Number of UAVs and Mission Completion Time Minimization in Multi-UAV-Enabled IoT Networks

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Abstract. The application of unmanned aerial vehicles (UAVs) in IoT networks, especially data collection, has received extensive attention. Due to the urgency of the mission and the limitation of the network cost, the number and the mission completion time of UAVs are research hotspots. Most studies mainly focus on the trajectory optimization of the UAV to shorten the mission completion time. However, under different data collection modes, the collection time will also greatly affect the mission completion time. This paper studies the data collection of ground IoT devices (GIDs) in Multi-UAV enabled IoT networks. The problem of data collection is formulated to minimize the number and the maximum mission completion time of UAVs by jointly optimizing the mission allocation of UAVs, hovering location, and the UAV trajectory. In view of the complexity and non-convexity of the formulated problem, we design improved ant colony optimization (IACO) algorithm to determine the number of UAVs by the mission allocation. Then, based on the data collection scheme combining flying mode (FM) and hovering mode (HM), a joint optimization algorithm (JOATC) is proposed to minimize flight time and collection time by optimizing the trajectory of the UAV. Simulation results show that our scheme achieves better performance.

Keywords: Multi-UAV IoT Networks· mission allocation· flying mode· hovering mode.

1 Introduction

The Internet of things plays an important role in mobile detection application scenarios [1]. In these IoT networks, many ground IoT devices (GIDs) are deployed in areas to monitor information. The wide distribution and diverse demands of GIDs have also brought new challenges about the data collection in the IoT networks. Fortunately, unmanned aerial vehicle (UAV) plays an important role in the communication network associated with GIDs because of its mobility and flexibility.

The UAV, also known as drone, is a new mobile platform. In some emergency situations, such as disaster rescue, there is a strict deadline for the completion of data collection missions of UAVs [2]. In addition, the limited energy also poses new challenges for the data collection of UAVs. Hence, it is an important issue to optimize the trajectory of the UAV to minimize the mission completion time of UAV.

Another challenging problem is how to set the appropriate number of UAVs in the Internet of things network. Due to the uncertainty of data size and the limitation of the UAV power, a fixed number of UAVs [3] may not be able to complete the data collection mission. Therefore, it is significant to determine the appropriate number of UAVs.

Based on the above two challenges, we study the data collection problem in multi-UAV enabled IoT networks. To meet the needs of shortening the maximum mission completion time of UAVs and reducing network costs, we jointly optimize the mission allocation, hovering location, and trajectory of UAVs to minimize the number of UAVs and the maximum mission completion time. The main contributions of this paper are summarized as follows:

(1) Considering the energy budget of the UAV and the association between the UAV and the GID, we formulate the problem for data collection in multi-UAV enabled IoT networks. Our goal is to minimize the number of UAVs and the maximum mission completion time.
(2) To balance the mission load of each UAV, we design the improved ant colony optimization algorithm (IACO) to determine the number and mission allocation of the UAVs by optimizing the association between the UAV and the GID.
(3) We prove the efficiency of the data collection on flying mode (FM) and hovering mode (HM) with mathematical analysis. Since the interaction between the flight service time and collection service time of each GID, we propose a joint optimization algorithm (JOATC) for the flying into point, hovering point and flying out point in the transmission area of GIDs to optimize the trajectories of all UAVs and minimize mission completion time of the UAV.
(4) Extensive simulations illustrate the effectiveness of our proposed scheme in the data collection scenario with many actual parameter settings.

2 Related Work

Most of the existing work studies the correct deployment location and coverage efficiency of the UAV to improve the efficiency of the whole system in processing missions [4]. However, in large-scale wireless communication networks, the flight time of the UAV accounts for the largest proportion of the total time cost. Therefore, the trajectory optimization of the UAV is particularly important to improve the overall energy consumption of the system.

There are a lot of literatures for the data collection of multi-UAV-enabled IoT networks. Two kinds of data collection schemes assisted by the UAV are mainly adopted: FM and HM. In order to shorten the mission completion time of the UAV data collection, authors have conducted many related studies on this basis [5]. In [6], based on the mathematical analysis of the collection time on FM and

HM, the authors propose a V-shaped trajectory to minimize the data collection time.

