Regional Scanning Strategy of UAV Cluster Platform for Mobile Emergency Broadcasting

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***Abstract*—With the development of release and retrieval technology for unmanned air vehicles (UAVs), the aerial cluster platform composed of carrier aircraft and multiple rotor UAVs can be used as a new approach for mobile emergency broadcasting operations. It indicates that we can resolve the paradoxical relationship between limited endurance of UAVs and large scale mission area. This paper proposes a region scanning strategy based on the aerial UAV cluster platform. The system can achieve all-region broadcasting in disaster ares, as well as audio and video collection for disaster assessment and emergency rescue.**

***Index Terms*—mobile emergency broadcasting, air cluster platform, region scanning strategy**

I. Introduction

At present, UAVs are widely used in various fields, such as aerial photography [1], delivery [2], [3], disaster rescue [4], [5], electric power inspection [6], agricultural plant protection [7], border monitoring inspection [8], [9], fire monitoring [10], [11], etc. However, limited by the payload, endurance and data information integration capability , a single UAV cannot adapt to diverse environments and satisfy complex requirements. To alleviate these problems, scholars propose using multiple UAVs to cope with complicated work in various fields: Shavbo Salehi proposes an optimal multi-UAV deployment model for UAV-assisted smart farming [12]; Reza Bairam Zadeh proposes a comparison of environment traversal algorithms applied multiple UAVs in bushfire situational awareness [13]; Armaan Garg and Shashi Shekhar Jha propose a multi-UAV based system with directed explorations of flooded areas to gather time-critical ground information [14], etc.

In emergency broadcasting events, the ground infrastructure are always destroyed when disaster striked.Thus, it is very difficult for emergency information to propagate to general public. To deal with this problem, scholars proposed emergency broadcasting system with ATSC Mobile DTV [15] and CDR system for terrestrial audio broadcasting [16]. However, these methods require the public to prepare corresponding recievers in advance. In fact, people stuck in the disaster area always not possess these equipments. In response to the actual situation, mobile emergency broadcasting vehicle is applied [17]. The vehicle equipped with emergency broadcasting device will travel to the alerted area. However, there are still constraints that sometimes the vehicle cannot reach the target area like earthquake-strciken or landslide zone. But we can figure the constraint out through the UAVs which carry the emergency broadcasting device.

This work was supported in part by the National Natural Science Foundation of China (62071294, 61671295, 61671128), and the Shanghai Key Laboratory of Digital Media Processing and transmission; it is also partly sponsored by Shanghai Pujiang Program (16PJD029) , the 111 Project (B07022), Open Foundation of State key Laboratory of Networking and Switching Technology (Beijing University of Posts and Telecommunications) (SKLNST-2021-1-08). (Corresponding author: Jian Xiong)

In major emergency broadcasting events, the cooperation of multiple UAVs enables emergency broadcasting to handle more complicated situations and improve its credibility. The rotor UAVs (UAV-T, task UAV) are equipped with emergency broadcasting device which allows themselves to carry out emergency broadcasting operations at high altitude. Such as rebroadcasting emergency broadcasting program, on-site audio and video acquisition,tweeter broadcasting, high beam lighting and emergency rescue. Besides, the carrier aircraft (UAV-C) can transfer the UAV-Ts to each post-disaster area quickly. Moreover, it is convenient to supply maintenance and energy of the UAV-Ts in the UAV-C. Through the aerial cluster platform, emergency broadcasting can get rid of the constraint of complicated environments and increase the search radius of UAV-Ts and promote UAV-Ts' survivability as well.

This paper propose a regional scanning strategy based on aerial cluster platform. Aerial cluster platform composed of UAV-T and UAV-C is first proposed and used in mobile emergency broadcasting system. Our strategy realizes full region emergency broadcasting task in more extensive area compared to other methods. Our experiments demonstrate that our strategy,a multi-segment heuristic algorithm, can reasonably plan the scanning paths of rotor UAVs and flight path of carrier aircraft, which ensure emergency broadcasting task can be finished as soon as possible.

The remainder of the paper is organized as follows. The regional scanning strategy based on aerial cluster platform and the system model are introduced in Section II . The specific approach is described in Section III . The simulation results and analyses are presented in Section IV, and the paper is summarized in Section V.

