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Coordination for dynamic weighted task allocation in disaster environments with time, space and communication constraints

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HIGHLIGHTS

- Factors of multi-agent task allocation in disaster environments.
- Dynamic task allocation in disaster environments under multiple constraints.
- Decentralised group formation mechanism under multiple constraints.
- Utility calculation mechanism for group coordination and task allocation.

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ABSTRACT

Coordination for dynamic task allocation based on available resources is a very challenging research issue in disaster environments with time, space and communication constraints. In addition, the space and communication constraints and the dynamic features of disaster environments make an extra difficulty to achieve efficient coordination through centralised coordination approaches, which require the coordinators to have global knowledge of the environments. To this end, a coordination approach for dynamic weighted task allocation is proposed in this paper. The proposed approach considers time, space and communication constraints in disaster environments and urgent degrees of workloads of tasks without requiring the global knowledge of the environment. In particular, a dynamic group formation mechanism is developed to help agents to form groups and share information for task allocation under space and communication constraints in a decentralised manner, which can reflect real-life situations in disaster environments. The efficient coordination for task allocation is achieved through the utility calculation within each group. The experimental results show that the proposed approach outperforms most of other coordination approaches, such as the group formation approach proposed by Glinton et al. and the heuristics task allocation approach proposed by Ramchurn et al. in terms of group formation and weighted task allocation in disaster environments with time, space and communication constraints.

1. Introduction

Nowadays, agent-based coordination for task allocation has been widely applied in many environments such as disaster rescue, space exploration and distributed computing. [29,1,37,23,3]. The main objective of task allocation is to allocate limited resources (agents) to suitable tasks in a rational way. Task allocation in disaster environments is a challenging issue in both research and applications.

In general, disaster environments have the following particular requirements which need to be considered for task allocation. (1) **Time constraints**. In disaster environments, tasks include locating and saving survivors in debris, extinguishing fire of buildings, etc. In such circumstances, each task should have a hard deadline and a task is worthy to be finished before its deadline [28,6,12] (i.e. the time point until which the survivor is still alive or the building is still standing). (2) **Space constraints**. In disaster environments, agents can move to different locations and tasks can also be discovered at different locations. If an agent wants to work on a task, it first needs to move to the location of the task, which will consume time [2,5,12]. Therefore, both locations of tasks and agents are important issues to be considered during task allocation. (3) **Communication constraints**. In disaster environments,

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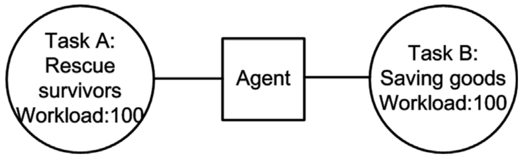

Fig. 1. Two tasks with different urgent degrees of workloads.

communication constraints [15,27,36] include two aspects. The first aspect is the constraint of communication capacities. The second aspect is the constraint of communication ranges. Due to the destruction of local infrastructures and other conditions in disaster environments, the amount of information transferred between agents is limited (i.e. the constraint of communication capacities). In addition, agents can only directly communicate with other agents within a certain distance in many real-life situations (i.e. the constraint of communication ranges). (4) **Dynamic features of the environments**. In disaster environments, agents can be continuously entering and leaving the environments and tasks can be continuously being discovered and finished in the environments [28,31]. (5) **The urgent degrees of workloads of tasks**. The workloads of different tasks should have different urgent degrees [26,16]. Tasks with higher urgent degrees of workloads need to be finished first, while tasks with lower urgent degrees of workloads should be disregarded during task allocation if resources are not sufficient. An example is demonstrated in Fig. 1.

In Fig. 1, an agent discovers two tasks (i.e. *Task A* and *Task B*). Both of tasks need the agent to provide 100 workload to finish. However, one task (i.e. *Task A*) is to rescue survivors in a collapsed building, while the other task (i.e. *Task B*) is to save good in debris. When the agent makes decision on task allocation, it is no doubt that the task of rescuing survivors (i.e. *Task A*) should take precedence over the task of saving goods (i.e. *Task B*). From above example, it can be seen that the urgent degree of the workload of each task is obviously a key issue to be considered during task allocation, especially in disaster environments. In most existing related approaches [17,28,10], the researchers only emphasise on finishing as many tasks as possible before their deadlines, but ignore the difference between urgent degrees of workloads of tasks.

