

Resource Allocation and AP Selection Optimization for Full-duplex CFMM Systems with ISAC

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Abstract—This paper proposes a new design for multiple-target detection using a full-duplex (FD) cell-free massive multi-input multi-output (CFMM) integrated sensing and communication (ISAC) system. In this framework, distributed multi-antenna access points (APs) operate in FD mode to serve multiple single-antenna uplink and downlink users on the same frequency band while simultaneously transmitting probing signals toward designated sensing zones in ISAC mode. To balance sensing and communication performance, APs dynamically switch between ISAC and communication-only modes. To address the challenges of interference from user equipments (UEs), APs, residual self-interference in FD, and clutter in ISAC, we introduce a novel target-AP pairing strategy with an efficient interference management approach. Our solution jointly optimizes downlink communication and sensing beamforming, uplink power control, and target-AP pairing to maximize the average sum rate. We first relax the binary pairing variables into continuous ones and then develop an iterative algorithm based on the inner convex approximation method. Numerical results demonstrate that the proposed design significantly improves communication performance in FD while maintaining robust sensing capabilities in ISAC.

Index Terms—Cell-free massive multi-input multi-output (CFMM), integrated sensing and communication (ISAC), full-duplex (FD) convex optimization, optimal pairing.

I. INTRODUCTION

The rapid growth of internet of things (IoT) and applications such as autonomous driving has increased the demand for both communication and radar sensing, which are among the essential elements in future 6G networks. High-frequency bands have facilitated joint communication and radar sensing, leading to the development of integrated sensing and communication (ISAC), which enables spectrum and hardware sharing within a single base station [1]. To enhance coverage and sensing resolution, cell-free massive multi-input multi-output (CFMM) has emerged as a scalable extension of conventional massive MIMO, employing distributed access points (APs) connected to a central processing unit (CPU) to serve spatially distributed user equipments (UEs) [2], [3]. Integrating CFMM with ISAC presents a promising solution to meeting future communication and sensing requirements.

In-band full-duplex (FD) enhances spectral efficiency by enabling simultaneous downlink and uplink transmissions on the same time-frequency resource, potentially doubling spectral efficiency. Advances in self interference (SI) suppression have made FD feasible, and its integration with ISAC demonstrates superior potential and efficiency compared to traditional

half-duplex (HD) methods [4]. Combining FD with CFMM improves both communication and sensing capabilities while enabling a practical and cost-effective implementation using low-power FD-enabled APs.

Recent studies have explored ISAC integration into CFMM. The authors in [5] examined an architecture where a subset of APs transmits downlink sensing signals while others receive echo signals to sense a single target. This concept was extended in [6] for multiple target detection, where APs were divided into subsets dedicated to either downlink communication or radar sensing through a mode selection strategy. However, these works assumed that all APs operated in HD mode. The study in [7] investigated FD-enabled CFMM for multi-target detection but restricted APs to either uplink reception or downlink transmission, with the CPU determining their mode.

In this study, we propose a novel ISAC-FD-assisted CFMM (ISAC-FD-CFMM) system for multi-target detection, where all APs operate in FD mode to simultaneously serve uplink and downlink UEs. Our goal is to maximize the average sum rate by jointly optimizing downlink beamforming, power control, and AP mode selection of target-AP pairing. To mitigate interference from APs, UEs, SI in FD mode, and clutter in ISAC, we relax binary variables into continuous ones and apply the inner approximation method. This approach enables the formulation of a successive convex program, which is efficiently solved using a low-complexity iterative algorithm to obtain a locally optimal solution.

II. SYSTEM MODEL AND PROBLEM FORMULATION

As illustrated in Fig. 1, we consider an ISAC-FD-CFMM system comprising multiple APs, each equipped with two uniform linear arrays (ULAs): N_t antennas for transmission and N_r antennas for reception. Leveraging FD technology, the APs simultaneously serve $K = K_{ul} + K_{dl}$ single-antenna UEs, where K_{ul} and K_{dl} represent the number of uplink and downlink UEs, respectively. In sensing mode, APs utilize the transmitted sensing signals to detect T passive desired targets in the presence of C clutter sources. This enables simultaneous communication and sensing operations. We assume that the number of APs exceeds both the number of UEs and targets, i.e., $M > T$, $M > K$. The uplink UEs are represented by the set $\mathcal{K}_{ul} = \{1, 2, \dots, K_{ul}\}$, where $u \in \mathcal{K}_{ul}$ denotes the u -th uplink UE, UE_u^{ul} . Similarly, the downlink UEs are in $\mathcal{K}_{dl} = \{1, 2, \dots, K_{dl}\}$, with $d \in \mathcal{K}_{dl}$ representing the d -th downlink UE, UE_d^{dl} . The APs are indexed by $\mathcal{M} = \{1, 2, \dots, M\}$, where $m \in \mathcal{M}$ represents the m -th AP, AP_m . The set of

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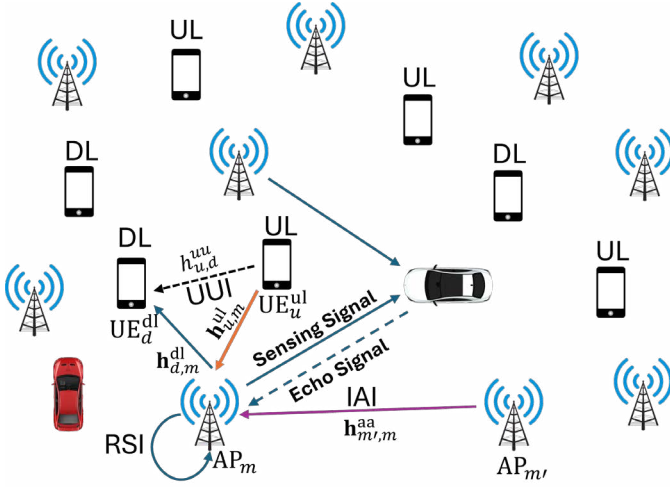


Fig. 1. ISAC-FD-assisted CFMM system.

targets including desired targets and clutter sources, is denoted as $\mathcal{T} \cup \mathcal{C} = \{1, 2, \dots, T, T+1, \dots, T+C\}$, where $t \in \mathcal{T}$ corresponds to the t -th desired target, T_t .