Besides, it is also necessary to find the appropriate number of UAVs. In most of the literatures, the number of UAVs is fixed to solve the problem of the UAV data collection. In the single UAV system, the authors of [7] propose a new trajectory search algorithm based on spatial pruning (SPTs) to minimize the overall mission completion time. In the multi-UAV system, the authors select two UAVs to complete data collection, and jointly optimize the UAV trajectory, wake-up time allocation and the transmit power of SNs to minimize the mission completion time [8].

Different from the above work, we study a data collection problem that simultaneously minimizes the number of UAVs and the maximum mission completion time. We design the IACO algorithm to achieve mission allocation and determine the number of UAVs. In order to minimize the flight time and collection time of each UAV, we design the JOATC algorithm for the flying into point (FIP), hovering point (OH) and the flying out point (FOP) on the UAV trajectory.

3 System Model and Problem Formulation

3.1 System Model

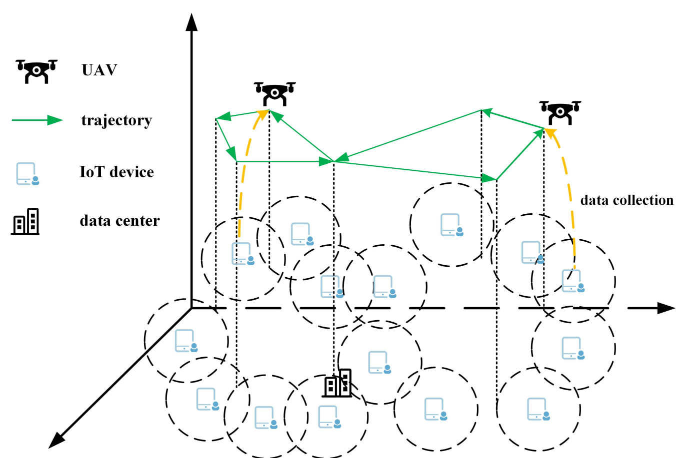


Fig. 1: Multi-UAV enabled data collection system in remote IoT scenarios.

System Architecture As shown in Fig. 1, we consider a wireless communication network with multiple UAVs for data collection, which consists of several UAVs, denoted by $\mathcal{N} \triangleq \{1, 2, \cdots, N\}$. We assume N is a sufficiently large integer, which is greater than or equal to the number of UAVs put into scheduling. In addition, there are M GIDs, represented as $\mathcal{M} \triangleq \{1, 2, \cdots, M\}$. All UAVs fly at the same altitude h. Each GID corresponds to a dotted circle. When the UAV flies into this circle, it can continuously collect the data of the corresponding GID. We establish a three-dimensional Cartesian coordinate system, where the coordinate of the UAV n is expressed as $UAV_n = \left(UAV_{n_x}, UAV_{n_y}, h\right)$, and the coordinate of the GID m is denoted by $GID_m = \left(GID_{m_x}, GID_{m_y}\right)$. Each GID corresponds to one hovering point (OH). In the process of data collection, the association and scheduling status of the UAV n among the adjacent GIDs is expressed as $\alpha_{m,k}[n]$. If the UAV n flies from the OH m to the OH k, $\alpha_{m,k}[n] = 1$. Otherwise, $\alpha_{m,k}[n] = 0$. The index of the data center is expressed as 0. $\alpha_{0,k}[n] = 1$ means that the UAV n starts from the data center to the adjacent OH k. Hence, $Nu = \sum_{n=1}^{N} \sum_{k=1}^{M} \alpha_{0,k}[n]$ indicates the number of UAVs.

Channel model and Transmission model The signal transmission channel between the UAV and the GID considers the Los link and the non-Los link. The relevant path losses are as follows:

$$L_\xi(d_{m,n}) = \begin{cases} \left(\frac{4\pi f d_{m,n}}{c}\right)^2 \eta_0 & ,\xi = 0 \\ \left(\frac{4\pi f d_{m,n}}{c}\right)^2 \eta_1 & ,\xi = 1 \end{cases} \tag{1}$$

where $\xi = 0$ and $\xi = 1$ represent Los link and non-Los link, respectively, f is the carrier frequency, and c is the speed of light. η_0 and η_1 are the path loss parameters for the Los link and the non-Los link, respectively. Let $d_{m,n}$ denote the Euclidean distance between the scheduled the GID m and the UAV n.

