Time Sensitive Sweep Coverage with Multiple UAVs

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Abstract—The sweep coverage of UAVs can provide emergency communication support and conduct disaster surveys in emergency disaster relief. These rescue operations are extremely time sensitive. If the UAVs cannot arrive on time, the best rescue opportunity may be missed. When the number and energy of UAVs are limited, it is likely that some Points of Interest (POI) cannot be covered. Thus it's crucial to design a collaborative sweep coverage scheme for multiple UAVs to achieve the maximum effective coverage rate. In this paper, we propose the MES-TS problem. Under the constraints of time sensitivity and the number of UAVs, the objective of the MES-TS problem is to maximize the effective coverage rate in sweep coverage. We prove that the DS-RSC problem is NP-hard. Accordingly, we propose the GCS algorithm for the MES-TS problem. Finally, we conduct extensive simulations and the experimental results demonstrate the advantage of the proposed algorithm.

Index Terms—Sweep coverage, UAVs, Time sensitivity.

I. Introduction

In recent years, with the development of unmanned aerial vehicle (UAV) technology, UAVs have attractive application prospects in many fields, such as smart logistics, agricultural planting, infrastructure inspection, public safety, and aerial media. In these application areas, multiple UAVs are often required to sweep covering given area to complete specific tasks.

The concept of sweep coverage originates from Wireless Sensor Networks (WSNs). In some monitoring tasks, it is not necessary to continuously monitor the Point Of Interest (POI) with static sensors, but only need to patrol the POI with mobile sensors periodically. In this way, a small number of mobile sensors can be used to cover more POIs, and this coverage mode is called sweep coverage [1], [2].

As intelligent aircraft, the new generation of UAVs can carry specialized equipment to perform special tasks. Multiple UAVs can form a UAV network to work cooperatively to improve work efficiency. Compared with traditional mobile sensors, UAVs move faster, have a wider deployment range, and work longer [3]. They are more suitable for performing various coverage tasks and improve coverage performance. They can be widely used in aerial survey, military reconnaissance, fire monitoring, emergency relief, forest fire prevention, ecological monitoring, flood control and drought relief, etc.

In this paper, we study the time sensitive sweep coverage with multiple UAVs in the context of emergency and disaster relief. In emergency and disaster relief, UAVs are often required to quickly cover designated locations within a specified time to provide emergency communications support, material supply, disaster surveys, and other special tasks. These rescue operations are extremely time sensitive. If the UAV cannot arrive on time, the best rescue opportunity may be missed. And each coverage target has different time sensitivity. As shown in Figure 1, if the time sensitivity of a POI is 60 minutes, it wants an UAV to cover it in 60 minute. For example, UAV equipped with aerial base stations flying over the disaster area can bring communication signals to the disaster area. When communication is interrupted in the disaster area, the time sensitivity is higher in densely populated areas. It is expected that UAVs equipped with aerial base stations can cover the area in a shorter time, so that more people in the disaster area can communicate with the outside world in a timely manner, reducing the casualty rate. In uninhabited mountainous areas, time sensitivity is low, giving UAVs a longer time limit to reach the area. Therefore, how to plan the UAVs' sweep coverage path to meet the time sensitivity of different POIs is the focus of this paper. In addition, when the number and power of UAVs are limited, it is likely that some POIs cannot be covered. At this time, it is necessary to increase the effective coverage rate of the UAVs as much as possible, and those POIs that are covered within an acceptable time can be regarded as effectively covered. How to improve the effective coverage

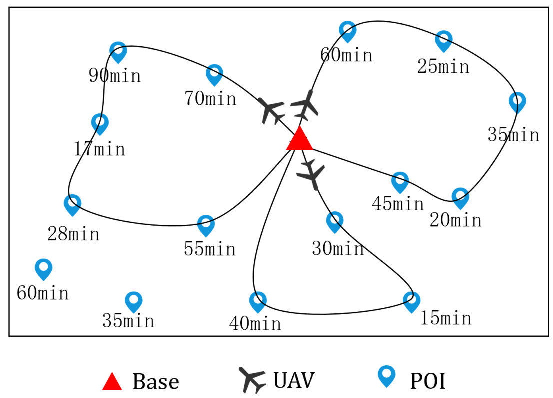


Fig. 1. time sensitive of POIs

is another research focus of this paper.

