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Secure energy efficiency maximization for dual-UAV-assisted intelligent reflecting surface system

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A R T I C L E I N F O

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A B S T R A C T

In this paper, we focus on minimizing energy consumption under the premise of ensuring the secure offloading of ground users. We used dual UAVs and intelligent reflective surfaces (IRS) to assist ground users in offloading tasks. Specifically, one UAV is responsible for collecting task data from ground users, and the other UAV is responsible for sending interference noise to counter potential eavesdroppers. The IRS can not only improve the transmission capacity of ground users, but also reduce the acceptance of eavesdroppers. The original problem is strong non-convex, so we consider using the block coordinate descent method. For the proposed sub-problems, we use Lagrangian duality and first-order Taylor expansion to obtain the results, and finally achieve system design through alternate optimization. The simulation results show that our proposed scheme is significantly better than other existing schemes.

1. Introduction

With the development of communication technology and the popularization of smart devices, the amount of data generated by user terminals has gradually increased [1,2]. Some real-time applications required by smart devices often require a lot of calculations, which poses new challenges to the computing capabilities and energy storage capabilities of smart terminal devices [3,4]. An important feature of this type of calculation task is the large amount of data in the calculation task, high latency requirements, and the amount of data in the calculation result is much smaller than the amount of data in the calculation task [5,6]. For such applications, mobile edge computing technology has attracted the attention of a broad range of academic and industrial circles [7].

Mobile edge technology can upload computing task data to the mobile edge computing server, and after the server completes the calculation, the result is returned [8,9]. The main advantage of MEC lies in the powerful computing capability of the MEC server and the fast data transmission capability of wireless communication, which makes the data transmission delay far greater than the delay caused by local computing. However, a major drawback of the mobile edge computing technology is that the deployment of MEC servers is expensive and the number of them is scarce. At this time, users who are far away from the MEC server are less efficient in using MEC [10].

UAV technology and intelligent reflective surface technology have been extensively studied as technologies to improve system performance. For UAVs, the advantages are twofold: (1) As there are fewer airborne obstructions, the air-to-ground channel can be approximately regarded as the line-of-sight channel dominated, so the channel gain is higher, which is convenient for signal transmission; (2) The flexibility of the UAV can complete different tasks in different time slots, thereby improving system performance [11].

In [12], the author considers to carry the MEC server on the drone, use the high mobility of the drone to serve users in the coverage area, and jointly optimize the UAV's trajectory and task allocation ratio. However, limited by the carrying power of the drone itself, it is unable to provide high-quality services. In [13], in order to solve the problem of insufficient energy supply for drones, the energy harvesting device is deployed in the drone, and the power is supplied by the transmission signal of the ground user, which alleviates the excessive power consumption of the drone problem. In [14], The introduction of multiple drones into the MEC system improves the performance of the system by jointly designing the trajectory of multiple UAVs [15].

On the other hand, as a passive device, the smart reflector can achieve potential gains in wireless communication and interference to eavesdroppers by adjusting the phase shift matrix [16]. It is worth noting that the smart reflector cannot change the signal transmission power, but can only provide designed multi-path transmission [17]. Therefore, the diagonal element modulus of the phase shift matrix is one, and the random phase shift matrix does not necessarily bring about the system Gain, and

Abbreviations: UAV, unmanned aerial vehicle; MEC, mobile edge computing; IRS, intelligent reflective surfaces; LoS, Line-of-Sight

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may bring negative effects. Therefore, it is necessary to jointly design the phase shift matrix on the premise that the channel state information is fully known [18].

In the wireless communication environment, the security of communication is also an indicator that cannot be ignored. Considering that eavesdroppers can obtain corresponding communication content through wireless communication signals in the same frequency band, adding redundant information to communication signals to counter potential eavesdroppers is a common technical means [19]. However, the addition of redundant information will increase the transmission burden of the communication system, and because the ground users usually cannot obtain the accurate location information of the eavesdropper, it increases the difficulty of the design [20]. The UAV can easily find the location of the eavesdropper through the wide-open view in the sky, and obtain the corresponding channel state information. In addition, the drone sends jamming signals to counter eavesdroppers with higher efficiency [21].