The Los link probability which is affected by environmental factors can be expressed as follows:

$$p_0(d_{m,n}, h) = \frac{1}{1 + a\exp\left(-b(\theta - a)\right)} \tag{2}$$

where a and b are the environmental constants, and $\theta = \frac{180}{\pi} arcsin(\frac{h}{d_{m,n}})$ is the elevation angle between the UAV and the GID. $1 - p_0\left(d_{m,n}, h\right)$ is the probability of the non-Los link.

Let γ_{mn} denote the signal-to-noise ratio (SNR) between the GID m and the UAV n, and P_m denote the transmission power of the GID m. According to the SNR formula, the SNR is calculated as follows:

$$\gamma_{mn} = \frac{\beta P_m}{\sigma^2 L_\xi(d_{m,n})} \tag{3}$$

where β is the channel power gain at the reference distance of 1 meter, and σ^2 means the noise power of the UAV receiver. All UAVs operate in non-overlapping frequency channel through frequency division multiplexing (FDM). Since the total bandwidth B is fixed and each UAV occupies the same bandwidth, the bandwidth of each UAV is B/Nu. The transmission rate from the GID m to the UAV n is shown as follows:

$$R_{mn} = \frac{B}{Nu} log_2(1 + \gamma_{mn}) \tag{4}$$

Data collection model The data collection process of the UAV are divided into two modes, flying mode (FM) and hovering mode (HM). FM indicates the mode of collecting data when UAVs are flying. HM represents the mode of data collection when UAVs are hovering at a certain point. During the data collection of the GID m, the UAV n enters the signal transmission range of the GID m from the flying into point FIP_m, passes through the point OH_m, and hovers at it for a period, then leaves the signal transmission range of the GID m from the flying out point FOP_m. The UAV n hovers at the point OH_m to collect data on HM. From FIP_m to OH_m and OH_m to FOP_m, the UAV n fights and collects data on FM. Within the signal transmission radius R, the UAV can successfully receive data from GIDs. If the distance between GIDs is less than 2R, the signal transmission range overlaps. Otherwise, it does not overlap. The coordinates of the passing points of the UAV in the data collection area are expressed as $FIP_m\left(FIP_{m_x}, FIP_{m_y}\right)$, $FOP_m\left(FOP_{m_x}, FOP_{m_y}\right)$, $OH_m\left(OH_{m_x}, OH_{m_y}\right)$.

We define t^c_{hm} as the collection time on HM and t^c_{fm} as the collection time on FM. Let C_m be the data size of the GID m. The distance between FIP and OH in the transmission area of the GID m is $||FIP_m - OH_m||$, and the distance between OH and FOP is $||OH_m - FOP_m||$. All UAVs fly at the optimal flight speed v_{opt}. On FM, the collection time of the UAV in the transmission area of the GID m is $t^c_{fm} = \frac{||FIP_m - OH_m||}{v_{opt}} + \frac{||OH_m - FOP_m||}{v_{opt}}$. On HM, the collection time of the UAV in the transmission area of the GID m is $t^c_{hm} = \frac{C_m - \int_0^{t^c_{fm}} R_{mn}(t)dt}{R_h}$, where R_h is the transmission rate from the GID m to the UAV n in hovering state. Hence, the collection time t^c_m of data collected by the UAV n from the GID m can be expressed as

$$t^c_m = t^c_{fm} + t^c_{hm} = \frac{||FIP_m - OH_m||}{v_{opt}} + \frac{||OH_m - FOP_m||}{v_{opt}} + \frac{C_m - \int_0^{t^c_{fm}} R_{mn}(t)dt}{R_h} \tag{5}$$

For the distance between FOP_{m-1} and FIP_m, the flight time t^f_m of the UAV can be expressed as

$$t^f_m = \begin{cases} \frac{d_{m1}}{v_{opt}} & , in\ non\text{-}overlapped\ scenario \\ 0 & , in\ overlapped\ scenario \end{cases} \tag{6}$$

where $d_{m1} = \sqrt{(FOP_{m-1_x} - FIP_{m_x})^2 + (FOP_{m-1_y} - FIP_{m_y})^2}$.

