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Secure Rate Maximization for ISAC-UAV Assisted Communication Amidst Multiple Eavesdroppers

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***Abstract*—Unmanned aerial vehicles (UAVs) equipped with integrated sensing and communication (ISAC) technology have been employed in the field of communication. In this paper, we propose an ISAC-UAV assisted secure communication system amidst multiple eavesdroppers. In each time slot, we implement ISAC and communication functions. Since there are multiple eavesdroppers in the system, jammer UAV is required to send jamming signals to the eavesdroppers. During the ISAC process, the source UAV identifies multiple eavesdroppers, relaying their position information to a jammer UAV. During the communication process, multiple eavesdroppers attempt to intercept the communication link between source UAV and users. We use the center of all users as the horizontal location of the jammer UAV. To maximize the secure data transmit rate, we propose a joint optimization problem involving user scheduling, transmit power, and source UAV trajectory. We break down the non-convex optimization problem into three subproblems, and then achieve the suboptimal solution to the original problem through iteratively optimizing these subproblems. Simulation results indicate that the proposed solution can achieve significant secure transmit rate even in the presence of multiple eavesdroppers.**

***Index Terms*—UAV, secure rate, ISAC, resource optimization, multiple eavesdroppers.**

I. Introduction

With the development of wireless communication devices with sensing capabilities, the competition for spectrum resources between radar and wireless communication is highlighted, emphasizing the need for efficient spectrum management solutions [1]. The integrated sensing and communication (ISAC) technology is proposed as a way to address spectrum scarcity issues effectively [2]. Recently, unmanned aerial vehicles (UAVs) are increasingly utilized in communication systems due to their cost-effectiveness and mobility [3]. Integrating ISAC devices onto UAVs not only conserves spectrum resources but also enables simultaneous sensing and communication services to ground users [4]. In [5], Liu *et al.* tried to maximize the energy efficiency of UAV-ISAC system under the condition of sensing fairness by jointly optimizing user scheduling, transmit power, and UAV trajectory. In [6], Zhao *et al.* used ISAC to estimate the channel states of UAV-assisted communications.

Nonetheless, the UAV-ISAC will introduce new security challenge due to the open and line of sight (LoS) UAV-to-ground channels, resulting in that the UAV communications can be easily intercepted by ground eavesdroppers [7], [8]. In [9], Chu *et al.* aimed to reduce the highest eavesdropping signal-to-noise ratio (SNR) for multiple authorized users in an ISAC system, while simultaneously ensuring the quality of service (QoS) for legitimate users. And the transmit beaforming is designed to meet the radar detection performance under the transmit power constraints for both the radar and communication. In [10], Wu *et al.* proposed a real-time optimization problem to design the trajectory of a secure ISAC enabled UAV, and devised an efficient iterative algorithm to achive a near-optimal solution. However, the secure ISAC transmission in [9] does not leverage the high mobility of the UAV. While the physical layer security in [10] focuses solely on a single eavesdropper. Consequently, issues pertaining to the physical layer security of UAV-ISAC systems with multiple eavesdroppers become particularly crucial.

In this paper, we propose an ISAC-UAV-assisted secure communication system from the perspective of physical layer security. The source UAV detects the eavesdroppers, relays their positions information to the jammer UAV, and then simultaneously communicates with the ground users. To imporve communication security, we introduce a jammer UAV to interfere with the eavesdroppers by sending beamformed jamming signals. To maximize the secure system rate, we formulate a joint optimization problem of user scheduling, transmit power, and source UAV trajectory. We decompose the original optimization problem into three subproblems, each of which can be solved by successive convex approximation (SCA) and relaxation techniques, and then propose an alternating iterative optimization algorithm of these subproblems to obtain the solution of the original problem.