The use of dual drones and intelligent reflector technology in the same system has not yet been studied. In this article, we consider the use of dual drones and intelligent reflective surfaces to simultaneously assist the MEC system. Specifically, the two drones take on different roles: the first drone acts as the receiver and collects computing tasks from ground users in the coverage area; the second drone acts as the sender and sends interference signals. Fight against potential eavesdroppers. It is worth noting that the interference signal of the second UAV may also interfere with the communication link, but it can be avoided by adjusting the angle of the antenna. The intelligent reflecting surface can enhance the transmission signal from the ground user and the interference signal sent by the second UAV, while reducing the eavesdropping ability of the eavesdropper. The specific design requires a trade-off between the three. Our main contributions are summarized as follows:

1. For the first time, we proposed a dual UAV and intelligent reflective surface to assist MEC services. Our goal is to minimize system energy consumption while ensuring a safe rate.

2. We established the original optimization problem by jointly designing the transmission power and task allocation ratio of ground users, the flight trajectory and transmission power of the UAV, and the phase shift matrix of IRS. The original problem is highly non-convex due to the coupling of optimization variables. We propose an alternate optimization strategy based on the block coordinate descent method.

3. The simulation results show that the proposed scheme has better performance than the traditional scheme. In the case of high task bit count and high security rate requirements, it still maintains low energy consumption.

The structure of this paper is as follows: In the second section, we propose the system model and suggest the original optimization problem; in the third section, we decompose the original problem, propose 3 sub-problems and give the corresponding solutions; In the fourth section, we illustrate the performance of our proposed scheme in the form of simulation experiments; in the fifth section, we summarize the full text.

2. System model and problem formulation

We consider a dual UAV and IRS-assisted MEC system, where the first UAV receives mission data from the ground, and the second UAV sends jamming signals to counter potential eavesdroppers. The structure of the system is shown in Fig. 1. It is worth noting that the two drones are responsible for different tasks. The UAV on the left is only the receiver, and the UAV on the right is only the sender. This allocation mode not only improves the flexibility of UAV deployment, but also each drone

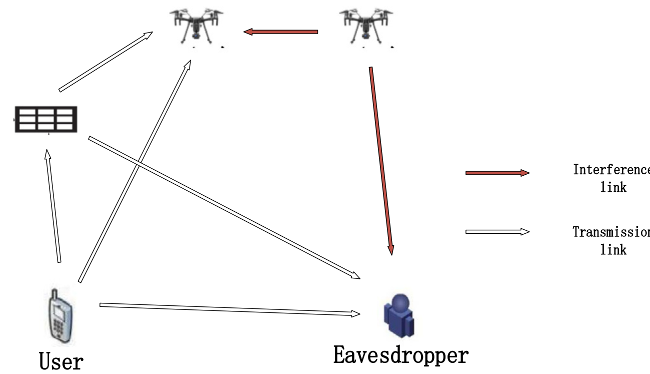

Fig. 1. UAV-assisted mobile edge computing system.

works in half-duplex mode to avoid self-interference. Our goal is to minimize the total energy consumption of the system while ensuring a minimum safe rate.

Specifically, we divide the total flight time of the drone into N time slots, each of which has a length of $\delta = T/N$, and assumes that within each time slot, the locations of the UAVs are approximately certain. We use a Cartesian three-dimensional coordinate system and assume that the flying height of the UAV is fixed. The coordinates of the UAVs at nth time slot are expressed as $\mathbf{q}_1[n] = [x_{q_1}[n], y_{q_1}[n], H_1]$ and $\mathbf{q}_2[n] = [x_{q_2}[n], y_{q_2}[n], H_2]$, respectively, in which H_1 and H_2 are the heights for the UAVs. The reason why we use different heights for the two UAVs is to prevent them from colliding. Further, we define the coordinates of the user and the eavesdropper as $\mathbf{q}_u = [x_u, y_u, 0]$ and $\mathbf{q}_e = [x_e, y_e, 0]$. We consider the trajectory constraints of the UAVs as follows:

$$\begin{aligned} \|\mathbf{q}_1[n+1]-\mathbf{q}[n]\|^2 \le l^2, n=1,\ldots,N-1 \\ \|\mathbf{q}_1[1]-\mathbf{q}_0\|^2 \le l^2 \\ \mathbf{q}_1[N]=\mathbf{q}_{1,F} \\ L = v_1 \times \frac{T}{N} \end{aligned} \tag{1}$$

$$\begin{aligned} \|\mathbf{q}_2[n+1]-\mathbf{q}_2[n]\|^2 \le D^2, n=1,\ldots,N-1 \\ \|\mathbf{q}_1[1]-\mathbf{q}_0\|^2 \le D^2 \\ \mathbf{q}_2[N]=\mathbf{q}_{2,F}, \\ D = v_2 \times \frac{T}{N} \end{aligned} \tag{2}$$

where v represent the maximum distance for the UAVs flying in each time slot.

As we discussed before, it is assumed that the channels between the UAV and the ground users and potential eavesdroppers are all LoS channels, and the acquisition of channel state information depends on the UAV's location estimation of the ground users and eavesdroppers.

$$h_{TD-UAV_1} = \frac{\rho_0}{\|\mathbf{q}_1[n]\|^2 + H_1^2} \tag{3}$$

Further, we obtain the channel between the ground user to the second UAV in ith time slot as

$$h_{TD-UAV_2} = \frac{\rho_0}{\|\mathbf{q}_2[n]\|^2 + H_2^2} \tag{4}$$

Similarly, the channel between the potential eavesdropper and the second UAV in ith time slot is expressed as:

$$h_{UAV_2-E} = \frac{\rho_0}{\|\mathbf{q}[n]-\mathbf{q}_E\|^2 + H_2^2} \tag{5}$$

On the other hand, due to the density of ground buildings and the complexity of the environment, the channel is usually assumed to be affected by multipath fading. In this article, in order to simplify the model, we assume that the terrestrial channel obeys the empirical model as follows:

$$g = \rho_0 d^{-\varphi}\varepsilon, \tag{6}$$

in which ε is a constant related to the environment, it determines the potential relationship between channel gain and distance.

We then define $P_{TD}[n]$ and P_{U_2} as the transmission power of the ground user and the second UAV, which should satisfy the following constrains:

$$\frac{1}{N}\sum_{n=1}^{N} P_{TD}[n] \le \overline{P_{TD}} \quad 0 \le P_{TD}[n] \le P_{TDMAX} \tag{7}$$

$$\frac{1}{N}\sum_{n=1}^{N} P_2[n] \le \overline{P_{U_2}} \quad 0 \le P_{U_2}[n] \le P_{U_2MAX} \tag{8}$$

In summary, we obtain the security rate in nth time slot as

$$R_{\text{sec}}[n] = R_{TD-u}[n] - R_{TD-g}[n] \tag{9}$$

with

$$\begin{aligned} R_{TD-U}[n] &= \log_2\left(1 + \frac{h_{TD-uav_1}P_{TD}[n]}{h_{TD-UAV_2}P_{u_2}[n] + \sigma^2}\right), \\ R_{TD-g}[n] &= \log_2\left(1 + \frac{gP_{TD}[n]}{h_{TD-E}P_{u_2}[n] + \sigma^2}\right), \end{aligned} \tag{10}$$

It is worth noting that we assume that the UAV and the ground user are cooperative, that is, the ground user knows the accurate information of the interference signal sent by the UAV, which causes the ground user to reduce the interference from the UAV through interference cancellation technology. In particular, the following equations are proposed:

$$SINR_{TD-UAV_1} = \frac{h_{TD-UAV_1}P_{TD}[n]}{h_{TD-UAV_2}P_{U_2}[n] + \sigma^2} \tag{11}$$

$$SINR_{TD-E} = \frac{gP_{TD}[n]}{h_{TD-E}P_{U_2}[n] + \sigma^2} \tag{12}$$

In order to minimize the total energy consumption of the system, we established the following original optimization problem:

$$\begin{aligned} \min_{\mathbf{P}_{TD},\mathbf{P}_{U_2},f,\mathbf{q}_1,\mathbf{q}_2} & \sum_{n=1}^{N-1} P_{TD}[n]\frac{T}{N} + \sum_{n=1}^{N-1} P_{U_2}[n]\frac{T}{N} \\ & + \sum_{i=2}^{N} \gamma_c f^3[i]\frac{T}{N} + \frac{1}{2}\sum_{n=1}^{N} m_1 v_1^2[n]\frac{T}{N} \\ & + \frac{1}{2}\sum_{n=1}^{N} m_2 v_2^2[n]\frac{T}{N} \\ s.t.\ & (1), (2), \\ & \sum_{j=2}^{N} f[j]\frac{T}{CN} \ge \sum_{i=1}^{N-1} R_{\text{sec}}[i]\frac{T}{N} \\ & \sum_{i=1}^{n-1} R_{\text{sec}}[i]\frac{T}{N} \ge \sum_{j=2}^{n} f[j]\frac{T}{CN}, n = 2, 3, \ldots, N \end{aligned} \tag{13}$$

It is worth noting that (13) is highly non-convex, since its optimization variables are all coupled. In order to solve (13), we consider using the block coordinate descent method to solve a certain parameter while fixing other parameters.

3. System energy consumption optimization design

The difficulty of the original problem comes from the high coupling of multiple random variables and the difficulty of decoupling. In this chapter, we consider using the block coordinate descent method to solve the original problem.

3.1. Frequency optimization with fixed UAV trajectory and power optimization

We first focus on the optimization of the transmission power. For any given $p_{TD}, p_{u_2}, \mathbf{q}_1, \mathbf{q}_2$, the problem is reformulated as

$$\begin{aligned} \min_{f[i]} & \sum_{i=2}^{N} \gamma_c [f[i]]^3 \frac{T}{N} \\ s.t.\ & (1), (2), \\ & \sum_{i=1}^{N-1} R_{\text{sec}}[i]\frac{T}{N} = \sum_{j=2}^{N} f[j]\frac{T}{CN} \end{aligned} \tag{14}$$

Note that (P2) is a convex optimization problem which can be tackled via the existing toolbox such as CVX. However, we would like to provide some insight about this problem by applying the Lagrange duality theory. To achieve it, we first reformulate the following dual problem:

$$\begin{aligned} L(f[i], \lambda_i, \nu) = & \sum_{i=2}^{N} \gamma_c [f[i]]^3 \frac{T}{N} + \sum_{a=1}^{N} \lambda_a \left(f[a+1]\frac{T}{CN} - R_{\text{sec}}[a]\frac{T}{N}\right) \\ & + \nu\left(\sum_{b=1}^{N-1} R_{\text{sec}}[b]\frac{T}{CN} - \sum_{b=2}^{N} f[b]\frac{T}{N}\right) \end{aligned} \tag{15}$$

By using KKT conditions, we obtain the minimization of $L(f[i], \lambda_a, \nu)$ as

$$\frac{\partial(L)}{\partial f[i]} = 3\gamma_c \sum_{i=2}^{N} f[i]^2 \frac{T}{N} + \sum_{a=1}^{N-1} \lambda_a \frac{T}{CN} - \nu\frac{T}{CN} \tag{16}$$

On the other hand, we apply $\frac{\partial(L)}{\partial \nu} = 0$, which results in

$$f[i] = \sqrt{\frac{1}{3}\frac{\frac{\nu T}{CN} - \sum_{a=1}^{N-1}\lambda_a}{\gamma_c(N-1)}} \tag{17}$$

Meanwhile, we obtain the $\theta_p(f[i])$ as

$$\theta_p(f[i]) = \max_{\lambda_a, \nu} L(f[i], \lambda_a, \nu) = +\infty \tag{18}$$

Further, the energy consumption of the first UAV is obtained as follows:

$$\theta_p(f[i]) = \begin{cases} \gamma_c(f[i])^3\frac{T}{N}, \text{when all constraints are fit} \\ +\infty, \text{others} \end{cases} \tag{19}$$

Finally, we obtain a semi-closed-form solution for (P2) as

$$\min \theta_p(f[i]) = \min_{f[i]} \max_{\lambda_a, \nu} L(f[i], \lambda_a, \nu) = \min_{f[i]} \gamma_c (f[i])^3 \frac{T}{N} \tag{20}$$

