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Communications in Computer and Information Science 1042

Computer Supported Cooperative Work and Social Computing

14th CCF Conference, ChineseCSCW 2019
Kunming, China, August 16–18, 2019
Revised Selected Papers

Springer

中国计算机学会 CCF

Contents

Solving the Signal Relay Problem of UAV in Disaster Relief via Group Role Assignment

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Abstract. When an earthquake occurs, disaster relief is an urgent, complex and critical mission. Decision makers must possess critical role awareness to prioritize the numerous interrelated tasks arising from such an event. High on the list is communication network recovery within the disaster area. Unmanned aerial vehicles (UAVs) are often used in this regard. Some of them are used as repeaters to provide the required network coverage. Their timely, efficient deployment to specific locations is a challenging exercise for disaster relief planners. In response to such a need, this paper formalizes and solves the problem of UAV deployment for signal relay via group role assignment (GRA). The minimum spanning tree algorithm is applied to model a rapidly deployed optimal relay network. It can help establish the minimum number of relay points necessary to ensure communication stability. In this scenario, UAVs (agents) adopt roles as communication relays. The task of distributing UAVs to relay points can be solved quickly via the assignment process of GRA, which can solve the x-ILP problem with the help of the PuLP package of Python. Results from thousands of experimental simulations indicate that our solutions are effective, robust and practical. The process can be used to establish an optimal, efficient relay network using UAVs. Their rapid deployment can be a significant contribution in earthquake disaster relief.

Keywords: Disaster relief in earthquake · Signal relay · Unmanned aerial vehicle (UAV) · Group role assignment (GRA)

1 Introduction

China experiences many earthquake disasters. When such an event occurs, communication recovery within the disaster area plays a vital role in disaster relief. Unmanned aerial vehicles (UAVs) can be rapidly deployed to reestablish communications when physical infrastructure has been damaged or destroyed.

UAVs [1–3] can perform various roles in disaster relief such as patrolling, detecting and relaying. Decision makers face the challenge of quickly determining the numbers of and roles adopted by such equipment. In communication recovery, it is necessary to

Y. Sun et al. (Eds.): ChineseCSCW 2019, CCIS 1042, pp. 18–29, 2019.
https://doi.org/10.1007/978-981-15-1377-0_2

have efficient tools to send the minimum number of UAVs to locations that provide stable coverage over the disaster area.

The key of deploying UAVs as communication relays is an awareness of the number and locations of relay points. Next comes the task of role and location assignment of drones from different base stations into a successfully coordinated network. There are many combination methods which can do this job. However, the specific scenario and scale of an earthquake often change. A comprehensive model is needed to deal with different but equally urgent incidents. It is critical that a solution distributes a minimum number of mobile communication devices into a robust, economical network in the shortest time possible. Consideration must also be given to other important tasks that a UAV fleet must perform disaster relief and re-construction.

This paper formalizes and solves the problem of establishing UAV signal relay networks via group role assignment (GRA). GRA [4, 5] is a complex process throughout the life cycle of RBC [6–8]. RBC has become a practical method for decision makers relative to task distribution.

Signal relay networks over a disaster area can be established by considering relay points as roles and UAVs as agents. This paper firstly provides an effective and comprehensive solution to the problem via GRA. In modeling the rapid reestablishment of communications over a disaster area, we initially use the minimum spanning tree algorithm to determine an optimal relay network that requires the minimum number of UAVs at locations that offer stable, full coverage of the affected area. Using the assignment process of GRA, relay locations are considered roles and UAVs are agents.

This paper has listed the contributions below:

(1) Clearly formalizing the problem of establishing signal relay networks using UAVs over a disaster area via GRA, which can provide a uniform method;
(2) An efficient, comprehensive method for deploying UAVs as repeaters to the right places within an acceptable time; and
(3) Creation of an economical yet stable communication network that uses the minimum number of UAVs as a timely, significant contribution to earthquake disaster relief.

The organization of the paper is listed: It firstly uses a real-world scenario to illustrate the problem in Sect. 2. Then, we formally define the problem via RBC and its E-CARGO model in Sect. 3. Section 4 proposes a solution to the problem via GRA, with simulation experiments. Section 5 discusses related work. The paper concludes with future work in Sect. 6.

