Joint Transmit Power and Trajectory Optimization for Two-Way Multi-Hop UAV Relaying Networks

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***Abstract*—Unmanned aerial vehicle (UAV) has been regarded as a promising means to supplement ground communications. As flying relays, UAVs can be rapidly and flexibly deployed to assist data transmissions in many practical scenarios. In this paper, we investigate a two-way multi-hop UAV relaying network, where there are two ground users as sources and multiple UAVs as relays to help the two ground sources exchange information. We first provide an efficient two-way multi-hop UAV relaying pattern, which can achieve a data rate of $\frac{2}{4}$ data packets per time slot with decode-and-forward (DF) protocol. Then, we further formulate a joint transmit power and trajectory optimization problem for the UAVs in this two-way multi-hop relaying scenario. The formulated problem is non-convex which makes it difficult to solve directly, hence we propose an iterative algorithm to obtain an approximate optimal solution. Numerical results demonstrate that our proposed network achieves significant throughput gains.**

***Index Terms*—UAV communications, two-way multi-hop relaying, trajectory optimization**

I. Introduction

As one of the important applications, UAV communications has attracted extensive attention from both industry and academia in recent years [1]. Compared with traditional single-hop communications, relay transmission technology can significantly improve the coverage of the network, effectively suppress the loss of wireless channels for information delivery, and enhance the reliability of wireless communications[2]. The advantages of UAV make it a promising candidate to behave as a flexible flying relay to assisted data transmissions.

In recent years, a variety of researches have been devoted to UAV relaying communications. In [3], the authors considered a system with a single UAV relay serving a pair of ground source/destination nodes, where a throughput maximization algorithm that jointly optimizes source/relay transmit power and UAV trajectory was designed. Also based on the joint optimization of trajectory and power, [4] analyzed the outage probability minimization of a base station and a mobile device served by a UAV relay. In [5], one static rotary-wing UAV was designed as relay to serve multiple user pairs on the ground, where the UAV's position, bandwidth, transmit power, and transmission rate were investigated jointly. Considering the spectrum sharing between the UAV relay and ground Device-to-Device (D2D) pairs, the throughput maximization based on transmit power optimization was designed in [6]. Aiming at the reliability of the UAV relay, [7] analyzed the optimal altitude of the UAV relay driven by overall bit error rate, overall outage, and total power loss, respectively. Furthermore, the performance of amplify-and-forward (AF) and decode-and-forward (DF) relaying schemes was compared under these different reliability measures. [8] investigated the radio resource optimization scheme for UAV relaying, respectively. For the multi-UAV relay system, [9] compared the advantages and disadvantages of multi-hop single link option and dual-hop multi-link option in terms of two indices of bit error rate and outage probability. Considering the joint optimization of trajectory and transmit power, [10] further analyzed the end-to-end throughput maximization problem of multi-hop single link option. Existing researches mainly focus on single UAV relay system or one-way multi-UAV relay system.

In this paper, to the best of the authors' knowledge, we for the first time investigate a multi-UAV-assisted two-way relaying network. In order to realize efficient two-way multi-UAV relaying, we provide a developed four-time-slot (FTS) two-way multi-hop UAV relaying protocol. Based on the designed pattern, the maximum achievable throughput of two-way multi-hop UAV relaying transmission can achieve $\frac{2}{4}$ data packets per time slot at high SNR regions in DF mode, which is the current best achievable throughput known for general DF relaying schemes. Moreover, we further formulate a joint transmit power and trajectory optimization problem for the UAVs in this two-way multi-hop relaying scenario. To overcome the non-convexity of the formulated problem, we propose an iterative algorithm to obtain an approximate optimal solution based on block coordinate descent and successive convex optimization techniques.

The rest of this paper is organized as follows. Section II introduces the system model of two-way multi-hop UAV relaying network. Section III presents a developed FTS two-way multi-hop UAV relaying pattern and the problem formulation. Section IV gives an iterative algorithm to optimize power and trajectory jointly. Section V demonstrates the numerical results. Finally, Section VI concludes this paper.