A. Channel Model

The downlink channel $\mathbf{h}_{d,m}^{\text{dl}}$ and uplink channel $\mathbf{h}_{u,m}^{\text{ul}}$ follow a Rician model between UE_d^{dl} , UE_u^{ul} , and AP_m while the UE-to-UE $h_{u,d}^{\text{uu}}$ channel and AP-to-AP channel $h_{m',m}^{\text{aa}}$ are modeled as Rayleigh fading due to the dense environment. The target-to-AP channel $\mathbf{h}_{t,m}^{\text{ut}}$ is assumed to be LoS-dominated. Each channel consists of both small-scale and large-scale fading. Therefore, the channels $\mathbf{h}_{d,m}^{\text{dl}}$, $\mathbf{h}_{u,m}^{\text{ul}}$, $h_{u,d}^{\text{uu}}$, $h_{t,m}^{\text{ut}}$, and $h_{m',m}^{\text{aa}}$ are respectively expressed as follows: $\mathbf{h}_{d,m}^{\text{dl}} = \sqrt{\beta_{d,m}^{\text{dl}}} \mathbf{g}_{d,m}^{\text{dl}}$, $\mathbf{h}_{u,m}^{\text{ul}} = \sqrt{\beta_{u,m}^{\text{ul}}} \mathbf{g}_{u,m}^{\text{ul}}$, $h_{u,d}^{\text{uu}} = \sqrt{\beta_{u,d}^{\text{uu}}} g_{u,d}^{\text{uu}}$, $h_{t,m}^{\text{ut}} = \sqrt{\beta_{t,m}^{\text{ut}}} \mathbf{a}(\phi_{t,m}^{\text{ut}})$, $h_{m',m}^{\text{aa}} = \sqrt{\beta_{m',m}^{\text{aa}}} \mathbf{g}_{m',m}^{\text{aa}}$, where $\mathbf{g}_{d,m}^{\text{dl}} = \sqrt{\frac{\kappa}{\kappa+1}} \mathbf{g}_{\text{LoS},d,m}^{\text{dl}} + \sqrt{\frac{1}{\kappa+1}} \mathbf{g}_{\text{NLoS},d,m}^{\text{dl}} \in \mathbb{C}^{1 \times N_t}$ and $\mathbf{g}_{u,m}^{\text{ul}} = \sqrt{\frac{\kappa}{\kappa+1}} \mathbf{g}_{\text{LoS},u,m}^{\text{ul}} + \sqrt{\frac{1}{\kappa+1}} \mathbf{g}_{\text{NLoS},u,m}^{\text{ul}} \in \mathbb{C}^{N_r \times 1}$ represent small-scale fading components for Rician channels AP_m and UE_d^{dl} , and between AP_m and UE_u^{ul} . The LoS component of the Rician channel is expressed as $\mathbf{g}_{\text{LoS},d,m}^{\text{dl}} = \mathbf{a}(\phi_{d,m}^{\text{dl}})$, and the NLoS component $\mathbf{g}_{\text{NLoS},d,m}^{\text{dl}}$, $g_{u,d}^{\text{uu}}$, and $\mathbf{g}_{m',m}^{\text{aa}}$ follow a complex Gaussian distribution with zero mean and unit variance. Furthermore, $\beta_{d,m}^{\text{dl}} = C_0(d_{d,m}^{\text{dl}})^{-\alpha_{d,m}^{\text{dl}}}$ denotes the path loss between AP_m and UE_d^{dl} , and C_0 denotes the path loss at a reference distance $D_0 = 1$ meter. In addition, $d_{d,m}^{\text{dl}}$ and $\alpha_{d,m}^{\text{dl}}$ represent the distance and path loss exponent between AP_m and UE_k , respectively. Similar notation applies for $\beta_{u,m}^{\text{ul}}$, $\beta_{u,d}^{\text{uu}}$, $\beta_{t,m}^{\text{ut}}$, and $\beta_{m',m}^{\text{aa}}$ with the assumption that $\alpha_{d,m}^{\text{dl}} = \alpha_{u,m}^{\text{ul}} = \alpha_{u,d}^{\text{uu}} = \alpha_{t,m}^{\text{ut}} = \alpha_{m',m}^{\text{aa}} = \alpha = 2$. Considering AP_m and T_t , small-scale fading is modeled as an array response (steering) vector $\mathbf{a}(\phi_{t,m}^{\text{ut}}) = [1, \dots, e^{-j2\frac{\pi d}{\lambda}(N-1)\sin(\phi_{t,m}^{\text{ut}})}]$, which depends on the angle-of-arrival (AoA) or angle-of-departure (AoD) $\phi_{t,m}^{\text{ut}}$, the wavelength λ , and antenna spacing d .

A key challenge in FD implementation is SI from the AP's own transmitter to its own receiver. Although recent advances

in SI suppression have reduced this interference to near-noise levels, residual SI (RSI) persists due to imperfect suppression. The SI channel at AP_m is modeled as $\mathbf{h}_{0,m}$, expressed as: $\mathbf{h}_{0,m} = \sqrt{\rho_{\text{RSI}}} \mathbf{h}_m^{\text{SI}}$, where ρ_{RSI} denotes the RSI suppression level after analog and digital domain cancellations. The fading loop channel $\mathbf{h}_m^{\text{SI}}$ follows a Rician model with a small Rician factor of 5 dB.

B. Communication Model

The APs in this study operate in two modes: ISAC and communication-only. In communication mode, they serve all UEs in both downlink and uplink. In ISAC mode, APs integrate radar signals with communication signals, enabling simultaneous UE service and target sensing. This flexibility ensures optimal communication and effective sensing. To ensure reliable sensing and communication performance while maintaining effective sensing capabilities. We assume that each target is assigned exclusively to a single AP. For notational convenience, $\mathbf{c} \triangleq \{c_{t,m}\}_{|t \in \mathcal{T}, m \in \mathcal{M}}$ is defined as the pairing variable set between the APs and targets, where $c_{t,m} = 1$ if AP_m is assigned to sense target T_t , and $c_{t,m} = 0$ otherwise. Therefore, the transmitted signal $\mathbf{x}_m \in \mathbb{C}^{N_t \times 1}$ at AP_m in the downlink phase is expressed as $\mathbf{x}_m = \sum_{d=1}^{K_{\text{dl}}} \mathbf{w}_{d,m} s_d + \sum_{t=1}^T c_{t,m} \mathbf{z}_m b_m$, where s_d denotes the desired data symbol of UE_d^{dl} with the corresponding beamforming vector $\mathbf{w}_{d,m} \in \mathbb{C}^{N_t \times 1}$. Meanwhile, b_t represents the dedicated radar signal with the corresponding vector beamforming $\mathbf{z}_m \in \mathbb{C}^{N_t \times 1}$, which is designed by AP_m to extend the degrees of freedom (DoF) of the transmitted signal for enhanced sensing. The data symbols $\{s_d\}_{d=1}^{K_{\text{dl}}}$ and radar signal $\{b_m\}_{m=1}^M$ are assumed to be independent of each other to prevent mutual interference between radar and communication signals, i.e., $\mathbb{E}\{s_d b_m^H\} = 0, \forall d \in \mathcal{K}_{\text{dl}}, m \in \mathcal{M}$. Notably, $c_{t,m} = 0, \forall t \in \mathcal{T}$ indicates that AP_m operates in communication-only mode.