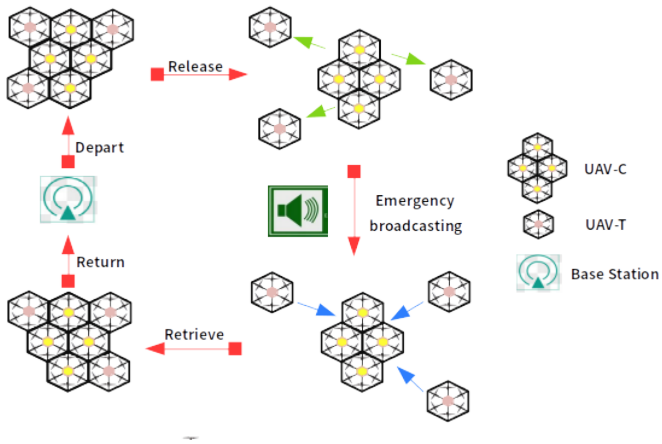


Fig. 1. Release and Retrieve operations in UAV cluster platform

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. SYSTEM MODEL

Limited by UAV's endurance and complex environments, single UAV cannot finish the emergency broadcasting work for the whole target area. In the proposed model, rotor UAVs (UAV-T)are responsible for specific tasks according the requirements of emergency broadcasting, such as scanning the target area, collect the video and audio data, high beam lighting, etc. As for carrier aircraft (UAV-C), it is used to transfer the rotor UAVs from the base station to an appropriate position and then release UAV-Ts uniformly. When UAV-Ts finish their emergency broadcasting work, the UAV-C will retrieve the UAV-Ts uniformly in another proper position. Then UAV-C will carry UAV-Ts to next release position. During the transfer process, UAV-Ts can be charged or replace its battery immediately.These operations ensure that UAV-Ts can constantly complete emergency broadcasting work. During the time interval of each pair of release and retrieve operation, multiple UAV-Ts released from UAV-C collaboratively complete the emergency broadcasting task in the local area. With continuous iteration of release and retrieve operation, the whole target area will be covered. Then the UAV-C will return to the initial base station together with the retrieved UAV-Ts. The reason why the carrier releases and recovers UAVs uniformly is based on the consideration of the existing release and recovery technology. Through the uniform operation, UAV-C can save a lot preparation time for each release and retrieve operation. The whole system is illustrated in Fig.1 .

B. PROBLEM FORMULATION

To facilitate problem formulation, table I shows the notations used in the process. During the emergency broadcast operation for target area S, we denote the location of the initial base station as N_{base}. During the process, UAV-C released and retrieved UAV-Ts n_s times and the ith release position and retrieved position is denoted as $\{Prel_i, Pret_i\} \in P, \quad i = 1, \dots, n_s$. The time to finish the whole work, T, can be divided into two parts. The first part is transfer time T_{tf} that UAV-C carries UAV-Ts from one position to another position. The second part is time T_{ac} needed to complete scanning task in collaboration with UAV-Ts.

TABLE I
TABLE OF NOTATION

Parameter	Definition
T	Total time for emergency broadcasting work
T_{tf}	Transfer time of UAV-C
T_{ac}	Task time of UAV-Ts in emergency broadcasting
T_r	Time for a unified release and retrieve operation
T_{max}	Endurance time of UAV-T
N_{base}	Base station
P	Set of the release position and retrieved position
M	Maximum number of UAV-Ts that UAV-C carry
S	Set of points in rasterized target region
A_S	Total area of target region
D	Scan area in unit time of UAV-T
Q	Control scale constant in R-ACO
$Dist(\cdot)$	Euclidean distance for a UAV-T's coverage path
$Tabu$	Taboo list in R-ACO, record the visited points
$d(\cdot,\cdot)$	Euclidean distance function
v_c	Flight speed of UAV-C
v_d	Flight speed of UAV-T
n_s	Number of release and retrieve operations
m	Number of cluster platforms in ant colony of R-ACO
τ	Pheromone factor
η	Visibility factor
α	Pheromone heuristic factor
β	Expectation heuristic factor
ρ	Evaporation factor
δ_τ	Increment of pheromone factor
DARP	Divide Areas Algorithm for multi-robots
R-ACO	Revised ant colony optimization algorithm
PSO	Particle Swarm optimization algorithm