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II. SYSTEM MODEL

As shown in Fig. 1, in this paper, we consider a half-duplex Multi-UAV-assisted two-way multi-hop relaying network, where M UAVs, denoted by $R_1, \cdots, R_M, M \geq 2$, are employed as intermediate relay nodes to exchange information between two fixed source nodes, S_0 and S_1. We assume that there is no direct communication link between these two source nodes.We also assume that each node can only exchange information with its left and right nearest neighbor nodes. Within T relay durations (i.e., the UAVs' task period), UAVs fly from a specified initial spot to a pre-determined final spot and work as Decode-and-Forward (DF) relays, in which the duration of one one-hop data transmission two adjacent nodes is d_t.

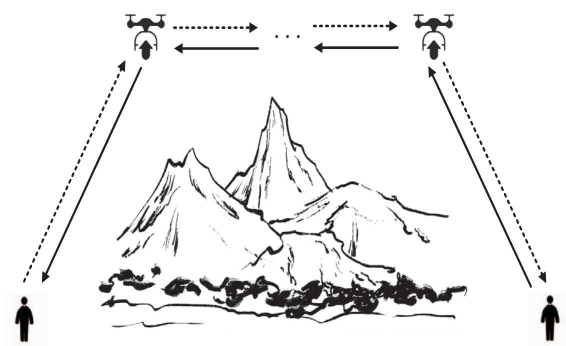

Fig. 1. An illustrated two-way multi-hop relaying network.

In the Cartesian coordinate system, suppose the ground source nodes S_0 and S_1 are located at $\mathbf{C}_{S_0} = [\mathbf{q}_{S_0}^T, 0]^T$ and $\mathbf{C}_{S_1} = [\mathbf{q}_{S_1}^T, 0]^T$, respectively, where the horizontal coordinates are denoted by $\mathbf{q}_{S_0} = [x_{S_0}, y_{S_0}]^T$ and $\mathbf{q}_{S_1} = [x_{S_1}, y_{S_1}]^T$. We assume that all UAVs fly horizontally at a fixed altitude H [3]. Note that for simplicity, the take-off and landing phases of the UAVs are ignored. Therefore, the coordinate of the mth UAV at time t can be denoted as $\mathbf{C}_{R_m} = [\mathbf{q}_m(t)^T, H]^T$, $m \in \{1, \ldots, M\}$, $0 \leq t \leq T$, where $\mathbf{q}_m(t) = [x_m(t), y_m(t)]^T$ denotes the horizontal coordinate of the mth UAV at time t.

For simplicity of analysis, the time period T is divided into N equal time slots, i.e., $T = Nd_t$. The length of a time slot is set as d_t, which is small enough such that the positions of the UAVs in each time slot can be considered to be approximately constant. Hence, the mth UAV's horizontal trajectory $\mathbf{q}_m(t)$ during period T can be approximately discretized by N two-dimensional vector sequences $\mathbf{q}_m[n] = [x_m[n], y_m[n]]^T$, $n \in \{1, \ldots, N\}$. The maximum flying speed of all UAVs is denoted as v_{max}, and then the maximum flying distance of all UAVs in each time slot is $D_{max} = v_{max} d_t$. Furthermore, we represent the initial and final horizontal locations of the mth UAV by $\mathbf{q}_{0,m} = [x_{0,m}, y_{0,m}]^T$ and $\mathbf{q}_{F,m} = [x_{F,m}, y_{F,m}]^T$, respectively. As a result, the mobility constraints of UAVs can be denoted as

