

Dual-RIS Assisted 3D Positioning and Beamforming Design in ISAC System

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Abstract— Integrated sensing and communication (ISAC) technology as a research focus in 6G communications commonly works in high frequency band, which may suffer severe fading caused by obstacle. Reconfigurable intelligent surface (RIS) can overcome the above issue and improve the performance of ISAC system through phase adjustment. In this paper, dual-RIS assisted 3D positioning and beamforming design in ISAC system are studied. Firstly, the localization in the ISAC system is transformed into a compressed sensing (CS) problem, and a stepwise matching pursuit (SMP) algorithm is proposed for better positioning ability and lower complexity, compared with the typical matching pursuit (MP) algorithm. Then, the positioning information is utilized for the beamforming design of the RISs to maximize the system achievable rate through the alternating optimization algorithm based on the triangle inequality (TI-AO). Simulation results show that the system achievable rate of the optimization design is close to the optimal one and verifies the effectiveness of the proposed framework.

Keywords— Integrated sensing and communication (ISAC), reconfigurable intelligent surface (RIS), stepwise matching pursuit (SMP), beamforming design

I. INTRODUCTION

Integrated sensing and communication (ISAC) has become one of the main technologies in 6G communications [1]. By realizing the communication and sensing in the same spectrum, ISAC can avoid the interference and improve the spectrum efficiency. However, the increasing demands for high communication spectrum leads to the increase of costs and energy consumption, which also influences the signal propagation range. The emerging reconfigurable intelligent surface (RIS) technology can properly adjust the transmission environment and control the wireless channel to a certain extent. It is feasible to introduce RIS into the ISAC system and improve the communication quality and coverage [2].

In the case of non-line-of-sight (NLoS) transmission, various obstacles may affect the accurate positioning of the ISAC system. However, the RIS can work as a good solution to this problem by establishing a virtual line of sight (VLoS) path between the transmitter and the receiver, and further achieve reliable communication by adjusting the signal phases

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[3][4]. At present, there have been many studies on the design of RIS assisted ISAC systems. R. Liu *et al.* proposed a location method based on the time difference of arrival (TDOA), which realized user positioning in RIS assisted wireless network [5]. The authors in [6] employed RISs to increase the received signal intensity at the adjacent locations, so that multiple users can be located based on the received signal strength (RSS). An iterative positioning algorithm with centimeter-level positioning accuracy was presented in [7] based on the angle of arrival (AOA) and angle of departure (AOD) estimated by the maximum likelihood (ML) algorithm. [8] deduced the analytic position error bound (PEB) and rotation error bound (REB) based on the RIS phase shift functions. Then, to optimize all RISs' phase shifts, the lowest attainable PEB and REB were obtained by the particle swarm optimization (PSO) algorithm. In [9]-[11], it was shown that the passive RIS and semi-passive RIS can be jointly taken into ISAC system to realize the user positioning and share the position information for the beamforming design. The authors in [12] proposed an ISAC system based on a hybrid RIS with active and passive components, and employed the alternating optimization (AO) for better worst-case target illumination power performance.

Currently, AO algorithm is commonly utilized to optimize the transmit beamforming and RIS phase shifts. A hybrid RIS-assisted ISAC system similar to [12] was studied in [13], which can sense the positions of nearby targets by the traditional multiple signal classification (MUSIC) algorithm and complete the optimization by maximizing the total power of average echo signals of the RIS sensors. The AO algorithm based beamforming in the single RIS assisted communication system was presented in [14] to maximize the total received signal power of the users. Meanwhile, [15] further investigated a multi-user communication system assisted by two RISs with collaborative passive beamforming design, where the base station (BS) in the uplink can obtain a larger receive signal-to-noise ratio (SNR) by the AO algorithm. In this paper, we study the 3D positioning and beamforming design in dual-RIS assisted ISAC system, then we transform the localization in the ISAC system into a compressed sensing (CS) problem and propose a stepwise matching pursuit (SMP) algorithm. Based on the positioning information, we complete the beamforming design of the BS and RISs by an alternating optimization algorithm based on the triangle inequality (TI-AO).