3.2. Power optimization with fixed frequency and UAV trajectory optimization

we consider the power consumption of TD first, which can be simplified to

$$\begin{aligned} \min_{P_{TD}} & \sum_{n=1}^{N-1} P_{TD}[n]\frac{T}{N}, \\ s.t.\ & (1), (2). \end{aligned} \tag{21}$$

$$R_{\sec}[n] = \log_2(1+\frac{h_{TD-uav_1}P_{TD}[n]}{h_{TD-UAV_2}P_{u_2}[n]+\sigma^2}) - \log_2(1+\frac{gP_{TD}[n]}{h_{TD-E}P_{u_2}[n]+\sigma^2}) \approx \frac{1}{\lg 2}\left(\frac{cst_1[n]}{1+cst_1[n]} - \frac{cst_2[n]}{1+cst_2[n]}\right)(P^* - P_k) \tag{22}$$

with $cst_1[n] = \frac{h_{\text{TD}-\text{UAV}_1}}{h_{\text{TD}-UAV_2}P_{U_2}[n]+\sigma^2}$ and $cst_2[n] = \frac{g}{h_{TD-E}P_{U_2}[n]+\sigma^2}$, where P^* is the fixed point.

then we consider the power consumption of UAV-2, which can be expressed as

$$\min_{p_{U_2}} \sum_{n=1}^{N-1} P_{U_2}[n]\frac{T}{N} \tag{23}$$
$$s.t.\ (1), (2).$$

Since the goal of the problem is convex, we pay attention to the non-convex term in the constraint and use convex approximation to solve it. we obtain the optimal solution for (P2) as

$$\begin{aligned} R_{\sec} = &-\frac{1}{\lg 2}(\frac{h_{TD-uav_1}P_{TD}[n]h_{TD-UAV_2}}{h_{TD-UAV_2}P_k+\sigma^2} \\ &\cdot \frac{1}{h_{TD-uav_1}P_{TD}[n]+h_{TD-UAV_2}P_k+\sigma^2} \\ &- \frac{gP_{TD}[n]b_2}{h_{TD-E}P_k+\sigma^2}\cdot\frac{1}{gP_{TD}[n]+h_{TD-E}P_k+\sigma^2}) \\ &\times (P^* - P_k) \end{aligned} \tag{24}$$

3.3. UAV trajectory optimization for fixed power allocation

We would like to obtain the optimal dual UAVs trajectory for fixed power allocation of ground user and dual UAVs. In specific, we solve the third subproblem of (P1) of optimizing the UAV trajectory. For any given p_{TD}, p_{u_2}, f, the problem is reduce to

$$\min_{\mathbf{P}_{TD},\mathbf{P}_{U_2},f} \frac{1}{2}\sum_{n=1}^{N} m_1 v_1^2[n]\frac{T}{N} + \frac{1}{2}\sum_{n=1}^{N} m_2 v_2^2[n]\frac{T}{N} \tag{25}$$
$$s.t.\ (1), (2).$$

We focus on the assumption when the second UAV fly in a given trajectory, which is expressed as:

$$\min_{\mathbf{P}_{TD},\mathbf{P}_{U_2},f} \frac{1}{2}\sum_{n=1}^{N} m_1 v_1^2[n]\frac{T}{N} \tag{26}$$
$$s.t.\ (1), (2).$$

When we paid attention to the flight trajectory design of the first UAV, we found that it could not get a closed solution. Therefore, we consider using the first-order Taylor expansion to approximate the original problem.

$$\min_{\mathbf{P}_{TD},\mathbf{P}_{U_2},f} \frac{1}{2}\sum_{n=1}^{N} m_1 v_1^2[n]\frac{T}{N} + \frac{1}{2}\sum_{n=1}^{N} m_2 v_2^2[n]\frac{T}{N} \tag{27}$$
$$s.t.\ (1), (2).$$

In an ideal situation, we assume that the interference to ground users from the interference signal sent by the second UAV is negligible, i.e.,

$$\log_2\left(1+\frac{h_{TD-UAV_1}P_{TD}[n]}{h_{TD-UAV_2}P_{U_2}[n]+\sigma^2}\right) \approx \log_2\left(1+\frac{h_{TD-UAV_1}P_{TD}[n]}{h_{TD-UAV_2}P_{U_2}[n]}\right) \tag{28}$$