Since the distance of the POI is not related to its time sensitivity, it's difficult to coordinate well whether UAVs should prioritize access to POI that are close in distance or POI that are time-critical. If the relationship between the two cannot be coordinated well, it will seriously affect the effective coverage rate. Therefore, how to coordinate the relationship between distance and time sensitivity and make every step of the decision for UAV path planning is a challenge to our algorithm design. The details of our contributions can be summarized as follows:

(1) We consider a new problem named Maximum Effective Coverage Rate in Time Sensitive Sweep Coverage with Multiple UAVs (MEC-TS). Given a limited number of UAVs and the time sensitivity of each POI, considering the performance constraints of UAVs, the objective of ME-TSC problem is to design a collaborative scanning coverage scheme for multiple UAVs to maximize the effective coverage.

(2) We prove that maximizing effective coverage rate in time sensitive sweep coverage with multiple UAVs is NP-hard.

(3) We design a heuristic algorithm GCS to solve the MEC-TS problem.

(4) We evaluate the performance of the proposed algorithm, the experimental results demonstrate the advantage of the proposed algorithm.

The rest of the paper is organized as follows. Section II describes the related work. Section III formulates the MEC-TS problem. Section IV presents the GCS algorithm and the corresponding complexity analysis. Simulation results are displayed in Section V. Finally, Section VI concludes this paper.

II. Related Work

A. Traditional sweep coverage

As an emerging field in WSN, sweep coverage has received considerable attention in recent years. In general, problems in sweep coverage can be divided into three types in terms of the optimization objectives:

1) Sensor Quantity Optimization. The objective of this type of problem is to minimize the quantities of mobile sensors in sweep coverage. The general starting point of solving such problems is to reduce the travel distance of mobile sensors in the target region. In [4], [5], Cheng et al. proved that finding the minimum number of mobile sensors is NP-hard. Thus a heuristic algorithm called CSWEEP was proposed to tackle the problem. Subsequent studies present a series of algorithms such as MinExpand and PDBA which have achieved better performance than CSWEEP [6], [7]. Later, more factors such as the return time constraint and communication range are discussed in sweep coverage [8]–[14].

2) Sweep Period Optimization. The objective of this type of problem is to minimize the required sweep period of POIs in sweep coverage. In [15], Feng et al. formulated a novel problem, the objective of which is to minimize the makespan of sweep paths(M^3SR). By means of reducing the makespan, the sweep period of POIs can correspondingly be shortened. Considering requirements of different scenarios, Gao et al. accordingly devised three algorithms with constant approximation ratio, namely CycleSplit, HeteroCycleSplit and PathSplit [16].

3) Sensor Speed Optimization. The objective of this type of problem is to minimize the moving speed of mobile sensors in sweep coverage. In [17], Zhao et al. focused on reducing the moving speed of sensors in sweep coverage under both the sensing delay and transmission delay constraints. Two approximations, STSP and ITSP, were then proposed to provide sweep coverage under the delay constraints.

Unlike previous studies, the objective of our study is to achieving the maximum effective coverage rate in time sensitive sweep coverage. We will optimize the UAV's sweep coverage path in combination with existing sweep coverage research under time sensitivity constraints.