2 A Real-World Scenario

Sichuan is a frequent earthquake area. For instance, in 2008, the Wenchuan earthquake of magnitude 8 occurred in Sichuan. Unfortunately, another 7.0-magnitude earthquake jolted Jiuzhaigou County on August 8th, 2017. According to the China Earthquake

Networks Center, the quake struck at a depth of 20 km. More than 90 emergency vehicles and 1,200 personnel were dispatched to participate in the rescue work.

The communication system was affected by the quake. This essential component of search and rescue required the deployment of several mobile communication vehicles to resume communication. Because the earthquake destroyed most of the roads in Jiuzhaigou, the vehicles were only capable of communication within a 2 km radius (see Fig. 1(a)).

To restore communication over the disaster area, the communication department decided to deploy UAVs carrying communication equipment. These UAVs departed from various bases in Jiuzhaigou simultaneously. We assume that each UAV hover stably in the air with a small radius so that we treat it as stationary state. Due to load limitations of the drones, the on-board communication equipment had to be within 3 km of the mobile communication vehicle (see Fig. 1(b)). The communication distance between drones was limited to 6 km.

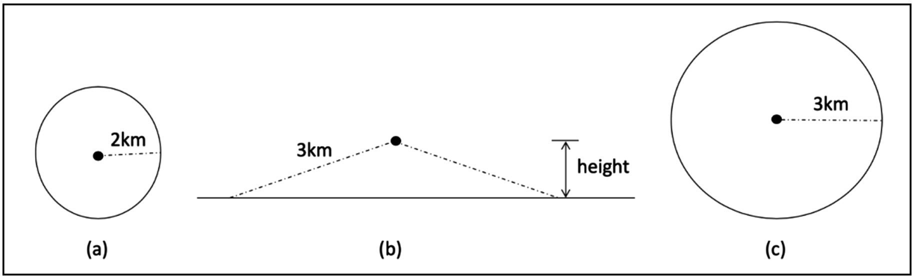

Fig. 1. The covered shape of the communication vehicle and the drone.

To ensure communication quality, the altitude of each drone is much smaller than its coverage radius; hence the administrators can consider that a drone's coverage shape is also a circle (see Fig. 1(c)). In general, for robust performance, the rescue center assumed that one UAV could only guarantee stable communication with one other link. However, it can be used as a back-up communication drone for other links if some of the intersected UAVs fail to work.

To guarantee the effectiveness of our solution, partial real-world elevation data of Jiuzhaigou was used to carry out all of the simulation experiments. Figure 2 is the contour map drawn from the partial elevation data of Jiuzhaigou. The square shape in Fig. 2 represents the base station, and the circle shape is the communication vehicle. To keep our visualization distribution result clearly displayed, it set the covered radius of a UAV as 3 km, and the number of bases is 8. The number of communication vehicles is set as 15.

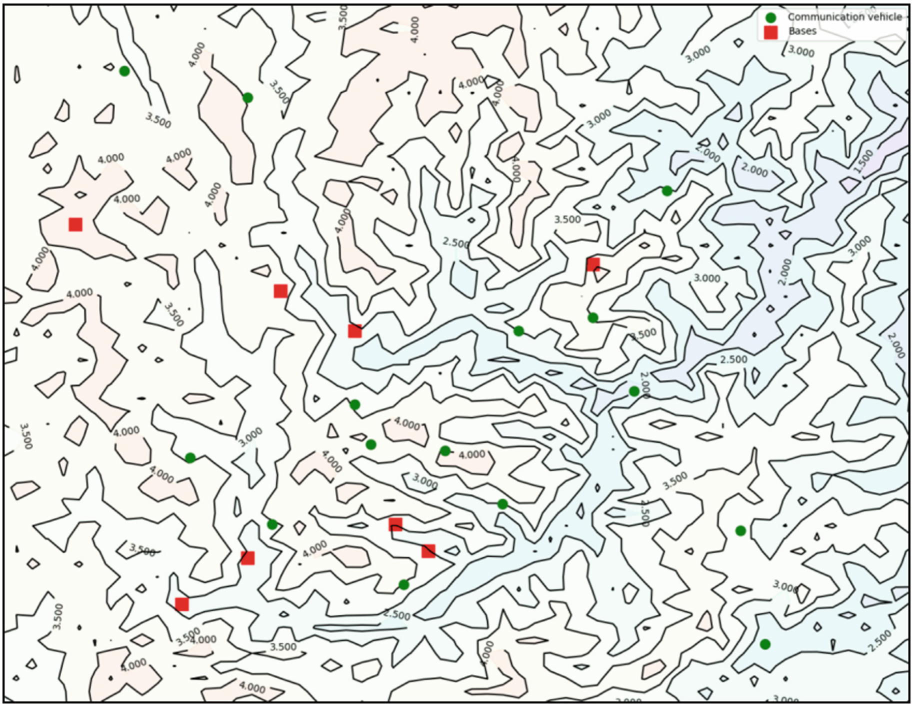

Fig. 2. The contour map of the partial real-world elevation data of Jiuzhaigou. Notes: A red square represents a base station, and a green circle represents a communication vehicle. The location of the communication vehicles in a range from 3 km to 98 km. (Color figure online)

