CLEAN-based Multi-Target Detection for ISAC Systems

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Abstract

In this paper, we propose a Coherent CLEAN algorithm to enhance multi-target discrimination in 28 GHz OFDM-based ISAC systems. Standard beamforming often suffers from the sidelobe masking effect, where spectral leakage from dominant targets obscures weaker signals regardless of physical resolution limits. Consequently, it fails to distinguish adjacent targets due to this inherent interference. To address this, the proposed method iteratively estimates and removes the interference of dominant targets, thereby recovering the visibility of masked signals. Validated through simulations based on a 28 GHz ISAC testbed, the proposed approach effectively resolves targets with significant power disparities, demonstrating superior discrimination performance.

***Index Terms*—Multi-target discrimination, Integrated Sensing and Communication (ISAC), Coherent CLEAN, Sidelobe Masking**

I. INTRODUCTION

The 28 GHz millimeter-wave (mmWave) band is essential for high-resolution sensing and high-speed data transmission in 5G and 6G ISAC systems [1]. Despite the high spatial resolution offered by mmWave systems, multi-target detection performance can still be severely degraded by masking due to sidelobes. This energy leakage effectively buries weaker targets, merging them into a single entity even if they are well within the resolution limits. Such interference leads to false alarms and missed detections in standard methods such as simple thresholding and CFAR. To address this masking problem, we propose applying the CLEAN algorithm for ISAC systems [2]. In this paper, we demonstrate that the proposed method successfully mitigates the masking effect and separates merged signals, thereby significantly enhancing multi-target discrimination capability.

II. SYSTEM MODEL

A. Signal Model

We consider a bistatic ISAC system equipped with uniform linear arrays (ULAs) at both the TX and RX, each consisting of $N = 4$ antenna elements. Angular information is acquired through beam sweeping, while range information is obtained via frequency-domain processing across OFDM subcarriers. After beam sweeping and range processing, the system output is represented as a two-dimensional range–angle map.

The observed range–angle map can be modeled as

$$I_{\text{dirty}}(r,\theta) = \sum_{k=1}^{K} \alpha_k \, \text{PSF}(r,\theta;\, r_k,\theta_k) + n(r,\theta), \tag{1}$$

where (r_k, θ_k) denote the range and angle of the k-th propagation path, α_k represents the estimated amplitude and phase associated with the k-th detected target in the range–angle map, and $n(r,\theta)$ denotes additive noise. The point spread function (PSF) characterizes the beamformed response of the system to a single scatterer. In practice, the PSF is obtained by simulating the beam sweep response of the system for a unit-amplitude scatterer and applying the same processing chain.

Algorithm 1 Proposed Coherent CLEAN Algorithm

Require: Dirty Map $\mathbf{I}_{dirty}$, Threshold η, Gain γ
Ensure: Estimated Target Set $\mathcal{K}$
1: $\mathbf{I}_{res} \leftarrow \mathbf{I}_{dirty}$, $\mathcal{K} \leftarrow \emptyset$
2: **while** $\max(|\mathbf{I}_{res}|) > \eta$ **do**
3: **Peak Extraction:** Find $(\hat{r}, \hat{\theta}) \leftarrow \arg\max |\mathbf{I}_{res}|$ and get $\hat{\alpha}$
4: **PSF Generation:** Generate unit PSF map $\mathbf{I}_{PSF}$ for $(\hat{r}, \hat{\theta})$
5: **Subtraction:** $\mathbf{I}_{res} \leftarrow \mathbf{I}_{res} - \gamma \cdot \hat{\alpha} \cdot (\mathbf{I}_{PSF} / \mathbf{I}_{PSF}(\hat{r}, \hat{\theta}))$
6: **Update:** $\mathcal{K} \leftarrow \mathcal{K} \cup \{(\hat{r}, \hat{\theta}, \hat{\alpha})\}$
7: **end while**
8: **return** $\mathcal{K}$

The structure of the PSF is primarily determined by the array steering vectors used during beam sweeping. For a uniform linear array, the steering vector $\mathbf{a}(\theta)$ represents the spatial phase response of a target at angle θ and is defined as

$$\mathbf{a}(\theta) = \left[1,\ e^{-j\beta},\ e^{-j2\beta},\ e^{-j3\beta}\right]^T, \tag{2}$$

where $\beta = 2\pi d \sin(\theta)/\lambda$ denotes the electrical phase shift between adjacent antenna elements, d is the inter-element spacing, and λ is the carrier wavelength. In bistatic configurations, θ corresponds to the angle-of-departure (AoD) at the TX or the angle-of-arrival (AoA) at the RX, depending on the beam sweeping configuration. In this work, the antenna spacing is set to $d = \lambda/2$.

B. Proposed Coherent CLEAN Detection Algorithm

Standard beamforming techniques produce a "dirty map" where weak targets are often masked by the spectral leakage of dominant interferers. To mitigate this masking effect and accurately resolve closely spaced targets in the range-angle domain, we employ the proposed Coherent CLEAN algorithm.