II. SYSTEM MODEL AND PROBLEM FORMULATION

The dual-RIS assisted ISAC system is presented in Fig. 1, where two RISs, RIS₁ and RIS₂, each with M passive reflection units, are deployed to assist the uplink transmission from a single antenna user to a BS with N receive antennas.

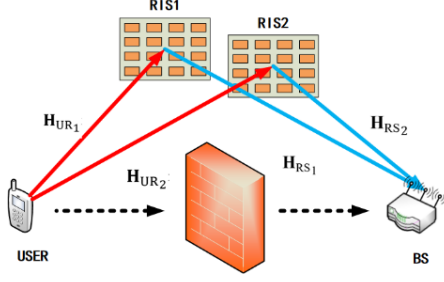


Figure 1. Dual-RIS assisted ISAC system

It is assumed that the positions of the BS and RISs are known. $\mathbf{H}_{RS_i}$ denotes the channel matrix between the i th RIS and the BS, and it is written as

$$\mathbf{H}_{RS_i} = \delta_{RS_i} \mathbf{a}(\varphi_{iDR}, \theta_{iDR}) \otimes \mathbf{b}(\varphi_{iAS})^T, \quad (1)$$

where δ_{RS_i} is the free space path loss as [16], $\mathbf{a}(\varphi_{iDR}, \theta_{iDR})$ represents the response of the i th RIS transmit array, and $\mathbf{b}(\varphi_{iAS})$ is the response of receive antennas at the BS. The uniform linear array (ULA) characteristics of the BS antennas and the uniform planar array (UPA) characteristics of the RISs are denoted respectively as

$$\mathbf{b}(\varphi_{iAS}) = \mathbf{b}_{isy}(\varphi_{iAS}), \quad (2)$$

and

$$\mathbf{a}(\varphi_{iDR}, \theta_{iDR}) = \mathbf{a}_{irz}(\theta_{iDR}) \otimes \mathbf{a}_{iry}(\varphi_{iDR}, \theta_{iDR}), \quad (3)$$

where we have

$$\mathbf{b}_{isy}(\varphi_{iAS}) = \left[1, \dots, e^{j(N-1)\frac{2\pi d \cos \varphi_{iAS}}{\lambda}} \right], \quad (4)$$

$$\mathbf{a}_{iry}(\varphi_{iDR}, \theta_{iDR}) = \left[1, \dots, e^{-j(\sqrt{M}-1)\frac{2\pi d \sin \varphi_{iDR} \cos \theta_{iDR}}{\lambda}} \right], \quad (5)$$

$$\mathbf{a}_{irz}(\theta_{iDR}) = \left[1, \dots, e^{-j(\sqrt{M}-1)\frac{2\pi d \sin \theta_{iDR}}{\lambda}} \right], \quad (6)$$

$\otimes$ is the Kronecker product, φ_{iAS} represents the signal AOA at the BS, φ_{iDR} and θ_{iDR} are the transmit azimuth angle and the transmit elevation angle at the i th RIS, respectively, d is the distance between the neighboring RIS reflection units, and λ is the signal wavelength.

Similarly, $\mathbf{H}_{UR_i}$ means the channel matrix from the user to the i th RIS and is expressed as

$$\mathbf{H}_{UR_i} = \delta_{UR_i} \mathbf{a}(\varphi_{iAR}, \theta_{iAR}), \quad (7)$$

where $\mathbf{a}(\varphi_{iAR}, \theta_{iAR})$ is the receive array response of the i th RIS.

According to the above setting, the channel matrix of the user-RIS-BS link can be modelled as

$$\mathbf{G}_i = \mathbf{H}_{RS_i} \mathbf{\Phi}_i (\mathbf{H}_{UR_i})^H, \quad i = 1, 2, \quad (8)$$

where $\mathbf{\Phi}_i = \text{diag} \left[e^{j\phi_i^1}, e^{j\phi_i^2}, \dots, e^{j\phi_i^M} \right]$ is the reflection coefficient matrix of the i th RIS and ϕ_i^m is the corresponding phase of the m th reflection unit.