Energy consumption model The power consumption of the UAV mainly includes the related power consumption during data collection and flight. The flying power can be given by $P^f = P(v_{opt})$. Then, the hovering power can be expressed as $P^h = P(0)$. Therefore, the energy consumption of the UAV n to complete the data collection mission can be calculated as follows:

$$\begin{aligned} E_n &= \int_0^{T_n^f} P^f dt + \int_0^{T_f^c} (P^f + P^c) dt + \int_0^{T_h^c} (P^h + P^c) dt \\ &= \sum_{m=1}^{M_n} \int_0^{t_m^f} P^f dt + \int_0^{t_0^f} P^f dt + \sum_{m=1}^{M_n} \int_0^{t_{fm}^c} \left(P^f + P^c\right) dt \\ &+ \sum_{m=1}^{M_n} \int_0^{t_{hm}^c} (P^h + P^c) dt \end{aligned} \tag{7}$$

where M_n means the number of GIDs visited by the UAV n, T_n^f represents the total flight time of the UAV n outside the transmission area of GIDs, T_f^c indicates the total data collection time on FM, T_h^c indicates the total data collection time on HM. t_0^f denotes the flight time from the last collected GID by the UAV to the data center. P^c is the circuit power in the process of the UAV data collection.

3.2 Problem Formulation

The UAV n completes the data collection on the planned trajectory $U_n(t)$. The $U_n(t)$ and M_n affect the mission completion time of UAVs. $\Lambda \triangleq \{\alpha_{m,k}[n] | m, k \in \mathcal{M}, n \in \mathcal{N}\}$ is the association status and sequence among the GIDs. The set Λ affects the number of UAVs.

The mission completion time of a single UAV is the sum of all flight time and data collection time on its trajectory. Therefore, minimizing the number of UAVs and the maximum completion time of UAVs can be formulated as follows:

$$P_1: \min_{U_n(t), \Lambda, M_n} F_1 Nu + F_2 \max_{n \in \mathcal{N}} \left(\sum_{m=0}^{M_n} \sum_{k=1}^{M_n} \alpha_{m,k}[n] \, t_{m,k}^f + \sum_{m=1}^{M_n} \alpha_{m,0}[n] \, t_{m,0}^f + \sum_{m=1}^{M_n} t_m^c\right) \tag{8}$$

$$\begin{aligned} s.t. \quad & C_1: \gamma_{mn}(t) \geq \gamma_{th} \\ & C_2: \sum_{n=1}^{Nu} M_n = M \\ & C_3: E_n \leq E_{th} \\ & C_4: M_n = \sum_{m=0}^{M} \sum_{k=1}^{M} \alpha_{m,k}[n] \leq M_{max} \\ & C_5: \sum_{n \in \mathcal{N}} \left(\sum_{m=0}^{M_n} \sum_{k=1}^{M_n} \alpha_{m,k}[n] \, t_{m,k}^f + \sum_{m=1}^{M_n} \alpha_{m,0}[n] \, t_{m,0}^f + \sum_{m=1}^{M_n} t_m^c\right) \leq D_n \end{aligned}$$

$$C_6 : \sum_{n=1}^{N} \sum_{m=0}^{M} \alpha_{m,k}[n] = 1, \forall k \in \mathcal{M}$$

where F_1 and F_2 denote the weight coefficients of the number of UAVs and the maximum completion time of UAVs, respectively. $t^f_{m,k}$ denotes the flight time between the FOP_m and the FIP_k. $t^f_{m,0}$ indicates the flight time between the FOP_m and the data center. D_n represents the total mission completion delay. Constraint C_1 indicates that, within the transmission range, the real SNR is higher than γ_{th} and the UAV can continuously collect data from the GIDs. Constraint C_2 means that the data collection mission of M GIDs is assigned to several UAVs. Constraint C_3 gives the energy budget E_{th} of the UAV. Constraint C_4 represents the maximum number of GIDs that can be served of the UAV n. Constraint C_5 ensures that the mission completion time of all UAVs cannot exceed the total mission completion time delay. Constraint C_6 states that each GID only transmits its data to one UAV.