Due to FD operation, all downlink UEs receive signals from both APs and uplink UEs. The received signal at UE_d^{dl} is given by

$$\begin{aligned} y_d^{\text{dl}} &= \sum_{m=1}^M \mathbf{h}_{d,m}^{\text{dl}} \mathbf{x}_m + \sum_{u=1}^{K_{\text{ul}}} h_{u,d}^{\text{uu}} \sqrt{p_{\text{max}}^{\text{ul}}} \eta_u^{\text{ul}} v_u + n_d, \\ &= \underbrace{\sum_{m=1}^M \mathbf{h}_{d,m}^{\text{dl}} \mathbf{w}_{d,m} s_d}_{\text{Desired downlink signal DU}_{d,m}^{\text{dl}}} + \underbrace{\sum_{u=1}^{K_{\text{ul}}} h_{u,d}^{\text{uu}} \sqrt{p_{\text{max}}^{\text{ul}}} \eta_u^{\text{ul}} v_u}_{\text{User-user interference UUI}_{u,d}^{\text{ul}}} \\ &\quad + \underbrace{\sum_{m=1}^M \sum_{d'=1|d' \neq d}^{K_{\text{dl}}} \mathbf{h}_{d,m}^{\text{dl}} \mathbf{w}_{d',m} s_{d'}}_{\text{Inter-downlink user interference IUI}_{d',d,m}^{\text{dl}}} \\ &\quad + \underbrace{\sum_{m=1}^M \mathbf{h}_{d,m}^{\text{dl}} \bar{\mathbf{z}}_m b_m}_{\text{Sensing interference SI}_{d,m}} + \underbrace{n_d}_{\text{Noise N}_d^{\text{dl}}}, \end{aligned} \quad (1)$$

where $\bar{\mathbf{z}}_m \triangleq \sum_{t=1}^T c_{t,m} \mathbf{z}_m$. Thus, the SINR of UE_d^{dl} is calculated according to (2) (see the top of the next page).

In the uplink phase, all uplink UEs simultaneously transmit signals to all APs. To decode the signal from UE_u^{ul} , AP_m applies

$$\gamma_d^{\text{dl}} = \frac{\sum_{m=1}^M |\text{DU}_{d,m}^{\text{dl}}|^2}{\sum_{u=1}^{K_{\text{ul}}} |\text{UI}_{u,d}^{\text{dl}}|^2 + \sum_{m=1}^M \sum_{d'=1|d' \neq d}^{K_{\text{dl}}} |\text{IUI}_{d,d',m}^{\text{dl}}|^2 + \sum_{m=1}^M |\text{SI}_{d,m}|^2 + |\text{N}_d^{\text{dl}}|^2}, \quad (2)$$

$$\gamma_u^{\text{ul}} = \frac{\sum_{m=1}^M |\text{DU}_{u,m}^{\text{ul}}|^2}{\sum_{m=1}^M \sum_{u'=1|u' \neq u}^{K_{\text{ul}}} |\text{IUI}_{u',u,m}^{\text{ul}}|^2 + \sum_{m=1}^M \sum_{t=1}^{T+C} |\text{ESI}_{t,u,m}|^2 + \sum_{m=1}^M \sum_{m'=1|m' \neq m}^M |\text{IUA}_{u,m',m}^{\text{ul}}|^2 + \sum_{m=1}^M |\text{RSI}_{u,m}^{\text{ul}}|^2 + \sum_{m=1}^M |\text{N}_{u,m}^{\text{ul}}|^2}, \quad (3)$$

$$\gamma_{t,m}^{\text{rad}} = \frac{|\text{DU}_{t,m}^{\text{rad}}|^2}{\sum_{u=1}^{K_{\text{ul}}} |\text{IUI}_{u,t,m}^{\text{rad}}|^2 + \sum_{t'=1|t' \neq t}^{T+C} |\text{CCI}_{t',t,m}|^2 + \sum_{m=1}^M \sum_{m'=1|m' \neq m}^M |\text{IUA}_{t,m',m}^{\text{rad}}|^2 + |\text{RSI}_{t,m}^{\text{rad}}|^2 + |\text{N}_{t,m}^{\text{rad}}|^2}, \quad (4)$$

a receive beamforming vector $\mathbf{o}_{u,m}$ (i.e., matched-filtering) to the received signal y_m^{ul} . The combined received signal at the CPU through all APs for UE_u^{ul} is expressed as

$$\begin{aligned} \hat{y}_u^{\text{ul}} &= \sum_{m=1}^M \mathbf{o}_{u,m} y_m^{\text{ul}} \\ &= \sum_{m=1}^M \underbrace{(\mathbf{o}_{u,m} \mathbf{h}_{u,m}^{\text{ul}} \sqrt{p_{\text{max}}^{\text{ul}}} \eta_u^{\text{ul}} v_u)}_{\text{Desired uplink signal DU}_{u,m}^{\text{ul}}} + \sum_{m'=1|m' \neq m}^M \underbrace{\mathbf{o}_{u,m} \mathbf{h}_{m',m}^{\text{aa}} \mathbf{x}_{m'}}_{\text{IUA}_{u,m',m}^{\text{ul}}} \\ &+ \sum_{m=1}^M \left(\sum_{u'=1|u' \neq u}^{K_{\text{ul}}} \underbrace{\mathbf{o}_{u,m} \mathbf{h}_{u',m}^{\text{ul}} \sqrt{p_{\text{max}}^{\text{ul}}} \eta_{u'}^{\text{ul}} v_{u'}}_{\text{Inter-uplink user interference IUI}_{u',u,m}^{\text{ul}}} + \underbrace{\mathbf{o}_{u,m} \mathbf{h}_{0,m} \mathbf{x}_m}_{\text{RSI}_{u,m}^{\text{ul}}} \right) \\ &+ \sum_{m=1}^M \sum_{t=1}^{T+C} \left(\underbrace{\mathbf{o}_{u,m} \beta_{t,m}^{\text{ut}} \alpha_{t,m} \mathbf{A}(\phi_{t,m}^{\text{ut}}) \mathbf{x}_m}_{\text{Echo signal interference ESI}_{t,u,m}} + \underbrace{\mathbf{o}_{u,m} \mathbf{n}_m}_{\text{Noise N}_{u,m}^{\text{ul}}} \right), \end{aligned} \quad (5)$$

where $\mathbf{A}(\phi_{t,m}^{\text{ut}}) = \mathbf{a}_r(\phi_{t,m}^{\text{ut}}) \mathbf{a}_t(\phi_{t,m}^{\text{ut}})^H$, $\mathbf{a}_t(\phi_{t,m}^{\text{ut}})$ and $\mathbf{a}_r(\phi_{t,m}^{\text{ut}})$ correspond to transmit and receive steering vector to direction $\phi_{t,m}^{\text{ut}}$, and $\alpha_{t,m}$ is the complex reflection coefficient due to the target's radar cross section (RCS). Thus, the SINR of UE_u^{ul} is achieved as (3) (see the top of the next page). From (2) and (3), the achievable downlink and uplink rates (in bps/Hz) corresponding to UE_d^{dl} and UE_u^{ul} are obtained as follows:

$$\begin{cases} R_d^{\text{dl}} = \log_2(1 + \gamma_d^{\text{dl}}), \\ R_u^{\text{ul}} = \log_2(1 + \gamma_u^{\text{ul}}). \end{cases} \quad (6)$$