$$\begin{aligned} &\|\mathbf{q}_m[1] - \mathbf{q}_{0,m}\| \leq D_{max}, \forall m \\ &\|\mathbf{q}_{F,m} - \mathbf{q}_m[N]\| \leq D_{max}, \forall m \\ &\|\mathbf{q}_m[n+1] - \mathbf{q}_m[n]\| \leq D_{max}, n = 1, \ldots, N-1, \forall m \end{aligned} \tag{1}$$

which represent the initial position constraint, the final position constraint, and the speed constraint, respectively. Moreover, the collision avoidance constraints between the UAVs are denoted as

$$\|\mathbf{q}_m[n] - \mathbf{q}_k[n]\| \geq d_{\min}, \quad \forall n, m > k \tag{2}$$

where $d_{\min}$ represents the minimum distance between any two UAVs to avoid collision.

Furthermore, we suppose that the channels of UAV-ground and UAV-UAV communications are dominated by line-of-sight (LoS) links, and the Doppler effect caused by the UAVs' mobility can be completely compensated [4]. Time division duplex (TDD) for two-way data transmissions is adopted in this paper. Therefore, the channel gains from node N_i to node N_j and from node N_j to node N_i, where $N_i, N_j \in \{S_0, S_1, R_1, \cdots, R_M\}$, are reciprocal and follow the free-space path loss model as

$$h_{N_i,N_j}[n] = h_{N_j,N_i}[n] = \beta_0 d_{N_i,N_j}^{-2}[n] = \frac{\beta_0}{\left\|\mathbf{C}_{N_i}[n] - \mathbf{C}_{N_j[n]}\right\|^2} \tag{3}$$

where β_0 denotes the channel gain at the reference distance $d_0 = 1$ meter, and $d_{N_i,N_j}[n] = \left\|\mathbf{C}_{N_i}[n] - \mathbf{C}_{N_j[n]}\right\|$ is the link distance between node N_i and node N_j at time slot n.

III. TWO-WAY MULTI-HOP UAV RELAYING SCHEME

In this section, we first provide a developed two-way multi-hop UAV relaying scheme which only requires four time slots for information exchange between two source nodes in stable state. And then with the provided two-way four-time-slot (FTS) DF relaying scheme, we further formulate the joint system optimization problem in terms of both UAV trajectory and power allocation.

A. Four-Time-Slot Two-Way Multi-hop Relaying Protocol

Some existing studies have focused on the two-way multi-hop transmission design based on general relays in the literature. [11] proposed a DF-based multi-hop transmission scheme with asymptotic transmission rate up to $\frac{2}{5}$, where the asymptotic transmission rate was further increased to $\frac{2}{4}$ in [12]. Referring to [12], in this paper, we provide an efficient four-time-slot two-way multi-UAV relaying protocol, which can work on any number of intermediate UAVs (i.e., M) in the UAV-assisted two-way multi-hop relaying system.

For easy understanding, we illustrate the data transmission pattern of the designed FTS two-way multi-hop UAV relaying protocol with four UAVs in Fig. 2. The data packets transmitted from S_0 to S_1 are represented by $\{A_1, A_2, A_3, ...\}$, while the data packets transmitted from S_1 to S_0 is represented by $\{B_1, B_2, B_3, ...\}$. As shown in Fig. 2, we initialize the system through the first six time slots, and then the system enters the steady state since time slot 7. From then on, a stable two-way relaying cycle is performed every four time slots until the data transmission task is completed. In the steady state, based on the proposed protocol, the multi-hop relaying with four UAVs achieves the highest throughput of $\frac{2}{4}$ packets/time slot at high SNR regions in DF mode.