B. Sweep coverage of UAVs

At present, there is not much research literature on the sweep coverage of UAVs. The author of [19] proposed a new coverage path planning method for the energy limitation of multiple UAVs. They defined a typical mission as five mission segments: take-off, cruise, hovering, turning and landing, and proposed a new path-based optimization model that can track the energy required for different mission phases. The path planning of man-machine and multi-drone is effective. In [20], Luo et al. conducted fine-grained trajectory planning for the data collection of multiple UAVs in wireless sensor networks, and used approximate algorithms to minimize the maximum flight time of UAVs, but did not consider the UAV's maximum flight time. Turning angle and turning time. Sun et al. [3], [21] proposed the problem of target detection in UAV-based wireless sensor network (UWSN), while considering static and dynamic targets to plan the path of UAVs, and generate the best of multiple UAVs. Mobile plan. Parikshit et al. [22] considered both polygonal obstacles and turning angle restrictions in the path planning of UAVs, and found feasible paths for UAVs by improving the Dijkstra algorithm and the method of visual reverse search, but this method has limitations. The path planning of a single UAV in a specific scenario cannot be directly applied to the scanning and coverage tasks of multiple UAVs, but its processing method for the limitation of the turning angle is worthy of reference. [23] Also studied the coverage problem of UAVs to provide users with emergency communications in emergency situations, but divided users into indoor and outdoor users, and proposed a scheme based on three-dimensional location, power and bandwidth allocation, which can maximize Realize the coverage of indoor users and outdoor users. This article studies this problem from the aspects of scan coverage and time urgency. Li et al. [24] proposed the shortest time maximum coverage problem (MTMC) of UAVs, that is, under the constraints of UAV performance, in a given area, the maximum coverage can be reached in the shortest time. The author considers the performance of the UAV for mathematical modeling, and uses the objective function to convert the multi-objective optimization problem into a single-objective problem for path planning, and achieves a good coverage effect. However, the algorithm proposed in this article ignores the return time of the UAV. There is a problem that the drone continues to fly beyond the maximum endurance time. This article has made improvements to this problem to ensure that the UAV can return to the base station before the end of the mission time.

III. Problem Formulation

TABLE I

Basic Definitions

Symbol	Definition
P	Set of POIs
U	Set of UAVs
B_0	Base Station
Ts	Set of POIs' time sensitivity
T	The endurance of UAV
t_{start}	The moment when the UAV take off
T_a	The time of ascent phase of UAV
T_{max}	The maximum time of a sweep coverage mission
T_k	The time spent by the UAV u_k after t_{start}
t_i	The time for an UAV flies to POI p_i
t_{ir}	The time flies to POI p_i and then return to base
v	Moving speed of UAVs
ω	Angular speed of UAVs
d_{ij}	Euclidean distance between POI p_i and p_j
$cost_i$	The cost of covering the POI p_i
R_e	effective coverage rate
R_o	on time rate
e	Tolerance coefficient
m	Total number of UAVs
n	Total number of POIs

In this section, we first introduce some assumptions and definitions. With these definitions, the MEC-TS problem is formally modeled.

Assume that n POIs, denoted by $P = \{p_1, p_2, ..., p_n\}$ are randomly distributed in the target area. All of them are static with known position. And m UAVs $U = \{u_1, u_2, ..., u_m\}$ in the base are responsible for covering these POIs. The position of Base B is fixed, each UAV starts from the base, performs the sweep coverage mission, and finally returns to the base.

The endurance of UAV can be divided into three phases:

$$T = T_a + T_c + T_d \tag{1}$$

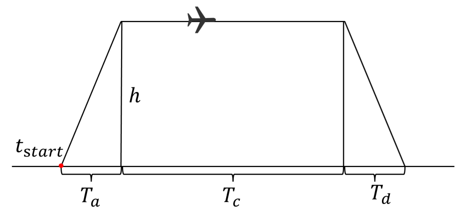


Fig. 2. endurance of UAV

As shown in Figure 2, the UAV takes off at time t_{start}. T_a represents the time of ascent phase, in which the UAV climbs from the base to a specified altitude. T_c represents the time of cruise phase, during which UAV performs the sweep coverage mission. T_d stands for the time of descent phase, which means the UAV finishes its mission and returns to the base on the ground. In this paper, we require the UAVs to complete the sweep coverage mission before the descent phase, so the maximum mission time is set to T_{max}:

$$T_{max} = T_a + T_c \tag{2}$$

In cruise phase, the UAVs fly in fixed altitude h and fixed speed v to sweep covering the POIs, so that the three-dimensional path planning problem for UAVs can be reduced to two dimensions. We simplify that all the POIs are in a Euclidean plane, and the distance between any two POIs p_i and p_j are their Euclidean distance d_{ij}.