As each drone has a maximum flight time, it needs to be replaced by other drones from the same base station when it nears its maximum flight time. Also, each base station needs to dedicate some drones to carry out patrolling and detecting tasks in the disaster area. Therefore, each station has a limited number of assigned drones for communication (see Table 1).

Table 1. The limited numbers of UAV

Base station	1	2	3	4	5	6	7	8
The limited numbers of UAV	10	13	16	9	11	14	12	15

This signal relay task is a great challenge in the deployment of UAVs in Jiuzhaigou. It is vital to quickly determine the number of signal relaying UAVs and send them to the right locations within an acceptable time, while having other UAVs available to do other relief jobs.

From the above scenario, the problem can be dealt with by following the initial steps of RBC and a related GRA problem. The first part is role negotiation, which needs to be aware of and propose the fewest relay points and related roles. After that, the primary objective is to minimize the number of distributed UAVs while ensuring global communication in Jiuzhaigou.

3 Problem Formalization with GRA

To solve the problem, we initially describe it using the GRA method, which is the kernel of RBC and its formalization model E-CARGO.

3.1 The Brief of E-CARGO Model

To better definition of the problem, we first concisely describe the required concepts and definitions of the E-CARGO model. The key of the E-CARGO model is a system Σ which can be defined as a 9-tuple $\Sigma ::= <\mathcal{C}, \mathcal{O}, \mathcal{A}, \mathcal{M}, \mathcal{R}, \mathcal{E}, \mathcal{G}, s_0, \mathcal{H}>$, where $\mathcal{C}$ represents the classes, $\mathcal{O}$ represents the objects, $\mathcal{A}$ represents the agents, $\mathcal{M}$ represents the messages, $\mathcal{R}$ represents the roles, $\mathcal{E}$ represents the environments, $\mathcal{G}$ represents the groups, s_0 is the initial state of the system, and $\mathcal{H}$ represents the users.

Furthermore, we use nonnegative integers m ($=|\mathcal{A}|$) to express the number of the agent set $\mathcal{A}$, n ($= |\mathcal{R}|$) the size of the role set $\mathcal{R}$, $i, i_1, i_2, \ldots$ the indices of agents, and $j, j_1, j_2, \ldots$ the indices of roles.

Before formalizing our problem by E-CARGO, it is important to classify the role, the agent and the qualification matrix that evaluates the agent when assigning it to a specific role. In our scenario, considering UAVs as agents is straightforward, but considering the relay points as roles poses quite challenging. For this reason, role negotiation was dealt with first. This was needed prior to using the GRA method.

3.2 Role Negotiation

The role negotiation process in this paper, called role awareness, aims to set up a relay network by specifying the specific properties of relay points, i.e., roles.

Our target is to achieve global communication in the disaster area through the establishment of a practical, optimal relay network formed by UAVs from different base stations. It is clear that drones (UAVs) from different bases can be regarded as agents. As for the relay network, we need to decompose it into the relay points so as to assign the UAVs specifically and evaluate the qualification of the drones from different base stations. There exists a mutually exclusive relationship and a collaborative relationship among these relay points, which are suited to become roles.

Based on the relay network's property, we decide to use the prim algorithm to set up the relay network (see Fig. 3). It is a kind of minimum spanning tree algorithm. We use it here because it has the property of the least global communication cost if the positions of communication vehicles are determined before the relay points are selected and the number of UAVs is sufficient for fully covering all of the communication vehicles. Using the Minimum Spanning Tree is practical and it makes the relay network easier to expand.

After getting the practically optimal relay network, the next task is to determine the location of relay points. To solve it, we propose a method (see Sect. 4) find the proper relay points from the optimal relay network.

