Throughput Maximization for the System of UAV as Mobile Relay Between Moving Vehicles

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Abstract. In recent years, due to the strong mobility and maneuverability of unmanned aerial vehicle (UAV), many scholars began to pay attention to the research of UAV as mobile relay auxiliary vehicle network. However, how to improve the throughput of the vehicle network which UAV as mobile relay is always an urgent problem. In this paper, we use the UAV as a mobile relay between two disconnected mobile vehicles to establish a new communication link to carry and forward traffic information. Firstly, we propose a throughput optimization model of UAV as inter-vehicle mobile relay under the limits of the propulsion power and the amount of data successfully transmitted by the UAV. Then, the objective function is proved to be convex, and the optimization model is solved by using Lagrange multiplier method with Karush-Kuhn-Tucker (KKT) condition. Finally, numerical simulation is carried out, we can see that the throughput of the information transmission system of the UAV as a mobile relay decreases with the increase of the amount of data required to be successfully transmitted, and it can be proved that the proposed optimization method is superior to other mobile relay methods under sufficient propulsion energy.

Keywords: UAV · Relay · Throughput

1 Introduction

UAVs have been widely used to assist the Internet of vehicles (IOV) in collecting real-time road traffic information, and have been proved to be effective in reducing the delay and loss of information [1,2]. With the addition of UAV, the

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communication connectivity between vehicles with disconnected or weak communication connection is enhanced, which can increase the stability of vehicle network. The traditional IOV is a network that vehicles collects and shares real-time information through wireless communication between vehicles and road side units (V2R), wired communication between road side units (R2R), single-hop and multi-hop communication between vehicles (V2V) in [3]. However, in some road networks, there may be insufficient RSU deployment and sparse vehicles on the road, disconnection of communication may occur during information transmission, and this will leads to delay and loss of information. The addition of UAV is equivalent to the addition of a new sensor node, which can act as a mobile relay when there is a lack of RSU or a long distance between vehicles on the road, assist vehicles to carry and forward road traffic information, and realize the sharing of information between vehicles.

Scholars have previously proposed the use of ferries in mobile ad-hoc networks to assist the information transfer between nodes, often referred to as data ferrying. Ferries collect information from the source node and forward it to the destination node, which improves the transmission performance and reduces energy consumption of the system in [4]. Then with the development of UAV technology, UAV as mobile relay is widely used in various mobile ad-hoc networks, and in order to improve the performance of the relay system has done a lot of research. UAV is used as mobile relay between two fixed sensors on the ground in literature [5,6], with different transmission modes, but both maximize the throughput of the system by optimizing UAV flight paths, UAV transmission power and source nodes transmission power. In addition, the authors in [7] use the UAV as a mobile relay between a fixed base station (BS) and multiple mobile users, and then maximizes the total data transmission rate of all users by optimizing the flight path of the UAV and the transmission power of the UAV to each mobile user. However, in the above research on UAV as mobile relay, the propulsion energy consumption of UAV was not considered in the optimization of UAV flight path. Regarding the energy consumption of UAV as a mobile relay, both calculation energy consumption and propulsion energy consumption are considered in literature [8]. UAV as the mobile relay between the fixed user on the ground and the moving edge computing access point (AP), under the bandwidth limitation, the trajectory movement limitation of the UAV and the limitation of computing tasks, so as to minimize the weighted energy consumption of the UAV and the user of completing the computing task. In fact, for UAV, the communication energy consumption is often ignored because it is far less than the propulsion energy consumption. In literature [9] and [10], the propulsion energy of UAV is also considered. Literature [9] is that when upward communication is carried out between UAV and multiple fixed nodes on the ground, the maximum energy efficiency of UAV can be obtained by optimizing the flight path of UAV. Then in literature [10], the UAV still acts as a mobile relay between two fixed nodes, but the UAV flies along the circular trajectory between two nodes, and maximizes the energy efficiency of the UAV by optimizing the radius of the circular trajectory, power distribution and the flight speed of UAV. However, we can find that the above literatures do not consider that the communication range of the source nodes is limited so that the nodes cannot communicate with each other, and do not consider the amount of successful data transmission required by the UAV in the relay process, after all, the purpose of UAV as relay is to ensure the transmission of information.

In this paper, we use the UAV as a mobile relay to establish new communication between two vehicles which cannot communicate because of the long distance, such application scenarios are rarely analyzed. Here, because the driving direction of the vehicle is fixed along the road, the flight direction of the UAV as a mobile relay auxiliary vehicle is also fixed, so there is no need to optimize the flight path of the UAV. In addition, in order to ensure sufficient information transmission time and efficient communication between vehicles and UAV, we use maximum power for both vehicles and UAV. What's more, we considered not only the limitation of the propulsion power of the UAV but also the amount of data that the UAV needs to successfully transmit as a relay. The main contributions in this paper are as follows:

Firstly, we propose a throughput optimization model of UAV as a mobile relay between moving vehicles, which consider the constraints of UAV propulsion energy, the limits of vehicle communication range and the amount of data needs to successfully transmit in the progress of UAV as a relay.