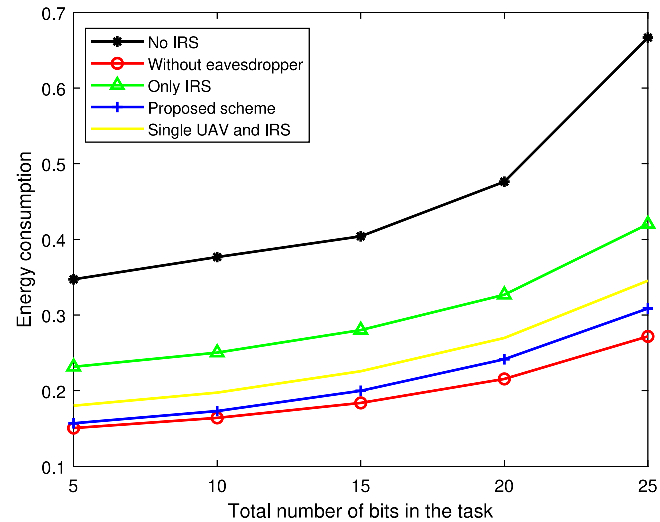

Fig. 2. Energy consumption versus the number of calculated bits.

$$\begin{aligned} R_{\sec}[n] = &\log_2(1+\frac{h_{TD-uav_1}P_{TD}[n]}{h_{TD-UAV_2}P_{u_2}[n]+\sigma^2}) \\ &- \log_2(1+\frac{gP_{TD}[n]}{h_{TD-E}P_{u_2}[n]+\sigma^2}) \\ \approx &\frac{1}{\lg 2}\left(\frac{cst_1[n]}{1+\text{cst}1[n]} - \frac{cst_2[n]}{1+cst_2[n]}\right)(P^* - P_k) \\ \approx &\frac{1}{\lg 2}\cdot\frac{2cst_5[n]\mathbf{q}_k}{cst_5[n]\cdot H_2^2+1+cst_5[n]|\mathbf{q}_{2k}|^2}\left|\mathbf{q}^* - \mathbf{q}_k\right| \end{aligned} \tag{29}$$

with $cst_5[n] = \frac{h_{TD-UAV_1}P_{TD}[n]}{P_0P_{U_2}[n]}$

Then we transform (28) and (29) as

$$\begin{aligned} \sum_{j=2}^{N} f[j]\frac{T}{CN} \geq &\sum_{i=1}^{N-1}\frac{1}{\lg 2}\cdot\frac{2cst5[n]\mathbf{q}_k}{cst5[n]\cdot H_2^2+1+cst5[n]|\mathbf{q}_{2k}|^2} \\ &\times \left|\mathbf{q}^* - \mathbf{q}_k\right|\frac{T}{N} \end{aligned} \tag{30}$$

$$\begin{aligned} &\sum_{i=1}^{n-1}\frac{1}{\lg 2}\cdot\frac{2cst5[n]\mathbf{q}_k}{cst5[n]\cdot H_2^2+1+cst5[n]|\mathbf{q}_{2k}|^2}\left|\mathbf{q}^* - \mathbf{q}_k\right|\frac{T}{N} \\ &\geq \sum_{j=2}^{n} f[j]\frac{T}{CN},\ n = 2, 3, \ldots, N \end{aligned} \tag{31}$$

It is worth noting that both (30) and (31) are convex, which results in that (P4) is a convex problem that can be solved via CVX.

4. Simulation results

In this section, we use simulation experiments to illustrate the performance of our proposed scheme. We assume that all channel state information is fully known. The air-to-ground channel is a line-of-sight link, and its channel gain is determined by the location of the UAV in the current time slot and the coordinates of the ground user. The terrestrial channel is randomly generated by the empirical Rayleigh fading channel model.