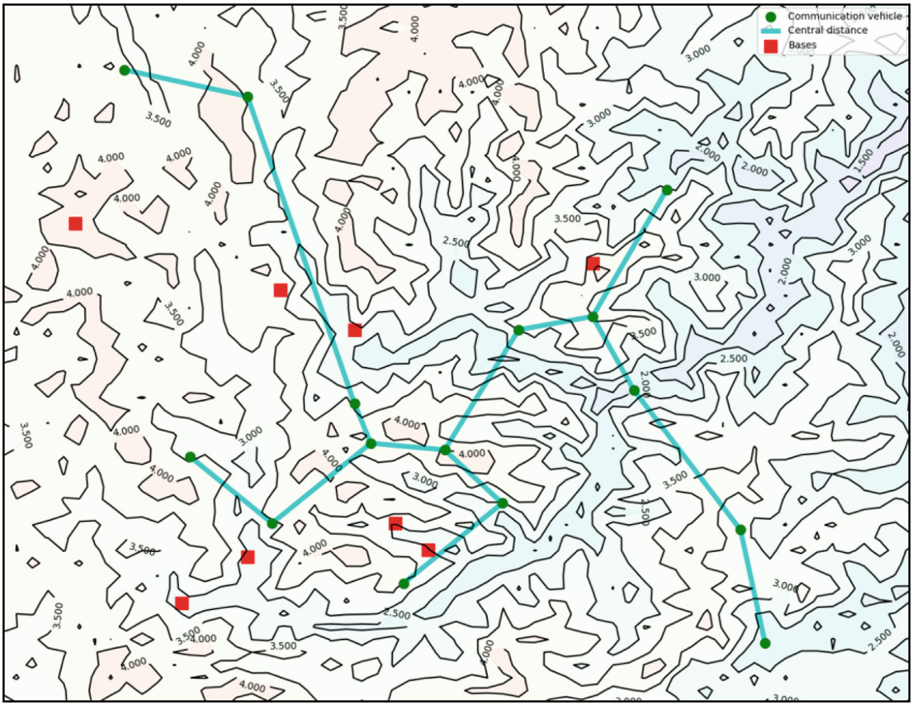

Fig. 3. The minimum spanning tree of relay points. Notes: A red square represents a base station, and a green circle represents a communication vehicle. (Color figure online)

3.3 Problem Formalizations

According to the analysis above, we define the relay points obtained by role awareness as roles and base stations as agents. To better describe RBC and its E-CARGO model, we use one small scale experiment as an example here. The role number we found by using role awareness based on our proposed method is 58, and the value for the base station is 8; The covered radius of the drone is 3 km, and the max communication distance between the UAVs is 6 km.

***Definition* 1.** L is a lower bound of range vector for roles in environment e of group g.

Note: In our scenario, each role can only be assigned to one agent, so the L vector here can be formalized as: L = [1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1].

***Definition* 2.** L^a is an m ability limit vector, where $L^a[i]$ $(0 \le i < m)$ indicates the maximum number of agents for each role.

The L^a here is [10 13 16 9 11 14 12 15].

***Definition* 3.** Q is an $m \times n$ qualification matrix, where $Q[i, j] \in [0, 1]$ expresses the qualification value of agent i for role j. $Q\ [i, j] = 0$ indicates not qualified and 1 means qualified.

Note: In this scenario, we define the qualification of one agent as the distance between the base which the agent belongs to a specific relay point. We now get the $Q'[i, j]$, which is not normalized. Here we use max-min normalization method to normalize $Q[i, j]$ as the following:

$$Q[i,j] = \frac{Q'[i,j] - min\{Q'[i][j]\}}{\max\{Q'[i,j]\} - min\{Q'[i,j]\}}$$

The Q matrix for the scenario here is shown in Fig. 4.

