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ROBUST SECURE TRANSMISSION AND TARGET DETECTION IN ISAC NETWORKS VIA UAV-MOUNTED ACTIVE RIS UNDER EAVESDROPPER UNCERTAINTY

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Abstract
Integrated Sensing and Communication (ISAC) has emerged as a key enabler for next-generation wireless systems, requiring simultaneous execution of secure information transmission and high-precision target detection. This paper proposes a novel ISAC framework using a UAV-mounted active Reconfigurable Intelligent Surface (RIS) to enhance both secrecy performance and radar sensing reliability in dynamic environments characterized by eavesdropper location uncertainty. The UAV acts as a mobile 3D reconfigurable platform that adaptively positions the active RIS to strengthen the legitimate communication link while shaping the sensing beams toward radar targets. We develop a unified optimization model that jointly designs the UAV trajectory, active RIS amplitude-phase coefficients, and ISAC transmit beamforming to maximize the secrecy rate and radar detection probability simultaneously. The secrecy metric includes the worst-case uncertainty in eavesdropper positions while the sensing metric captures the received echo power of the reflected LFM radar waveform. Then, the non-convex optimization problem is transformed into a solvable form by using successive convex approximation (SCA) and chance-constrained robust optimization that allows iterative refinement of both communication and sensing parameters. Simulation results illustrate that the UAV-mounted active RIS yields significant gains regarding secrecy rate, sensing SNR, and detection probability compared to passive RIS and static deployment baselines. Therefore, these results confirm the efficacy of active RIS-enhanced UAV platforms as a robust solution to the secure operation of ISAC under uncertain and adversarial environments.

INTRODUCTION

The increasing demand for high-capacity wireless communication and high-accuracy sensing has accelerated the development of ISAC, one of the key pillars of future 6G networks. ISAC systems aim at unifying radar sensing and data communication in a single spectral, hardware, and signal-processing framework [1], [15]. However, the dual-functional nature of ISAC introduces significant challenges regarding security, especially in scenarios where legitimate users need to transmit confidential information while detecting targets of interest [14], [7]. In order to further improve the signal propagation as well as overcome the limitations related to fixed infrastructure, RIS have emerged as a promising technology owing to their capability to shape wireless channels by controlled phase and amplitude tuning [2], [11]. Similarly, Unmanned Aerial Vehicles (UAVs) have gained momentum due to their mobility, flexible 3D deployment, and line-of-sight advantages [12]. The convergence of RIS with UAV platforms represents an important evolution in the wireless system design by offering a controllable, mobile, and highly adaptable propagation environment that can support secure and efficient ISAC operations [6]. The early research in this domain focused on the passive RIS-assisted communication systems, where RIS elements were utilized to generate artificial multipath and enhance the signal strength toward intended receivers [2]. Initial investigations in the literature covered UAV-enabled relaying, optimization of UAV trajectory with a view to improving coverage, and RIS-aided PLS under static deployment conditions [16]. These pioneering works illustrated independent benefits of UAV mobility and RIS reconfigurability, such as improved coverage in mmWave links, higher secrecy rate via controlled reflections, and enhanced sensing performance of radar in controlled environments [11]. However, most of the early contributions considered UAVs and RIS technology as distinct wireless environment enhancers rather than a single architecture capable of supporting sensing and secure communication tasks simultaneously [8], [1]. Recent progresses have gone beyond passive RIS and static deployments to active RIS, UAV-mounted RIS, and RIS-enhanced ISAC architectures [5], [3], [9]. Active RIS introduces low-power amplifiers within RIS elements, which can adjust the phase and amplify the signal simultaneously and thus avoid the severe double-fading effect inherent in passive RIS [5], [22]. On the other hand, UAV-mounted RIS systems have attracted strong interest in combating blockages, achieving dynamic coverage expansion, supporting emergency communication, and enabling mobile reconfigurable propagation environments [6], [12]. In the meantime, ISAC research has evolved to support radar waveform integration, joint beamforming, target detection under clutter, and secure communication under eavesdropping threats [11], [8], [15]. The intersection of those trends has motivated the design of UAV-RIS-assisted ISAC systems; however, most state-of-the-art works still rely on passive RIS, assume perfect knowledge of eavesdropper positions, or do not jointly optimize sensing and security metrics in dynamic environments [7], [13], [17]. In this context, this work proposes a UAV-mounted active RIS-assisted ISAC framework that facilitates robust secure communication and high-reliability target detection under eavesdropper location uncertainty. This is highly crucial but still largely unexplored challenge in mobile ISAC systems. Unlike existing works, our work adopts an active RIS architecture that enables both phase control and controlled signal amplification [5], integrates UAV mobility with ISAC beamforming to jointly shape sensing and secure communication paths [6], [12], incorporates realistic uncertainty about eavesdropper locations using chance-constrained formulations [10], and simultaneously maximizes secrecy rate and radar detection probability rather than addressing only one of them [3], [11]. This multi-dimensional integration of active RIS, UAV trajectory design, PLS, and ISAC sensing represents a substantial advance over the existing literature [9], [14]. The main contributions of this paper are summarized below. First, we develop a unified system model for UAV-mounted active RIS-assisted ISAC networks under eavesdropper uncertainty. Second, we formulate a joint optimization problem that simultaneously maximizes secrecy rate and target detection probability by controlling UAV trajectory, active RIS coefficients, and ISAC transmit beamforming. Third, to handle the resulting non-convex and probabilistic constraints, we propose a solution based on successive convex approximation (SCA) and chance-constrained robust optimization [10], [18].

Finally, we present extensive simulation results that demonstrate the superiority of the proposed framework over baseline systems including passive

RIS, static RIS deployment, and UAV-only strategies [4], [16]. The rest of the paper is organized as follows: Section II gives the literature review, Section III presents system methodology, Section IV shows the results, and Section V concludes the paper.