From (6), the average sum rate for the proposed FD-enabled CFMM system in bps/Hz is given as

$$R_{\text{SE}} = \frac{1}{K_{\text{dl}}} \sum_{d=1}^{K_{\text{dl}}} R_d^{\text{dl}} + \frac{1}{K_{\text{ul}}} \sum_{u=1}^{K_{\text{ul}}} R_u^{\text{ul}}. \quad (7)$$

C. Sensing Radar Model

In sensing signal processing, AP_m employs a matched filtering by multiplying the received signal with the beamforming

vector $\mathbf{r}_{t,m}$ to maximize the radar SINR for target T_t . The received echo signal at AP_m for target T_t is given as

$$\begin{aligned} \hat{y}_{t,m}^{\text{rad}} &= \mathbf{r}_{t,m} y_m^{\text{ul}} \\ &= \underbrace{\mathbf{r}_{t,m} \beta_{t,m}^{\text{ut}} \alpha_{t,m} \mathbf{A}(\phi_{t,m}^{\text{ut}}) \mathbf{x}_m}_{\text{Desired radar signal DU}_{t,m}^{\text{rad}}} + \sum_{m' \in \mathcal{M}|m' \neq m} \underbrace{\mathbf{r}_{t,m} \mathbf{h}_{m',m}^{\text{aa}} \mathbf{x}_{m'}}_{\text{IUA}_{t,m',m}^{\text{rad}}} \\ &+ \sum_{t'=1|t' \neq t}^{T+C} \underbrace{\mathbf{r}_{t,m} \beta_{t',m}^{\text{ut}} \alpha_{t',m} \mathbf{A}(\phi_{t',m}^{\text{ut}}) \mathbf{x}_m}_{\text{Target and Clutter Interference CCI}_{t',t,m}} + \underbrace{\mathbf{r}_{t,m} \mathbf{h}_{0,m} \mathbf{x}_m}_{\text{RSI}_{t,m}^{\text{rad}}} \\ &+ \sum_{u=1}^{K_{\text{ul}}} \underbrace{\mathbf{r}_{t,m} \mathbf{h}_{u,m}^{\text{ul}} \sqrt{p_{\text{max}}^{\text{ul}}} \eta_u^{\text{ul}} v_u}_{\text{Inter-uplink user interference IUI}_{u,t,m}^{\text{rad}}} + \underbrace{\mathbf{r}_{t,m} \mathbf{n}_m}_{\text{Noise N}_{t,m}^{\text{rad}}}. \end{aligned} \quad (8)$$

In information theory, mutual information (MI) quantifies the shared information between two variables, reducing uncertainty. In radar systems, MI evaluates the correlation between the transmitted signal and the target response, thereby improving detection accuracy. The MI metric assesses the accuracy of the radar target impulse response [8] and is influenced by waveform design, target spectrum, clutter, and propagation loss. Maximizing MI enhances radar estimation by linking detection metrics to MI. Specifically, in MIMO radar, target detection probability is proportional to the output SINR, making it a key sensing performance metric, as seen in (4).

III. PROBLEM FORMULATION

Before defining the optimization problem, we determine the beamforming vectors $\mathbf{r}_0$ and $\mathbf{c}_u$ for matched filtering during the uplink and sensing phases. Given that the AP is equipped with multiple antennas, we apply zero-forcing (ZF) beamforming to maximize SINR and improve sensing performance. The ZF beamforming vectors are expressed as $\mathbf{o}_m = ((\mathbf{H}_m^{\text{ul}})^H \mathbf{H}_m^{\text{ul}})^{-1} (\mathbf{H}_m^{\text{ul}})^H$ and $\mathbf{r}_m = ((\mathbf{A}_m^H)^H \mathbf{A}_m)^{-1} \mathbf{A}_m^H$, where $\mathbf{H}_m^{\text{ul}} \triangleq [\mathbf{h}_{1,m}^{\text{ul}}, \dots, \mathbf{h}_{K_{\text{ul}},m}^{\text{ul}}]$ and $\mathbf{A}_m \triangleq [\mathbf{a}_r(\phi_{1,m}^{\text{ut}}), \dots, \mathbf{a}_r(\phi_{T,m}^{\text{ut}})]$. $\mathbf{o}_{u,m}$ and $\mathbf{r}_{t,m}$ corresponds to the u -th and t -th row of $\mathbf{o}_m$ and $\mathbf{A}_m$. The optimization problem for maximizing the spectral efficiency of the proposed ISAC-FD-CFMM system while maintaining sensing perfor-

mance constraints is formulated as follows:

$$\max_{\mathbf{w}, \mathbf{z}, \boldsymbol{\eta}, \mathbf{c}} \quad \frac{1}{K_{\text{dl}}} \sum_{d=1}^{K_{\text{dl}}} R_d^{\text{dl}} + \frac{1}{K_{\text{ul}}} \sum_{u=1}^{K_{\text{ul}}} R_u^{\text{ul}} \quad (9a)$$

$$s.t. \quad 0 \leq \sum_{d=1}^{K_{\text{dl}}} |\mathbf{w}_{d,m}|^2 + |\bar{\mathbf{z}}_m|^2 \leq p_{\text{max}}^{\text{dl}}, \forall m \in \mathcal{M}, \quad (9b)$$

$$0 \leq \eta_u \leq 1, \quad \forall u \in \mathcal{K}_u, \quad (9c)$$

$$\sum_{m=1}^M c_{t,m} \gamma_{t,m}^{\text{rad}} \geq \gamma_0^{\text{rad}}, \quad \forall t \in \mathcal{T}, m \in \mathcal{M}, \quad (9d)$$

$$c_{t,m} \in \{0, 1\}, \quad \forall t \in \mathcal{T}, m \in \mathcal{M}, \quad (9e)$$

$$R_d^{\text{dl}} \geq R_0^{\text{dl}}, \quad \forall d \in \mathcal{K}_d, \quad (9f)$$

$$R_u^{\text{ul}} \geq R_0^{\text{ul}}, \quad \forall u \in \mathcal{K}_u, \quad (9g)$$

where constraints (9b) and (9c) ensure the transmit power condition for APs (downlink) and UEs (uplink), respectively. Constraints (9d) and (9e) enforce the radar performance threshold and binary criterion for APs. The constraints (9f) and (9g) guarantee the quality of service (QoS) requirements for downlink and uplink, respectively.