$$\begin{pmatrix}
0.34 & 0.31 & 0.38 & 0.35 & 0.32 & 0.38 & 0.37 & 0.40 & 0.21 & 0.26 & 0.15 & 0.32 & 0.19 & 0.16 & 0.22 & 0.15 & 0.30 & 0.35 & 0.25 & 0.40 & 0.46 & 0.41 & 0.51 & 0.37 & 0.56 & 0.59 & 0.54 & 0.63 & 0.61 & 0.63 & 0.60 & 0.72 & 0.67 & 0.77 & 0.62 & 0.82 & 0.62 & 0.61 & 0.63 & 0.60 & 0.62 & 0.66 & 0.67 & 0.65 & 0.68 & 0.52 & 0.57 & 0.47 & 0.62 & 0.43 & 0.67 & 0.39 & 0.73 & 0.35 & 0.75 & 0.73 & 0.77 & 0.72 \\
0.34 & 0.37 & 0.31 & 0.34 & 0.36 & 0.33 & 0.31 & 0.36 & 0.47 & 0.41 & 0.53 & 0.36 & 0.53 & 0.53 & 0.54 & 0.52 & 0.46 & 0.40 & 0.51 & 0.35 & 0.22 & 0.28 & 0.17 & 0.33 & 0.12 & 0.10 & 0.14 & 0.07 & 0.13 & 0.08 & 0.19 & 0.05 & 0.04 & 0.09 & 0.08 & 0.14 & 0.30 & 0.24 & 0.36 & 0.19 & 0.41 & 0.47 & 0.53 & 0.41 & 0.58 & 0.34 & 0.36 & 0.32 & 0.39 & 0.32 & 0.43 & 0.33 & 0.46 & 0.34 & 0.56 & 0.51 & 0.62 & 0.46 \\
0.15 & 0.17 & 0.14 & 0.22 & 0.17 & 0.12 & 0.15 & 0.11 & 0.16 & 0.15 & 0.19 & 0.17 & 0.27 & 0.22 & 0.31 & 0.18 & 0.01 & 0.06 & 0.06 & 0.11 & 0.24 & 0.18 & 0.29 & 0.13 & 0.34 & 0.35 & 0.33 & 0.39 & 0.35 & 0.38 & 0.33 & 0.48 & 0.43 & 0.54 & 0.37 & 0.59 & 0.33 & 0.32 & 0.34 & 0.33 & 0.36 & 0.37 & 0.39 & 0.36 & 0.41 & 0.45 & 0.51 & 0.40 & 0.57 & 0.34 & 0.62 & 0.28 & 0.68 & 0.22 & 0.74 & 0.70 & 0.78 & 0.67 \\
0.24 & 0.21 & 0.28 & 0.25 & 0.22 & 0.29 & 0.27 & 0.31 & 0.11 & 0.16 & 0.05 & 0.22 & 0.12 & 0.07 & 0.17 & 0.05 & 0.22 & 0.26 & 0.18 & 0.31 & 0.36 & 0.31 & 0.41 & 0.27 & 0.46 & 0.49 & 0.44 & 0.53 & 0.51 & 0.53 & 0.51 & 0.62 & 0.56 & 0.67 & 0.52 & 0.72 & 0.53 & 0.51 & 0.55 & 0.51 & 0.57 & 0.58 & 0.59 & 0.57 & 0.61 & 0.44 & 0.49 & 0.39 & 0.55 & 0.34 & 0.60 & 0.29 & 0.66 & 0.25 & 0.69 & 0.67 & 0.71 & 0.65 \\
0.27 & 0.24 & 0.30 & 0.18 & 0.24 & 0.35 & 0.29 & 0.40 & 0.30 & 0.26 & 0.34 & 0.24 & 0.28 & 0.31 & 0.26 & 0.34 & 0.42 & 0.41 & 0.44 & 0.40 & 0.27 & 0.28 & 0.27 & 0.30 & 0.28 & 0.32 & 0.27 & 0.37 & 0.40 & 0.36 & 0.43 & 0.41 & 0.38 & 0.44 & 0.36 & 0.48 & 0.53 & 0.48 & 0.58 & 0.44 & 0.63 & 0.67 & 0.71 & 0.63 & 0.76 & 0.06 & 0.11 & 0.04 & 0.17 & 0.08 & 0.22 & 0.13 & 0.28 & 0.18 & 0.33 & 0.30 & 0.37 & 0.27 \\
0.17 & 0.16 & 0.21 & 0.11 & 0.16 & 0.25 & 0.19 & 0.31 & 0.25 & 0.20 & 0.30 & 0.16 & 0.26 & 0.28 & 0.26 & 0.30 & 0.34 & 0.31 & 0.37 & 0.30 & 0.17 & 0.18 & 0.18 & 0.24 & 0.19 & 0.23 & 0.18 & 0.29 & 0.30 & 0.28 & 0.33 & 0.34 & 0.30 & 0.38 & 0.27 & 0.42 & 0.43 & 0.38 & 0.48 & 0.34 & 0.53 & 0.57 & 0.61 & 0.53 & 0.65 & 0.13 & 0.19 & 0.08 & 0.24 & 0.03 & 0.30 & 0.05 & 0.36 & 0.11 & 0.42 & 0.38 & 0.46 & 0.35 \\
0.50 & 0.46 & 0.54 & 0.41 & 0.46 & 0.59 & 0.53 & 0.64 & 0.47 & 0.46 & 0.49 & 0.46 & 0.39 & 0.45 & 0.35 & 0.49 & 0.63 & 0.63 & 0.64 & 0.64 & 0.53 & 0.53 & 0.53 & 0.54 & 0.54 & 0.57 & 0.53 & 0.62 & 0.65 & 0.61 & 0.69 & 0.64 & 0.62 & 0.67 & 0.61 & 0.69 & 0.78 & 0.74 & 0.83 & 0.69 & 0.88 & 0.92 & 0.96 & 0.88 & 1.00 & 0.26 & 0.25 & 0.29 & 0.24 & 0.33 & 0.25 & 0.37 & 0.27 & 0.41 & 0.23 & 0.25 & 0.23 & 0.27 \\
0.11 & 0.12 & 0.12 & 0.18 & 0.12 & 0.11 & 0.12 & 0.13 & 0.11 & 0.10 & 0.15 & 0.12 & 0.22 & 0.17 & 0.26 & 0.14 & 0.07 & 0.09 & 0.09 & 0.13 & 0.21 & 0.16 & 0.27 & 0.11 & 0.32 & 0.34 & 0.30 & 0.38 & 0.35 & 0.37 & 0.33 & 0.47 & 0.41 & 0.53 & 0.36 & 0.58 & 0.35 & 0.34 & 0.37 & 0.33 & 0.40 & 0.41 & 0.43 & 0.40 & 0.46 & 0.40 & 0.46 & 0.35 & 0.52 & 0.29 & 0.58 & 0.23 & 0.63 & 0.18 & 0.69 & 0.66 & 0.72 & 0.62
\end{pmatrix}$$