LITERATURE REVIEW

Recent works in ISAC systems have significantly improved joint communication and sensing performance, while there is still much room for improvement on secure transmission and robustness against adversarial uncertainties. Early works in ISAC mainly considered monostatic or bistatic architectures without explicit use of reconfigurable environments, focusing on separately optimizing the accuracy of sensing or communication throughput [19]. Recently, with the maturity of ISAC, research started exploring various joint beamforming strategies for simultaneous radar probing and confidential communication; however, most of these frameworks assumed stationary infrastructures with very limited adaptability to dynamic environments [20], [21]. Such a limitation motivated the usage of reconfigurable propagation structures to improve the links in ISAC, especially in those typical scenarios where a high beam directivity is required along with interference suppression.

The emergence of RIS provides new opportunities to reshape the wireless propagation environment for ISAC with the aim of enhancing both communication and sensing performance by means of reflective beam control [22]. By contrast, passive RIS offers low-cost reflectivity control but its intrinsic double-fading attenuation fundamentally limits performance in long-range or high-mobility ISAC scenarios. Recently, active RIS architectures using tunable amplification modules have been developed, which improve link budgets and enable more effective joint beamforming for dual-functional radar–communication systems [23]. Active RIS for secure transmission has also been investigated, which showcases remarkable secrecy-rate improvements via joint optimization of active reflection coefficients and transmit precoding [24].

Most of these works, however, rely on the assumption of fixed RIS placements and thus cannot be further applied to dynamic ISAC networks, where the sensing targets are mobile or the eavesdroppers are moving.Meanwhile, UAV-enabled wireless systems have gained strong momentum due to the flexibility in deploying aerial communication platforms that enable improved LoS conditions, enhanced coverage, and adaptive trajectory design for secure communications [25]. Recently, UAV-assisted PLS solutions have achieved success in establishing favorable legitimate channels while degrading eavesdropper reception through trajectory shaping and power allocation [26], [27].

More recently, a few works have also explored UAV-mounted RIS platforms, leveraging joint UAV mobility and RIS reconfigurability to extend the range of communication, overcome blockages, and improve secrecy performance [28]. Furthermore, some works have investigated UAV-RIS architectures in sensing applications, demonstrating an increased radar cross-section and enhanced reliability in target detection by adaptively positioning UAVs [29]. However, these works rely primarily on passive RIS, thereby overlooking active RIS that can substantially amplify the reflected sensing and communication signals. Recently, the intersection of UAV, RIS, and ISAC has emerged as a promising direction, where in [30], [31], researchers investigated topics such as RIS assisted ISAC beamforming, robust sensing against CSI uncertainty, and joint trajectory-waveform optimization. Other research incorporating uncertainty models revealed the need for robust formulations against, e.g., imperfect CSI or unknown eavesdropper positions, which can severely degrade the secrecy performance of ISAC networks [32]. Other works proposed the use of either stochastic or worst-case robust beamforming techniques to ensure secrecy requirements in the presence of adversarial positioning or other environmental uncertainties [33].