4 Algorithm Design

In this section, we will optimize problem P_1. At first, we assign the data collection mission of M GIDs to several UAVs. Then, we will optimize the UAV's FIP, FOP and OH in the transmission area of each GID and the optimal flight trajectory of the UAV.

4.1 Optimization of UAV number and mission allocation

We assume that the nominal values of the number of UAVs and the maximum mission completion time of UAVs are expressed as $(\widetilde{N}, \widetilde{T})$. Under the condition of $w^{Nu} + w^T = 1$, by combining a group of weight factors $\{w^{Nu}, w^T\}$, the relative importance of the number of UAVs and the maximum mission completion time of UAVs can be reflected respectively. Consequently, problem P_1 is transformed into optimization problem P_2 denoted by

$$P_2 : \underset{S_n \in S, M_n}{min} \Psi \triangleq \frac{w^{Nu}}{\widetilde{N}} Nu + \frac{w^T}{\widetilde{T}} (\underset{n \in \mathcal{N}}{max} (\sum_{m=1}^{M_n} T_{mn})) \quad (9)$$

$$s.t. \quad C_1 - C_6$$

where S is the set of the UAV collection sequences, S_n is the collection sequence of the UAV n. T_{mn} is the service time of the UAV n to the GID m.

We propose an improved ant colony optimization algorithm (IACO) to obtain the optimal solution of problem P_2. The initial OH is just right above the associated GID m. The first part is to find the allocation sequence of each UAV. The process of this algorithm after initializing pheromones is summarized as follows:

- *Step*1-1: From the set of GIDs that have data collection missions and have not been visited, select the GIDs that make constraints C_1 and C_3 satisfied.
- *Step*1-2: If there is no GID that meets the above requirements, add the initial point to the end of the current trajectory. This search process is completed.
- *Step*1-3: Calculate the heuristic information and the transition probability of each satisfied GID based on the pheromone.

The heuristic information $\phi_{mk}(t+1)$ reflects the predetermined factors on the sub path $\alpha_{m,k}[n]$ in the hover point search process of the $(t+1)-$th iteration and can be calculated as follows:

$$\phi_{mk}(t+1) = \varpi \cdot \frac{e^{-\sum_{k=1}^{M_n} E_{kn}}}{(dis(m,k)+1) \cdot lnNu} \quad Nu \geq 1 \tag{10}$$

where ϖ is used to adjust the value of $\phi_{mk}(t+1)$, $dis(m,k)$ is the shortest path length between OHs, and $\sum_{k=1}^{M_n} E_{kn}$ is the total energy consumption from departure to the next OH k.

We use $R_{mk}(t+1)$ to describe the probability of selecting a certain OH k as the next OH of the current OH m in the hover point search process of the $(t+1)$-th iteration. Let $\tau_{mk}(t+1)$ denote the rule of pheromone update. α and β describe the importance of pheromone concentration $\tau_{mk}(t+1)$ and heuristic information $\phi_{mk}(t+1)$ respectively. The transition probability is defined as follows:

$$R_{mk}(t+1) = \frac{(\tau_{mk}(t+1))^{\alpha} \cdot (\phi_{mk}(t+1))^{\beta}}{\sum_{k \in M_n} (\tau_{mk}(t+1))^{\alpha} \cdot (\phi_{mk}(t+1))^{\beta}} \tag{11}$$

- *Step*1-4: Ants choose the next GID according to (11), then go to *Step*1-1.

The second part of this algorithm is to optimize the number of UAVs. The main steps in this section are summarized as follows:

- *Step*2-1: Each ant will search the trajectory of the current UAV in sequence. If there are still GIDs that have not been visited, go to *Step*2-3.
- *Step*2-2: If there is no GID that meets the requirements of C_1 and C_3, add one UAV and recalculate the transmission rate of each GID, then go to *Step*2-1.
- *Step*2-3: At the end of each iteration, we update the global optimal solution and the pheromone value. The rules for updating pheromones are defined as:

$$\tau_{mk}(t+1) = (1-\rho)(\tau_{mk}(t)) + \Delta\tau_{mk}(t) \tag{12}$$

where ρ is pheromone evaporation coefficient, and $\Delta\tau_{mk}(t)$ is the pheromone update value based on the feedback.