Secondly, the convexity of the objective function is proved, and the objective function is solved by Lagrange multiplier method with KKT condition.

Thirdly, according to the actual vehicle movement and UAV flight restrictions, we set reasonable parameters and conducted numerical simulation to verify the accuracy of our model. Compared with other methods of UAV as mobile relay, it is verified that the optimization method proposed by us is obviously superior to other methods.

The structure of this paper is as follows: Sect. 2 is the process of establishing the system model; Sect. 3 is the problem formulation and solution of the model; Sect. 4 is the result analysis of the simulation; Sect. 5 is the summary of the paper.

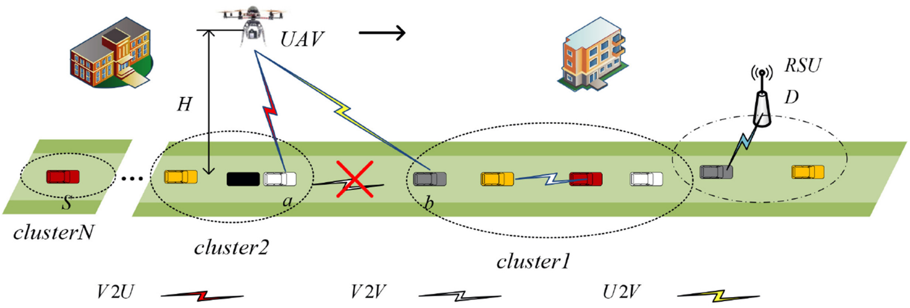

Fig. 1. UAV relay between moving vehicles on the road

2 System Model

As shown in Fig. 1, we consider a scenario where there is an RSU at one end of the road, single lane and the length of the road is L_{SD}, vehicles on the road need to send data packets to the RSU by means of carry and forward (packages contains information about the vehicle's speed, location, and destination, etc.). Here, we randomly divided the vehicles into clusters according to the communication range of the vehicles. The vehicles in the cluster can communicate through multiple hops, but vehicles between clusters, such as vehicle a in cluster 2 and vehicle b in cluster 1, cannot communicate because the distance between them is beyond the communication range of vehicles. Moreover, if the speed of vehicle a is always less than the speed of vehicle b, vehicle a cannot send its own package until it reaches the range of RSU, which may cause a huge delay. Therefore, we take advantage of the strong mobility of the UAV to make it act as a mobile relay between the cluster head vehicles of the clusters to establish a new information transmission link.

We take the disconnect between cluster 1 and cluster 2 as an example, and assume that vehicle a and vehicle b are the cluster head vehicles of cluster 2 and cluster 1 respectively. Here, we assume that the speed of vehicle a is V_a, the speed of vehicle b is V_b, $V_a \leq V_b$ and we assume that their speed will not change for the duration of the UAV as relay. The initial distance between vehicle a and vehicle b is set as L_{ab}, all vehicle has the same communication range and set as R_v, and $L_{ab} > 2R_v$. The UAV cruised above the road at the height of H, and as shown in the figure1, it forwarded the data of vehicle a to vehicle b. The vehicle's communication range is R_v, so when the distance between the UAV's projection point on the ground and vehicle a is $R_a = \sqrt{R_v^2 - H^2}$, vehicle a can communicate with the UAV. Once vehicle a can upload packets to the UAV, the three-dimensional coordinate system is established. At this time, the coordinates of UAV, vehicle a and vehicle b are set as $(0, 0, H)$, $(R_a, 0, 0)$ and $(L_{ab} + R_a, 0, 0)$ respectively. We assume that the UAV flies at a speed of V_U in the process of acting as a relay, there are two ways to collect data when UAV receives data uploaded by vehicle a, so there are two ways for UAV to act as mobile relay between vehicles.

2.1 Relay During Flying Forward

The UAV flies over the communication range of vehicle a at a speed of V_U, $V_a < V_U \leq V_{max}$. As soon as the UAV enters the communication range of vehicle a, vehicle a uploads data to the UAV. Therefore, the instantaneous transmission rate when vehicle a sends data to the UAV is:

$$R_a(t) = B_v \log_2(1 + \frac{P_v \cdot \gamma_0}{(H^2 + (R_a + V_a t - V_U t)^2)^{\frac{\alpha}{2}}}) \tag{1}$$

Here, B_v is the bandwidth of the vehicle a, P_v is the transmitting power of the vehicle a and we assume that the transmitting power of all vehicles are the same. $\alpha(\alpha \geq 2)$ is the path loss exponent and we set $\alpha = 2$ in this paper, γ_0 is the signal-to-noise ratio (SNR) when the reference distance is 1.