In Fig. 2, we considered (1) the solution proposed in this article; (2) the scheme using only dual UAVs; (3) the scheme using only the IRS; (4) the scheme without eavesdroppers; (5) The scheme with single UAV and IRS. We considered the relationship

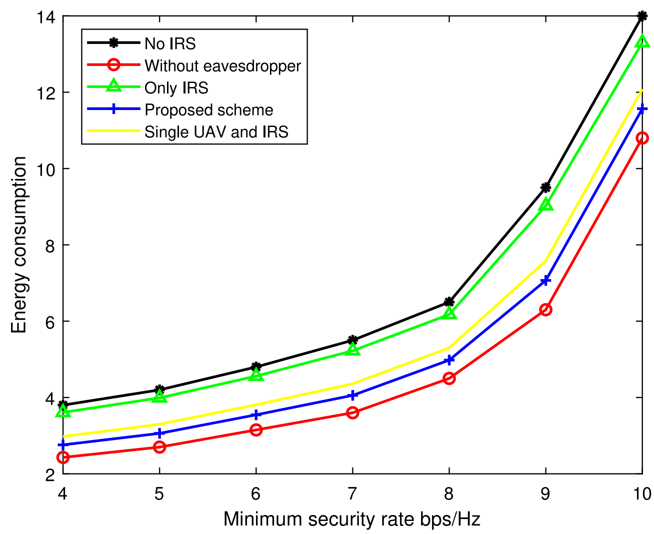

Fig. 3. Energy consumption versus the minimum secure rate.

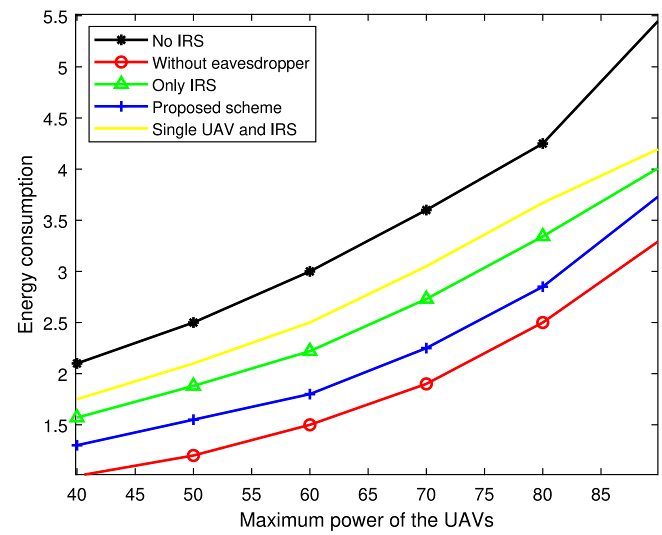

Fig. 4. Energy consumption versus maximum power of UAVs.

between the energy consumption of the system and the total number of bits in the task. It is worth noting that as the total number of bits in the task increases, the energy consumption will become faster and faster. This is because when the total number of mission bits increases, it will not only increase the computational energy consumption, but also force the UAV to send more interference signals to ensure the lowest safe rate. Therefore, the increase in the number of task bits puts a double burden on the energy consumption of the system. However, the proposed scheme can still maintain better performance when the total number of bits is high. This is because the intelligent reflector can reduce the eavesdropping ability of eavesdroppers by adjusting the phase shift matrix, and at the same time enhance the signal transmission rate, which greatly reduces Safety energy consumption.

In Fig. 3, we propose the relationship between the minimum safe rate and energy consumption. As the minimum safe rate increases, system energy consumption also increases. And the increase speed of the system energy consumption is greater than the increase speed of the minimum safe rate. This is because an increase in the minimum safe rate will lead to an increase in the transmission power of ground users and an increase in the power of the UAV interference signal.

We show the relationship between the total energy consumption and the maximum power of the UAVs in Fig. 4. When the maximum power of the drone is low, the total energy consumption of the system will be relatively high. This is because when the maximum power of the UAV is low, the proportion of the total power required to maintain the flight will increase greatly, so the power of sending interference signals will be weakened. At this time, in order to ensure the lowest safe rate, it is necessary for ground users to send more redundant information to improve safety. When the maximum power of the UAV is high, it can flexibly complete the flight mission and the jamming mission. When the maximum power of the UAV is greater than the given threshold, increasing the maximum power of the UAV will not reduce the energy consumption of the system. This is because the UAV has been able to complete the flight mission and isolate the eavesdropper's eavesdropping ability. The excess power will not be consumed.