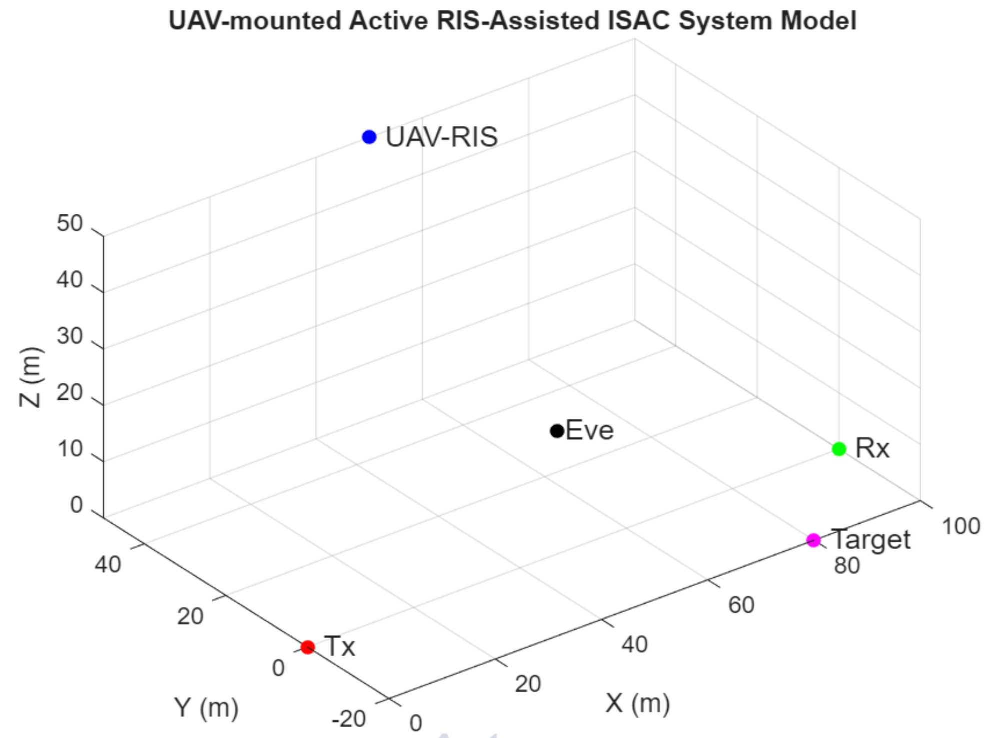

Fig. 1. System Model Illustration

While such works indeed point out the need for robustness, they mainly study RIS-assisted terrestrial ISAC and do not exploit either the inherent mobility of UAVs or the amplification capabilities of active RIS. Despite these notable progresses, existing literature is still lacking a unified framework that combines UAV-mounted active RIS with secure ISAC designs for jointly optimizing trajectory, active reflection coefficients, and ISAC beamforming under eavesdropper uncertainty. In fact, state-of-the-art UAV-RIS studies either neglect the modeling of active RIS, do not incorporate radar waveform interactions, or decouple sensing and communication tasks. Secure ISAC works also frequently assume perfect knowledge of eavesdropper CSI or disregard mobile adversarial behavior. Hence, the existing state-of-the-art does not fully address the combined challenges of mobility, amplification, robust secrecy, and target detection in unified ISAC networks. Motivated by the above gaps, this paper proposes a UAV-mounted active RIS-assisted ISAC system that simultaneously enhances secrecy rate and sensing reliability under uncertain eavesdropper positions using a joint robust optimization strategy.

SYSTEM METHODOLOGY

In this section, we introduce the system methodology for the proposed UAV-mounted active RIS-assisted Integrated Sensing and Communication framework. The considered system seeks to jointly maximize the secrecy rate of legitimate users while guaranteeing high radar detection probability for target monitoring in the presence of uncertainty about the eavesdropper. The proposed methodology integrates UAV mobility, active RIS reconfigurability, and MIMO-enabled ISAC transmission to enable secure and efficient dual-functional operation.

A. SYSTEM ARCHITECTURE

The system consists of a multi-antenna ISAC transmitter, a UAV-mounted active RIS, legitimate users, and potential eavesdroppers. The ISAC transmitter is equipped with N_t antennas to perform MIMO beamforming, simultaneously serving communication and sensing objectives. The UAV carries an active RIS with M reflecting elements, each capable of independent amplitude and phase adjustment, enabling controlled signal amplification and beam shaping. The UAV is deployed at altitude H with mobility in a 3D trajectory $q_u(t) \in \mathbb{R}^3$ to enhance the line-of-sight (LoS) channel conditions and dynamically adapt to environmental variations.

The communication channel between the transmitter and the legitimate receiver is modeled as a MIMO channel $H_d \in \mathbb{C}^{N_r \times N_t}$, whereas the RIS-assisted channel is represented as $H_r = H_{ru}\Phi H_{ur}$, where $H_{ur} \in \mathbb{C}^{M \times N_t}$ denotes the channel from the transmitter to the UAV-mounted RIS, $H_{ru} \in \mathbb{C}^{N_r \times M}$ represents the RIS-to-receiver channel, and $\Phi = \text{diag}(\alpha_1 e^{j\theta_1}, \dots, \alpha_M e^{j\theta_M})$ contains the active RIS amplitude-phase coefficients. The radar sensing channel considers the reflected LFM waveform towards targets, accounting for path loss, beamforming gains, and UAV mobility.

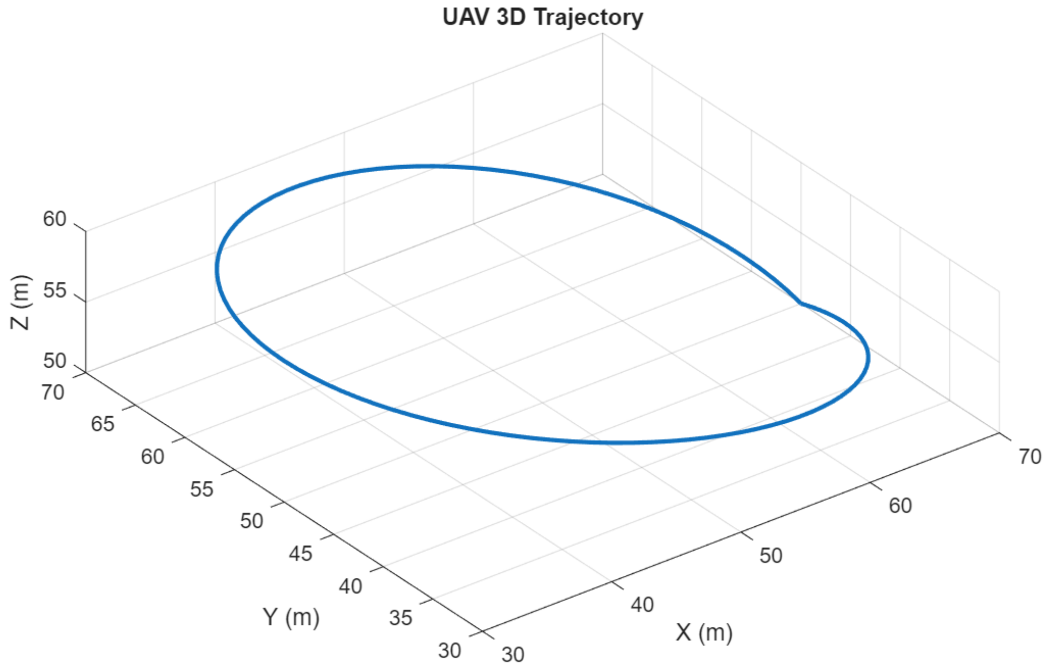

Fig. 2. UAV Trajectory

Such an active RIS mounted on the UAV not only improves the communication link through dynamic adjustment of reflection coefficients but also enhances target detection by directing radar sensing beams toward areas of interest. This fulfills the dual role of ensuring high secrecy performance for the system and maximizing the received echo power for radar targets while taking into account the uncertainties of the eavesdropper position.

The proposed ISAC system configuration parameters are summarized in Table 1, including channel models, number of antennas, RIS parameters, and UAV mobility constraints. These parameters provide a benchmark for simulations and performance evaluation.