Fig. 4. Q Matrix in our scenario.

***Definition* 4.** T is defined as an $m \times n$ role assignment matrix. $T\ [i, j] = 1$ means one role assign to one agent and 0 means no.

***Definition* 5.** σ means the group performance of group g. It is defined as the sum of qualifications of the assigned agents,

$$\sigma = \sum\nolimits_{i=0}^{m-1} \sum\nolimits_{j=0}^{n-1} Q[i,j] \times T[i,j].$$

***Definition* 6.** The UAVs assignment problem can be formalized as follows:

$$\min \sigma = \sum\nolimits_{i=0}^{m-1} \sum\nolimits_{j=0}^{n-1} Q[i,j] \times T[i,j] \tag{1}$$

subject to

$$T[i,j] \in \{0, 1\}(0 \leq \mathrm{i} < m, 0 \leq j < n) \tag{2}$$

$$\sum\nolimits_{i=0}^{m-1} T[i,j] = L[j](0 \leq j < n) \tag{3}$$

$$\sum_{j=0}^{j-1} T[i,j] \leq \frac{L^a[i]}{2} (0 \leq i < m) \tag{4}$$

Where expression (1) is the objective function; expression (2) is a 0–1 constraint; and (3) indicates that each role must have the requested quantity of agents to solve its assignment. (4) is different from the traditional GRA problem, and it describes that the number of each agent has been limited to assign to the roles; each base needs to keep at least half of the limited number of roles for replacing those assigned drones with low battery.

For instance, Fig. 5 is a T with L = [1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1] and L^a = [10 13 16 9 11 14 12 15]. The total cost of the drones from 8 bases is 12.30, which is an optimal result via GRA.

$$\begin{pmatrix}
0&0&0&0&0&0&0&0&1&0&1&0&1&1&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&1&0&1&1&1&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&1&1&1&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&1&0&0&0&0&1&0&1&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&1&0&1&0&0&0&0&0&0\\
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0&0&0&1&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0&1&0&1&0&1&1&1&1&1&1\\
1&0&1&0&0&1&1&1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{pmatrix}$$

Fig. 5. T Matrix in our scenario

Figure 6 shows the assignment result for our solutions.