The m UAVs perform sweep coverage mission simultaneously. A POI is said to be covered when an UAV fly to its position. In a sweep coverage mission, each POI needs to be covered by an UAV only once. As mentioned in [24], it's necessary to consider the turning time in the flight of UAV, because it takes a certain amount of time for the UAV to turn, which may affect the path planning of the UAV for time-sensitive tasks. Figure 3 shows the turning angle of UAV.

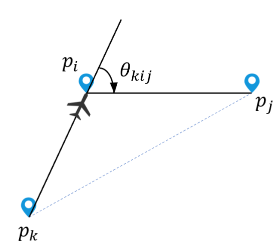


Fig. 3. turning angle of UAV

The UAV flies from POI p_k to p_i, and then from p_i to p_j. θ_{kij}, the turning angle at p_i, can be calculated by the cosine theorem:

$$\theta_{kij} = \pi - \arccos \frac{d_{ij}^2 + d_{ki}^2 - d_{kj}^2}{2 \cdot d_{ij} \cdot d_{ki}} \tag{3}$$

The time for an UAV flies from POI p_i to p_j is consist of two parts [24]:

$$t_j = \frac{\theta_{kij}}{\omega} + \frac{d_{ij}}{v} \tag{4}$$

The first part is turning time, and the second part is distance time. ω and v represent the angular speed and moving speed of UAV respectively.

If p_j is the last POI visited by the UAV, then the UAV will return to base B_0 from p_j. The time to choose the p_j to cover and then return to base B_0 is defined as t_{jr}.

$$t_{jr} = t_j + \frac{\theta_{ijB_0}}{\omega} + \frac{d_{jB_0}}{v} \tag{5}$$

Due to different emergency situations in different regions, n POIs have their own time sensitivity $Ts = \{ts_1, ts_2, ..., ts_n\}$,ts_i represents POI p_i expected to be covered by an UAV within time ts_i. In order to be more realistic, we set up a tolerance coefficient e, $0 \leq e \leq 1$. $e \cdot ts_i$ represents the time that the POI p_i allows the UAVs to be late, because the time sensitivity is not so strict sometimes. Although p_i expects to be covered within ts_i time, it is acceptable for the UAVs to arrive at $(1+e) \cdot ts_i$ time. When the UAVs take off at time t_{start}, the timing starts.

$Definition\, 1\, (on\ time\ rate, R_o)$: A POI p_i is said to be covered on time when an UAV visit it within its time sensitivity ts_i. The on time rate is defined as follows:

$$R_o = \frac{\sum_{k=1}^{m} \sum_{i=1}^{n} x_{ik}}{n} \tag{6}$$

x_{ik} represents whether the i_{th} POI p_i can be covered by the k_{th} UAV u_k, which only has two values of 0 and 1. If p_i can be covered by u_k, $x_{ik} = 1$; otherwise, $x_{ik} = 0$. The on time rate R_o is the ratio of the number of POIs covered on time to the total number of POIs.