IV. PROPOSED OPTIMIZATION

The objective function can be transformed into a more tractable form as

$$R_{\text{SE}} = \left(\frac{1}{K_{\text{dl}}} \sum_{d=1}^{K_{\text{dl}}} \ln(1 + \gamma_d^{\text{dl}}) + \frac{1}{K_{\text{ul}}} \sum_{u=1}^{K_{\text{ul}}} \ln(1 + \gamma_u^{\text{ul}}) \right) / \ln(2), \quad (10)$$

with a new auxiliary positive variable set $\boldsymbol{\lambda} \triangleq \{\boldsymbol{\lambda}^{\text{dl}}, \boldsymbol{\lambda}^{\text{ul}}\}$, where $\boldsymbol{\lambda}^{\text{dl}} \triangleq \{\lambda_{1,d}\}_{\forall d \in \mathcal{K}_{\text{dl}}}$ and $\boldsymbol{\lambda}^{\text{ul}} \triangleq \{\lambda_{2,u}\}_{\forall u \in \mathcal{K}_{\text{ul}}}$ being introduced. These variables are subject to the constraints:

$$1 + \gamma_d^{\text{dl}} \geq \lambda_{1,d}, \quad (11)$$

$$1 + \gamma_u^{\text{ul}} \geq \lambda_{2,u}. \quad (12)$$

Thus, we can rewrite the objective function into a concave logdet function as

$$R_{\text{SE}} \geq \frac{\frac{1}{K_{\text{dl}}} \ln \det(\text{diag}(\boldsymbol{\lambda}^{\text{dl}})) + \frac{1}{K_{\text{ul}}} \ln \det(\text{diag}(\boldsymbol{\lambda}^{\text{ul}}))}{\ln(2)} := F_s(\boldsymbol{\lambda}^{\text{dl}}, \boldsymbol{\lambda}^{\text{ul}}).$$

To deal with the binary constraint (9e), we relax $c_{m,t}$ into a continuous variable: $0 \leq c_{m,t} \leq 1$. Hence, problem (9) is rewritten into a more tractable form as follows:

$$\max_{\boldsymbol{\lambda}, \mathbf{w}, \mathbf{z}, \boldsymbol{\eta}, \mathbf{c}} \quad F_s(\boldsymbol{\lambda}^{\text{dl}}, \boldsymbol{\lambda}^{\text{ul}}) \quad (13a)$$

$$s.t. \quad (9b) - (9d), (11), (12), \quad (13b)$$

$$\lambda_{1,d} \geq 2^{R_0^{\text{dl}}}, \quad (13c)$$

$$\lambda_{2,u} \geq 2^{R_0^{\text{ul}}}, \quad (13d)$$

$$0 \leq c_{t,m} \leq 1, \quad (13e)$$

$$0 \leq \sum_{t=1}^T c_{t,m} \leq 1, \quad (13f)$$

$$0 \leq \sum_{m=1}^M c_{t,m} \leq 1, \quad (13g)$$

where constraints (13e)-(13g) guarantee that each target is assigned to a single AP for sensing.

Before optimization, we introduce IA-based approximation functions used at each iteration. For the convex function $\mathbf{f}_{\text{fr}}(\mathbf{x}, y) \triangleq \frac{|\mathbf{x}|^2}{y}$ and the multiplication function $\mathbf{f}_{\text{mul}}(x, y) \triangleq xy$ with $x, y > 0$, $\mathbf{x} \in \mathbb{C}^n$, their concave lower and convex upper bounds around a feasible point $(x^{(i)}, y^{(i)})$ are given as

$$\mathbf{f}_{\text{fr}}(\mathbf{x}, y) \geq \frac{2\mathcal{R}\{\mathbf{x}^{(i)H} \mathbf{x}\}}{y^{(i)}} - \frac{|\mathbf{x}^{(i)}|^2}{(y^{(i)})^2} y := \mathbf{f}_{\text{fr}}^{(i)}(\mathbf{x}, y), \quad (14)$$

$$\mathbf{f}_{\text{mul}}(x, y) \leq \frac{x^{(i)}}{2y^{(i)}} y^2 + \frac{y^{(i)}}{2x^{(i)}} x^2 := \mathbf{f}_{\text{mul}}^{(i)}(x, y). \quad (15)$$

Convexifying constraint (9b): To handle the quadratic constraint, we introduce auxiliary variables $\hat{\mathbf{c}} \triangleq \{\hat{c}_m\}$, $\hat{\mathbf{z}} \triangleq \{\hat{z}_m\}_{\forall m \in \mathcal{M}}$, which satisfy the following conditions:

$$\left(\sum_{t=1}^T c_{t,m} \right)^2 \leq \hat{c}_m, \quad |\mathbf{z}_m|^2 \leq \hat{z}_m. \quad (16)$$

Thus, constraint (9b) can be rewritten in convex form as

$$\sum_{d=1}^{K_{\text{dl}}} |\mathbf{w}_{d,m}|^2 + \mathbf{f}_{\text{mul}}^{(i)}(\hat{z}_m, \hat{c}_m) \leq p_{\text{max}}^{\text{dl}}. \quad (17)$$

Convexifying constraint (11): We set $\mathbf{z}^{\text{SI}} \triangleq \{z_{d,m}^{\text{SI}}\}_{\forall d \in \mathcal{K}_{\text{dl}}, m \in \mathcal{M}}$. Using approximation functions (14) and (15), we obtain the following constraints:

$$\begin{aligned} \frac{|\mathbf{h}_{d,m}^{\text{dl}} \mathbf{w}_{d,m}|^2}{\lambda_{1,d} - 1} &\geq \mathbf{f}_{\text{fr}}^{(i)}(\mathbf{h}_{d,m}^{\text{dl}} \mathbf{w}_{d,m}, \lambda_{1,d} - 1), \\ |\mathbf{h}_{d,m}^{\text{dl}} \mathbf{z}_m|^2 &\leq z_{d,m}^{\text{SI}} \Leftrightarrow |\mathbf{SI}_{d,m}|^2 = |\mathbf{h}_{d,m}^{\text{dl}} \bar{\mathbf{z}}_m|^2 \leq \mathbf{f}_{\text{mul}}^{(i)}(z_{d,m}^{\text{SI}}, \hat{c}_m). \end{aligned} \quad (18)$$