- *Step*2-4: Update the global pheromone until the number of iterations is reached, and then go to *Step*2-1.

Algorithm 1 Joint optimization algorithm of mission completion time on HM and FM (JOATC).

Input: the coordinates of the data center and GIDs; the transmission radius R; the data size of the GID C_m; the optimal speed of the UAV v_{opt}; the data size C_n collected by the UAV n in the GID m.

$l_{min} = ||FIP_m - FOP_m||$, $l_{max} = ||FIP_m - GID_m|| + ||FOP_m - GID_m||$; calculate d_{1min} and d_{1max}, d_{2min} and d_{2max};
Divide l, d_{m1}, and d_{m2} into $\Delta_1 = l_{min} : k : l_{max}$, $\Delta_2 = d_{1min} : k : d_{1max}$, and $\Delta_3 = d_{2min} : k : d_{2max}$, and establish matrix A and B.
while $C_n \neq C_m$ and $E_n < E_{th}$ **do**
  if $(||FOP_{m-1} - GID_m|| \leq R) \cap (||GID_m - FIP_{m+1}|| \leq R)$ **then**
    else if $||FOP_{m-1} - GID_m|| \leq R$ **then**
      while Δ_3 is not empty C_1 and C_5 **do**
        Calculate $t_m^f + t_m^c$, store in the matrix B.
      end while
      Calculate d_{m2} of the minimum value in matrix B.
    else if $||GID_m - FIP_{m+1}|| \leq R$ **then**
      while Δ_2 is not empty **do**
        Calculate $t_m^f + t_m^c$, store in the matrix B.
      end while
      Calculate d_{m1} of the minimum value in matrix B.
      Calculate the FIP_m, FOP_m based on the d_{m1} and the d_{m2}.
      while Δ_1 is not empty **do**
        Calculate data collection time t_m^c of the GID m, store in the matrix A.
      end while
      Calculate l_{min} of the minimum value in matrix A.
      Calculate OH_m of l_{min}.
  else
    while Δ_2 is not empty **do**
      for each Δ_3 **do**
        Calculate $t^f + t_m^c$, store in the matrix B.
      end for
    end while
    Calculate d_{m1} and d_{m2} of the minimum value in matrix B.
    Calculate the FIP_m, FOP_m based on d_{m1} and d_{m2}.
    Calculate OH_m.
  end if
end while

Output: The coordinates of FIP_m, FOP_m, OH_m, the number of UAVs; the mission completion time of the UAV n.

4.2 Joint optimization of flight time and data collection time of UAV

In this section, we redefine the flight time t_m^f of the UAV n as the flight time of two adjacent GIDs, $t_m^f = \frac{d_{m1}}{v_{opt}} + \frac{d_{m2}}{v_{opt}}$, where d_{m1} and d_{m2} are the flight distances of the UAV for the GID m and the GID $m+1$, respectively. When the transmission areas of the former or the latter overlap, FOP_{m-1} and FIP_m may overlap. Then, d_{m1} or d_{m2} equals 0.

We redefine the total mission completion time of the UAV n on the predetermined trajectory as

$$\min_{FIP_m, FOP_m, OH_m} \left(\frac{\sum_{m=0}^{M_n} d_{m1}}{v_{opt}} + \sum_{m=1}^{M_n} t_m^c \right) \tag{13}$$

$$s.t. \quad C_1,\ C_3,\ C_5$$

$$d_{1min} \leq d_{m1} \leq d_{1max}$$

$$d_{1min} = \begin{cases} ||FOP_{m-1} - GID_m|| - R, & ||FOP_{m-1} - GID_m|| > R \\ 0, & ||FOP_{m-1} - GID_m|| \leq R \end{cases}$$