To handle task allocation in disaster environments, various models, mechanisms and approaches have been proposed to achieve efficient coordination for task allocation from different perspectives [4,22,14,38,20]. These approaches can be divided into the centralised approaches and the decentralised approaches.

A number of centralised approaches [17,28] have been developed to coordinate task allocation in disaster environments. The centralised approaches can guarantee an optimal allocation solution, if the coordinator can have the global knowledge of overall tasks and agents in an environment. However, in most disaster environments, it is hard for a coordinator to have such kind of knowledge due to the time, space and communication constraints as well as the dynamic features of tasks and agents in disaster environments.

To overcome the limitations of centralised approaches, some decentralised approaches [7,4,2] have been developed for disaster environments in the last twenty years. One of the famous approaches is the fast-max-sum proposed by Ramchurn et al. [27], which employs the message passing mechanism (from the max-sum algorithm [7]) to enable agents to share information and make decision for task allocation in a decentralised manner. However, if the number of agents is large and the connections among agents are complicated, agents need to spend a great deal of time and resources for message passing so as to create a near-optimal solution for task allocation. Therefore, the fast-max-sum approach does not work well in disaster environments under multiple constraints, especially under the dynamic features of the environments. In addition, the fast-max-sum approach does not consider the different urgent degrees of workloads of tasks. Actually, even if some task allocation approaches consider the communication constraints, most of them only consider either the constraint of communication capacities or the constraint of communication ranges and few of them consider both.

In order to meet the challenges of task allocation in disaster environments, a coordination approach for dynamic weighted task allocation is proposed in this paper. The proposed approach first collects information for tasks allocation through forming temporary groups in a decentralised manner. Then, a token passing mechanism [21,19] is employed to assist members of each group to share information for task allocation under space and communication constraints. Finally, the coordinator of each group employs the proposed utility calculation mechanism to find the most suitable task allocation solution within its group. The proposed approach has the following merits. (1) The proposed approach considers time, space and communication constraints to reflect the real-life situations in disaster environments. (2) The proposed approach considers the workloads of tasks and their urgent degrees as well as dynamic features of disaster environments so as to meet the requirements of task allocation in disaster environments. (3) In the proposed approach, an innovative group formation mechanism is developed to help agents to form groups and share information for task allocation under space and communication constraints. (4) A comprehensive utility function for task allocation is designed to help the coordinator of each group to find the most suitable task allocation solution in its group. The experimental results show that in disaster environments with time, space and communication constraints, the proposed approach outperforms the group formation mechanism proposed by Glinton et al. [11] and the heuristics task allocation approach proposed by Ramchurn et al. [28] in terms of group formation and weighted task allocation, respectively.

The rest of this paper is organised as follows. The problem is formulated and definitions are given in Section 2. The principle of the proposed approach is introduced in detail in Section 3. The experiments and analysis are given in Section 4. The related work and discussions are given in Section 5. The paper is concluded and the future work is outlined in Section 6.

2. Problem description and definition

In general, agent-based task allocation involves to model the coordinating problem of a set of agents during the task allocation process. The set of agents contains M number of agents, which can be described as $\{A_1, A_2, A_3, \ldots, A_M\}$, where A_i represents the ith agent and $1 \leq i \leq M$. Each agent can scan its surrounding area, discover tasks within its scanning range and give an ID to each task as T_{ij}, where T_{ij} represents the jth task discovered by A_i. In the proposed approach, the following definitions are given to describe the coordinating problem in detail.

Definition 1. An *Agent* (A_i) can be defined as a six-tuple $A_i = \langle ANo, Uti_i, Loc_i, MSp_i, Comm_i, ASta_i \rangle$, where ANo is the ID of A_i; Uti_i is the work efficiency of A_i, which represents how many units of workload that A_i can perform per time unit; Loc_i is the current location of A_i; MSp_i is the moving speed of A_i, which represents how many units of distance that A_i can move per time unit; Com_i is the communication range of A_i, which represents the maximum units of distance that A_i can directly communicate with; and $ASta_i$ is the status of A_i, which can be either 'available' or 'working'.

In order to distinguish different urgent degrees of workloads among tasks, the variable Emg_{ij} is proposed. By taking Emg_{ij} into account, the definition of a task is given as follows.