We assume that the UAV immediately forwards the data uploaded by vehicle a to vehicle b. Therefore, when the UAV forwards the packet to vehicle b, the instantaneous transmission rate can be expressed as:

$$R_U(t) = B_U \log_2(1 + \frac{P_{Umax} \cdot \gamma_0}{(H^2 + (L_{ab} + R_a + V_b t - V_U t)^2)^{\frac{\alpha}{2}}}) \tag{2}$$

Here, B_U is the bandwidth of the UAV, P_{Umax} is the maximum transmission power of the UAV to ensure that the UAV can maintain communication with vehicle b.

In addition, the upload time of data packet sent by vehicle a to UAV can be expressed as:

$$t_u = \frac{2 \cdot R_a}{V_U - V_a} \tag{3}$$

Therefore, the total amount of data uploaded by vehicle a during the upload time can be expressed as:

$$Q_a = \int_0^{t_u} R_a(t)dt \tag{4}$$

And in the process transmitting information by UAV, the amount of data required to be successfully forwarded is greater than Q. Then the total amount of data forwarded from the UAV to vehicle b can be expressed as: We all know that when the UAV flies in the air as a mobile relay, it needs to consume communication energy and propulsion energy to maintain the UAV's communication capability and flight status in the air. And the actual communication energy consumption is much less than the propulsion energy, so it is often ignored. According to literature [11], the energy consumption of maintaining the flight state of UAV in the air can be written as:

$$E_{fly} = t_u \cdot (c_1 V_U^3 + \frac{c_2}{V_U}) \tag{5}$$

Where c_1 and c_2 are two parameters related to the weight of the aircraft, air density, wing area, etc. What's more, the energy of the UAV is very limited, and some energy needs to be reserved for recall. Therefore, the UAV propulsion energy in the relay process required to keep the UAV in the air must not be greater than E_{max}.

2.2 Relay When Relative Hovering

The UAV flies directly above vehicle a at maximum speed, and then receives data uploaded by vehicle a at the same speed as vehicle a, that is $V_U = V_a$. In fact, at this time, vehicle a and the UAV remain relatively stationary. Assume that the time that the UAV stays in relative hover is t_h, then the total amount of data transmitted from vehicle a to UAV can be expressed as:

$$Q_{ah} = t_h \cdot B_v \log_2(1 + \frac{P_v \cdot \gamma_0}{H^\alpha}) \tag{6}$$

When the UAV reaches the top of vehicle a, the distance between vehicle a and vehicle b increases to $L = L_{ab} + \frac{(V_b - V_a)\cdot R_a}{V_{max} - V_a}$. Then, when the UAV forwards data to vehicle b, the instantaneous transmission rate can be expressed as:

$$R_{Uh}(t) = B_U \log_2(1 + \frac{P_{Umax} \cdot \gamma_0}{(H^2 + (V_U t - L - V_b t)^2)^{\frac{\alpha}{2}}}) \tag{7}$$

And the data forwarded by the UAV to vehicle b can be expressed as:

$$Q_{Uh} = \int_0^{t_h} R_{Uh}(t)dt \geq Q \tag{8}$$

The propulsion energy consumption of UAV in the relay process can be expressed as:

$$E_{fh} = t_h \cdot (c_1 V_U^3 + \frac{c_2}{V_U}) \leq E_{max} \tag{9}$$

3 Problem Formulation and Analysis

The purpose of the UAV as a relay is to forward the traffic information of vehicle a in cluster 2 to vehicle b in cluster 1 in this paper, so as to establish communication between random clusters of vehicles on the road. In this paper, our goal is to maximize the throughput of the UAV as a mobile relay system by optimizing the speed of the UAV while meeting the data requirements for successful transmission of the UAV and the constraints of propulsion energy. Therefore, the objective function can be expressed as follows:

$$\max_{V_U} \quad \frac{Q_{U_{total}}}{t} \tag{10a}$$

$$s.t. \quad V_a \leq V_U \leq V_{max} \tag{10b}$$

$$E_f = t \cdot (c_1 V_U^3 + \frac{c_2}{V_U}) \leq E_{max} \tag{10c}$$

$$Q \leq Q_{U_{total}} \leq Q_{a_{total}} \tag{10d}$$

Where $t = t_u \cdot I_{(V_U > V_a)} + t_h \cdot I_{(V_U = V_a)}$, $Q_{U_{total}} = Q_U \cdot I_{(V_U > V_a)} + Q_{Uh} \cdot I_{(V_U = V_a)}$ and $Q_{a_{total}} = Q_a \cdot I_{(V_U > V_a)} + Q_{ah}(t) \cdot I_{(V_U = V_a)}$. $I_{condition}$ is an indicator function, which is 1 when the condition is true, or 0 otherwise. And because the data forwarded by the UAV to vehicle b must be not greater than the data uploaded by vehicle a, so here we set $Q_{U_{total}} \leq Q_{a_{total}}$.