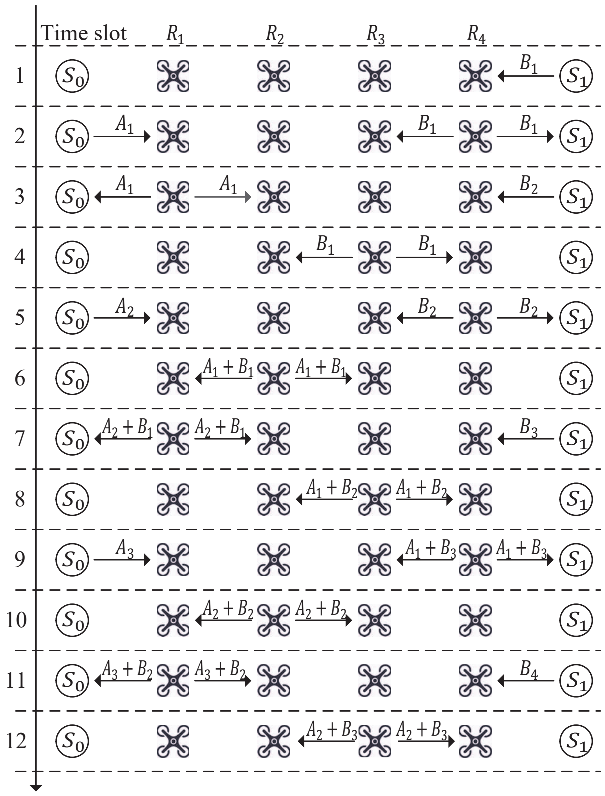

Fig. 2. FTS two-way multi-hop UAV relaying protocol.

B. Problem Formulation

Note that in practical applications, the number of UAVs required to establish a communication link between two source nodes is determined by a variety of factors, including the specific terrain, the distance between source nodes, and the communication capability of UAVs, and so on. Therefore, for simplicity of expression and without loss of generality, in this paper, we take the case of four UAV relays as an example, which can be generalized to the case of any number of UAV relays.

The transmit power of the two source nodes and the mth UAV relay, $m \in M$, in time slot n are denoted as $P_{S_0}[n]$, $P_{S_1}[n]$, and $P_m[n]$, respectively, which are subject to both average power and peak power constraints. Specifically, we have

$$\begin{aligned} &\frac{1}{N}\sum_{n=1}^{N} P_{N_i}[n] \le \overline{P}_{N_i} \\ &0 \le P_{N_i}[n] \le P_{N_i,\max}, \quad \forall n \end{aligned} \tag{4}$$

where $\overline{P}_{N_i}$ and $P_{N_i,\max}$ denote the average power limit and peak power limit. In addition, we assume that $\overline{P}_{N_i} < P_{N_i,\max}$.

The transmission rate from node N_i to node N_j can be expressed as

$$\begin{aligned} G_{N_i,N_j}[n] &= \log_2\left(1 + \frac{P_{N_i}[n] h_{N_i,N_j}[n]}{\sigma^2}\right) \\ &= \log_2\left(1 + \frac{P_{N_i}[n]\gamma_0}{\left\|\mathbf{C}_{N_i}[n] - \mathbf{C}_{N_j}[n]\right\|^2}\right) \end{aligned} \tag{5}$$

where σ^2 is the additive white Gaussian noise (AWGN) power at the receiver and $\gamma_0 = \beta_0/\sigma^2$ is the reference signal-to-noise ratio (SNR).

Then, the transmission rate of A_l and B_l through multi-hop relaying can be expressed as $G_{A_1} = \min(G_{S_0,1}[2], G_{1,2}[3], G_{2,3}[6], G_{3,4}[8], G_{4,S_1}[9])$ and $G_{B_1} = \min(G_{S_1,4}[1], G_{4,3}[2], G_{3,2}[4], G_{2,1}[6], G_{1,S_0}[7])$. For $l > 1$, $G_{A_l} = \min(G_{S_0,1}[4l-3], G_{1,2}[4l-1], G_{2,3}[4l+2], G_{3,4}[4l+4], G_{4,S_1}[4l+5])$ and $G_{B_l} = \min(G_{S_1,4}[4l-5], G_{4,3}[4l-3], G_{3,2}[4l], G_{2,1}[4l+2], G_{1,S_0}[4l+3])$. In this case, $4L+5$ time slots are required to complete the two-way transmission of L pairs of data packets, i.e., $L = \lceil \frac{N-5}{4} \rceil$. The transmission rate of lth pair of two-way massages is $G^l_{mim} = \min(G_{A_l}, G_{B_l})$.