The transfer time T_{tf} means the time needed for the whole process. The whole process includes the UAV cluster platform depart from the base station N_{base} to the first release position. And then the platform departs from the first retrieve position to the next release position until returning to the base station N_{base} from the last retrieve position:

$$D_{tf} = d(N_{base}, Prel_1) + \sum_{i=1}^{n_s-1} d(Pret_i, Prel_{i+1}) + d(Pret_{n_s}, N_{base}) \tag{1}$$

$$T_{tf} = \frac{D_{tf}}{v_c} \tag{2}$$

where $d(\cdot,\cdot)$ denotes the distance between two positions and D_{tf} indicates the total transfer flight of the UAV-C carrying UAV-Ts.v_c represents the average flying speed of UAV-C.

As for the time for UAV-C and UAV-Ts to complete the scanning task in collaboration T_{ac}, it is composed of the time for each release and retrieve operation and the time for completing the corresponding local emergency broadcast operation:

$$T_{ac} = n_s * T_r + \sum_{i=1}^{n_s} T_{ac}^i \tag{3}$$

where T_r is time consumed for a unified release and retrieve operation, T_{ac}^i indicates the time needed for ith emergency broadcasting in corresponding local area.

The ith emergency broadcasting in corresponding local area, in fact, consists of two parallel parts. One is UAV-C transfers from release position to retrieve position, the other is UAV-Ts finish their own scanning task. UAV-Ts will start their emergency broadcasting work from the release position. After completing the work, they will return to retrieve position to be retrieved uniformly.

$$T_{ac}^i = max\{\frac{d(Prel_i, Pret_i)}{v_c}, t_{ac}^i\}, i = 1, 2, ..., n_s \tag{4}$$

Here t_{ac}^i denotes the time consumed by UAV-Ts to finish the ith emergency broadcasting in corresponding area :

$$\begin{cases} t_{ac}^{ik} = \frac{l_{ac}^{ik}}{v_d} \\ t_{ac}^i = max\{t_{ac}^{ik}\} \\ i = 1, 2, ..., n_s, k = 1, 2, ..., m_i \end{cases} \tag{5}$$

where $\{t_{ac}^{ik}\}$, $\{l_{ac}^{ik}\}$ indicate the time taken and total distance of scanning path for the kth UAV-T to complete the corresponding operation in the ith local task individually, the number of UAV-T deployed in the ith local task denoted as m_i.

In the mean time, limited by the endurance, the time consumed by UAV-T for local task must satisfy the constraint:

$$t_{ac}^{ik} \leq T_{max} \tag{6}$$

where the endurance time of UAV-T is denoted as T_{max}.

From above instructions, the problem can be summarized as follows:

$$\begin{aligned} \min_{Prel_i, Pret_i} \quad & T = T_{tf} + T_{ac} \\ s.t. \quad & \mathcal{C}1 : t_{ac}^{ik} \leq T_{max} \\ & \mathcal{C}2 : \bigcup_{i=1,\ldots,n_s;k=1,\ldots,m_i} A_{ac}^{ik} \geq A_S \\ & \mathcal{C}3 : m_i \leq M \end{aligned} \tag{7}$$

where $\mathcal{C}1$ ensures that the UAV-T can execute and complete the mission under the constraint of endurance time, $\mathcal{C}2$ ensures the overall local area can cover the whole target area A_S and $\mathcal{C}3$ indicates the the number of UAV-T released every time less than the number of carried UAV-T.

III. PROBLEM SOLUTION

In this paper, a piece-wise heuristic algorithm is proposed to solve the problem shown in (7) and there are two phases included in algorithm. Phase I: divide the target region into several local emergency broadcast areas. Each area will be scanned by the UAV-Ts during one release and retrieve operation; Phase II: select the appropriate release and retrieve location in the divided local area. Then the problem is transformed into the area coverage path planning problem for multiple UAV-Ts and the traveling salesman problem for UAV-C. The carrier aircraft will travel all the release and recovery locations from the base station and return to the base station in the end.

