractive research topic in various industries and is a vital technique for intelligent wireless systems. Conventional DOA estimation methods, such as multi-signal classification and estimation of signal parameters via rotational invariance techniques, usually rely on array antennas and have high latency in signal processing, leading to complex hardware architecture, high cost, and low efficiency in in-situ estimation. Besides, some metasurface-based estimating DOA methods have emerged as alternatives, but they have limited applications due to the stringent requirements for equipment and environment.

In this report, we will present a different method to lift these limitations by combining artificial neural networks (ANNs) with space-time-coding (STC) programmable metasurfaces. The ANN-enabled DOA estimation method can achieve high accuracy by simply analyzing the spatial-spectral characteristics of space-time-coding modulation, which utilizes only harmonic amplitudes without phases and also features a much-simplified hardware architecture. The proposed method does not require large computational resources and is robust in practical applications. For validation, we present several ANN models trained with simulated and measured data in the microwave region. The proposed theory and metasurface provide on-demand selections of ANN models for reaching optimal DOA estimations in different scenarios, which holds promising application potentials in wireless sensing, communication, radar, and other self-adaptive information systems.