Therefore, extra power constraints according to the proposed relaying protocol are given as below

$$\begin{aligned} P_{S_0}[n] &= 0, \forall n \notin \{2, 4l+1 | l \in 1, \ldots, L-1\} \\ P_1[n] &= 0, \forall n \notin \{4l-1 | l \in 1, \ldots, L+1\} \\ P_2[n] &= 0, \forall n \notin \{4l+2 | l \in 1, \ldots, L\} \\ P_3[n] &= 0, \forall n \notin \{4l | l \in 1, \ldots, L\} \\ P_4[n] &= 0, \forall n \notin \{2, 4l+1 | l \in 1, \ldots, L+1\} \\ P_{S_1}[n] &= 0, \forall n \notin \{1, 4l-1 | l \in 1, \ldots, L-1\} \end{aligned} \tag{6}$$

IV. Joint Power and Trajectory Optimization

In order to maximize the total transmission rate between two source nodes, we further formulate a joint UAV trajectory and power allocation optimization problem constrained by the mobility constraints in (1), the collision avoidance constraints in (2), and the transmit power constraints in (4) and (6), where there are four variables: trajectories of UAVs $\mathbf{q}_m \triangleq \{\mathbf{q}_m[1], \ldots, \mathbf{q}_m[N]\}$, transmit power of UAVs $\mathbf{P}_m \triangleq [P_m[1], \ldots, P_m[N]]^T$, and transmit power of two source nodes $\mathbf{P}_{S_0} \triangleq [P_{S_0}[1], \ldots, P_{S_0}[N]]^T$ and $\mathbf{P}_{S_1} \triangleq [P_{S_1}[1], \ldots, P_{S_1}[N]]^T$. As a result, the formulated optimization problem can be given as

$$\begin{aligned} \text{(Pl):} \quad &\max_{\{\mathbf{q}_m\},\{\mathbf{P}_m\},\mathbf{P}_{S_0},\mathbf{P}_{S_1}} \sum_{l=1}^{L} G^l_{mim} \\ \text{s.t.} \quad &(1), (2), (4), (6) \end{aligned} \tag{7}$$

This is a non-convex optimization problem because the objective function and constraints in (2) are non-convex, which makes the problem difficult to solve directly. Therefore, we propose an algorithm for (P1) by iteratively optimizing the UAV trajectory and power allocation.

A. Power Optimization with Fixed Trajectory

With fixed trajectory $\{\mathbf{C}_m\}$, the sub-problem of power allocation is a solvable convex optimization problem.

B. Trajectory Optimization with Fixed Power

With fixed transmit power, this subsection considers the sub-problem for UAV trajectory optimization. Let $\gamma_{S_0}[n] \triangleq P_{S_0}[n]\gamma_0, \gamma_{S_1}[n] \triangleq P_{S_1}[n]\gamma_0, \gamma_m[n] \triangleq P_m[n]\gamma_0$. Then we define

$$O_{N_i,N_j}(\mathbf{C}_{N_i}[n], \mathbf{C}_{N_j}[n]) \triangleq \log_2\left(1 + \frac{\gamma_{N_i}[n]}{\left\|\mathbf{C}_{N_i}[n] - \mathbf{C}_{N_j}[n]\right\|^2}\right) \tag{8}$$

Notice that the altitudes of all the nodes are constant, so $O_{N_i,N_j}(\mathbf{C}_{N_i}[n],\mathbf{C}_{N_j}[n])$ can be replaced by $O_{N_i,N_j}(\mathbf{q}_{N_i}[n],\mathbf{q}_{N_j}[n])$.