II. System Model

A. System Model

In Fig. 1, we consider an ISAC-UAV assisted secure communication system constituting of K users and M eavesdroppers. In this system, the source UAV performs ISAC to

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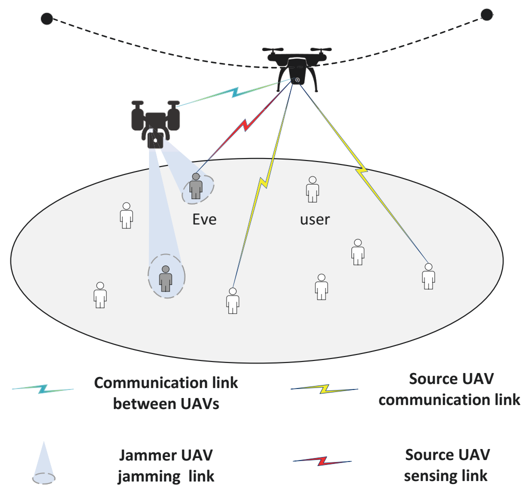

Fig. 1. ISAC-UAV assisted secure communication system.

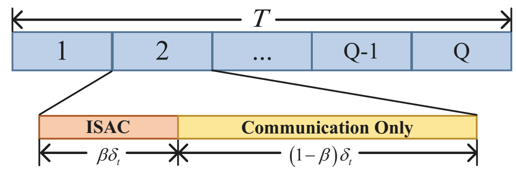

Fig. 2. Time slot division.

both jammer UAV and eavesdroppers, and then communicates with the ground users. The horizontal coordinate of user $k \in \mathcal{K} = \{1, 2, ...K\}$ are denoted as $g_k = [x_k, y_k]^T$. It is assumed that the jammer UAV remains stationary, and the source UAV moves at a fixed altitude H. We divide the flight time T into Q equal time slots with the legnth of $\delta_t = \frac{T}{Q}$. These time slots are sufficiently short to allow us to consider the UAV's motion parameters as constants. In Fig. 2, each time slot is further divided into two sub-time slots by an allocation factor β. In the first sub-slot, by the ISAC dual-function signal, the source UAV can sense the eavesdroppers and send the sensed information to the jammer UAV. In the second sub-time slot, the source UAV communicates with users, while the jammer UAV sends jamming signals to the eavesdroppers. We assume that the horizontal coordinate of eavesdropper $m \in \mathcal{M} = \{1, 2, ...M\}$, expressed as $g_m = [x_m, y_m]^T$, can be obtained by the ISAC. In order to cause enough interference to every eavesdropper, the horizontal coordinate of the jammer UAV, expressed as $g_j = [x_j, y_j]^T$, is set as the center of all the eavesdroppers.

The horizontal flight position of the source UAV in time slot $q \in \mathcal{Q} = \{1, 2, ...Q\}$ can be expressed as $u(q) = [x(q), y(q)]^T$. The kinematics trajectory constraints for source UAV can be stated as follows

$$u(1) = u_I, u(Q) = u_F \tag{1}$$

$$\|u(q+1) - u(q)\| \le D, n = 1, 2...Q-1 \tag{2}$$

$$\|u(q) - g_j\| \ge d_{\min}, q = 1, 2...Q-1 \tag{3}$$

where u_I and u_F represent the starting and ending positions of the source UAV, respectively, $D = v_{\max}\delta_t$ is the maximum horizontal displacement of UAV in one time slot, $v_{\max}$ is the largest horizontal UAV speed, and $d_{\min}$ is the anti-collision distance between source UAV and jammer UAV.

Considering the UAV-to-ground channel as LoS, the channel power gain of the communication link from source UAV to user k at time slot q can be expressed as

$$h_k^c(q) = \frac{G_t G_c \lambda^2}{(4\pi)^2 d_k^2(q)} = \frac{\rho_{com}}{d_k^2(q)} \tag{4}$$

where G_t and G_c are the antenna gains of source UAV transmitter and user receiver, respectively, $d_k(q)$ is the distance from source UAV to user k, λ is the wavelength, and $\rho_{\text{com}} = \frac{G_t G_c \lambda^2}{(4\pi)^2}$. Similarly, the channel power gain of the communication link from source UAV to jammer UAV can be givn by

$$h_j^c(q) = \frac{\rho_{com}}{d_{s,j}^2(q)} \tag{5}$$

where $d_{s,j}(q)$ is the distance from source UAV to jammer UAV.