The signal sent by the user at time l is $x(l)$ with power $p = \mathbb{E} \left[x(l)x^H(l) \right]$. The received signal at the BS from the two RISs is

$$y(l) = \sqrt{p} \mathbf{\omega}^H \left(\mathbf{H}_{RS_1} \mathbf{\Phi}_1 (\mathbf{H}_{UR_1})^H + \mathbf{H}_{RS_2} \mathbf{\Phi}_2 (\mathbf{H}_{UR_2})^H \right) x(l) + \mathbf{\omega}^H (n_1(l) + n_2(l)), \quad (9)$$

where $\mathbf{\omega} \in \mathbb{C}^{1 \times N}$ is the receive beamforming vector at the BS, and $n_i(l) \sim \mathcal{CN}(0, \sigma^2)$ represents the complex additive white Gaussian noise (AWGN) with mean 0 and variance σ^2 . $(\varphi_{iDR}, \theta_{iDR})$ in $\mathbf{H}_{UR_i}$ can be obtained by the received signal, and the user position can be estimated according to the geometric information of the user and RISs. Considering the signal sparsity in the channel estimation, the angle estimation problem can be transformed into a traditional CS problem.

Firstly, the angles of azimuth and elevation are uniformly sampled into discrete values with the size of W and Q , respectively, as

$$\boldsymbol{\varphi} = [\varphi_0, \varphi_1, \dots, \varphi_{W-1}]^T, \varphi_w \in \left(0, \frac{\pi}{2} \right), w \in (0, W-1), \quad (10)$$

$$\boldsymbol{\theta} = [\theta_0, \theta_1, \dots, \theta_{Q-1}]^T, \theta_q \in \left(0, \frac{\pi}{2} \right), q \in (0, Q-1). \quad (11)$$

Based on (10) and (11), the received signal at the BS from the i th RIS can be reformulated as

$$y_i(l) = \sum_{w=0}^{W-1} \sum_{q=0}^{Q-1} \sqrt{p} \mathbf{\omega}^H \mathbf{H}_{RS_i} \mathbf{\Phi}_i \left(\mathbf{H}_{UR_i}(\varphi_w, \theta_q) \right)^H x(l) \xi_i^{w,q} + \mathbf{\omega}^H n_i(l), \quad (12)$$

with

$$\mathbf{\Gamma}_i = \sum_{w=0}^{W-1} \sum_{q=0}^{Q-1} \sqrt{p} \mathbf{\omega}^H \mathbf{H}_{RS_i} \mathbf{\Phi}_i \left(\mathbf{H}_{UR_i}(\varphi_w, \theta_q) \right)^H x(l) \in \mathbb{C}^{1 \times WQ}, \quad (13)$$

$\xi_i = [\xi_i^{0,0}, \xi_i^{0,1}, \dots, \xi_i^{W-1,Q-1}]^T$, and $\xi_i^{w,q} \in \{0, 1\}$. Due to the sparsity of ξ_i , the location recovery problem can be transformed into a classical CS problem. Thus, $y_i(l)$ can be viewed as the observed value in the CS problem, and $\mathbf{\Gamma}_i$ is the sensing matrix.

III. POSITION AWARENESS AND BEAMFORMING DESIGN

A. Construct Perception Matrix

According to the above CS problem, only the user's angle corresponding to each RIS is unknown in the formula. We assume the uniform sampling for $\boldsymbol{\varphi} = [\varphi_0, \varphi_1, \dots, \varphi_{W-1}]^T$ as $\varphi_0 = 0$ and $\varphi_w = \varphi_0 + \pi w / 2W$. Similarly, we have $\theta_0 = 0$ and $\theta_q = 0 + \pi q / 2Q$. Thus, $\mathbf{H}_{UR_i}(\varphi_w, \theta_q)$ can be rewritten as

$$\mathbf{H}_{UR_i}(\varphi_w, \theta_q) = \delta_{UR_i} \mathbf{a}_{irz}(\theta_q) \otimes \mathbf{a}_{iry}(\varphi_w, \theta_q). \quad (14)$$

Since $\mathbf{H}_{RS_i}$ and $\mathbf{\Phi}_i$ are assumed to be known, we can construct the sensing matrix $\mathbf{\Gamma}_i$.