Note that, with fixed transmit power P_{S_0}, P_{S_1}, and $\{P_m\}$, the objective function and several constraints of (P1) are still non-concave with respect to $\{\mathbf{q}_m\}$, which makes it difficult to solve. Hence, we adopt the iterative method to obtain an approximate optimal solution. Consider one step in the iterative process, expressed as (z+1)th iteration, where $\mathbf{q}_m^z[n], \forall m$, denote the obtained trajectories of the lth iteration. Let's consider the above non-convexity problem. It can be seen that $O_{N_i,N_j}(\mathbf{q}_{N_i}[n],\mathbf{q}_{N_j}[n])$ is convex with respect to $\left\|\mathbf{q}_{N_i}[n]-\mathbf{q}_{N_j}[n]\right\|^2$. According to the properties of first-order Taylor expansion, it is a global lower-bound of a convex function. Therefore, we use first-order Taylor expansion of $O_{N_i,N_j}(\mathbf{q}_{N_i}[n],\mathbf{q}_{N_j}[n])$ at $\left\|\mathbf{q}_{N_i}[n]-\mathbf{q}_{N_j}[n]\right\|^2$ as the lower-bound, denoted as $O^{lb}_{N_i,N_j}(\mathbf{q}_{N_i}[n],\mathbf{q}_{N_j}[n])$

$$\begin{aligned}&O_{N_i,N_j}(\mathbf{q}_{N_i}[n],\mathbf{q}_{N_j}[n])\\&=\log_2\left(1+\frac{\gamma_{N_i}[n]}{\left\|\mathbf{C}_{N_i}[n]-\mathbf{C}_{N_j}[n]\right\|^2}\right)\\&\geq O^{lb}_{N_i,N_j}(\mathbf{q}_{N_i}[n],\mathbf{q}_{N_j}[n])\\&\triangleq \alpha^z_{N_i,N_j}[n]-\beta^z_{N_i,N_j}[n](\left\|\mathbf{q}_{N_i}[n]-\mathbf{q}_{N_j}\right\|^2-\left\|\mathbf{q}^z_{N_i}[n]-\mathbf{q}_{N_j}\right\|^2),\end{aligned} \tag{9}$$

where

$$\alpha^z_{N_i,N_j}[n]=\log_2\left(1+\frac{\gamma_{N_i}[n]}{\left\|\mathbf{C}_{N_i}[n]-\mathbf{C}_{N_j}[n]\right\|^2}\right), \tag{10}$$

$$\begin{aligned}&\beta^z_{N_i,N_j}[n]\\&=\frac{(\log_2 e)\gamma_{N_i}[n]}{(\gamma_{S_i}[n]+\left\|\mathbf{C}_{N_i}[n]-\mathbf{C}_{N_j}[n]\right\|^2)(H^2+\left\|\mathbf{C}_{N_i}[n]-\mathbf{C}_{N_j}[n]\right\|^2)}.\end{aligned} \tag{11}$$

Now, $O^{lb}_{N_i,N_j}(\mathbf{q}_{N_i}[n],\mathbf{q}_{N_j}[n])$ is concave with respect to $\mathbf{q}_{N_i}[n]$ and $\mathbf{q}_{N_j}[n]$. Then, let's move on to the non-concavity of the constrain $d^2_{\min} \leq \|\mathbf{q}_m[n]-\mathbf{q}_k[n]\|^2$. The properties of first-order Taylor expansion are also useful here, which can help find the global lower bound of $\|\mathbf{q}_m[n]-\mathbf{q}_k[n]\|^2$, as below

$$\begin{aligned}\|\mathbf{q}_m[n]-\mathbf{q}_k[n]\|^2 \geq &-\|\mathbf{q}^z_m[n]-\mathbf{q}^z_k[n]\|^2\\&+2(\mathbf{q}^z_m[n]-\mathbf{q}^z_k[n])^T(\mathbf{q}_m[n]-\mathbf{q}_k[n]).\end{aligned} \tag{12}$$