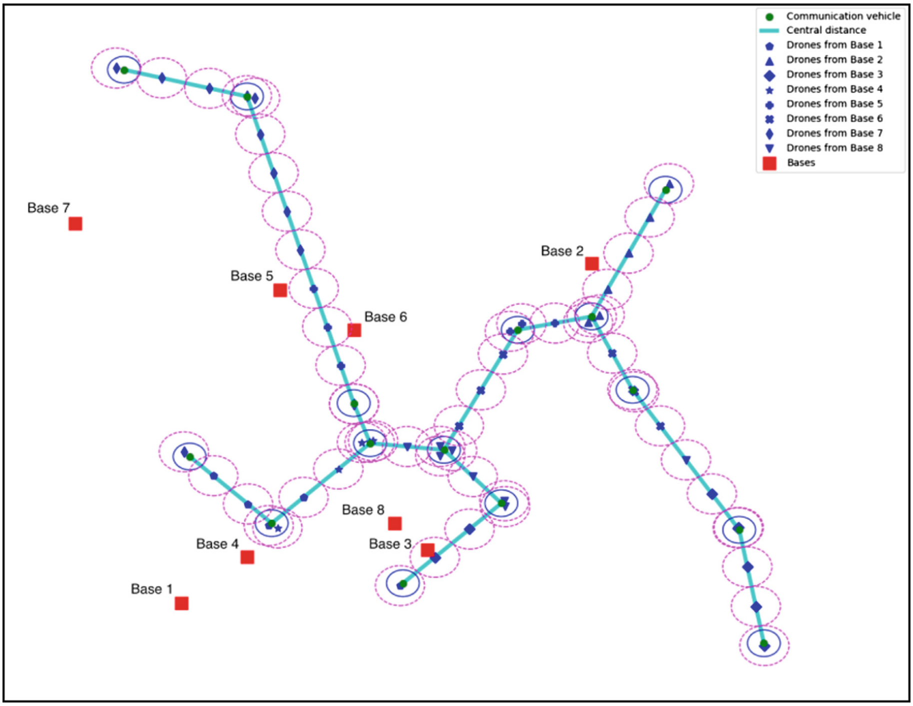

Fig. 6. The assignment result of our solution. Notes: Different kinds of shapes of the minimum spanning tree or near the minimum spanning tree represent the UAVs from different base stations, and a solid circle represents the communication coverage radius of a communication vehicle while a dotted circle is the communication coverage radius of a UAV.

4 Solutions and Experiments

4.1 Role Awareness

Here we propose a role awareness method to find the relay point as follows.

The Method of Finding the Relay Points
Step 1: Evaluate the minimum UAVs' number for each edge of the minimum spanning tree and find the central point of each edge. **Step 2:** For the edges with the even minimum UAVs' number, parallelly put the UAVs from two sides of the central point with multiple distance of the UAV covered radius from the central point's location and finally check the boundary drones' position and adjust the boundary drones' positions based on the distance between the boundary drone and the closed edge point if necessary. **Step 3:** For the edges with the odd minimum UAVs' number, put one UAV over the central point and then follow the same procedure as **Step 2**.

4.2 Experiments

Based on above analysis, we formalize the problem as an x-ILP problem and solve it using the PuLP package of Python [9]. The experimental platform is: the CPU is 2.6 GHz Intel Core i7, and the Memory is 16 GB 2400 MHz DDR4, and the programming language is python, with the version 3.7.1. In order to ensure that our solutions are practical in a real-world scenario, we have tested our algorithms from different scales of simulation experiments for thousands of times. The runtime on different scales of our simulation experiments is shown in Fig. 7.

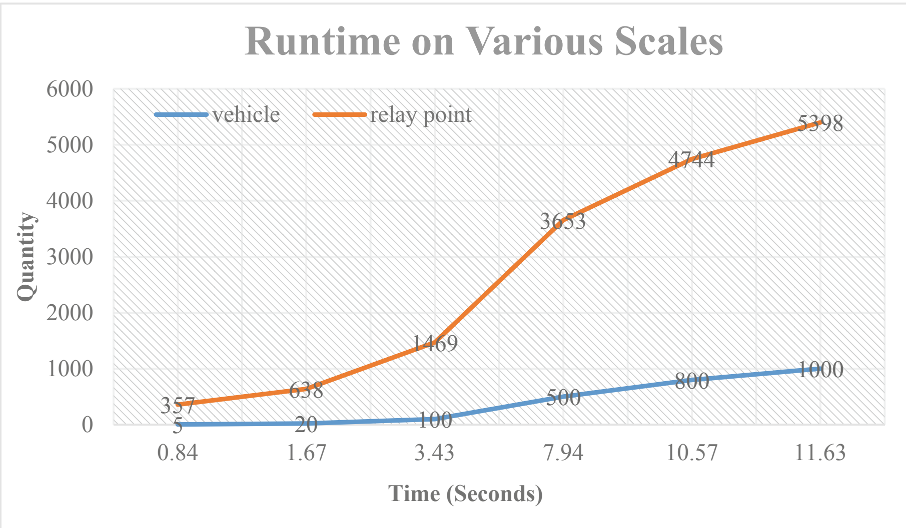

Fig. 7. Runtime on various scales. Notes: To analyze the impact of the number of vehicles on time, we set the covered radius of the UAVs as 3 km, the number of bases is 8, and the location of the communication vehicles range from 3 km to 1200 km for discretely generating them so as to cover the whole disaster area.