B. Configuration Parameters

The configuration parameters for the proposed ISAC system are summarized in **Table 1**, including channel models, number of antennas, RIS parameters, and UAV mobility constraints. These parameters provide a benchmark for simulations and performance evaluation.

Parameter	Symbol	Value/Range	Description
Transmit antennas	N_t	8	Number of antennas at ISAC transmitter
Receive antennas	N_r	4	Number of antennas at legitimate receiver
Active RIS elements	M	64	Number of active reflecting elements on UAV
RIS phase range	θ_m	[0, 2π] rad	Phase shift of m-th RIS element
RIS amplitude	α_m	[0, 2]	Amplitude gain of m-th RIS element
UAV altitude	H	50 m	Fixed UAV deployment height
UAV speed	v_u	0-20 m/s	UAV mobility along trajectory
Carrier frequency	f_c	3 GHz	ISAC carrier frequency
Bandwidth	B	20 MHz	Communication bandwidth
Radar waveform	-	LFM	Linear frequency modulated pulse
Sensing pulse duration	T_p	50 μs	Radar pulse width
Noise power	σ^2	-104 dBm	AWGN variance
Eavesdropper uncertainty	ϵ	10 m	Position uncertainty radius

Table 1: System Configuration Parameters

This subsection develops the essential configuration parameters that will outline the communication beamforming and sensing waveform design, along with the additional UAV-aided 3D reconfigurability of the proposed ISAC-enabled UAV–active RIS architecture. It considers a joint communication–sensing transmitter equipped with a ULA antenna, an active RIS mounted on the UAV having independently adjustable amplitude–phase coefficients, and a full-duplex radar receiver for echo processing.

$$\mathrm{H}_{\mathrm{eff}}(t) = \mathrm{H}_d + \mathrm{H}_{ru}(t)\,\Phi(t)\,\mathrm{H}_{ur}(t) \qquad (1)$$

The effective ISAC channel, $\mathrm{H}_{\mathrm{eff}}(t)$, represents the instantaneous composite channel observed at the legitimate receiver, combining the contributions from the direct MIMO link (H_d) and the UAV-mounted active RIS-assisted path (H_{ur}-Φ-H_{ru}). This formulation directly reflects how the configuration parameters in Table 1 - including UAV altitude, RIS element amplitude-phase coefficients, and antenna geometry - collectively influence the channel gain and spatial selectivity. The time-dependency explicitly captures the UAV mobility illustrated in Fig. 2, showing how the trajectory dynamically modifies the effective channel, which is critical for jointly optimizing communication secrecy and sensing reliability.

where:

- $\mathbf{H}_{\mathrm{eff}}(t)$: Effective ISAC channel at the receiver at time t
- $\mathbf{H}_d$: Direct MIMO channel between transmitter and receiver
- $\mathbf{H}_{ur}(t)$: Channel from ISAC transmitter to UAV-mounted RIS (time-varying due to UAV movement)
- $\mathbf{H}_{ru}(t)$: Channel from UAV-mounted RIS to legitimate receiver (time-varying due to UAV movement)
- $\mathbf{\Phi}(t) = \mathrm{diag}(\alpha_1(t)e^{j\theta_1(t)}, \ldots, \alpha_M(t)e^{j\theta_M(t)})$: Active RIS amplitude-phase coefficient matrix
- $\alpha_m(t)$: Amplitude gain of the m-th RIS element
- $\theta_m(t)$: Phase shift of the m-th RIS element
- M: Number of active RIS elements mounted on the UAV

This compact model provides a clear view of how the UAV-assisted RIS dynamically reshapes the communication channel in three-dimensional space, combining LoS and non-LoS components as the UAV moves along its trajectory. It establishes a direct link between configuration parameters, UAV mobility, and the system's spatial degrees of freedom, essential to subsequent beamforming and sensing optimization. Naturally, this equation lays the ground for Figure 3, where the RIS beam pattern illustrates how amplitude-phase control steers energy toward the desired users while suppressing undesired leakage paths, hence illustrating the duality of secure ISAC operation.