The channel power gain of the radar sensing link from source UAV to eavesdropper m at time slot q can be expressed as

$$h_{s,m}^r(q) = \frac{G_t G_r \lambda^2 \sigma}{(4\pi)^3 d_{s,m}^4(q)} = \frac{\rho_{rad}}{d_{s,m}^4(q)} \tag{6}$$

where G_r is the antenna gain of UAV radar receiver, σ denotes target radar cross-section (RCS), $d_{s,m}(q)$ is the distance from source UAV to eavesdropper m, and $\rho_{rad} = \frac{G_t G_r \lambda^2 \sigma}{(4\pi)^3}$.

The jammer UAV is equipped with multiple sets of uniform linear arrays (ULA), each of which contains N_t transmit antennas. The jammer UAV transmits jamming signal to each eavesdropper by one set of ULA. The angle of arrival (AoA) for each ULA can be calculated as

$$\theta_m = \arcsin \frac{H}{\sqrt{(x_j - x_m)^2 + (y_j - y_m)^2 + H^2}} \tag{7}$$

The steering vector of the mth set of ULA can be expressed as $\boldsymbol{a_m} = \left[1, e^{-j\frac{2\pi}{\lambda}d\sin(\theta_m)}, ..., e^{-j\frac{2\pi}{\lambda}d(N_t-1)\sin(\theta_m)}\right]^T, \forall m$, where d is the distance between antennas. Thus, the channel power gain from the jammer UAV to the mth eavesdropper can be expressed as

$$H_{j,m}^c(q) = \boldsymbol{a_m}^T h_{j,m}^c(q) \tag{8}$$

where $h_{j,m}^c(q) = \frac{\rho_{com}}{d_{j,m}^2(q)}$, and $d_{j,m}$ is the distance from jammer UAV to eavesdropper m.

We introduce binary variables $w_k(q)$ to represent the user scheduling. When $w_k(q) = 1$, the source UAV communicates with user k, otherwise, $w_k(q) = 0$. To guarantee that the UAV serves at most one user per time slot, we can get the constraint

$$w_k(q) \in \{0, 1\}, \forall q, k \tag{9}$$

$$\sum_{k=1}^{K} w_k(q) \le 1 \tag{10}$$

The communication SNR from source UAV to user k and jammer UAV can be expressed as $\Gamma_k^c(q) = \frac{p_s(q)h_k^c(q)}{N_0}$ and $\Gamma_j^c(q) = \frac{p_s(q)h_j^c(q)}{N_0}$, respectively, where N_0 is the power of noise and $p_s(q)$ is the transmit power of source UAV. The sensing SNR from source UAV to eavesdropper m can be expressed as $\Gamma_{s,m}^r(q) = \frac{p_s(q)h_{s,m}^r(q)}{N_0}$. The eavesdropping SNR can be given by $\Gamma_m^c(q) = \frac{p_s(q)h_{s,m}^c(q)}{N_0+H_{j,m}^c(q)\boldsymbol{P_j}}$, where $h_{s,m}^c(q) = \frac{\rho_{com}}{d_{s,m}^2(q)}$, and $\boldsymbol{P_j}$ is the jamming UAV's transmit power vector of $N_t \times 1$.

To ganatanee the sensing performance for all the eavesdroppers, the sensing SNRs need to satisfy $\Gamma_{s,m}^r(q) \ge \Gamma_{th}^r, \forall m, q$, where Γ_{th}^r represents the minimum SNR for accurate radar detection. The radar estimation rate of source UAV to m eavesdropper at time slot q can be expressed as

$$R_m^{rad}(q) = \beta \log_2\left(1 + \Gamma_{s,m}^r(q)\right) \tag{11}$$

Thus, the sum of radar estimation rate can be expressed as

$$R^{rad}(q) = \sum_{m=1}^{M} R_m^{rad}(q) \tag{12}$$

The communication rate of source UAV to jammer UAV at time slot q can be expressed as