By replacing the terms $O_{S_0,1}(\mathbf{q}_1[n])$, $O_{1,S_0}(\mathbf{q}_1[n])$, $O_{M,S_1}(\mathbf{q}_M[n])$, $O_{S_1,M}(\mathbf{q}_M[n])$, $O_{m,m+1}(\mathbf{q}_m[n],\mathbf{q}_{m+1}[n])$, $O_{m,m-1}(\mathbf{q}_m[n],\mathbf{q}_{m-1}[n])$, and $\|\mathbf{q}_m[n]-\mathbf{q}_k[n]\|^2$ with their lower bounds shown in (9) and (12), problem (P1) can be formulated as its approximate problem, which is a convex optimization problem that can be easily solved.

C. Overall Algorithm

Based on the analysis of the above two parts, the joint optimization algorithm of transmit power and UAV trajectory is proposed in Algorithm 1.

Algorithm 1 Joint Power and Trajectory Optimization Algorithm

1: Initialize a feasible trajectory q^0_m. Let $z=0$
2: **repeat**
3: Solve problem (P2) with given q^z_m. Denote the obtained solution as $\{P^{z+1}_m\}$, $\{P^{z+1}_{S_0}\}$, and $\{P^{z+1}_{S_1}\}$.
4: Solve problem (P4) with given $\{P^{z+1}_m\}$, $\{P^{z+1}_{S_0}\}$, $\{P^{z+1}_{S_1}\}$, and q^z_m. Denote the obtained solution as q^{z+1}_m.
5: Update $z=z+1$.
6: **until** The fractional increase of the end-to-end throughput is smaller than a given threshold $\epsilon>0$.

V. SIMULATION RESULTS

In this section, numerical results are demonstrated to evaluate the efficiency of our proposed two-way multi-hop UAV relaying scheme together with the joint power and trajectory optimization algorithm (denoted as "t.s. & joint opt."). We consider a UAV-assisted two-way multi-hop relay system where the coordinates of sources S_0 and S_1 are set as $[0,0,0]^T$ m and $[2000,0,0]^T$ m, respectively. The number of UAVs as relay nodes is set as $M=4$. The altitude of four UAVs is fixed to $H=100$ m, and the initial and final horizontal locations of each UAV are set as $q_{0,m}=[1000,400]^T$ m and $q_{F,m}=[1000,-400]^T$ m, respectively. The length of one time slot is set as $d_t=5$ s, and the maximum speed of UAVs is assumed to be $v_{max}=10$ m/s. The minimum spacing between any two UAVs is set as $d_{min}=10$ m. Furthermore, we set $\overline{P}_{N_i}=\overline{P}$, $P_{N_i,\max}=P_{max}$, and $P_{max}=8\overline{P}$. The reference SNR at the reference distance $d_0=1$ m is set as $\gamma_0=80$ dB.

To demonstrate the performance of the designed transmission scheme, two benchmark schemes are adopted for performance comparison:

- Power optimization with fixed trajectory based on proposed two-way multi-hop UAV relaying scheme (denoted as "power opt. & t.s."). In this scheme, the trajectory optimization problem (P4) in Algorithm 1 is replaced by line-segment trajectory, in which the UAVs fly from the initial location to the four points equally spaced along the connection line between two source nodes according to the maximum speed, then stay stationary and finally fly to the final location with the maximum speed.
- Joint power and trajectory optimization without our designed FTS two-way relaying scheme (denoted as "joint opt. no t.s."). In this scheme, our proposed two-way multi-hop UAV relaying scheme is replaced by a basic two-way transmission scheme, in which two source nodes take turns transmitting messages every five slots.