B. Stepwise Matching Pursuit

Due to the existence of two unknown variables φ and θ in the sensing matrix $\mathbf{\Gamma}_i$, the computational complexity for the traditional CS algorithm is high, and the number of matching calculations is $W \times Q$. Meanwhile, different azimuth and

elevation angles may result in the same results and affect the positioning performance. Therefore, in this subsection, we take the SMP algorithm to realize the positioning and assume that the azimuth angle φ_{iDR} is $\pi/2$.

To reduce the effect of channel noise on the positioning perception, we first set $\mathbf{\Phi}_i = \text{diag}(\mathbf{\omega}\mathbf{a}(\varphi_{iDR}, \theta_{iDR})^H)$ and let the user send the identical signals in two adjacent time slots. After the completion of the first signal transmission, we have

$$\mathbf{\Phi}_i = -\mathbf{\Phi}_i, \quad (15)$$

$$\mathbf{\Phi}_i(k, k) = -1 \times \mathbf{\Phi}_i(k, k), k = 1: \sqrt{M} : M. \quad (16)$$

Then, the two received signals are superimposed, and the same operation is performed on the sensing matrix. Because of the change of $\mathbf{\Phi}_i$, the received signals from the i th RIS can be regarded as a column vector. Thus, $\mathbf{H}_{UR_i}(\pi/2, \theta_q)$ is equivalent to

$$\mathbf{H}_{UR_i}(\pi/2, \theta_q) = \delta_{UR_i} \begin{bmatrix} 1, \dots, 0, \dots, e^{-j(\sqrt{M}-1)\pi \sin \theta_q}, \dots, 0 \end{bmatrix}. \quad (17)$$

It can be seen that $\mathbf{H}_{UR_i}(\pi/2, \theta_q)$ only depends on $\sin \theta_q$.

We can take MP algorithm to obtain more accurate θ_{iAR} .

According to the above analysis, the available elevation angle θ_{iAR} can be substituted into $\mathbf{H}_{UR_i}(\varphi_w, \theta_q)$, and the azimuth angle can be further obtained by the MP algorithm. The specific procedure of the positioning algorithm is shown in Table I.

TABLE I. SMP ALGORITHM

Algorithm 1: SMP

Input: y_i, Γ_i

Result: ξ_i

Initialization: $r_0 = y_i, \Lambda_{i0} = \emptyset, \Gamma_{i0} = \emptyset, t = 1$;

Step 1: $\mathbf{\Phi}_i = \text{diag}(\mathbf{\omega}\mathbf{a}(\varphi_{iDR}, \theta_{iDR})^H)$, calculate y_i and Γ_i according to (13) and (14);

Step 2: Transform $\mathbf{\Phi}_i$ as shown in (16) and (17), then calculate y_i' and Γ_i' according to (13) and (14), so that $r_0 = y_i + y_i'$ and $\Gamma_i = \Gamma_i + \Gamma_i'$;

Step 3: Execute matching pursuit algorithm

for $t < C$ and $\epsilon_t > 0$ do

a) $\mathbf{J} = \arg \min_{j \in \Lambda_{i,t-1}} |\zeta_i^j - r_{i,t-1}|$ (for all $\zeta_i^j \in \Gamma_i$);

b) $\Lambda_{i,t} = \Lambda_{i,t-1} \cup \mathbf{J}, \Gamma_{i,t} = \Gamma_{i,t-1} \cup \zeta_i^j$ (for all $\zeta_i^j \in \Gamma_i$);

c) $\xi_{it} = \arg \min_{\xi_{it}} \|y_i - \Gamma_{it} \xi_{it}\| = (\Gamma_{it}^T \Gamma_{it})^{-1} \Gamma_{it}^T y_i$;

d) $r_t = y_i - \Gamma_{it} \xi_{it} = y_i - \Gamma_{it} (\Gamma_{it}^T \Gamma_{it})^{-1} \Gamma_{it}^T y_i$;