$$R_j^{com}(q) = \beta \log_2\left(1 + \Gamma_j^c(q)\right) \tag{13}$$

In order to send all the sensing information to the jammer UAV, the communication rate needs to be no less than the sum radar estimation rate. It can be expressed as

$$R_j^{com}(q) \ge R^{rad}(q) \tag{14}$$

The communication rate of UAV to user k at time slot q can be expressed as

$$R_k^{com}(q) = (1-\beta)\log_2(1 + \Gamma_k^c(q)) \tag{15}$$

The achievable rate obtained by the eavesdropper m is

$$R_m^{com}(q) = (1-\beta)\log_2(1 + \Gamma_m^c(q)) \tag{16}$$

The secure rate for each time slot is

$$R_{\sec}(q) = \sum_{k=1}^{K} w_k(q) R_k^{com}(q) - \sum_{m=1}^{M} R_m^{com}(q) \tag{17}$$

Thus, the sum secure rate is expressed as

$$R_{\sec} = \sum_{q=1}^{Q} R_{\sec}(q) \tag{18}$$

B. Problem Formulation

To maximize the secure rate of ISAC-UAV assisted communication system, we jointly optimize user scheduling **W**=$\{w_k(q), \forall q, k\}$, transmit power **P**=$\{p_s(q), \forall q\}$, and UAV trajectory **U**=$\{u(q), \forall q\}$. The optimization problem can be formulated as follows

$$\max_{\mathbf{W,P,U}} R_{\sec} \tag{19a}$$
$$\text{s.t.} \quad w_k(q) \in \{0,1\}, \forall q, k \tag{19b}$$
$$\sum_{k=1}^{K} w_k(q) \le 1, \forall q \tag{19c}$$
$$\Gamma_{s,m}^r(q) \ge \Gamma_{th}^r, \forall m, q \tag{19d}$$
$$R_j^{com}(q) \ge R^{rad}(q) \tag{19e}$$
$$0 \le p_s(q) \le p_{\max}, \forall q \tag{19f}$$
$$\|u(q+1) - u(q)\| \le D, q = 1, 2...Q-1 \tag{19g}$$
$$u(1) = u_I, u(Q) = u_F \tag{19h}$$
$$\|u(q) - g_j\| \ge d_{\min}, q = 1, 2...Q-1 \tag{19i}$$

where $p_{\max}$ is the maximum transmit power of source UAV.

Solving problem (19) directly poses challenges due to the binary integer constraint of (19c) and the non-convex constraints of (19a) and (19e).

III. Proposed Solution

To solve problem (19), we decompose the original optimization problem into three separate subproblems: user scheduling optimization, transmit power optimization, and UAV trajectory optimization. We can obtain the solution to the original problem by alternatly optimizing the three subproblems.

A. User Scheduling Optimization

The binary constraint (19c) is transformed into $0 \le w_k(q) \le 1$. Therefore, for the given trajectory **U** and power **P**, we can rewrite the user scheduling subproblem as follows

$$\max_{\mathbf{W}} R_{\sec} \tag{20a}$$
$$\text{s.t.} \quad 0 \le w_k(q) \le 1, \forall q, k \tag{20b}$$
$$\sum_{k=1}^{K} w_k(q) \le 1, \forall q \tag{20c}$$

which is a standard linear problem (LP) that can be solved using MATLAB's CVX solver.