In Fig. 5, we consider the curve of energy consumption with the number of IRS elements. When the number of IRS elements increases, energy consumption will decrease accordingly. It is

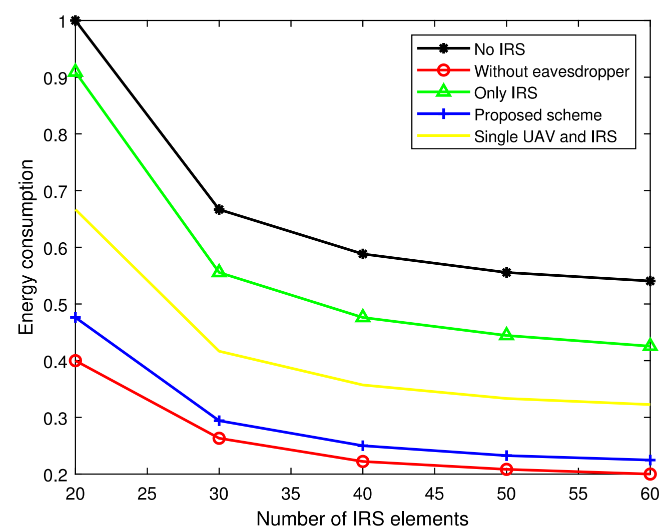

Fig. 5. Energy versus number of IRS elements.

worth noting that the downward trend will slow down and eventually tend to a stable result. This is because the IRS is a passive device and it cannot break through the maximum channel capacity characterized by Shannon's formula.

Finally, we show the results of energy consumption as a function of noise power in Fig. 6. It is worth noting that, for ease of representation, we set all background noises to the same magnitude. This means that when the noise power increases, it will not only reduce the transmission rate of the useful signal, but also cause some interference to the monitoring channel. Therefore, with the increase of noise power, our main power expenditure comes from the requirement to ensure the safe transmission rate itself, and the interference to eavesdroppers does not require additional power.

5. Conclusion

In this paper, we considered a mobile edge computing system assisted by dual UAVs and intelligent reflective surfaces. Specifically, our goal is to minimize the total energy consumption of the system. To this end, we jointly designed the transmission

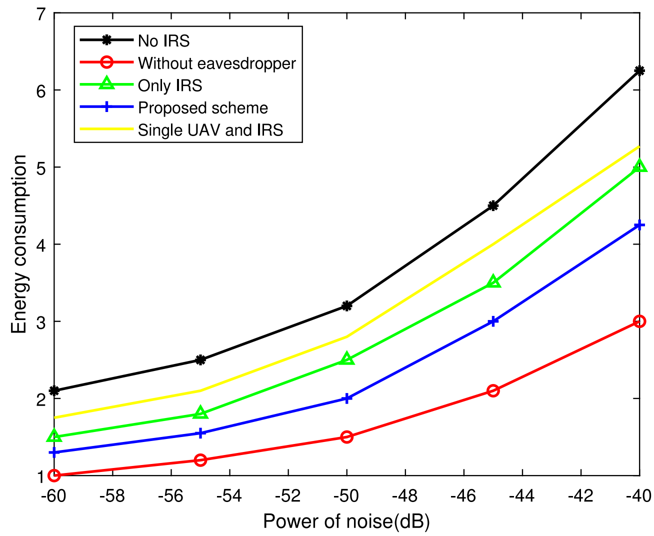

Fig. 6. Energy consumption versus power of noise.

power of the ground user, the transmission power of the UAV, and the phase shift matrix of the intelligent reflector. The original problem is highly non-convex and difficult to solve directly, because the considered optimization variables are highly coupled. We use the block coordinate descent method to divide the original problem into three sub-problems to solve, and theoretically prove the convergence of the algorithm. We conduct simulation experiments on the proposed algorithm and existing schemes. The simulation results show that the proposed scheme reduces energy consumption while ensuring the secure transmission of the system.

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CRediT authorship contribution statement

Hang Yang: Conceptualization, Writing, Software, Validation, Analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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