$Definition\, 2\, (Effective\ coverage\ rate, R_e)$: A POI p_i is said to be effectively covered when an UAV visit it within its acceptable time $(1+e) \cdot ts_i$. Before time $(1+e) \cdot ts_i$, we call POI alive, after time $(1+e) \cdot ts_i$, POI is dead. The effective coverage rate is defined as follows:

$$R_e = \frac{\sum_{k=1}^{m} \sum_{i=1}^{n} c_{ik}}{n} \tag{7}$$

c_{ik} represents whether the i_{th} POI p_i can be effectively covered by the k_{th} UAV u_k, which only has two values of 0 and 1. If p_i can be covered by u_k effectively, $c_{ik} = 1$; otherwise, $c_{ik} = 0$. The effective coverage rate R_e is the ratio of the number of POIs covered effectively to the total number of POIs.

Formally, the problem of achieving the maximum effective coverage rate in time sensitive sweep coverage with multiple UAVs(MEC-TS) can be defined as follows:

$Definition\, 3\, (MEC-TS)$: Given a set of POIs $P = \{p_1, p_2, ..., p_n\}$, n POIs have their own time sensitivity $Ts = \{ts_1, ts_2, ..., ts_n\}$. With m UAVs $U = \{u_1, u_2, ..., u_m\}$,the goal of MEC-TS is to maximize the effective coverage rate R_e in time sensitive sweep coverage while ensuring that m UAVs end their sweep coverage mission in maximum mission Time T_{max} and return to Base B_0.

The specific mathematical description of the problem is as follows:

$$\max \quad R_e \tag{8}$$

subject to

$$T_k(i) \leq (1+e) \cdot ts_i, \tag{9}$$
$$\forall k \in \{1, 2, ..., m\}, \forall i \in \{1, 2, ..., n\}, 0 \leq e \leq 1$$

$$T_k = T_a + \textstyle\sum_{i=1}^{n} x_{ik} t_i \leq T_{max} \tag{10}$$
$$\forall k \in \{1, 2, ..., m\}$$

$$\textstyle\sum_{k=1}^{m} x_{ik} \leq 1, \forall i \in \{1, 2, ..., n\} \tag{11}$$

where $T_k(i)$ represents the cumulative mission time of the k_{th} UAV when arrives at POI p_i and T_k represents the total time it takes for the k_{th} UAV to complete its mission and return to the base. The optimization goal is to maximize the effective coverage R_e of the entire sweep coverage mission. The first constraint in (9) represents satisfying the time sensitivity of each POI, that is, covering POIs within their acceptable time. The second constraint in (10) means that the mission time of each UAV does not exceed the maximum mission time T_{max}. The third constraint in (11) means that each POI can be covered at most once in a sweep coverage mission to prevent POI from being repeatedly covered.

Furthermore, the MEC-TS problem can be proved to be NP-hard. The details of the proof are as follows:

Theorem 1. The MEC-TS problem is NP-hard.

Proof 1. The MEC-TS's decision problem is that, in a sweep coverage mission, whether there exist such sweep paths for m UAVs that the effective coverage rate can achieve R_e and return to Base. If we consider a special case, i.e., $ts_i \gg T_{max}, \forall i \in \{1, 2, ..., n\}$, which means the time sensitivity of POIs on our problem can be ignored. Further, if we set $m = 1$ and $R_e = 1$, then the decision problem becomes if one UAV can access all POIs while ensuring that its travel distance is no more than vT_{max}. Apparently, the MEC-TS's decision problem under the special case is equivalent to the TSP decision problem. Since TSP problem is NP-hard, the MEC-TS problem is also NP-hard. □

IV. GCS Algorithm

In this section, we present the basic idea and details of the Greedy cost selection algorithm(GCS). Meanwhile, the complexity analysis of the GCS algorithm is also included.

The basic idea of GCS is to generate the sweep paths for each of the UAVs successively in a sweep coverage mission, and the starting point and ending point of each sweep path are the base station B_0. During path planning, we designed a cost function to calculate the cost of accessing each POI. This cost function takes into account the time required to access the POI, the time sensitivity of the POI, and the sweep coverage progress of the current UAV. We adopt a greedy strategy and choose the POI with the least cost to cover every time, geting the optimum sweep path for the current UAV.