$t = t + 1$

end

Step 4: Set the maximum K items of ξ_{it} obtained in **Step 3** to be 1, recover the elevation θ_{iAR} by ξ_{it} and substitute it into $\mathbf{H}_{UR_i}(\varphi, \theta)$;

Step 5: Reset $r_0 = y_i, \Lambda_{i0} = \emptyset, \Gamma_{i0} = \emptyset, t = 1$;

Step 6: Set $\mathbf{\Phi}_i = \text{diag}(\mathbf{\omega}\mathbf{a}(\varphi_{iDR}, \theta_{iDR})^H)$, and calculate y_i and Γ_i according to (13) and (14);

Step 7: Repeat the matching pursuit algorithm;

Step 8: Set the maximum K terms of ξ_{it} obtained in **Step 7** to be 1, and recover the azimuth angle φ_{iAR} .

The angle relationship between the user and the RISs can be obtained by the SMP algorithm, and then the user's

location can be reconstructed according to the geometric relationship. After having the above angles and positions, we can get the estimated RIS array response, and thus obtain the phase offset information of the channel. Therefore, the received signal can be rewritten as

$$y_i(l) = \sqrt{p} \mathbf{\omega} \mathbf{H}_{RS_i} \mathbf{\Phi}_i (\mathbf{H}_{UR_i}(\hat{\varphi}_{iAR}, \hat{\theta}_{iAR}))^H x(l) + \mathbf{\omega} n_i(l). \quad (18)$$

C. Beamforming Design

In this work, with the known channel state information (CSI), we aim to maximize the system achievable rate at the BS through the design of the receive beamforming of the BS antennas and the phase shift matrix of the RISs. The above optimization problem can be decomposed into two sub-problems, one is the phase shift design of the two RISs and the other is the receive beamforming design of the BS. We can first formulate the independent optimization problems by fixing two of these variables. Then, the optimal solution of each sub-problem can be obtained by decoupling. According to (18), the system achievable rate at the BS is computed as

$$R = \log_2(1 + \gamma), \quad (19)$$

with

$$\gamma = \frac{\left\| \sqrt{p} \mathbf{\omega} (\mathbf{H}_{RS_1} \mathbf{\Phi}_1 (\mathbf{H}_{UR_1}(\varphi_{1AR}, \theta_{1AR}))^H + \mathbf{H}_{RS_2} \mathbf{\Phi}_2 (\mathbf{H}_{UR_2}(\varphi_{2AR}, \theta_{2AR}))^H) \right\|^2}{2\sigma^2}. \quad (20)$$

where $\|\cdot\|$ is the two-norm.

The optimization problem of the RIS beamforming design can be described as

$$(P1) \quad \max \quad R \\ \text{s.t.} \quad |\phi_i^n| = 1, \forall i \in \{1, 2\}, n \in \{1, 2, \dots, N\}. \quad (21)$$

The above problem is not convex due to the constant modulus constraint of the phase shift matrix $|\phi_i^n| = 1$ and the coupling of $\mathbf{\Phi}_1$ and $\mathbf{\Phi}_2$. Considering that $\mathbf{\Phi}_1$, $\mathbf{\Phi}_2$, and $\mathbf{\omega}$ in (P1) should be optimized simultaneously, it is impossible to find the optimal solution directly. Therefore, as an approximate optimal solution, AO algorithm is considered. Firstly, we can transform (P1) into a sub-problem about $\mathbf{\omega}$ and find the optimal solution. Then, the sub-problems of $\mathbf{\Phi}_1$ and $\mathbf{\Phi}_2$ can be solved in turn, which can ensure the quality of the received signal of each time slot at the BS.