A. Local Operation Area Partition

In order to facilitate the division of regions, the target region S is rasterized in this paper. In the process of division, in order to minimize the time required for task execution, UAV-C will release all the UAV-Ts uniformly during each release operation:

$$m_i = M \quad i = 1, 2, ...n_s \tag{8}$$

More parallel UAV-Ts can greatly shorten the time needed for emergency broadcasting in local area. In the mean time, to save the release and retrieve operation time , we will divide the target area according to the maximum area covered by UAV-Ts. Based on this greedy idea, we can obtain the minimum number of local areas which indicates less release and retrieve operations.

$$\begin{aligned} & S_{max} = m_i * D * T_{max} \quad i = 1, 2, ...n_s \\ & n_s = \lceil \tfrac{A_S}{S_{max}} \rceil \end{aligned} \tag{9}$$

Here we use DARP [18] algorithm to divide target area to n_s partitions evenly.S_{max} indicates the largest region that all UAV-Ts can scan during endurance time T_{max}. We will treat the whole UAV cluster platform as a single robot. When UAV cluster platform implements the task of emergency broadcasting in different local areas in order, it can be considered as different robots work in respective area. The algorithm flow chart is described in Fig.2 .

B. mCPP for UAV-Ts

We will choose the proper release position first in each local area devided in Phase I .Then UAV-Ts will implement the task of emergency broadcasting in collaboration from the release position. In fact, this becomes a coverage path planning problem for multiple robots. After UAV-Ts finished the work, UAV-C will retrieve all the UAV-Ts uniformly in appropriate retrieve position.

The release position $\{Prel_i\}, i = 1, \ldots, n_s$ is randomly selected in each partition area. Given the start position and relative performance information of UAV-T, we can revised the ant colony optimization algorithm (ACO) to plan multiple UAV-Ts coverage paths. In this algorithm, we treat all the UAV-Ts as a uniform platform. Then, the ant colony is composed of m cluster platforms. Different from previous ant optimization algorithm, UAV cluster platform will choose the specific UAV-T firstly. Then it will select the grid each step from the remain grids except those in taboo list. The probability of being chosen as next grid is calculated by using the pheromone concentration.

$$P_{ij}^q = \frac{\tau_{ij}^\alpha * \eta_{ij}^\beta}{\sum_{s \in S \setminus Tabu} \tau_{is}^\alpha * \eta_{is}^\beta}, \quad j \in S \setminus Tabu \tag{10}$$

τ_{ij} is denoted as pheromone factor, η_{ij} is visibility factor between grid i and grid j. In the mean time, to ensure UAV-T can reach the next grid, the next grid j must satisfy the constraint:

$$\frac{Dist(lt_{id}^q) + d(et_{id}^q, j)}{v_d} \leq T_{max} \tag{11}$$

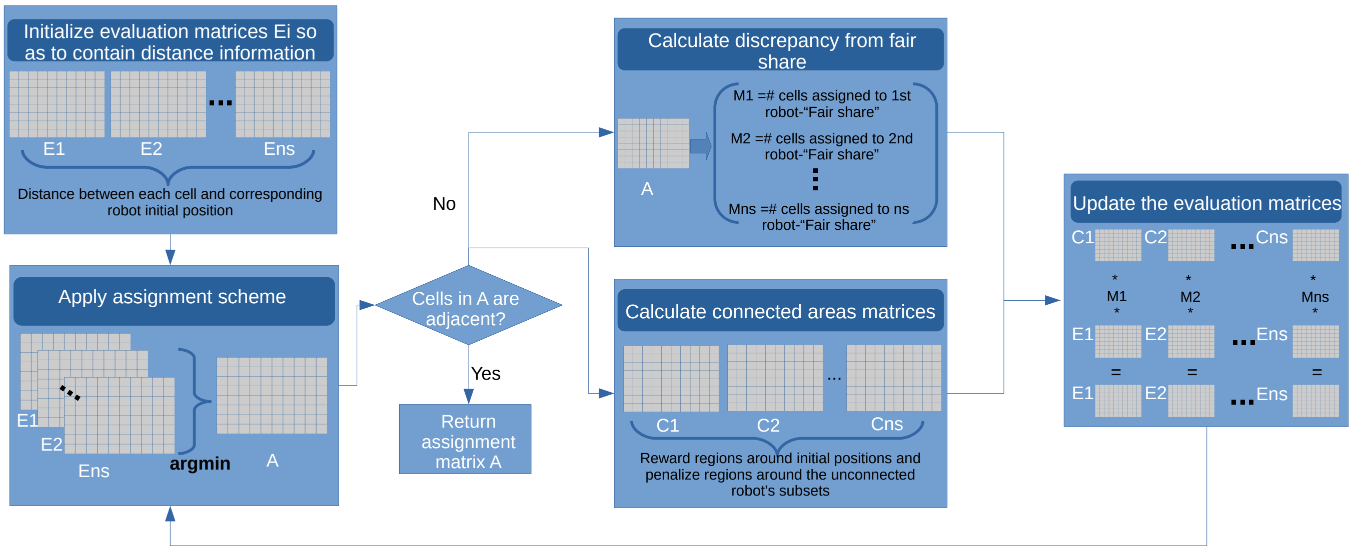


Fig. 2. Divide Areas based on Robots Initial Positions

where lt^q_{id} indicates the idth UAV-T's coverage path in qth aerial cluster platform,et^q_{id} is the end point of coverage path lt^q_{id}.

Our optimization goal is to minimize the maximum time of UAV-Ts finished all its covrage path and return to the retrieved position.Thus we use ant-cycle model to update pheromone factor τ_{ij} and the increment of pheromone $\delta_{\tau_{ij}}$ is inversely propotional to the maximum distance of UAV-Ts' coverage paths.The pheromone factor update equation is formulated as followings:

$$\begin{cases} \tau_{ij}^{itr+1} \leftarrow \rho * \tau_{ij}^{itr} + \delta_{\tau_{ij}(itr,itr+1)} \\ \delta_{\tau_{ij}(itr,itr+1)} \leftarrow \sum_{q=1}^{m} \delta^q_{\tau_{ij}(itr,itr+1)} \\ \delta_{\tau_{ij}(itr,itr+1)} \leftarrow \frac{Q}{max_{id\in\{1,\ldots,M\}}\{Dist(lt^q_{id})\}} \end{cases} \tag{12}$$

where $\delta_{\tau_{ij}(itr,itr+1)}$ is the increment of pheromone between the itr iteration and next iteration.

The revised ant optimization algorithm (R-ACO) is summarized in Alg.1

Algorithm 1 Revised Ant Colony Optimization Algorithm for Multiple UAVs

Input: the rasterized area S, M drones, depart position st
Output: the coverage paths l_i and end point $e_i, i = 1, \ldots, M$; the minimum task time T
Initialize the number of iteration N, maximum steps for each cluster platform Ms
Initialize table PT, P^q_{ij} denotes the probability of qth cluster platfrom transfers from ith grid to jth grid
if $st \in S$ **then**
  $S \leftarrow S \setminus \{st\}$
end if
for $itr = 1, \ldots, N$ **do**
  for $q = 1, \ldots, m$ **do**
    while $S \setminus Tabu$ not equals $\emptyset$ **do**
      Initialize taboo list $Tabu \leftarrow \emptyset$
      Initialize a list of UAV-T's path list lt^q_x, $x = 1, \ldots, M$
      Randomly choose a UAV-T, its id is denoted as $id, id \in \{1, 2, \ldots, M\}$
      Choose next city j that cluster platform most likely to go according to the probability:

$$j \leftarrow \arg\max_{j \in S \setminus Tabu} P^q_{ij}$$

      P^q_{ij} is calculated by following eq.(10)
      if grid j satisfy the constraint in eq.(11) **then**
        Add jth grid S_j into Tabu list: $Tabu \leftarrow \{S_j\} \cup Tabu$ and record the grid in lt^q_{id}
      end if
      $step \leftarrow step + 1$
      if $step \geq Ms$ **then**
        BREAK
      end if
    end while
  end for
  Update the pheromone factor τ
  if there is a UAV-T travels from grid i to grid j **then**
    τ is updated according to eq.(12)
  end if
  Calculate the minimum time T_{itr} of the m ants
  Record minimum coverage paths $\{l^{itr}_x\}, x = 1, \ldots, M$
  if $T_{itr} \leq T$ **then**
    $T \leftarrow T_{itr}$,$\{l_i\} \leftarrow \{l^{itr}_x\}, x = 1, \ldots, M$
  end if
end for
return $\{l_i\}, \{e_i\} \quad i = 1, \ldots, M; \quad T$