A. Details of GCS

Algorithm 1 GCS

Input: The POIs set $P = \{p_1, p_2, ..., p_n\}$, the time sensitivity set $Ts = \{ts_1, ts_2, ..., ts_n\}$, the UAVs set $U = \{u_1, u_2, ..., u_m\}$, the base station B_0, the maximum mission time T_{max}, the moving speed of UAVs v and angular speed ω.

Output: The sweep paths $O = \{O_1, O_2, \ldots, O_m\}$, the on time rate R_o, the effective coverage rate R_e.

1: Check Ts and make it reasonable.
2: **for** $k = 1 \to m$ **do**
3:   Set $O_k = \emptyset$
4:   Set the T_k= T_a
5:   Set xik,
6:   **while** $P \neq \emptyset$ *and* $B_0 \notin O_k$ **do**
7:     **for** $p_i \in P$ **do**
8:       calculate t_i and t_{ir}.
9:       $condition_1 = T_k + t_i \leq (1+e) \cdot ts_i$
10:       $condition_2 = T_{max} - T_k - t_{ir} \geq 0$
11:       **if** condition1 and condition2 **then**
12:         $\varphi = T_k/T_{max}$
13:         $cost_i = t_i + (ts_i - T_k)^{\varphi}$
14:       **else**
15:         $cost_i = +\infty$
16:       **end if**
17:     **end for**
18:     select the $p_j \in P$ who has the smallest cost.
19:     **if** p_j exists **then**
20:       add p_j into O_k.
21:       remove p_j from P.
22:       $T_k = T_k + t_j$
23:       $c_{jk} = 1$
24:       **if** $T_k < ts_j$ **then**
25:         $x_{jk} = 1$
26:       **end if**
27:     **else**
28:       add B_0 to O_k.
29:     **end if**
30:   **end while**
31: **end for**
32: Calculate the effective coverage rate R_e and on time rate R_o.
33: **return** O, R_e, R_o

The details of GCS are presented in Algorithm 1. Firstly, check whether the Ts is reasonable before starting. If ts_i is smaller than the direct distance time d_{iB_0}/v, it is inaccessible, and ts_i needs to be reset. The GCS plans the sweep paths $O = \{O_1, O_2, \ldots, O_m\}$ for m UAVs one by one. The initial sweep path O_k for the k_{th} UAV is an empty set. The variable T_k is a timer, which records the time spent by the UAV u_k after t_{start}. The initial value of T_k is T_a, which is the time of ascent phase. For each p_i in P, we firstly calculate the t_i and t_{ir} by equation (4) and (5). Then judge whether p_i is accessible by two conditions. The first condition is, when the drone flies to p_i, p_i is still alive. That is, when arriving at p_i, the time is within its acceptable range $(1+e) \cdot ts_i$. The second condition is, the remaining mission time is enough for the u_k to fly to p_i and then return to the base B_0. Only when these two conditions are met at the same time, we say that p_i is accessible. Then we design a cost function to evaluate the cost of visiting p_i.

$$\begin{gathered} \varphi = T_k/T_{max} \\ cost_i = t_i + (ts_i - T_k)^{\varphi}, \forall i \in \{1, 2, ..., n\} \end{gathered} \tag{12}$$

The coefficient φ reflects the sweep coverage progress of the current UAV. $(ts_i - T_k)$ represents the remaining access time of p_i. The closer to the end of the sweep coverage mission, the more priority should be given to access the POI with the short remaining access time. In the cost function, the POI that is closest to the current location and has the shortest remaining access time will have the least cost and will be accessed first. If p_i is inaccessible, we set the $cost_i$ to infinity. After calculating the cost for all POIs in P, select the POI p_j who has the smallest cost to cover. And then perform line 20 to 26, add p_j into O_k, remove p_j from P, update the timer T_k, and judge the effective coverage status and on time coverage status of p_j. If p_j does not exist, that is, the cost of all the POIs in current P are infinity, then it means that there is no suitable POI to continue to cover. In this case, the UAV u_k should return to the base B_0. When u_k returns to base or POI set P becomes empty, the path planning of u_k is completed. After planning the sweep paths for m UAVs, calculate the effective coverage rate R_e and on time rate R_o according to equation (7) and (6). The algorithm ends.