At the BS, in order to maximize the receive SNR, we can take the maximal ratio combining (MRC) method. With fixed $\mathbf{\Phi}_1$ and $\mathbf{\Phi}_2$, the optimal $\mathbf{\omega}$ can be obtained as

$$\mathbf{\omega}^* = \frac{\sqrt{p} (\mathbf{H}_{RS_1} \mathbf{\Phi}_1 (\mathbf{H}_{UR_1}(\hat{\varphi}_{1AR}, \hat{\theta}_{1AR}))^H + \mathbf{H}_{RS_2} \mathbf{\Phi}_2 (\mathbf{H}_{UR_2}(\hat{\varphi}_{2AR}, \hat{\theta}_{2AR}))^H)}{\left\| \sqrt{p} (\mathbf{H}_{RS_1} \mathbf{\Phi}_1 (\mathbf{H}_{UR_1}(\hat{\varphi}_{1AR}, \hat{\theta}_{1AR}))^H + \mathbf{H}_{RS_2} \mathbf{\Phi}_2 (\mathbf{H}_{UR_2}(\hat{\varphi}_{2AR}, \hat{\theta}_{2AR}))^H) \right\|}. \quad (22)$$

Since it is difficult to obtain the optimal solution of the non-convex optimization problem (P1), we can fix the phase shift matrix of one RIS, while optimizing the phase shift matrix of the other RIS. Specifically, for given $\mathbf{\omega}$ and $\mathbf{\Phi}_2$, we have

$$\left| \sqrt{p} \mathbf{\omega} (\mathbf{H}_{RS_1} \mathbf{\Phi}_1 (\mathbf{H}_{UR_1}(\varphi_{1AR}, \theta_{1AR}))^H + \mathbf{H}_{RS_2} \mathbf{\Phi}_2 (\mathbf{H}_{UR_2}(\varphi_{2AR}, \theta_{2AR}))^H) \right| \\ \leq \left| \sqrt{p} \mathbf{\omega} \mathbf{H}_{RS_1} \mathbf{\Phi}_1 (\mathbf{H}_{UR_1}(\hat{\varphi}_{1AR}, \hat{\theta}_{1AR}))^H \right| + A = |\mathbf{B} \Psi_1| + A, \quad (23)$$

with

$$A = \sqrt{p} \mathbf{\omega} \mathbf{H}_{RS_2} \mathbf{\Phi}_2 (\mathbf{H}_{UR_2}(\varphi_{2AR}, \theta_{2AR}))^H, \quad (24)$$

and

$$\mathbf{B} = \sqrt{p} \mathbf{\omega} \mathbf{H}_{RS_1} \text{diag}(\mathbf{H}_{UR_1}(\hat{\varphi}_{1AR}, \hat{\theta}_{1AR}))^H. \quad (25)$$

If and only if $\angle \mathbf{B}\Psi_1 = \angle A$ in (23) is valid, the optimal solution is obtained as

$$\Psi_1^* = e^{j(\angle A - \angle B)}. \quad (26)$$

Finally, the optimal solution Ψ_1^* is converted into a diagonal matrix $\Phi_1^* = \text{diag}(\Psi_1^*)$ for the convenience of subsequent iterations, and we can get Φ_1 correspondingly.

Similar to the solution of Φ_1 , for given ω and Φ_1 , we can set $D = \sqrt{p\omega} \mathbf{H}_{RS_1} \Phi_1 (\mathbf{H}_{UR_1}(\phi_{1AR}, \theta_{1AR}))^H$ and $\mathbf{E} = \sqrt{p\omega} \mathbf{H}_{RS_2} \text{diag}(\mathbf{H}_{UR_2}(\phi_{2AR}, \theta_{2AR}))^H$, and get the optimal solution of Ψ_2 as

$$\Psi_2^* = e^{j(\angle D - \angle E)}. \quad (27)$$

Then, Ψ_2^* can be further transferred into a diagonal matrix for the convenience of subsequent iterations.