The above problems can be divided into the following two sub-problems to solve. For the problem of the UAV acting as a relay during relative hover:

$t_h \leq \frac{E_{max}}{c_1 V_U^3 + \frac{c_2}{V_U}}$, and Q_{Uh} is a monotonically decreasing function of t_h, therefore $Q \leq Q_{Uh} \leq \int_0^{\frac{E_{max}}{c_1 V_U^3 + \frac{c_2}{V_U}}} R_{Uh}(t)dt$.

We define the system throughput of UAV maintaining relative hover is:

$$T_h = \frac{Q_{Uh}}{t_h} \tag{11}$$

Theorem 1. *T_h is monotonically decreasing function of t_h.*

Proof.

$$\frac{\mathrm{d}T_{Uh}}{\mathrm{d}t_h} = \frac{t_h R_{Uh}(t_h) - Q_{Uh}}{t_h^2} \tag{12}$$

Where $Q_{Uh} = \frac{B_U}{(V_b - V_a)} \cdot \{s_2 \log_2(1 + \frac{P_{Umax}\gamma_0}{H^2 + s_2^2}) - s_1 \log_2(1 + \frac{P_{Umax}\gamma_0}{H^2 + s_1^2}) + \frac{2}{\ln 2} \cdot [\frac{(H^2 + P_{Umax}\gamma_0)^{\frac{3}{2}}}{H^2 + P_{Umax}\gamma_0 + s_1 \cdot s_2} \arctan(\frac{s_2 - s_1}{\sqrt{H^2 + P_{Umax}\gamma_0}}) - \frac{H^3}{H^2 + s_1 \cdot s_2} \arctan(\frac{s_2 - s_1}{H})]\} > 0$, $s_2 = -L$ and $s_1 = (V_a - V_b)t_h - L$. And $R_{Uh}(t_h) = B_U \log_2(1 + \frac{P_{Umax}\gamma_0}{H^2 + s_1^2})$, so we can get that $R_{Uh}(t_h) - Q_{Uh} \leq 0$, T_h is monotonically decreasing function of t_h. When $Q_{Uh} = \int_0^{t_h} R_{Uh}(t)dt = Q$ and $t_h \leq \frac{E_{max}}{c_1 V_U^3 + \frac{c_2}{V_U}}$ is satisfied, the throughput T_h reaches the maximum value.

And the problem of the UAV acting as a relay only when flying forward can be rephrased as:

$$\max_{V_U} \quad \frac{Q_U}{t_u} \tag{13a}$$

$$s.t. \quad V_a < V_U \leq V_{max} \tag{13b}$$

$$Q \leq Q_U \leq Q_a \tag{13c}$$

$$E_{fly} \leq E_{max} \tag{13d}$$

Theorem 2. *The function 13(a) is convex.*

Proof. Let $f_0(V_U) = \frac{Q_U}{t_u}$, and we can calculate that $Q_U = \frac{A}{(V_U - V_b)\ln 2}$. Here, $A = \{Z_1 \ln(1 + \frac{P_{Umax} \cdot \gamma_0}{H^2 + Z_1^2}) - Z_2 \ln(1 + \frac{P_{Umax} \cdot \gamma_0}{H^2 + Z_2^2}) + \frac{2(H^2 + P_{Umax}\gamma_0)^{\frac{3}{2}} \arctan(\frac{Z_1 - Z_2}{\sqrt{H^2 + P_{Umax}\gamma_0}})}{H^2 + P_{Umax}\gamma_0 + Z_1 \cdot Z_2} - \frac{2H^3 \arctan(\frac{Z_1 - Z_2}{H})}{H^2 + Z_1 \cdot Z_2}\}$, $Z_1 = L + R_a$, $Z_2 = L + R_a + \frac{2R_a \cdot (V_b - V_U)}{V_U - V_a}$. The first derivative of Q_U can be obtained as follows:

$$Q_U^{'} = \frac{-A}{(V_U - V_b)^2 \ln 2} + \frac{2R_a(V_b - V_a)\ln(1 + \frac{P_{Umax}\gamma_0}{H^2 + (Z_2)^2})}{(V_U - V_b)(V_U - V_a)^2 \ln 2} \tag{14}$$