B. Complexity Analysis

In GCS, the time complexity for calculating the cost of all POIs in P from line 7 to line 17 is $O(n)$, since there are at most n POIs in P. Similarly, adding POI to the sweep path of UAV u_k from line 6 to 30 requires time complexity $O(n)$, because a sweep path can add n POIs at most. Finally, planning sweep paths for m UAVs, the number of iterations from line 3 to line 30 is m, thus the complexity of the GCS algorithm is $O(mn^2)$.

V. Performance Evaluation

In this section, simulations are conducted to demonstrate the advantage of the proposed algorithm on solving the MEC-TS problem. In the simulation, several algorithms from previous literature, G-MSCR and WTSC, are also implemented for performance comparison [8], [24].

A. Simulation Configuration

In the simulation, the target area is a square with the width of $50km$. The base station B_0 is at the bottom left corner of the square, which is more in line with emergency rescue situations. A number of POIs are randomly distributed in the area and the time sensitivity ts_i is a randomly generated value within a certain range. The maximum mission time is 180 min and the time of ascent phase for UAV is 10 min. The moving speed v of each UAV is set to $25m/s$ while the angular speed ω is $0.1rad/s$ with the minimum turning radius $100m$. In order to study the influence of different variables on the experiment, i.e., the number of UAVs m, the number of POIs n, the range of time sensitivity Ts, we carry out the experiment under three scenarios:

1) $n = 100$, range of Ts=(50min,140min), m varies from 0 to 10.

2) $m = 5$, range of Ts=(50min,140min), n varies from 1 to 400.

3) $m = 5$, $n = 100$, the range of Ts are (30min,120min), (50min,140min), (70min,160min) respectively.

These simulations are repeated for 50 times and the average value is taken as the result.

B. Simulation Results

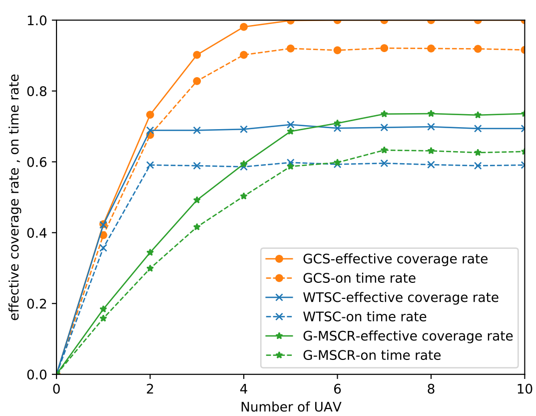


Fig. 4. $n = 100$, range of Ts=(50min,140min)

Scenario 1: Figure 4 illustrates the effective coverage rate R_e and on time rate R_o varying with the number of UAVs m. The solid line represents the effective coverage rate R_e, and the dotted line represents the on time rate R_o. The simulation results show that, regardless of the number of UAVs, the R_e and R_o of GCS are higher than those of WTSC and G-MSCR. When the number of UAV is small, the performance of GCS is similar to that of WTSC, and the performance of GCS is slightly higher than that of WTSC. But with the increase in the number of UAVs, the performance advantages of GCS are becoming more and more obvious. When the number of UAVs exceeds 5, the effective coverage of GCS can reach 100%. The performance of GCS is relatively good. Note that the effective coverage rate is almost 20% higher than the on time rate, this is because we set the tolerance coefficient e to 0.2 in the experiment. It can be seen that even if the tolerance coefficient e is not set, the on time rate of GCS is maintained at a high level.