By applying algebraic transformations, we obtain the convexified version of (11):

$$\begin{aligned} \sum_{u=1}^M \mathbf{f}_{\text{quad}}^{(i)}(o_{1,d,m}) &\geq \sum_{u=1}^{K_{\text{ul}}} |\mathbf{UUI}_{u,d}|^2 + \sum_{m=1}^M \sum_{d'=1}^{K_{\text{dl}}} \sum_{d' \neq d} |\mathbf{IUI}_{d',d,m}^{\text{dl}}|^2 \\ &+ \sum_{m=1}^M \mathbf{f}_{\text{mul}}^{(i)}(z_{d,m}^{\text{SI}}, \hat{c}_m) + |\mathbf{N}_d^{\text{dl}}|^2. \end{aligned} \quad (20)$$

Convexifying constraint (12): Using approximation functions (14) and (15), we achieve the following constraints:

$$\frac{|\mathbf{o}_{u,m} \mathbf{h}_{u,m}^{\text{ul}} \sqrt{p_{\text{max}}^{\text{ul}}} \eta_u^{\text{ul}}|^2}{\lambda_{2,u} - 1} \geq \mathbf{f}_{\text{fr}}^{(i)}(\mathbf{o}_{u,m} \mathbf{h}_{u,m}^{\text{ul}} \sqrt{p_{\text{max}}^{\text{ul}}} \eta_u^{\text{ul}}, \lambda_{2,u} - 1), \quad (21)$$

$$|\mathbf{ESI}_{t,u,m}|^2 \leq |\hat{\mathbf{ESI}}_{t,u,m}|^2 + \mathbf{f}_{\text{mul}}^{(i)}(z_{t,u,m}^{\text{ESI}}, \hat{c}_m), \quad (22)$$

$$|\mathbf{IUI}_{u,m',m}^{\text{ul}}|^2 \leq |\hat{\mathbf{IUI}}_{u,m',m}^{\text{ul}}|^2 + \mathbf{f}_{\text{mul}}^{(i)}(z_{u,m',m}^{\text{IUI}}, \hat{c}_m), \quad (23)$$

$$|\mathbf{RSI}_{u,m}^{\text{ul}}|^2 \leq |\hat{\mathbf{RSI}}_{u,m}^{\text{ul}}|^2 + \mathbf{f}_{\text{mul}}^{(i)}(z_{u,m}^{\text{RSI}}, \hat{c}_m), \quad (24)$$

where we define $|\hat{\mathbf{ESI}}_{t,u,m}|^2 = |\mathbf{o}_{u,m} \beta_{t,m}^{\text{ut}} \alpha_{t,m} \mathbf{A}(\phi_{t,m}^{\text{ut}}) \mathbf{w}_m|^2$, $|\hat{\mathbf{IUI}}_{u,m',m}^{\text{ul}}|^2 = |\mathbf{o}_{u,m} \mathbf{h}_{m',m}^{\text{aa}} \mathbf{w}_{m'}|^2$, and $|\hat{\mathbf{RSI}}_{u,m}^{\text{ul}}|^2 = |\mathbf{o}_{u,m} \mathbf{h}_{0,m} \mathbf{w}_m|^2$. Furthermore, the new variables $\mathbf{z}^{\text{RSI}} \triangleq$

$\{z_{u,m}^{\text{RSI}}\}$, $\mathbf{z}^{\text{ESI}} \triangleq \{z_{t,u,m}^{\text{ESI}}\}$, and $\mathbf{z}^{\text{IUI}} \triangleq \{z_{u,m',m}^{\text{IUI}}\}$, $\forall u \in \mathcal{K}_{\text{ul}}, m \in \mathcal{M}$, and $t \in \mathcal{T} \cup \mathcal{C}$ are for the quadratic constraints:

$$|\mathbf{o}_{u,m} \mathbf{h}_{0,m} \mathbf{z}_m|^2 \leq z_{u,m}^{\text{RSI}} \quad (25)$$

$$|\mathbf{o}_{u,m} \beta_{t,m}^{\text{ut}} \alpha_{t,m} \mathbf{A}(\phi_{t,m}^{\text{ut}}) \mathbf{z}_m|^2 \leq z_{t,u,m}^{\text{ESI}}, \quad (26)$$

$$|\mathbf{o}_{u,m} \mathbf{h}_{m',m}^{\text{aa}} \mathbf{z}_{m'}|^2 \leq z_{u,m',m}^{\text{IUI}}. \quad (27)$$

By applying algebraic transformations, (12) is convexified as

$$\begin{aligned} \sum_{m=1}^M \mathbf{f}_{\text{quad}}^{(i)}(o_{2,u,m}) &\geq \sum_{m=1}^M \left(\sum_{u'=1|u' \neq u}^{K_{\text{ul}}} |\text{IUI}_{u',u,m}^{\text{ul}}|^2 + \sum_{t=1}^{T+C} (|\hat{\text{ESI}}_{t,u,m}|^2 \right. \\ &+ \mathbf{f}_{\text{mul}}^{(i)}(z_{t,u,m}^{\text{ESI}}, \hat{c}_m) + \sum_{m'=1|m' \neq m}^M (|\text{IUI}_{u,m',m}^{\text{ul}}|^2 + |\mathbf{N}_{u,m}^{\text{ul}}|^2 \\ &+ |\hat{\text{RSI}}_{u,m}^{\text{ul}}|^2 + \mathbf{f}_{\text{mul}}^{(i)}(z_{u,m}^{\text{RSI}}, \hat{c}_m) + \mathbf{f}_{\text{mul}}^{(i)}(z_{u,m',m}^{\text{IUI}}, \hat{c}_m) \left. \right). \end{aligned} \quad (28)$$

Convexifying constraint (9d): To derive a lower bound on $\lambda_{3,t,m}$ of $\gamma_{t,m}^{\text{rad}}$, we introduce the following constraints utilizing approximation functions (14) and (15):

$$\begin{aligned} \left(\sum_{t=1}^T c_{t,m} \right)^2 &\geq (\bar{c}_m)^2 \geq \mathbf{f}_{\text{quad}}^{(i)}(\bar{c}_m) \geq \frac{1}{\bar{z}_m}, \quad (29) \\ \frac{|\text{DU}_{t,m}^{\text{rad}}|^2}{\lambda_{3,t,m}} &\geq \mathbf{f}_{\text{fr}}^{(i)}(\mathbf{h}_{t,m}^{\text{rad}} \mathbf{w}_m, \lambda_{3,t,m}) + \mathbf{f}_{\text{fr}}^{(i)}(\mathbf{h}_{t,m}^{\text{rad}} \mathbf{z}_m, \hat{\lambda}_{3,t,m}), \quad (30) \end{aligned}$$

$$\mathbf{f}_{\text{mul}}^{(i)}(\bar{z}_m, \lambda_{3,t,m}) \leq \hat{\lambda}_{3,t,m}, \quad (31)$$

$$|\text{CCI}_{t',t,m}|^2 \leq |\hat{\text{CCI}}_{t',t,m}|^2 + \mathbf{f}_{\text{mul}}^{(i)}(\bar{z}_{t',t,m}^{\text{CCI}}, \hat{c}_m), \quad (32)$$