And the second derivative of Q_U is:

$$\begin{aligned} Q_U^{''} = &\frac{2A}{(V_U - V_b)^3 \ln 2} - \frac{4R_a(V_b - V_a)\ln(1 + \frac{P_{Umax}\gamma_0}{H^2 + (z_2)^2})}{(V_U - V_b)(V_U - V_a)^3 \ln 2} \\ &+ \frac{8P_U\gamma_0 Z_2 R_a^2 (V_b - V_a)^2}{(V_U - V_a)^4 (V_U - V_b)(H^2 + Z_2^2)(H^2 + P_U\gamma_0 + Z_2^2)} \end{aligned} \tag{15}$$

Then, the first derivative of $f(V_U)$ can be obtained as follows:

$$f_0^{'}(V_U) = \frac{Q_U}{2R_a} + \frac{(V_U - V_a)Q_U^{'}}{2R_a} \tag{16}$$

The second derivative of $f(V_U)$ is:

$$f_0^{''}(V_U) = \frac{Q_U^{'}}{R_a} + \frac{(V_U - V_a)Q_U^{''}}{2R_a} \geq 0 \tag{17}$$

According to the convex function theorem, we prove that the problem 13(a) is a convex function.

For the constraint 13(b), here are two affine functions with respect to V_U. For constraint 13(c), Q_U is a function that decreases monotonically as the V_U increases, if we want satisfy $Q_U \geq Q$, the speed of the UAV should be less than or equal to a certain speed value, and here we set as V_Q. And for constraint 13(d), when $V_a < V_U \leq V_{max}$, E_{fly} is a function that decreases monotonically as the V_U increases. So when satisfy $E_{fly} \leq E_{max}$, the speed of the UAV as a relay should be greater than a certain speed, and here we set as V_{fly}. From the above discussion, we can find that the feasible region of solution exists only when $V_{fly} \leq V_Q$. However, if $V_{fly} > V_Q$, it indicates that the flight energy of the UAV is insufficient. At this time, the UAV maintains the same speed of vehicle a collects and forwards information directly above vehicle a, that is, the UAV remains in relative hover as a relay.

We construct the Lagrangian function as follows:

$$\begin{aligned}\ell(V_U, \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5) = f(V_U) + \lambda_1(Q_U - Q_a) + \lambda_2(Q - Q_U) \\ + \lambda_3(V_a - V_U) + \lambda_4(V_U - V_{max}) + \lambda_5(E_{fly} - E_{max})\end{aligned} \tag{18}$$

Suppose $(V_U^*, \lambda_1^*, \lambda_2^*, \lambda_3^*, \lambda_4^*, \lambda_5^*)$ is the set of optimal solutions with a maximum value of $f(V_U)$, that satisfies the KKT condition:

$$\frac{\partial \ell}{\partial V_U}|_{V_U = V_U^*} = 0 \tag{19a}$$

$$f_1(V_U^*) = (Q_U - Q_a) \leq 0 \tag{19b}$$

$$f_2(V_U^*) = (Q - Q_U) \leq 0 \tag{19c}$$

$$f_3(V_U^*) = (V_a - V_U^*) \leq 0 \tag{19d}$$

$$f_4(V_U^*) = (V_U^* - V_{max}) \leq 0 \tag{19e}$$

$$f_5(V_U^*) = (E_{fly} - E_{max}) \leq 0 \tag{19f}$$

$$\lambda_i^* \geq 0, i = 1 \sim 5 \tag{19g}$$

$$\lambda_i^* \cdot f_i(V_U^*) = 0, i = 1 \sim 5 \tag{19h}$$

19(a) is a necessary condition for obtaining feasible solution by Lagrange multiplier method, 19(b)–19(f) are the initial constraints, 19(g) is the condition that the inequality Lagrange multiplier has to satisfy, and 19(h) is the relaxed complementary constraint. Under the constraints in 19(a)–19(f) above, the maximum throughput value that satisfies the constraints can be calculated.

4 Simulation

In this section, we verify the effectiveness of our optimization algorithm by numerical experiments. We assume that the UAV altitude is $H = 100\,\text{m}$, the vehicle's communication radius $R_v = 150\,\text{m}$, therefore, $R_a = \sqrt{150^2 - 100^2} = 50\sqrt{5}\,\text{m}$. And we assume that the maximum speed of the UAV is $V_{max} = 50\,\text{m/s}$, the bandwidth $B_v = B_U = 500\,\text{Khz}$, and when the reference distance is 1, the SNR $\gamma_0 = 80\,\text{dB}$. The transmission power of the vehicle is $P_v = 3\,\text{dBm}$, and the maximum transmission power of the UAV is $P_{Umax} = 20\,\text{dBm}$ to ensure that the UAV can always communicate with vehicle b in the relay process.