Based on R-ACO algorithm, the complete coverage path planning algorithm is summarized in Alg. 2

Algorithm 2 Coverage Path Planning Algorithm for Multiple UAV-Ts

Input: the divided local area$\{S_i\}$, $i = 1, ..., n_s$,M drones
Output: the release and recycle points $\{Prel_i, Pret_i\}$ and coverage paths $\{U_k\}, k = 1, \ldots, M$ for UAV-Ts in each local area, the minimum time to finishe the whole work T
for $j = 1, 2 \ldots, n_s$ **do**
  $Prel_j \leftarrow$ randomly choice a point from S_j
  $Ut_j, Et_j, Tt_j = R - ACO(S_j, M, Prel_j)$
  for $k = 1, \ldots, M$ **do**
    $U_k \leftarrow U_k \bigcup Ut_j^k$
  end for
  for grid $p \in S_j$ **do**
    $C(p) = \sum_{k=1}^{M} d(Et_j^k, p)$
  end for
  $Pret_j \leftarrow \arg\min_{p \in S_j} \quad C(p)$
end for
Calculate T by eq.(7)
return $\{Prel_i, Pret_i\}, i = 1, ..., n_s$; $\{U_k\}, k = 1, \ldots, M; T$

C. TCP for UAV-C

In order to save the travel time, the order to access all the local areas need to be carefully considered. This in fact converts the original problem into a travelling salesman problem (TCP) if we treat each pair of release and retrieve position as a city.

IV. SIMULATION AND DISCUSSIONS

A serial of simulation experiments are conducted in this part and the parameters used in experiments are in table II. Here we use the proposed multi-segment heuristic algorithm to finish the mobile emergency broadcasting task in target area and explore the relationship between the number of UAV-Ts carried in UAV-C and the performance of the whole cluster platform. Fig.3 and Fig.4 correspond to the situation that UAV-C carries 3 UAV-Ts. As it can be seen in Fig.3 , the target area is divided into 4 parts: I,II,III,IV through DARP algorithm. Then we apply R-ACO algorithm in each local region part to obtain the coverage path for each UAV-Ts and the result is shown in Fig.4 . In part II and part IV , the retrieve position coincides with the release position. To this end, we use PSO algorithm [19] to calculate the flight path for UAV-C and the result is shown in Fig.3 .

We explore the performance of the air cluster platform when UAV-C carries different number of UAV-Ts. And here use three metrics: the time of UAV-Ts to finish the emergency broadcasting task, the time of UAV-C to transfer between each pair of release and retrieve position and the redundancy to evaluate the performance of the cluster platform. The metric

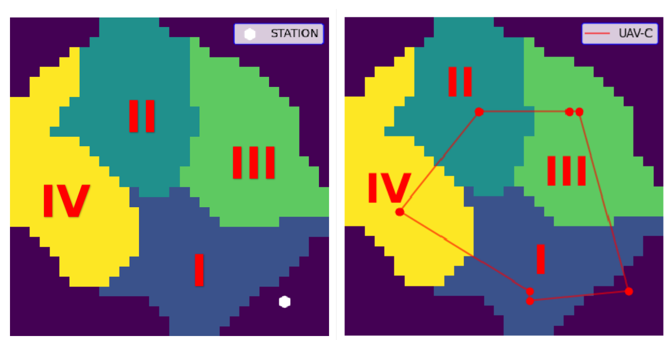
TABLE II
PARAMETER TABLE

Parameter	Value
m	200
τ	1
α	2
β	3
ρ	0.1
v_d	30 m/s
v_c	14 m/s
Q	100
D	0.19 km^2/min
T_{max}	68 min
A_S	136 km^2

redundancy R is the percentage of grids that are in excess of the rasterized grids V, L is the total length of all the UAV-Ts' coverage paths. The redundancy indicates the degree of coverage path repetition.