$$|\text{IUI}_{t,m',m}^{\text{rad}}|^2 \leq |\hat{\text{IUI}}_{t,m',m}^{\text{rad}}|^2 + \mathbf{f}_{\text{mul}}^{(i)}(\bar{z}_{t,m',m}^{\text{IUI}}, \hat{c}_m), \quad (33)$$

$$|\text{RSI}_{t,m}^{\text{rad}}|^2 \leq |\hat{\text{RSI}}_{t,m}^{\text{rad}}|^2 + \mathbf{f}_{\text{mul}}^{(i)}(\bar{z}_{t,m}^{\text{RSI}}, \hat{c}_m), \quad (34)$$

where $\lambda_3 \triangleq \{\lambda_{3,t,m}\}$, $\hat{\lambda}_3 \triangleq \{\hat{\lambda}_{3,t,m}\}$, and we define $|\hat{\text{CCI}}_{t',t,m}|^2 = |\mathbf{r}_{t,m} \beta_{t',m}^{\text{ut}} \alpha_{t',m} \mathbf{A}(\phi_{t',m}^{\text{ut}}) \mathbf{w}_m|^2$, $|\hat{\text{IUI}}_{t,m',m}^{\text{rad}}|^2 = |\mathbf{r}_{t,m} \mathbf{h}_{m',m}^{\text{aa}} \mathbf{w}_{m'}|^2$ and $|\hat{\text{RSI}}_{t,m}^{\text{rad}}|^2 = |\mathbf{r}_{t,m} \mathbf{h}_{0,m} \mathbf{w}_m|^2$. Moreover, the new variables $\bar{\mathbf{z}}^{\text{RSI}} \triangleq \{\bar{z}_{t,m}^{\text{RSI}}\}$, $\bar{\mathbf{z}}^{\text{CCI}} \triangleq \{\bar{z}_{t',t,m}^{\text{CCI}}\}$, and $\bar{\mathbf{z}}^{\text{IUI}} \triangleq \{\bar{z}_{t,m',m}^{\text{IUI}}\}$, $\forall u \in \mathcal{K}_{\text{ul}}, m \in \mathcal{M}$, $t \in \mathcal{T}$, and $t' \in \mathcal{T} \cup \mathcal{C}$ are introduced to satisfy the following quadratic constraints:

$$|\mathbf{r}_{t,m} \mathbf{h}_{0,m} \mathbf{z}_m|^2 \leq \bar{z}_{t,m}^{\text{RSI}}, \quad (35)$$

$$|\mathbf{r}_{t,m} \beta_{t',m}^{\text{ut}} \alpha_{t',m} \mathbf{A}(\phi_{t',m}^{\text{ut}}) \mathbf{z}_m|^2 \leq \bar{z}_{t',t,m}^{\text{CCI}}, \quad (36)$$

$$|\mathbf{r}_{t,m} \mathbf{h}_{m',m}^{\text{aa}} \mathbf{z}_{m'}|^2 \leq \bar{z}_{t,m',m}^{\text{IUI}}. \quad (37)$$

By applying algebraic transformations, the lower bound $\lambda_{3,t,m}$ of $\gamma_{t,m}^{\text{rad}}$ is obtained through the convexified constraint as

$$\begin{aligned} \mathbf{f}_{\text{quad}}^{(i)}(o_{3,t,m}) &\geq \sum_{u=1}^{K_{\text{ul}}} |\text{IUI}_{u,t,m}^{\text{rad}}|^2 + \sum_{t'=1|t' \neq t}^{T+C} (|\hat{\text{CCI}}_{t',t,m}|^2 \\ &+ \mathbf{f}_{\text{mul}}^{(i)}(\bar{z}_{t',t,m}^{\text{CCI}}, \hat{c}_m) + \sum_{m'=1|m' \neq m}^M (|\hat{\text{IUI}}_{t,m',m}^{\text{rad}}|^2 + |\mathbf{N}_{t,m}^{\text{rad}}|^2 \\ &+ \mathbf{f}_{\text{mul}}^{(i)}(\bar{z}_{t,m',m}^{\text{IUI}}, \hat{c}_m) + |\hat{\text{RSI}}_{t,m}^{\text{rad}}|^2 + \mathbf{f}_{\text{mul}}^{(i)}(\bar{z}_{t,m}^{\text{RSI}}, \hat{c}_m). \end{aligned} \quad (38)$$

The constraint (9d) is convexified by introducing a new

TABLE I
SIMULATION PARAMETERS FOR AN ISAC-FD-CFMM SYSTEM

Parameter	Value
Path loss at reference distance ($\mathcal{C}_0$)	-30 dB
Noise power (σ^2)	-104 dBm
AP antenna height	15 m
Residual SI suppression (SiS) level (ρ_{RSI})	-110dB
Required QoS threshold ($R_0^{\text{dl}}, R_0^{\text{ul}}$)	1 bps/Hz
Radar SINR threshold (γ_0^{rad})	10 dB
Power budget at UL UEs ($p_{\text{max}}^{\text{ul}}$)	23 dBm
Power budget at DL APs ($p_{\text{max}}^{\text{dl}}$)	40 dBm

Algorithm 1 Proposed Iterative Algorithm to Solve (9)

Initialization: Set $i = 0$ and generate feasible initial points $(\boldsymbol{\lambda}^{(0)}, \mathbf{w}^{(0)}, \mathbf{z}^{(0)}, \boldsymbol{\eta}^{(0)}, \mathbf{c}^{(0)}, \boldsymbol{\nu}^{(0)})$.

1: **repeat**

2: Solve the convex program (40) to obtain the optimal solution $(\boldsymbol{\lambda}^*, \mathbf{w}^*, \mathbf{z}^*, \boldsymbol{\eta}^*, \mathbf{c}^*, \boldsymbol{\nu}^*)$.

3: Update $(\boldsymbol{\lambda}^{(i+1)}, \mathbf{w}^{(i+1)}, \mathbf{z}^{(i+1)}, \boldsymbol{\eta}^{(i+1)}, \mathbf{c}^{(i+1)}, \boldsymbol{\nu}^{(i+1)}) = (\boldsymbol{\lambda}^*, \mathbf{w}^*, \mathbf{z}^*, \boldsymbol{\eta}^*, \mathbf{c}^*, \boldsymbol{\nu}^*)$.

4: Set $i = i + 1$.

5: **until** Convergence

6: Optimal target-AP pairing solution $\tilde{\mathbf{c}} = \lfloor \mathbf{c}^{(i)} + 0.5 \rfloor$.

7: Run the proposed algorithm with found binary $\tilde{\mathbf{c}}$.