B. Transmit Power Optimization

With given scheduling **W** and UAV trajectory **U**, the power optimization subproblem can be reformulated as

$$\max_{\mathbf{P}} R_{\sec} \tag{21a}$$
$$\text{s.t.} \quad \Gamma_{s,m}^r(q) \ge \Gamma_{th}^r, \forall m, q \tag{21b}$$
$$R_j^{com}(q) \ge R^{rad}(q) \tag{21c}$$
$$0 \le p_s(q) \le p_{\max}, \forall q \tag{21d}$$

where (21a) and (21c) are non-convex constraints. To handle this, we can obtain the upper bound for $R_m^{com}(q)$ as follows

$$R_m^{com}(q) = (1-\beta)\log_2\left(1 + \frac{p_s(q)h_{s,m}^c(q)}{N_0+H_{j,m}^c(q)\boldsymbol{P_j}}\right) \le \bar{R}_m^{com}(q) = (1-\beta)\left(\log_2\left(1 + \frac{p_s^i(q)h_{s,m}^c(q)}{N_0+H_{j,m}^c(q)\boldsymbol{P_j}}\right) + A(q)\left(p_s(q) - p_s^i(q)\right)\right) \tag{22}$$

where $A(q) = \frac{h_{s,m}^{c}(q)\log_2 e}{\left(H_{j,m}^{c}(q)\boldsymbol{P_j}+N_0+p_s^i(q)h_{s,m}^{c}(q)\right)}$ and $p_s^i(q)$ is the value of $p_s(q)$ in the i-th iteration.

Similarly, the upper bound for $R_m^{rad}(q)$ is given as follows

$$\begin{gathered} R_m^{rad}(q) = \beta\log_2\left(1+\frac{p_s(q)h_{s,m}^{r}(q)}{N_0}\right) \le \bar{R}_m^{rad}(q) = \\ \beta\left(\log_2\left(1+\frac{p_s^i(q)h_{s,m}^{r}(q)}{N_0}\right) + E(q)\left(p_s(q)-p_s^i(q)\right)\right) \end{gathered} \tag{23}$$

where $E(q) = h_{s,m}^{r}(q)\log_2 e/\left(N_0+p_s(q)h_{s,m}^{r}(q)\right)$.

Therefore, the subproblem (21) can be formulated as

$$\max_{\mathbf{P}} \sum_{q=1}^{Q}\left(\sum_{k=1}^{K} w_k(q)R_k^{com}(q) - \sum_{m=1}^{M}\bar{R}_m^{com}(q)\right) \tag{24a}$$

$$\text{s.t.} \quad \Gamma_{s,m}^{r}(q) \ge \Gamma_{th}^{r}, \forall m,q \tag{24b}$$

$$R_j^{com}(q) \ge \sum_{m=1}^{M}\bar{R}_m^{rad}(q) \tag{24c}$$

$$0 \le p_s(q) \le p_{\max}, \forall q \tag{24d}$$

which can be efficiently solved using the CVX solver .

C. UAV Trajectory Optimization

With given scheduling $\mathbf{W}$ and transmit power $\mathbf{P}$, the subproblem for optimizing UAV trajectory can be formulated as

$$\max_{\mathbf{U}} R_{\sec} \tag{25a}$$

$$\text{s.t.} \quad \Gamma_{s,m}^{r}(q) \ge \Gamma_{th}^{r}, \forall m,q \tag{25b}$$

$$R_j^{com}(q) \ge R^{rad}(q) \tag{25c}$$

$$\|u(q+1)-u(q)\| \le D, q=1,2...Q-1 \tag{25d}$$

$$u(1)=u_I, u(Q)=u_F \tag{25e}$$

$$\|u(q)-g_j\| \ge d_{\min}, q=1,2...Q-1 \tag{25f}$$

Due to the non-convexity of (25a), (25c) and(25f), solving problem (25) is challenging.We employ SCA and relaxation technique to convert (25) into a convex problem for resolution. The lower bounds of $R_k^{com}(q)$ and $R_j^{com}(q)$ can be given by

$$\begin{gathered} R_k^{com}(q) = (1-\beta)\log_2\left(1+\frac{\rho_{com}p_s(q)/N_0}{H^2+\|u(q)-g_k\|^2}\right) \ge \tilde{R}_k^{com}(q) \\ = (1-\beta)\left(C(q)-B(q)\left(\|u(q)-g_k\|^2-\left\|u^i(q)-g_k\right\|^2\right)\right) \end{gathered} \tag{26}$$