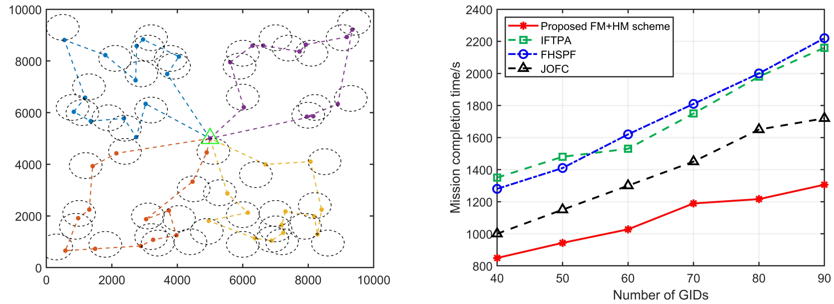
$$d_{1max} = \begin{cases} \sqrt{(||FOP_{m-1} - GID_m||)^2 - R^2}, & ||FOP_{m-1} - GID_m|| > R \\ 0, & ||FOP_{m-1} - GID_m|| \leq R \end{cases}$$

When the transmission areas of GIDs overlap, if GID m overlaps GID $m-1$, we only calculate the FOP of GID m. If GID m overlaps GID $m+1$, we only calculate the FIP of GID m. Then, we find the OH in the non-isosceles triangle region, which is described in Algorithm 1. When the transmission areas of GIDs do not overlap, we optimize the collection trajectory of UAV based on the Fermat points in the triangle. According to the properties of isosceles triangle, the Fermat point of isosceles triangle is on the midperpendicular of the triangle with the three points of the FIP, FOP and OH as the vertices.

5 Simulation Results

To demonstrate the performance of our proposed scheme, we compare our scheme with the other three schemes: improved fly-hover-fly trajectory planning algorithm (IFTPA) [9], FM or HM scheme based on partition algorithm for fixed trajectory (FHSPF) [10], and joint optimization algorithm for flight trajectory and collection trajectory (JOFC) [6]. In IFTPA, the OHs are optimized by clustering GIDs obtain the trajectory of each UAV. The FHSPF compares the two data collection modes. On FM, the optimal flight speed, and the optimal collection point (OCP) of the UAV are optimized. On HM, the UAV collects data only when hovering over GID. JOFC applies two collection modes to the V-shaped trajectory.

Fig. 2(a) shows the final collection trajectory obtained by using the scheme of combining FM and HM. The OH of the UAV within the transmission range



(a) (b)

Fig. 2: (a): The final trajectory of the proposed scheme of combining FM with HM. (b): The mission completion time with diverse number of UAVs.

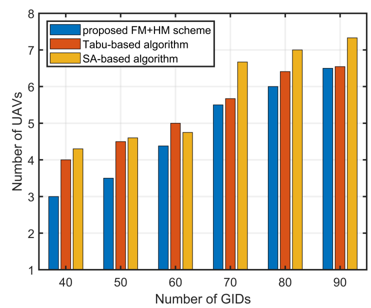


Fig. 3: The mission completion time with diverse number of UAVs.

of the GID deviates right above the GID, which shortens the overall length of the UAV trajectory and reduces the collection time on FM and HM, to achieve less mission completion time. Our scheme can achieve a compromise between the collection time on FM and that on HM by adjusting the flight distance of the UAV within the transmission range of the GID.

The overlap between GIDs is affected by the number of GIDs. Thus, in Fig. 2(b), we further test the impact of the number of GIDs on the mission completion time, including three UAVs, $C = 190Mbit$. Overall, our scheme achieves the best results. In FHSPF, the trajectory of the UAV is optimized, which may lead to longer transmission time of the UAV. On the contrary, in IFTPA, the trajectory of UAV can be shorter by combining the clustering method.

Next, we will compare the proposed algorithm with simulated annealing algorithm and tabu search algorithm, where $C = 95Mbit$. The results of more than 10 runs are averaged, resulting in that the results in Fig. 3 are not integers. The proposed algorithm searches the trajectory more comprehensively, obtaining better performance.

6 Conclusion

In this paper, we study the data collection of GIDs in the IoT networks supported by multiple UAVs to minimize the number and the maximum mission completion time of UAVs. Then we design the IACO algorithm to find the best service order between GIDs, which determines the number and mission allocation of UAVs. Since the interaction between the flight service time and collection service time of various GIDs, we propose the JOATC algorithm for the FIP, OH and FOP in the transmission area of GIDs to minimize the number and the maximum mission completion time of UAVs. Experimental results show that our scheme achieves better results in minimizing the number and the maximum mission completion time of UAVs.

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