8: **Output:** Optimal solution $\tilde{\boldsymbol{\lambda}}, \tilde{\mathbf{w}}, \tilde{\mathbf{z}}, \tilde{\boldsymbol{\eta}}, \tilde{\mathbf{c}}$.

positive variable set $\boldsymbol{\delta} \triangleq \{\delta_{t,m}\}_{\forall t,m}$ that satisfies

$$c_{t,m} \lambda_{3,t,m} \geq \delta_{t,m}^2 \Leftrightarrow \sum_{m=1}^M \mathbf{f}_{\text{quad}}^{(i)}(\delta_{t,m}) \geq \gamma_0^{\text{rad}}. \quad (39)$$

For clarity, we summarize all auxiliary variables used in the convexification process as $\mathcal{V} \triangleq \{\lambda_3, \hat{\lambda}_3, \hat{\mathbf{c}}, \hat{\mathbf{z}}, \mathbf{z}^{\text{SI}}, \mathbf{z}^{\text{RSI}}, \mathbf{z}^{\text{ESI}}, \mathbf{z}^{\text{IUI}}, \bar{\mathbf{z}}^{\text{RSI}}, \bar{\mathbf{z}}^{\text{CCI}}, \bar{\mathbf{z}}^{\text{IUI}}, \boldsymbol{\delta}\}$. As a result, the original problem (9) is reformulated into a convex optimization problem:

$$\bar{\mathbf{P}}: \max_{\boldsymbol{\lambda}, \mathbf{w}, \mathbf{z}, \boldsymbol{\eta}, \mathbf{c}, \boldsymbol{\nu}} F_s(\boldsymbol{\lambda}^{\text{dl}}, \boldsymbol{\lambda}^{\text{ul}}) \quad (40a)$$

$$\text{s.t.} \quad (9c), (13c) - (13g), \quad (40b)$$

$$(16) - (39), \quad (40c)$$

$$\boldsymbol{\nu} \succeq 0. \quad (40d)$$

After a finite number of iterations, the optimal solution to problem (40) converges to a stationary point satisfying the Karush–Kuhn–Tucker (KKT) conditions [9] using a convex solver [10]. Once the proposed algorithm in (40) converges, $\tilde{\mathbf{c}}$ tends to approach binary values (0 or 1). We convert $\tilde{\mathbf{c}}$ into binary variables using $\tilde{\mathbf{c}} = \lfloor \mathbf{c}^{(i)} + 0.5 \rfloor$ and re-run the proposed algorithm with the obtained binary $\tilde{\mathbf{c}}$ to compute downlink beamforming vector and uplink power control coefficients for the original problem (9).

V. NUMERICAL RESULTS

A. Simulation Setup

In this paper, we consider an environment where all APs, UEs, and targets are distributed within a square area of dimensions $L \times L$, $L = 500$ m. The parameters used for

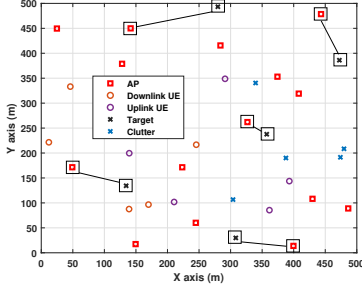


Fig. 2. Optimal pairing results in an ISAC-FD-CFMM system.

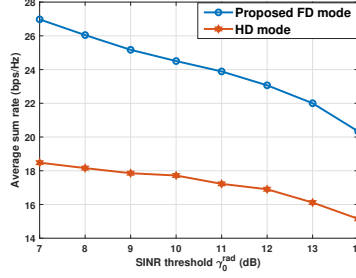


Fig. 3. Comparison between FD and HD modes of ISAC-CFMM system versus SINR threshold γ_0^{rad} .

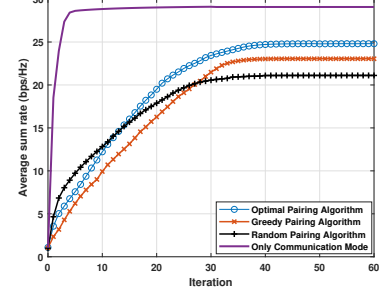


Fig. 4. Average sum rate of different pairing strategies as a function of the number of iterations.

wireless communication in the simulations are tabulated in Table I. To evaluate the effectiveness of the proposed dynamic pairing algorithm, we compare its performance against the following baseline strategies: random pairing, which assigns targets to APs randomly, and greedy pairing, which matches each target to the nearest AP to prioritize sensing performance.

B. Simulation Results

All comparison results are performed with $M = 15$, $K_{\text{dl}} = K_{\text{ul}} = 3$, $T = 5$, and $C = 5$. Fig. 2 illustrates the target-AP pairing results after applying the proposed optimization method, providing an intuitive visualization of the pairing strategy. The results indicate that APs predominantly select nearby targets to enhance echo signals, thereby improving overall sensing performance. This observation forms the basis of the greedy pairing baseline approach. Fig. 3 proves the efficiency of FD mode in proposed ISAC-CFMM compared to HD mode in [4] under the required radar threshold γ_0^{rad} .

Fig. 4 compares the performance of different target-AP pairing algorithms as a function of the number of iterations. All algorithms quickly converge to a saturated value after a certain number of iterations. Notably, the proposed algorithm achieves 95% of its maximum performance within just 30 iterations, demonstrating the effectiveness of the IA-based optimization method. For comparison, the communication-only mode approach represents a scenario where all APs operate exclusively in communication mode, i.e., pairing variables $\mathbf{c} \triangleq \mathbf{0}$. This setup achieves the highest average sum rate since resource allocation (beamforming and power control) is optimized without any constraints from sensing tasks. However, this scenario does not leverage ISAC capabilities, highlighting the trade-off between communication and sensing in the FD-CFMM system. The results underscore the significant impact of integrating ISAC into the FD-CFMM system, particularly in target-AP pairing. The proposed optimal pairing algorithm consistently achieves the highest sum rate, outperforming both random pairing and, importantly, the greedy pairing algorithm. The findings further emphasize the role of intelligent resource management, as interference from uplink UEs, neighboring APs, and especially clutters significantly impacts sensing performance, making proper pairing crucial to mitigating these effects and maximizing system performance. Overall,

the results highlight the superiority of the proposed approach in optimizing target-AP pairing, significantly enhancing system performance compared to random or greedy methods. This reinforces the importance of efficient resource allocation strategies in ISAC-FD-CFMM networks.

VI. CONCLUSIONS

This paper introduced a novel ISAC-FD-CFMM framework and an optimal joint resource management approach, encompassing downlink beamforming, power control, and target-AP pairing. Through extensive simulations, the proposed algorithm demonstrated superior performance in both communication and sensing, highlighting its effectiveness in optimizing system operations. Notably, the optimal pairing strategy consistently outperformed baseline methods, significantly enhancing overall system performance.

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