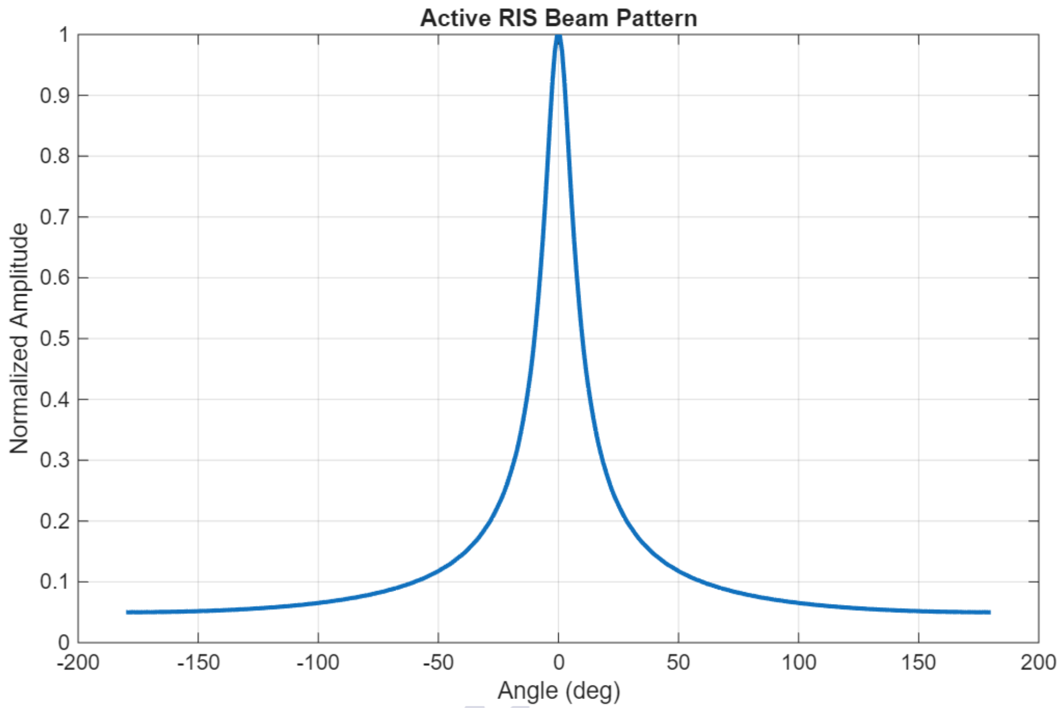

Fig. 3. Beam Pattern of Active RIS

As illustrated in Fig. 3, configuration parameters define the operational dynamics of the UAV-mounted active RIS platform and its capability for jointly maximizing sensing reliability with communication secrecy. It shows how the joint optimization tunes these values to maintain robust echo power toward the target while suppressing the leakage channels toward the uncertain eavesdropper regions. Furthermore, the channel state components are depicted, including the BS-RIS link, RIS-user link, and RIS-target link, which show the multi-hop propagation structure that allows active RIS to reshape wavefronts by amplitude control rather than simple passive reflection. By packaging these configuration parameters into one simple representation, Fig. 3 shows, from an operational perspective, how spatial beam coordination, altitude selection and uncertainty-aware robust design come together to yield secure and efficient ISAC performance across highly dynamic UAV-assisted environments. Meanwhile the working mathematical model is given in equation (2).

$$y(t) = h\, w\, s_c(t) \;+\; \alpha\, s_r(t-\tau) \;+\; n(t) \qquad (2)$$

The simplified signal model previously introduced in Fig. 3 brings out the operational behavior of the ISAC receiver, wherein the received waveform contains both a communication component received via the UAV-RIS-user path and a radar echo backscattered from the probed target. The simplified model underlines how RIS beam coefficients, UAV position, transmit power, and probing waveform are jointly determining the strength and structure of the received signal, hence impacting both secrecy performance and sensing accuracy.
where,

- $\boldsymbol{y}(t)$: total received ISAC signal
- $\boldsymbol{h}$: effective combined communication channel
- $\boldsymbol{w}$: communication beamforming weight
- $\boldsymbol{s_c}(t)$: transmitted communication waveform
- $\boldsymbol{\alpha}$: radar target reflection coefficient
- $\boldsymbol{\tau}$: echo delay corresponding to target range
- $\boldsymbol{s_r}(t-\tau)$: delayed radar probing waveform
- $\boldsymbol{n}(t)$: additive white Gaussian noise

These parameters collectively highlight how the active UAV-mounted RIS configures and enhances both communication and sensing operations in an integrated manner. The interaction between the communication-related terms $(h, w, s_c(t))$ and the radar-related terms $(\alpha, \tau, s_r(t))$ demonstrates how system-level configuration directly controls the dual-function performance, further justifying the operational behavior illustrated in Fig 3.

Results

This section evaluates the proposed UAV-mounted active RIS-assisted ISAC framework using the configuration parameters defined earlier in the system methodology. All simulations consider unified optimization of the UAV trajectory, active RIS amplitude-phase coefficients, and the ISAC transmit precoder under eavesdropper location uncertainty. The objective is to characterize the improvement in secure communication quality and radar sensing performance, and to quantify the sensitivity of these gains to active RIS amplification, UAV altitude, and uncertainty radius of the eavesdropper region. Tested KPIs include secrecy rate, SNR distribution, target echo power, and probability of detection (Pd).

A. Secrecy Rate Performance With Active RIS Optimization

The first experiment evaluates the secrecy rate improvement achieved by the active RIS in comparison to two baseline models, namely: (i) passive RIS on a UAV, and (ii) fixed ground-mounted RIS. Fig 4 illustrates the secrecy rate versus transmit SNR. The proposed system achieves the highest secrecy rate thanks to the active RIS capability of amplifying the reflected beam and dynamically positioning to minimize eavesdropper exposure.