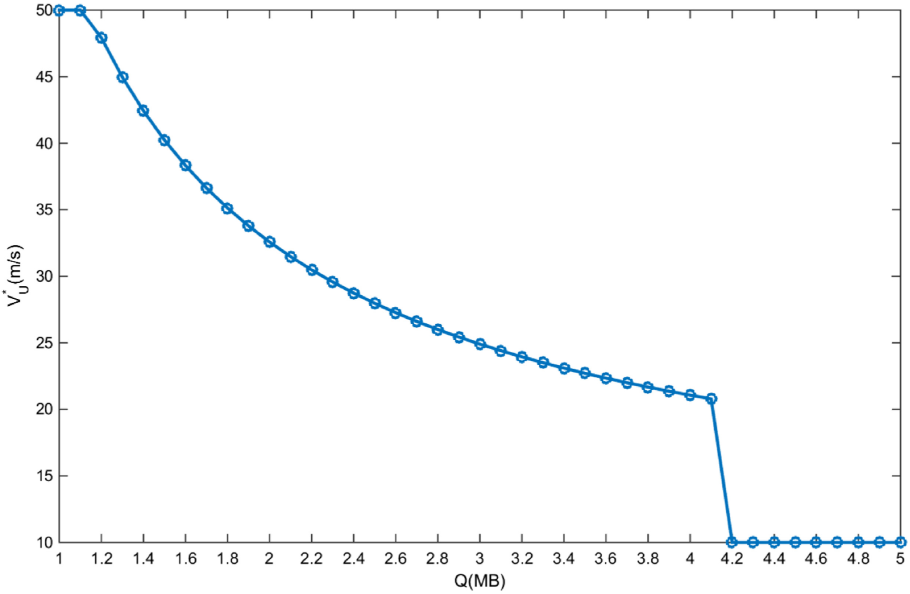

Fig. 2. Optimal flight speed V_U^* versus Q with $E_{max} = 2500\,\text{J}$, $V_a = 10\,\text{m/s}$ and $V_b = 15\,\text{m/s}$.

The optimal speed V_U^* of UAV changes with the limit of uploaded data Q can be seen in Fig. 2, and here we set $V_a = 10\,\text{m/s}$, $V_b = 15\,\text{m/s}$, $L_{ab} = 1000\,\text{m}$ and $E_{max} = 2500\,\text{J}$. As shown in Fig. 2, when the amount of data successfully transferred $Q \leq 1.2\,\text{MB}$, the UAV can fly at maximum speed. However, when $Q > 1.2\,\text{MB}$, V_U^* decreases with the increase of Q. And when $Q > 4.1\,\text{MB}$, the velocity of V_U^* plummets to $10\,\text{m/s}$, this is due to insufficient propulsion energy.

Then, we simulated the influence of flight energy constraint on the optimal speed of UAV. Here, we set $V_a = 10\,\text{m/s}$, $V_b = 15\,\text{m/s}$, $L_{ab} = 1000\,\text{m}$ and $Q = 5\,\text{MB}$. See Fig. 3, when the UAV flight energy $E_{max} \leq 3500\,\text{J}$, the UAV and vehicle a remain in relative hover mode. But when $E_{max} > 3500\,\text{J}$, the UAV can fly at optimized speed. We can conclude that when UAV flight energy is

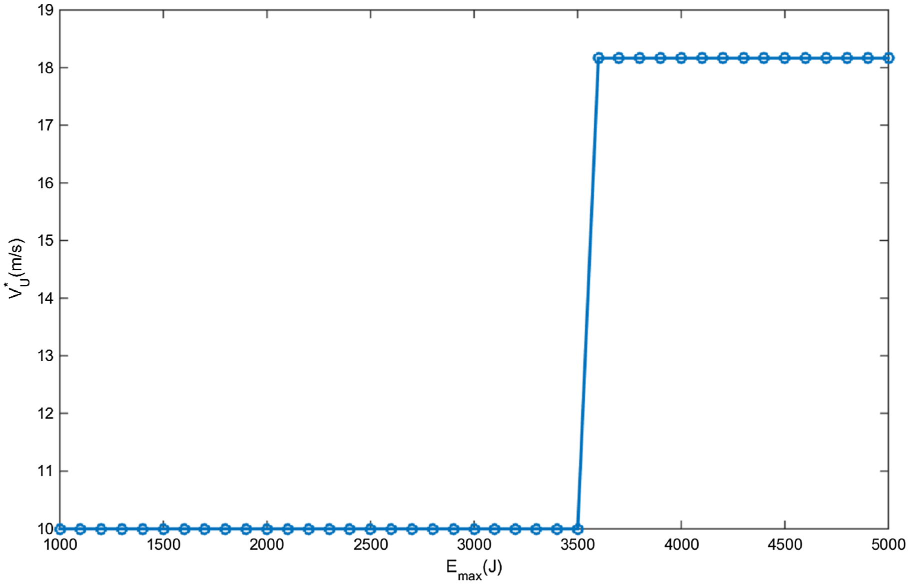

Fig. 3. Optimal flight speed V_U^* versus E_{max} with $Q = 5\,\text{MB}$, $V_a = 10\,\text{m/s}$ and $V_b = 15\,\text{m/s}$.