By utilizing the array steering vector, this framework processes the full complex-valued signal to reconstruct the precise interference pattern using estimated range ($\hat{r}$), angle ($\hat{\theta}$), amplitude ($|\hat{\alpha}|$), and phase ($\angle\hat{\alpha}$). With these parameters, instead of estimating patterns from the noisy observed image, we mathematically synthesize an ideal, noise-free Point Spread

TABLE I: SIMULATION PARAMETERS SPECIFICATIONS

Parameters	Value
Center frequency	28 GHz
Bandwidth	1.92 GHz
Number of Subcarriers	4000 (Spacing: 480 kHz)
Antenna size	Tx: 4 (ULA); Rx: 4 (ULA)
Tx beam AoD range	$-60°$ to $60°$ (Step: $5°$)
Rx beam AoA range	$-60°$ to $60°$ (Step: $5°$)

Function (PSF) corresponding to the detected peak parameters. This approach enables precise coherent subtraction by utilizing the phase alignment, effectively eliminating both the main lobe and the coherent sidelobes of strong interferers without amplifying the background noise.

The detection process operates iteratively as summarized in Algorithm 1. First, the algorithm identifies the dominant scatterer's location $(\hat{r}, \hat{\theta})$ and extracts its $\hat{\alpha}$ from the residual map. Second, the system-specific PSF is synthesized for the detected location and scaled by the extracted $\hat{\alpha}$. This synthesized response is then subtracted from the residual map. This sequential cancellation "cleans" the masking effect, revealing weaker targets that were previously hidden. Finally, the iteration terminates when the residual energy falls below a pre-defined noise threshold, yielding the final output set $\mathcal{K}$ which containing the estimated parameters $(\hat{r}, \hat{\theta}, \hat{\alpha})$ for all detected targets.

III. Simulation Setup and Results

A. Simulation Setup

To validate the multi-target discrimination capability of the proposed coherent CLEAN algorithm, we conducted system-level simulations mirroring a 28 GHz PXI testbed. The system models an OFDM-based radar using a 4-element Uniform Linear Array (ULA) for both Tx and Rx. The detailed system parameters are summarized in Table I.

To evaluate the detection performance, we constructed a scenario with two closely spaced targets as shown in Fig. 1. Specifically, the targets were intentionally positioned at similar bistatic ranges of approximately 6.53 m and 6.76 m, respectively, to create a severe masking scenario within the range-angle map.

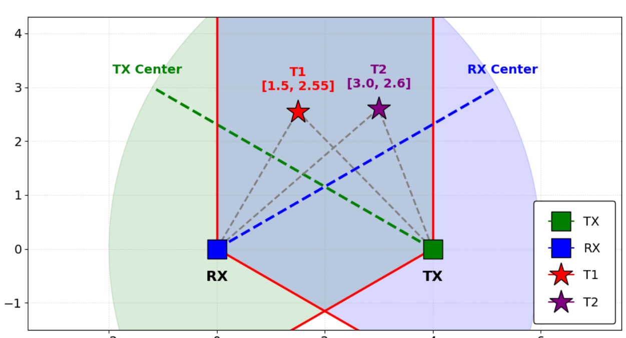

Fig. 1: Simulation geometry consisting of two closely spaced targets (T1 and T2).

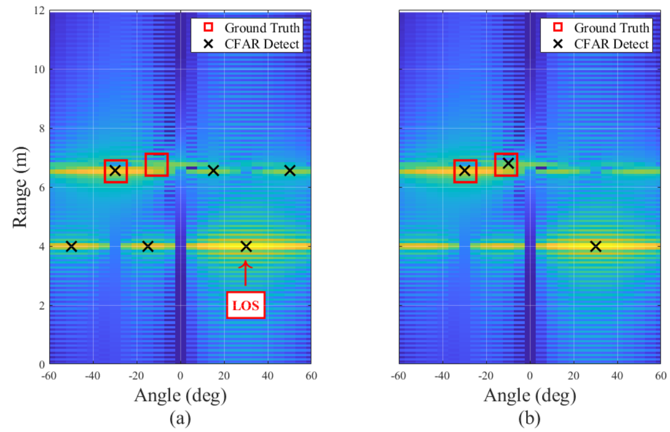

Fig. 2: Comparative evaluation between (a) the baseline method and (b) the proposed coherent CLEAN algorithm.

B. Simulation Results

To ensure a fair assessment, both 2D CA-CFAR and DBSCAN clustering [3] were identically applied to the baseline and proposed methods, as visualized in Fig. 2. As shown in Fig. 2(a), the baseline method fails to resolve the targets due to masking effects. Strong sidelobes are misidentified as targets, while the relatively weaker target remains undetected.

In contrast, Fig. 2(b) demonstrates that the proposed algorithm successfully detects both targets by resolving the masking effect. The estimation performance was validated with a Root Mean Square Error (RMSE) of 0.0374 m in range and $0.7255°$ in angle. These results confirm that the proposed algorithm successfully addresses the masking problem.

IV. Conclusions

This paper proposes a coherent CLEAN-based interference cancellation algorithm to address the sidelobe masking problem in mmWave ISAC systems. By performing iterative interference cancellation considering both phase and power information, the proposed method enables reliable multi-target separation even in the presence of sidelobe masking. Simulation results, based on a realistic 28 GHz ISAC testbed configuration, demonstrate that merged targets can be effectively resolved. These findings confirm that the proposed approach serves as an effective solution for enhancing multi-target detection performance in practical ISAC sensing scenarios.

Acknowledgment

The fundamental research described in this paper was supported by the National Research Foundation of Korea under Grant RS-2024-00409492.

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