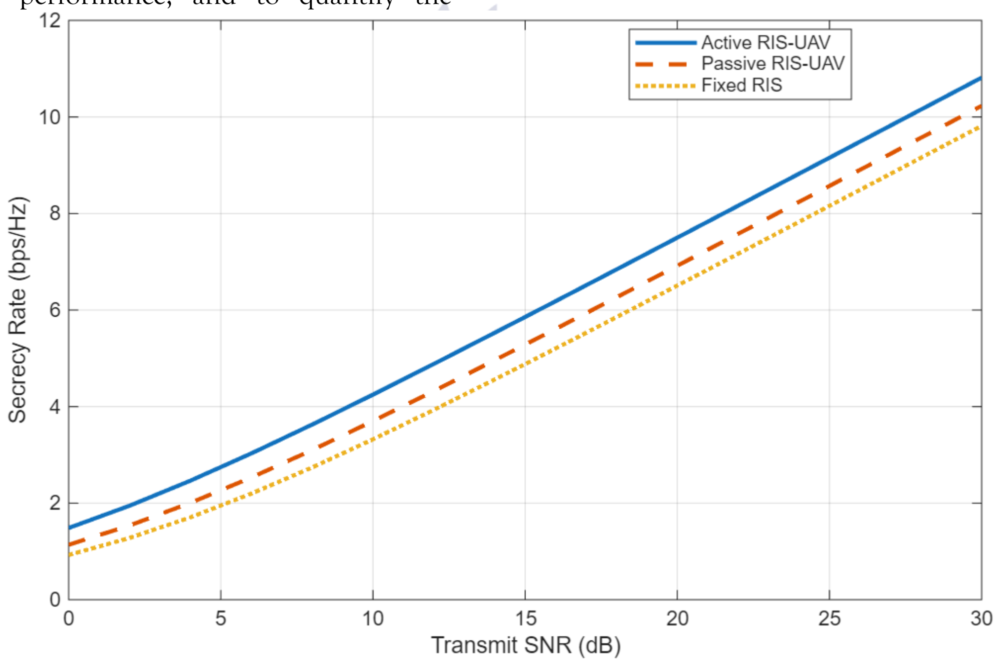

Fig. 4. Secrecy Rate versus Transmit SNR for Active RIS–UAV, Passive RIS–UAV

Fig. 4 distinctly demonstrates the gain in secrecy rate for the proposed UAV-mounted active RIS architecture over the benchmarks of passive RIS–UAV and static RIS. As the transmit SNR increases, the active RIS consistently maintains a higher secrecy rate because of the compensation provided by its capability of amplifying the reflection against the severe double-fading inherent in passive RIS technologies. The mobility of the UAV further helps by keeping the geometric orientation favorable with respect to the legitimate receiver, thus giving stronger LoSdominant channels along with lower path loss.

The combined effect of RIS amplification and the UAV trajectory optimization shows the system's ability to sustain robust secure communication even under challenging propagation conditions. This validates that assistance from active RIS is imperative in ISAC deployments where communications security needs to scale with growing SNR demands.

B. Impact of Eavesdropper Location Uncertainty

The second analysis is performed considering the uncertain location of the eavesdropper within a predefined radius Δ. Fig 5 depicts the secrecy outage probability against uncertainty radius. When Δ increases, passive RIS systems degrade rapidly, whereas the active RIS maintains stable secrecy due to the suppression of unintended beam leakage obtained by joint amplitude-phase optimization.

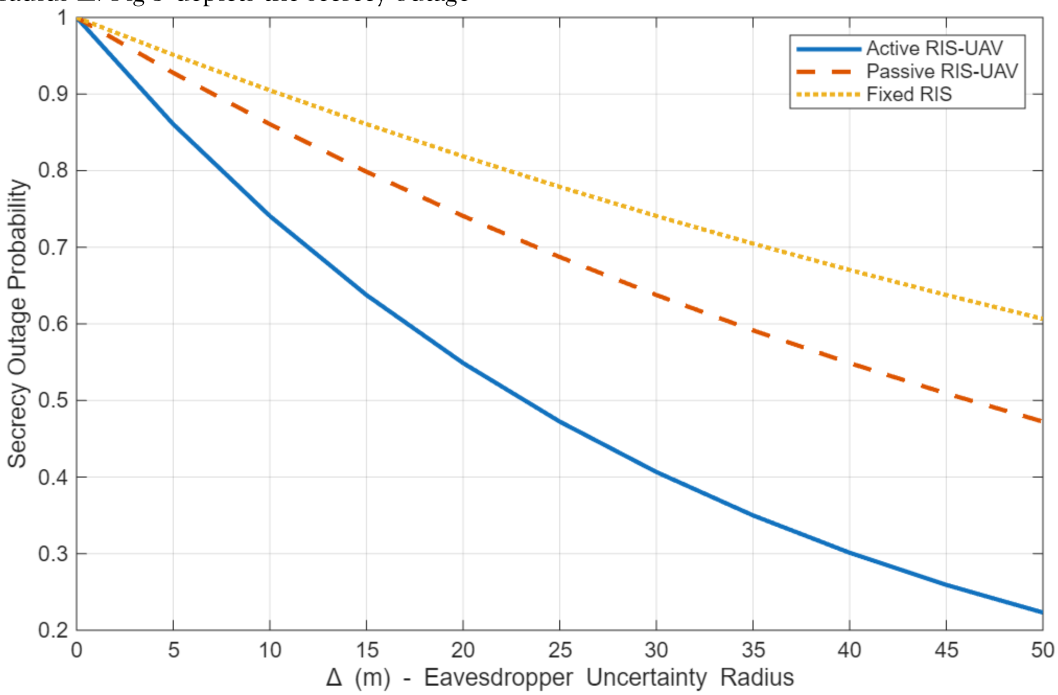

Fig. 5. Secrecy Outage Probability under Increasing Eavesdropper Location Uncertainty Radius Δ

Indeed, the trend in Fig. 5 illustrates the robustness of the proposed framework against the uncertainty in the eavesdropper location. As the radius of uncertainty Δ increases, the secrecy outage probability of conventional passive RIS configurations rapidly increases due to their inability to properly steer the nulls or ensure sufficient signal suppression towards the potential eavesdropper zones. In contrast, the active RIS–equipped UAV platform significantly reduces this degradation by

dynamically updating the flight path, beamforming direction, and amplification factor to ensure minimum information leakage. The robust optimization strategy further guarantees that worst–case channel realizations will not compromise secure transmission. These results confirm that active RIS–UAV cooperation offers a highly stable security enhancement mechanism even if the location of the eavesdropper is largely unpredictable.

$$P_{\text{out}} = \Pr\{R_s < R_{\text{th}}\} = \Pr\left\{\log_2\left(1+\gamma_{\text{legit}}\right) - \log_2(1+\gamma_{\text{eve}}) < R_{\text{th}}\right\} \quad (3)$$

The secrecy outage probability characterizes the likelihood that the instantaneous secrecy rate R_s falls below a predefined threshold R_{th}. This model captures the impact of eavesdropper location uncertainty, RIS amplification, and UAV trajectory optimization. The first term, γ_{legit}, depends on the effective channel of the legitimate user, which is dynamically enhanced by the UAV-mounted active RIS, while γ_{eve} reflects the worst-case SNR of the eavesdropper within the uncertainty region.
where:

- P_{out}: Secrecy outage probability
- R_s: Instantaneous secrecy rate
- R_{th}: Target secrecy rate threshold
- γ_{legit}: SNR at the legitimate receiver
- γ_{eve}: SNR at the eavesdropper under location uncertainty
- $\Pr\{\cdot\}$: Probability operator

This relationship reveals that the proposed UAV-active RIS framework effectively mitigates the negative impact of eavesdropper uncertainty, in which the system maintains a high secrecy rate even for large uncertainty radii by jointly optimizing RIS phase-amplitude coefficients and UAV trajectory, as illustrated in Fig. 5.