$$\begin{gathered} R_j^{com}(q) = \beta\log_2\left(1+\frac{\rho_{com}p_s(q)/N_0}{\|u(q)-g_j\|^2}\right) \ge \tilde{R}_j^{com}(q) \\ = \beta\left(G(q)-F(q)\left(\|u(q)-g_j\|^2-\left\|u^i(q)-g_j\right\|^2\right)\right) \end{gathered} \tag{27}$$

where $B(q) = \frac{\rho_{com}p_s(q)/N_0/\left(H^2+\left\|u^i(q)-g_k\right\|^2\right)}{\ln 2\left(H^2+\|u^i(q)-g_k\|^2+\frac{\rho_{com}p_s(q)}{N_0}\right)}$, $F(q) = \frac{\rho_{com}p_s(q)/N_0/\left\|u^i(q)-g_j\right\|^2}{\ln 2\left(\|u^i(q)-g_j\|^2+\frac{\rho_{com}p_s(q)}{N_0}\right)}$, $C(q) = \log_2\left(1+\frac{\rho_{com}p_s(q)/N_0}{H^2+\|u^i(q)-g_k\|^2}\right)$, $G(q) = \log_2\left(1+\frac{\rho_{com}p_s(q)/N_0}{\|u^i(q)-g_j\|^2}\right)$, and $u^i(q)$ represents the UAV trajectory in the i-th iteration. Therefore, the lower bound of the sum communication rate for all users at time slot q can be expressed as

$$\tilde{R}^{com}(q) = \sum_{k=1}^{K} w_k(q)\tilde{R}_k^{com}(q) \tag{28}$$

By introducing a slack variable $\chi = \chi_m(q), \forall m,q$, we can acquire the upper bounds of $R_m^{com}(q)$ and $R_m^{rad}(q)$ as

$$\begin{gathered} R_m^{com}(q) = (1-\beta)\log_2\left(1+\frac{\rho_{com}p_s(q)/\left(N_0+H_{j,m}^{c}(q)\boldsymbol{P_j}\right)}{H^2+\|u(q)-g_m\|^2}\right) \\ \le \tilde{R}_m^{com}(q) = (1-\beta)\log_2\left(1+\frac{\rho_{com}p_s(q)/\left(N_0+H_{j,m}^{c}(q)\boldsymbol{P_j}\right)}{H^2+\chi_m(q)}\right) \end{gathered} \tag{29}$$

$$R_m^{rad}(q) \le \tilde{R}_m^{rad}(q) = \beta\log_2\left(1+\frac{\rho_{rad}p_s(q)/N_0}{\left(H^2+\chi_m(q)\right)^2}\right) \tag{30}$$

$$\chi_m(q) \le \|u(q)-g_m\|^2, \forall m,q \tag{31}$$

Thus, the upper bound of the total eavesdropping rate can be expressed as

$$\tilde{R}_{eve}^{com}(q) = \sum_{m=1}^{M}\tilde{R}_m^{com}(q) \tag{32}$$

By applying the Taylor formula, we can obtain the lower bound of $\|u(q)-g_j\|^2$ as

$$\begin{gathered} \|u(q)-g_j\|^2 \ge \left\|u^i(q)-g_j\right\|^2 + \\ 2\left(u^i(q)-g_k\right)^T\left(u(q)-u^i(q)\right), \forall q \end{gathered} \tag{33}$$

where $u^i(q)$ is the value of $u(q)$ in the i-th iteration. Therefore, the subproblem for trajectory optimization can be reformulated as

$$\max_{\mathbf{U}} \sum_{q=1}^{Q}\left(\tilde{R}^{com}(q)-\tilde{R}_{eve}^{com}(q)\right) \tag{34a}$$

$$\text{s.t.} \quad \Gamma_{s,m}^{r}(q) \ge \Gamma_{th}^{r}, \forall m,q \tag{34b}$$

$$\tilde{R}_j^{com}(q) \ge \sum_{m=1}^{M}\tilde{R}_m^{rad}(q) \tag{34c}$$

$$\|u(q+1)-u(q)\| \le D, q=1,2...Q-1 \tag{34d}$$

$$u(1)=u_I, u(Q)=u_F \tag{34e}$$

$$\begin{gathered} \left\|u^i(q)-g_j\right\|^2 + 2\left(u^i(q)-g_k\right)^T\left(u(q)-u^i(q)\right) \\ \ge d_{\min}^2, \forall q \end{gathered} \tag{34f}$$

where (34a)-(34f) are all convex. The CVX solver can be employed to effectively solve this subproblem.