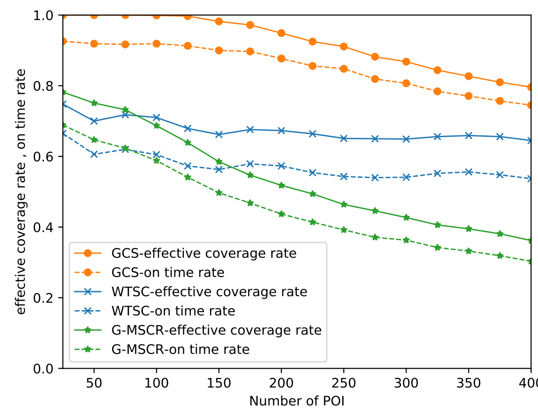


Fig. 5. $m = 5$, range of Ts=(50min,140min)

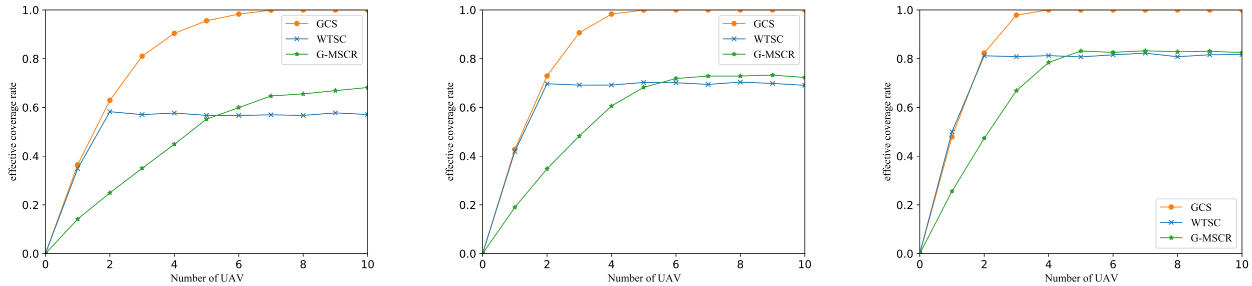
Scenario 2: Figure 5 illustrates the effective coverage rate R_e and on time rate R_o varying with the number of POIs n. Similarily, regardless of the number of POIs, the R_e and R_o of GCS are much higher than those of WTSC and G-MSCR. Note that as the number of POIs increases, the R_e and R_o of the three algorithms is declining. This is because the number and energy of UAVs are fixed, thus the number of POIs that can be covered is limited. The simulation results show that the proposed algorithm GCS has the best performance among these algorithms.

Scenario 3: Figure 6 illustrates the relationship between effective coverage rate R_e and the range of time sensitivity Ts. Range of Ts=(30min,120min) means that some POIs require UAVs to cover it within 30 minutes, which is relatively difficult. The shorter the time, the more difficult. However, in the three subfigures of Figure 6, the effective coverage of GCS is still better than the other two algorithms. It shows that GCS is effective in different time sensitivity ranges. And under the more severe conditions, the advantages of GCS are more obvious.

To sum up, the simulation results indicate that the proposed algorithm GCS achieves better performance than the comparison algorithm in terms of effective coverage rate under all these scenarios.

VI. Conclusions and Future Work

In this paper, we study the MEC-TS problem, the objective of which is to find such sweep paths that



(a) range of Ts=(30min,120min) (b) range of Ts=(50min,140min) (c) range of Ts=(70min,160min)

Fig. 6. $m = 5$, $n = 100$, the range of Ts are in three different ranges.

UAVs can achieve the maximum effective coverage rate. Through theoretical analysis, we prove the NP-hardness of the MEC-TS problem. In an effort to overcome the problem, we devise a heuristic algorithm called GCS which delivers an effective solution in the MEC-TS problem. In the experiment, we compare the proposed algorithm with algorithms from previous literature, namely WTSC, and G-MSCR. The experimental results indicate that, compared with WTSC and G-MSCR, GCS can better meet the time sensitivity of POIs and achieve high effective coverage rate.

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