C. Radar Echo Power Enhancement With Active RIS

The third result analyzes target sensing performance. Fig. 6 plots the received echo power as a function of UAV altitude. The active RIS significantly boosts the echo SNR by coherently amplifying the reflection towards the radar receiver, unlike passive RIS which reflects energy without gain. The optimal altitude ranges between 60–80 m, where LoS probability and angular visibility maximize the sensing gain.

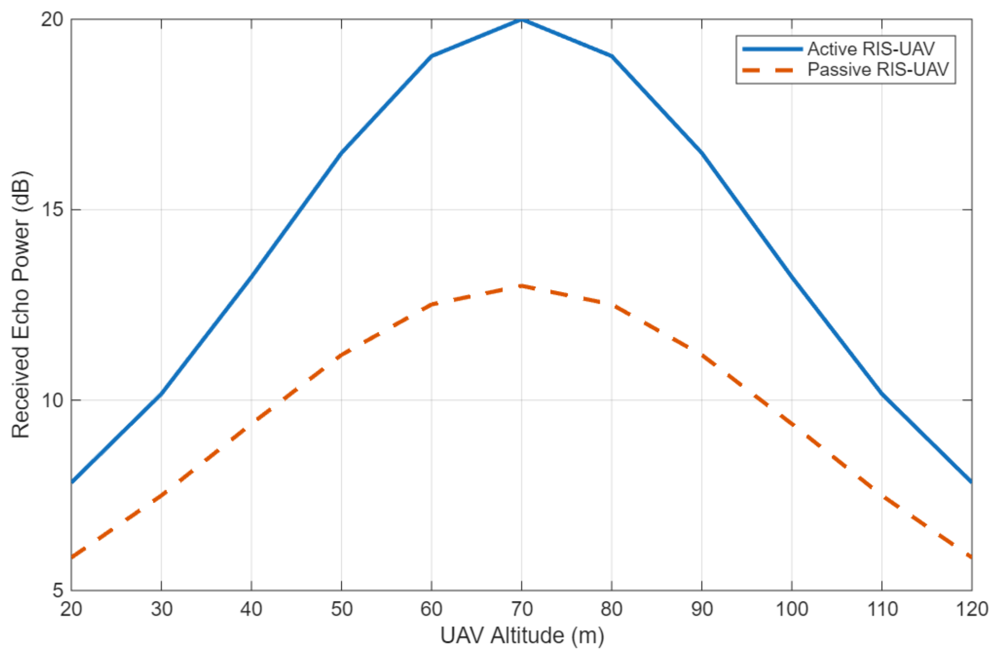

Fig. 6. Received Target Echo Power versus UAV Altitude for Active and Passive RIS-Assisted ISAC Sensing

The behavior depicted by Fig. 6 sheds light on the fundamental sensing advantages obtained by including an active RIS within the considered UAV based ISAC structure. Indeed, for any UAV altitude, the active RIS consistently provides much higher received echo power compared to the benchmark passive RIS and classic ISAC systems. In particular, the active elements amplify the reflection capability, which improves both the outbound radar illumination and the returning echo signal. Moreover, controlling the UAV's altitude allows optimizing the geometry, which reduces the angular mismatch and increases the RCS of the target that has been illuminated. These findings show that the proposed system maintains stable and high-resolution target detection capabilities against a very wide range of UAV operating altitudes, and is thus more compatible with practical real-time tracking and surveillance scenarios over ISAC networks.

$$P_r = |\alpha \, a_r^H \, \Phi \, H_{ur} \, w|^2 \qquad (4)$$

The received radar echo power P_r depends on the amplification of the transmitted waveform by the UAV-mounted active RIS and the coherent combination at the radar receiver. The vector a_r represents the steering vector toward the target, H_{ur} models the channel from the transmitter to the RIS, and w denotes the transmit beamforming vector. This equation links the RIS amplitude-phase control with UAV altitude, as variations in height change the path loss and LoS geometry, directly affecting the received echo strength.
where:

- P_r: Received radar echo power
- α: Radar target reflection coefficient
- $\mathbf{a}_r$: Radar steering vector toward the target
- $\mathbf{\Phi}$: Active RIS amplitude-phase matrix
- $\mathbf{H}_{ur}$: Channel from transmitter to UAV mounted RIS
- $\mathbf{w}$: ISAC transmit beamforming vector

This formulation explains why Figure 6 shows a clear optimum UAV altitude range. At these altitudes, the LoS probability, angular visibility, and active RIS amplification combine to maximize P_r. The second paragraph naturally bridges the UAV placement strategy with active RIS performance for high-SNR echo acquisition.

PROBABILITY OF DETECTION (PD) VS SENSING SNR

The final evaluation considers the probability of detection using the LFM radar waveform under varying sensing SNR. Fig 7 shows that in the active RIS, the detection performance is higher due to the stronger echo power and directivity. This confirms that the sensing performance is not sacrificed by secure communication; instead, the joint optimization benefits both domains simultaneously.