Fig. 3 shows the trajectories of four UAVs when $T=400$ s. It can be observed that, since T is large enough, the UAVs in "power opt. & t.s." scheme can reach the equal-diversion spots and stay stationary for a period of time. The trajectory trends of the proposed "t.s. & joint opt." scheme and the "power opt. & t.s." scheme are also similar. The difference is that the UAVs in "t.s. & joint opt." scheme fly back and forth along

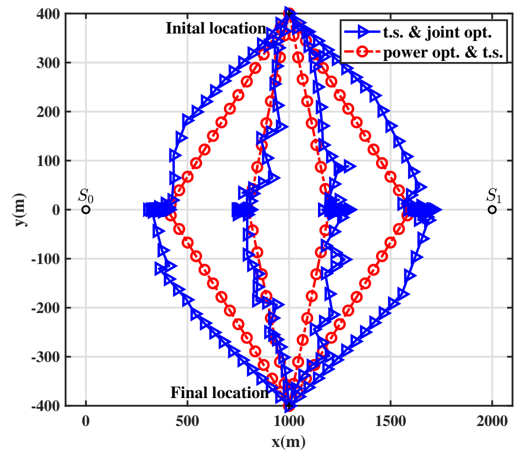

Fig. 3. UAV trajectories when T=400 s.

the direction of the two source nodes at the equal-diversion spots to get higher throughput.

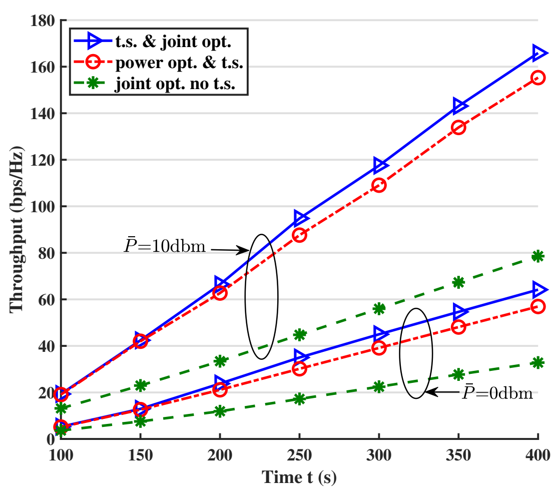

Fig. 4. Throughput versus time t.

Fig. 4 illustrates the system throughput of different UAV relaying schemes under different periods T with $\overline{P} = 0$ dBm and $\overline{P} = 10$ dBm. Note that the throughput of all schemes increases along T. This is expected since the longer the period, the more data packets are transmitted. It is also observed that the throughput of our proposed "t.s. & joint opt." scheme is optimal in all cases. The throughput performance difference between the "t.s. & joint opt." scheme and the "power opt. & t.s." scheme is not obvious, whereas they both significantly outperform the "joint opt. no t.s." scheme, which verifies the efficiency of the proposed two-way multi-hop UAV relaying scheme. That is, compared with other two-way UAV relaying schemes, the proposed scheme can complete more information transmission in the same time.

VI. Conclusions

In this paper, we investigated a UAV-assisted two-way multi-hop relaying network. To stimulate the efficiency of data exchange between two far-away ground sources, we proposed an efficient two-way multi-hop UAV relaying scheme, which can significantly improve network throughput compared with conventional two-way multi-hop relay transmission scheme. We also formulated and solved a joint optimization problem to maximize the throughput performance of the network in terms of both the trajectories of the UAV relays as well as the transmit powers of the source nodes and the UAV relays. Numerical results show that our proposed scheme achieves significant improvement in network throughput.

Acknowledgment

This work is supported in part by the National Key Research and Development Project under Grant 2017YFE0119300 and 2019YFB2102300, in part by the National Natural Science Foundation of China under Grant 61936014 and 61901302, in part by the Scientific Research Project of Shanghai Science and Technology Committee under Grant 19511103302, in part by the open research fund of National Mobile Communications Research Laboratory, Southeast University (No. 2020D01), and in part by the National Science Foundation under Grant CPS-1932413 and ECCS-1935915.

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