TABLE II. AO ALGORITHM BASED ON TRIANGLE INEQUALITY

Algorithm 2: TI-AO	
Input: $\mathbf{H}_{RS_1}, \mathbf{H}_{UR_1}(\hat{\phi}_{1AR}, \hat{\theta}_{1AR}), \mathbf{H}_{RS_2}, \mathbf{H}_{UR_2}(\hat{\phi}_{2AR}, \hat{\theta}_{2AR})$	
Result: $\omega^*, \Phi_1^*, \Phi_2^*$	
Initialization: $\Phi_1^{(0)}, \Phi_2^{(0)}, p = 100, k = 0, \gamma(0) = \infty$	
while $ \gamma(k+1) - \gamma(k) \& \& k < 100$ do	
Step 1: Calculate ω^* by (22);	
Step 2: Calculate Ψ_1^* by (26);	
Step 3: Calculate Ψ_2^* by (27);	
Step 4: Calculate $\gamma(k+1)$ from ω^*, Ψ_1^* , and Ψ_2^* ;	
$k = k + 1$.	
end	

IV. NUMERICAL RESULTS

In this section, we provide the simulation results of the proposed dual-RIS assisted ISAC system. The system settings in the simulation are as follows. The user's 3D location is $\mathbf{u} = (7, 6, 1)\text{m}$. Considering that the positioning accuracy is low when the heights of the two RISs are close [5], the coordinates of the two RISs are set as $\mathbf{r}_1 = (0, 2, 3)\text{m}$ and $\mathbf{r}_2 = (0, 3, 1)\text{m}$, and the coordinate of the BS is set to be $\mathbf{s} = (1, 1, 1)\text{m}$. We first set the number of RIS reflection units $M = 36$, the number of BS antennas $N = 8$, and the path loss coefficient $g = 2.2$ with $\text{SNR} = 50\text{dB}$. In the positioning stage, the sampling numbers W and Q for the azimuth and elevation angles are both set to be 1000.

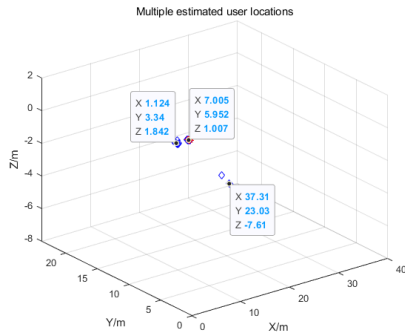


Figure 2. Location performance of SMP and MP Algorithms

As shown in Fig. 2, the red star-shaped dot set is the positioning result of the SMP algorithm, and the blue

diamond-shaped one is the result of the traditional MP algorithm. It is seen that the SMP algorithm achieves better positioning performance compared with the MP algorithm. The reason is that different combination values of $(\phi_{iAR}, \theta_{iAR})$ may get relatively similar results for the MP algorithm due to the two-dimensional CS and the positioning error may increase for the influence of noise. The SMP algorithm proposed in this paper can deal with this issue well and it can greatly reduce the computational complexity. The computational complexity of the MP algorithm is $\mathcal{O}(W \times Q)$, while the SMP algorithm has lower complexity as $\mathcal{O}(W + Q)$.

We further study the influence of the number of BS receive antennas on the mean square error (MSE) of positioning with different SNRs. The length of time is $L = 100$. We set $\text{SNR} = 50\text{dB}$, 60dB , and 70dB , respectively, and the number of BS antennas $N = 8$ and 16 , respectively. As seen from Fig. 3, the increasing SNR can significantly improve the positioning performance. That is, the positioning MSE decreases significantly with the increase of SNR since the influence of noise on the positioning error becomes marginal with the increase of SNR. If the SNR increases continuously, the MSE will become very small but not zero even with increasing reflection units of the RISs, which is due to the limitation of the uniform sampling number of angles. When the user is not at the grid points decided by the perception matrix, certain errors will happen and increasing the sampling number can further solve this problem. It is also shown that, when the number of BS receive antennas and the number of RIS reflection units increase, the MSE gradually decreases and then becomes marginal, indicating that the MSE can be affected by both of them, but with limited influence at large number. When the number of RIS units reaches 64, the subsequent MSE changes very little and becomes stable.