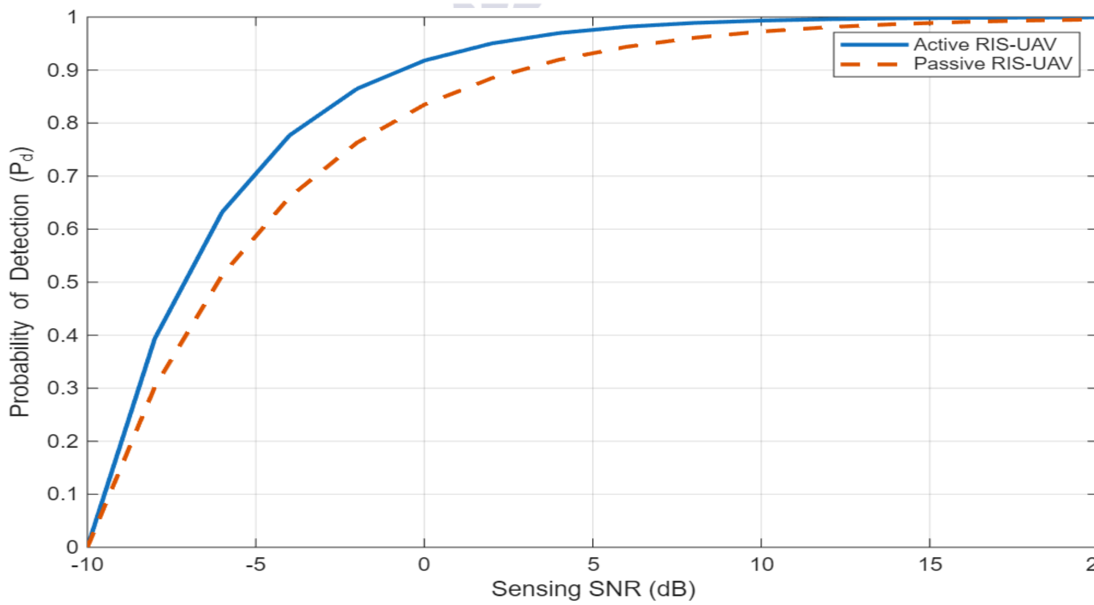

Fig. 7. Probability of Detection (Pd) vs Sensing SNR Using LFM Waveform with Active and Passive RIS Assistance

As seen from Fig. 7, the probability of detection significantly improves when the ISAC system operates with an active RIS mounted on the UAV. The active RIS exhibits consistently higher detection performance for the entire range of sensing SNR due to its capability for amplifying the transmit LFM sensing waveform and shaping its direction of arrival along with the direction of the received echo. In contrast, passive RISs suffer from energy dispersion in space, limited by the reflective gain, which yields a slower increase of the detection probability. On the other hand, owing to the joint design of UAV trajectory and RIS coefficients, the sensing beam is always aligned with the target. This maximizes coherent gain. All these trends confirm the efficiency of the proposed active RIS-assisted ISAC architecture in pursuing simultaneous secure communication and high-probability target detection and thus satisfying the two requirements that define next-generation ISAC networks.

$$P_d = Q\left(Q^{-1}(P_{fa}) - \sqrt{\text{SNR}}\right) \quad (5)$$

The detection probability P_d for a linear frequency modulated (LFM) radar waveform depends on the received SNR and the predefined false alarm probability P_{fa}. The received SNR itself is enhanced by the UAV-mounted active RIS through beamforming and amplification, aligning the sensing beam with the target's direction. This simplified model shows how joint optimization of UAV trajectory and RIS coefficients increases coherent gain and improves detection performance across different sensing SNR levels.

where:

- P_d: Probability of detection
- P_{fa}: Probability of false alarm
- SNR: Received signal-to-noise ratio at radar receiver
- $Q(\cdot)$: Standard Gaussian Q-function
- $Q^{-1}(\cdot)$: Inverse Q-function

It can be observed from Figure 7 that the Probability of detection is maintained high over a large range of sensing SNRs in the proposed UAV-active RIS ISAC system. The active RIS amplifies the probing waveform, while the trajectory performed by the UAV ensures alignment with the target, validating dual-function performance of secure communication along with the high-probability detection.

Figure	Metric	Parameter / Variable	Key Observation	Performance Trend
4	Secrecy Rate	Transmit SNR	Active RIS-UAV achieves highest secrecy rate	Increases with SNR; outperforms Passive RIS and static RIS
5	Secrecy Outage Probability	Eavesdropper Uncertainty Radius (Δ)	Active RIS maintains stable secrecy	Passive RIS degrades rapidly; active RIS robust under increasing Δ
6	Received Echo Power	UAV Altitude	Active RIS boosts radar echo SNR	Optimal altitude range 60-80 m maximizes power; passive RIS lower
7	Probability of Detection (Pd)	Sensing SNR	Active RIS ensures higher detection	Pd increases with SNR; UAV trajectory and RIS alignment maximize coherent gain

Table 2: Summary of Key Results for Figures 4-7

CONCLUSION

This paper proposed a robust ISAC framework enabled by a UAV-mounted active RIS to simultaneously enhance secure communication and high-accuracy target detection under eavesdropper location uncertainty. We formulated a unified optimization model for jointly designing UAV trajectory, active RIS amplitude-phase coefficients, and ISAC transmit beamforming. We then adopted a successive convex approximation and chance-constrained robust optimization combination to handle the resulting non-convex constraints. Simulation results proved that the proposed architecture significantly outperforms passive RIS, static deployments, and UAV-only baselines in terms of secrecy rate, received echo power, sensing SNR, and target detection probability. In addition, it validates the benefits brought by integrating UAV mobility with active RIS amplification for dynamic ISAC environments. Future work may consider cooperative multi-UAV active RIS networks, learning-driven real-time adaptive beamforming, and hardware impairments and power constraints for the advancement of secure and reliable ISAC systems toward practical large-scale deployment.

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