We introduce an alternating iterative optimization approach in Algorithm 1, where the suboptimal solution to the original problem can be achieved by iteratively optimizing the three subproblems until the convergence of the objective function is reached.

Algorithm 1 Alternating Iterative optimization.

1: initialize i=0, $\mathbf{U}^{[i]}$ and $\mathbf{P}^{[i]}$;
2: **repeat**
3: solve (20) with $\mathbf{U}^{[i]}$ and $\mathbf{P}^{[i]}$, and obtain $\mathbf{W}^{[i+1]}$;
4: solve (24) with $\mathbf{W}^{[i+1]}$ and $\mathbf{U}^{[i]}$, and obtain $\mathbf{P}^{[i+1]}$;
5: solve (34) with $\mathbf{W}^{[i+1]}$ and $\mathbf{P}^{[i+1]}$, and obtain $\mathbf{U}^{[i+1]}$;
6: $i = i+1$;
7: **until** the objective value converges within a specified threshold ε.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Number of ground users	K = 6
Number of eavesdroppers	M = 4
Total flight time of the UAV	T = 50 s
Height of each UAV	H=100m
Carrier frquencey	f_c = 28 GHz
The shortest distance between UAVs	$d_{\min}$ = 30 m
Maximum power of the source UAV	$p_{\max}$=1 W
Power of the jammer UAV	p_j=1 W
Noise power	N_0 = -130 dBm
RCS of the target	σ = 1 m^2
Sub-time slot division parameters	β=0.5
Maximum speed of each UAV	$v_{\max}$=40m/s
UAV transmitter antenna gain	G_t = 15 dBi
UAV radar receiver antenna gain	G_r = 10 dBi
User and jammer UAV receiver antenna gain	G_c = 0 dBi
Number of time slots	Q = 100
The minimum SNR for radar detection.	Γ^r_{th} = -10 dB
Convergence threshold	ε= 10^{-4}

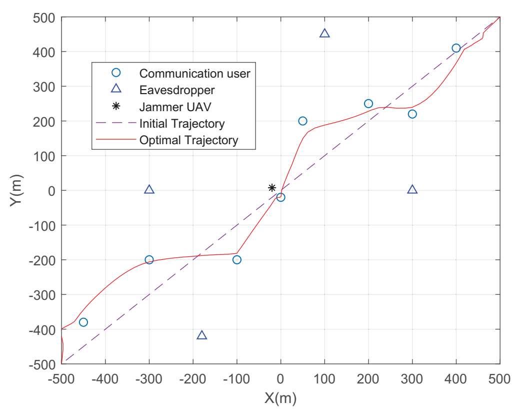

Fig. 3. Trajectory of source UAV .

IV. SIMULATION RESULTS

The simulation parameters are shown in Table 1. The jammer UAV is located at the center of the four eavesdroppers.

Figure 3 shows the optimized trajectory of the source UAV. It is seen that in order to achieve a higher secure rate, the source UAV endeavors to approach the communicating users as close as possible while keeping far distance from the eavesdroppers during its flight.

Figure 4 illustrates the flight speed of source UAV. It is evident that the optmized UAV speed decreases when approaching the served users and increases when leaving the served users, leading to more service time for users. Such a flight can enhance the communication rate with the ground users efficiently.

In Figure 5, we compare the secure rates of three flying schemes, including the proposed suboptimal solution scheme, the initial trajectory scheme, and the static UAV scheme. It is seen that as the number of iterations increases, the secure rates of the three schemes gradually rise until convergence, which verifies the effectiveness of the proposed optimization algorithm. Moreover, the secure rate of the proposed suboptimal scheme is higher than that of the initial trajectory scheme and the static UAV scheme.