5 Related Work

The Unmanned Aerial Vehicle has become a popular tool for search and rescue because it is fast and not affected by obstacles like heavy traffic congestion or road damage. There are many types of research involving the use of drones as a rescue tool. Such uses are communication recovery, emergency response and rescue, etc. [1–3]. As a matter of fact, they are essentially assignment problems, including our research.

Many researches allocate their tasks based on data-related or agent-related methods [10–13]. Many of these researches analyze the properties of the tasks or the distribution of the data, and then select a specific algorithm which is suitable for the tasks.

Geng *et al.* [10] use a modified centralized algorithm based on particle swarm optimization to solve the task allocation problem in the search and rescue domain. They suppose that a centralized algorithm should perform better than distributed algorithms because it has all the available information at hand to solve the problem.

It is difficult to compare our solution with these algorithms due to differences in experimental scenarios and objectives. Our approach can seek a practically global optimal solution by defining a formalization model with an assignment algorithm to deal with the x-ILP problem in our scenario. Thousands of simulation experiments demonstrate that our solution is scale-independent; it can swiftly determine the practically optimal result even though the task's scale becomes large.

Allocating tasks based on the role instead of the agent may help build a model regardless of the distribution of the tasks. It helps formalize the problem and build a robust model. There are some role-based assignment researches [5, 14–16].

Group Role Assignment (GRA) [7, 15] is a vital methodology. It greatly improves the collaboration efficiency by seeking an optimal team execution based on agent evaluations.

By proposing the KM_B algorithm based on the RBC and its E-CARGO model, Zhu *et al.* [17] solve the M–M assignment problem. They first formalize the problem in a second order bipartite graph. Next, they solve it by improving the K–M algorithm with backtracking, i.e., KM_B, which is verified to be practical through simulative experiments.

The primary steps to use the Role-Based Collaboration include defining the roles, the agents, and the qualification matrix for the agents to be assigned with a specific role. In our scenario, the role is not clear. Consequently, we improve the RBC by appending the role awareness procedure so as to transform our problem into an x-ILP problem and use GRA to get the practically optimal solution for our research.

In summary, our research clarifies the relay points problem using RBC and its E-CARGO model. The key of Role-Based Collaboration is Group Role Assignment. It concentrates on constructing a practically optimal relay network while minimizing communication cost using a minimum number of UAVs.

6 Conclusion

A successful approach is proposed in this paper to solve the x-ILP problem with the help of PuLP package of Python. It designs a uniform solution concerning the signal relay problem of UAV in a disaster area. And thousands of random simulation experiments show that our solution can quickly find the relay points and assign the UAVs from different base stations to these points. It also demonstrates that our solution is practical, robust, and practically global optimal.

This paper formalized and solve the signal relay problem of the UAVs in disaster relief via group role assignment (GRA). In modeling, it first uses the minimum spanning tree algorithm to design the practically optimal relay network. And our proposed method in Sect. 3 can establish an awareness of and propose the relay points as, with respect to roles, which UAVs (as agents) should be assigned. Secondly, distributing the UAVs to these relay points can be solved quickly via the assignment process of GRA. Through these strategies, it can quickly recover global communication in the disaster area with the least communication cost regardless of the scale and the distribution.

There are some future works for this paper:

(1) More constraints may be required for further investigations like the mutually exclusive constraints between drones from different bases, and the multi-task assignments for each drone.
(2) Some UAV properties such as stability, endurance and maximum flight altitude raise concerns worthy of additional study.
(3) Elevation differences in a disaster area suggest that the third dimension needs to be considered when assigning drones.

Acknowledgement. We appreciate Mike Brewes for his assistance in proofreading this paper.

Thanks to National Natural Science Foundation of China for supporting part of this work under Grant No. 61402118, Natural Sciences and Engineering Research Council of Canada (NSERC) under Grants RGPIN2018-04818, S&T Project of Guangdong Province, grant No. 2016B010108007 and S&T Project of Guangzhou, grant No. 201604020145.

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