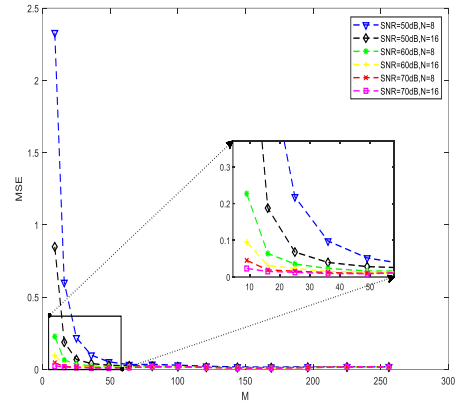
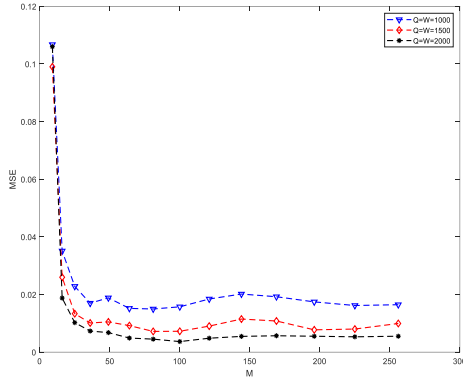


Figure 3. Effect of the receive antenna number N on MSE with different SNRs

The effect of angle division on the MSE of positioning is depicted in Fig. 4. The accuracy of CS depends largely on the meshing of channels in the MP algorithm. When the uniform sampling number is small and the user is not on the grid point, a large positioning error may appear. As illustrated in Figure 4, when the number of uniform samples increases, the MSE gradually decreases and the volatility of MSE also decreases. When the number of uniform samples increases indefinitely, the MSE will tend to be 0. If the user is located on the grid, the MSE also becomes 0. The MSE tends to be stable when the number of RIS reflection units exceeds 64.

Figure 4. Effect of sampling number W and Q on MSE

In the following, we study the TI-AO algorithm based beamforming design of the BS antennas and the RIS units according to the obtained positioning information. The system achievable rate with the proposed beamforming design is shown in Fig. 5. We set the uniform sampling number as 2000, the number of BS antennas as 8 and 16, and the number of RIS units as 36 and 64, respectively. The random phase shifts of RIS are also considered for comparison. It is shown that the increase of the SNR, the number of BS antennas, and the number of RIS units, will improve the system achievable rate. At the same time, it is found that, when the number of RIS units is small, the system achievable rate does not increase linearly with the increased SNR due to the large positioning MSE at the first stage shown in Fig. 3. However, when the number of RIS units is 64, the achievable system rate increases linearly with the SNR.

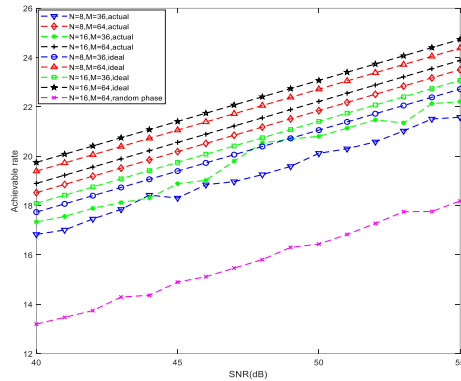


Figure 5. Achievable rate of the proposed beamforming design

V. CONCLUSION

In this paper, a dual-RIS assisted ISAC system is proposed to achieve high-precision accurate positioning of users in the uplink transmission and the optimal beamforming design of the BS and RISs is presented based on the positioning information. The proposed ISAC system realizes the sensing and communication under the same frequency and time resources. It is verified through simulation that the presented SMP algorithm has excellent positioning performance and the near-optimal system achievable rate can be achieved with the optimal beamforming design of the BS and RISs.

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