$$R = \frac{L}{V} - 1 \tag{13}$$

As it can be seen in Fig.5 , with the increase of the number of UAV-T, the time of UAV-T to finish the emergency broadcasting task is decreased. But when the number of UAV-T reach a certain level, the UAV-T time will not decrease since the redundancy of the path increased. Compared to finish the emergency broadcasting task with single UAV-T, proper number of multiple robots can lower the total time by about 75%. From Fig. 5 , the UAV-C carries 6 UAV-Ts can finish the emergency broadcasting task better since it gives consideration to both task time and redundancy.



(1) DARP for area division (2) TSP for carrier aircraft

Fig. 3. The area partition by DARP method is on left and the flight path of UAV-C is on right.

V. CONCLUSIONS

This paper proposes a region scanning strategy based on the aerial UAV cluster platform to realize the whole region emergency broadcasting work of the target area. Through the air cluster platform, emergency broadcasting can get rid of the constraints of complicated environments. We increase the search radius of UAV-Ts and promote the UAV-Ts' survivability as well, which enhances the UAV's large-scare mission execution capability greatly. Our results demonstrate

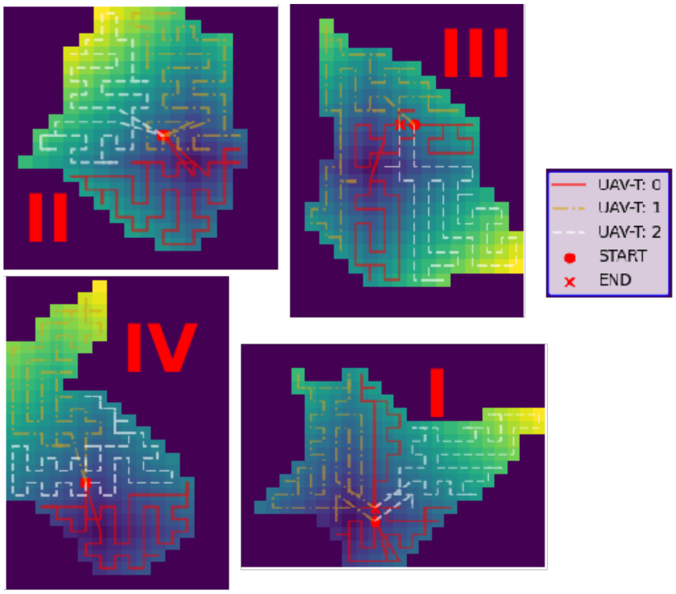


Fig. 4. Coverage Path Planning for Multiple UAV-Ts.

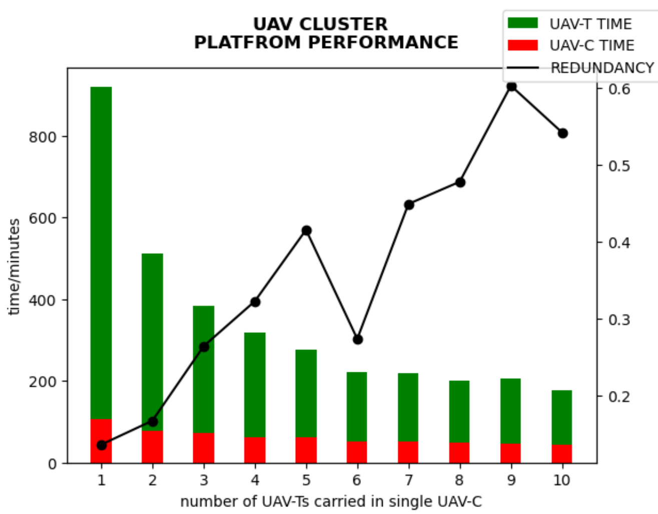


Fig. 5. Performance of UAV Cluster Platform.

that proper number of UAV-T in platform can shorten the time to finish work of the emergency broadcasting as well as lower the redundancy.

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