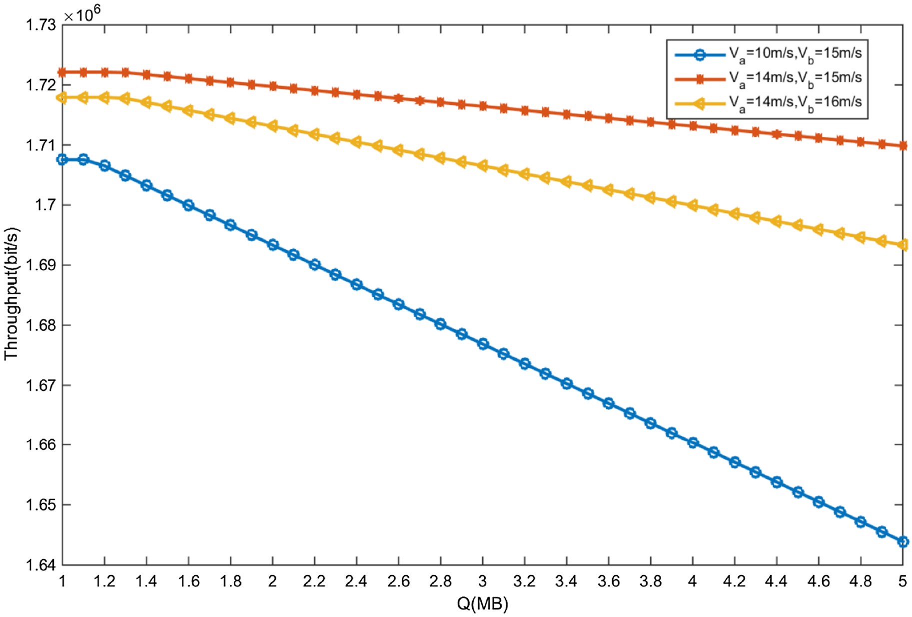

Fig. 4. Throughput of the system versus Q with random V_a and V_b.

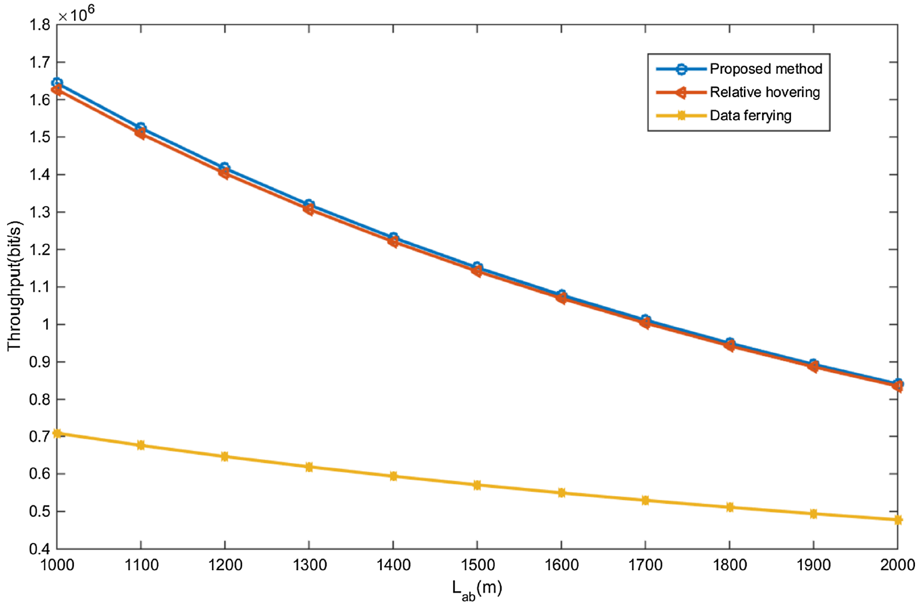

Fig. 5. Performance comparison of UAV operating in different modes of mobile relay with $V_a = 10\,\mathrm{m/s}$, $V_b = 15\,\mathrm{m/s}$.

insufficient, UAV needs to keep hovering relative to vehicle a for relay. However, when UAV flight energy is sufficient, UAV flight speed can be optimized to maximize the relay throughput of UAV.