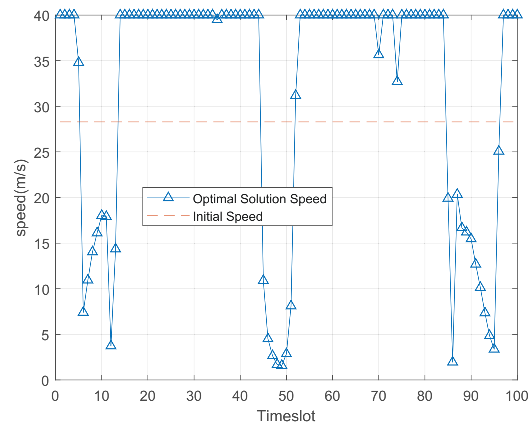

Fig. 4. Speed of source UAV.

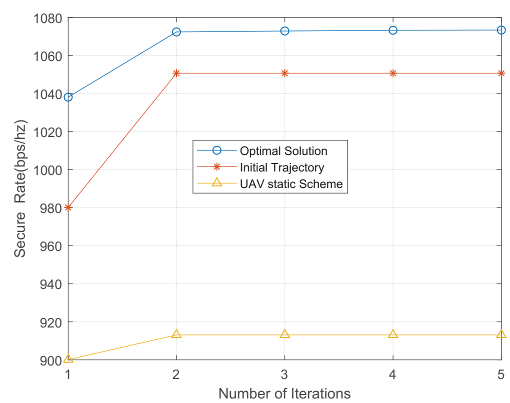

Fig. 5. Secure rate comparison of three UAV flying schemes.

In Figure 6, we compare the secure rates of six deployment schemes. Scheme 1 deploys one eavesdropper with a jammer UAV and one moving source UAV. Scheme 2 deploys four eavesdroppers with a jammer UAV and one moving source UAV. Scheme 3 deploys one eavesdropper with no jammer UAV and one moving source UAV. Scheme 4 deploys one eavesdropper with a jammer UAV and one static source UAV. Scheme 5 deploys four eavesdroppers with a jammer UAV and one static source UAV. Scheme 6 deploys one eavesdropper with no jammer UAV and one static source UAV. It is seen that the secure rate of the scheme with jammer UAV is significantly higher than that of the scheme without jammer UAV, and the security rate of the scheme with moving source UAV is significantly higher than that of the scheme with static source UAV. Moreover, the security rate decreases as the number of eavesdroppers increases.

V. CONCLUSIONS

In this paper, we propose an ISAC-UAV assisted secure communication system amidst multiple eavesdroppers. In this system, the source UAV uses ISAC to sense the eavesdroppers and send the sensed information to the jammer UAV. The jammer UAV emits the beamformed jamming signals to disrupt the eavesdroppers. To maximize the secure transmit rate of

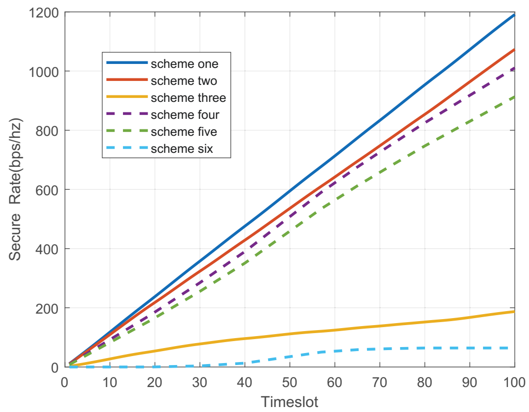

Fig. 6. Secure rate comparison with different schemes.

the system, we formulate a joint optimization problem of user scheduling, UAV transmit power, and source UAV trajectory. Simulation results demonstrate the significant secure performance improvement of the proposed scheme in the presence of multiple eavesdroppers.

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