In Fig. 4, we compare the throughput of the system with the increase of the data Q for successful transmission at different vehicle speeds under sufficient energy. Here we set $E_{max} = 5 \times 10^4\,\mathrm{J}$, and it can be found that the throughput of the system is decreasing with the increase of Q. Moreover, when the speed of vehicle b is the same, the greater the speed of vehicle a, the greater the throughput of the system. When the speed of vehicle a is the same, the greater the speed of vehicle b, the smaller the throughput of the system. That is, the smaller the speed difference between vehicle b and vehicle a, the greater the throughput of the system.

In the case of sufficient flight energy, we compared the throughput changes of UAV as a mobile relay in relative hover mode, data ferrying mode in [4] and our proposed optimization method with $V_a = 10\,\mathrm{m/s}$, $V_b = 15\,\mathrm{m/s}$. As shown in Fig. 5, it can be found that as the distance between vehicles increases, the throughput of UAV as a mobile relay in the three modes all shows a decreasing trend. In addition, the throughput of the proposed optimization method is always better than that of the relative hover method and the data ferrying method.

What's more, we also compared the throughput changes of UAV as a mobile relay in relative hover mode, data ferrying mode, power optimization method in [5] and our proposed optimization method with $V_a = V_b = 10\,\mathrm{m/s}$. The power optimization method is to optimize the transmission power of UAV and vehicle a after the flight path of UAV is fixed. When vehicle a and vehicle b are at the same speed, vehicle a and vehicle b are stationary relative to each other. As shown in Fig. 6, it can be found that as the distance between vehicles increases, the throughput of UAV as a mobile relay in the four modes all shows a decreasing trend. The communication distance between the UAV and the vehicle does not change with time, therefore, the throughput of the relay mode of UAV maintaining relative hover is as close as the throughput of the proposed method. And in this case, the proposed optimization method is superior to the throughput of other UAV as mobile relays.

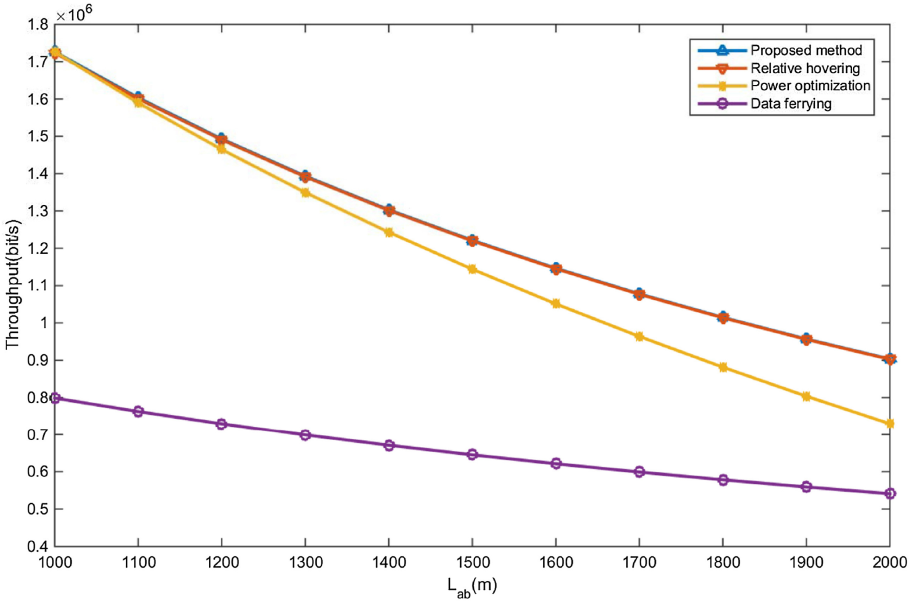

Fig. 6. Performance comparison of UAV operating in different modes of mobile relay with $V_a = V_b = 10\,\text{m/s}$.

5 Conclusion

In this paper, we use the UAV as a mobile relay between moving vehicles on the road. Under the limits of UAV flight energy and the amount of data successfully transferred, we optimize the speed of the UAV in the relay process to maximize the throughput of the UAV as a mobile relay system. Contrast with other system of UAV as mobile relay, our scenario was not considered, and we considered the requirements for the amount of data successfully transferred during the relay, the communication range of the source node, and the propulsion energy requirements of the UAV. However, we only consider the case that there is no communication between one cluster and another on the road. For the actual road, there may be a broken connection between multiple clusters. At this time, we need to consider the dynamic change due to the movement of vehicles, which is also the direction of our future work.

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