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Agent-based task allocation under uncertainties in disaster environments: An approach to interval uncertainty

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ABSTRACT

The uncertainty of task allocation in disaster environments is challenging both practically and theoretically. In real environments, agents encounter uncertain factors for the selection and execution of tasks. The present methods for task allocation seem inadequate in such environments. This paper aims to provide an efficient approach to improving the task allocation, despite the uncertainty in disaster environments. Therefore, after deduction of the major uncertainties in disaster environments, we propose a method for the agents' decision-making about the task allocation. The allocation procedure includes four phases of ordering the tasks, choosing the coordinating agent, implementing the auction by considering the uncertainties, performing tasks and observing the real environment. The main innovation of this research is using the concepts of interval uncertainty in the task ordering as well as in the auction implementing. The results were obtained by comparing the proposed method with the contract net protocol (CNP) at three scales. In addition, the results were evaluated in the presence of uncertainties at different ranges. On average, the proposed method was better than the CNP in terms of search and rescue (SAR) operation time (124 min), the number of dead people (8) and the number of incorrect allocations (180 tasks). The uncertainties range in the tasks' decision-making procedure affected SAR operation time by more than 26%. Therefore, considering that uncertainty in task allocation can be a great advantage in the disaster environment, and considering these factors in the decision-making procedure, we have improved confidence in allocating tasks with fewer errors.

1. Introduction

In multi-agent systems (MAS), a set of works is assigned to a group of agents in order to achieve a common goal. Task allocation is one of the main areas of research in the field of MAS [1]. It plays a significant role in the coordination and performance of MAS [2–4]. An appropriate task allocation in view of the uncertainties optimizes the collaboration between the agents and improves efficiency [5].

The majority of task allocation methods are proposed for environments with no uncertainty [6], assuming that the task characteristics and inter-task dependencies are well known before the allocation, while the assumption of complete information in real environments is negated due to various uncertainties [2]. Therefore, it is assumed that the task allocation in environments with no uncertainty is essentially an unreal scenario [7]. In task allocation, each agent encounters different risks, which must be considered in the decision-making process [8,9]. Assigning tasks based on incomplete information imposes some threats to the problem-solving procedure [10]; therefore, several mechanisms were proposed to improve the process of task allocation [11–13]. Suggesting an appropriate approach to consider the uncertainty in the accurate task allocation plays an important role in making decisions on search and rescue (SAR) operations in disaster areas [6].

Disasters such as earthquakes are always so complex because they cause widespread casualties, injuries and destruction of houses [14,15]. In traditional SAR models in disaster environments, task allocation is based on consistent information about the victims, the number of SAR teams and their access routes [3], while the task allocation procedure when searching for victims in disaster environments is completely dynamic and uncertain [16]. The disaster environments have specific conditions and origins for the uncertainty that should be considered in the task allocation. The uncertainty, in the form of various parameters, ultimately affects the performance of all actions [17,18].

In the past decade, several studies have been conducted on task allocation and the uncertainty is reflected in different approaches to task allocation in MAS. The analysis was limited to the interval approach for the agents' decision-making. The aim of this study is to improve SAR operations. This study provides a VIKOR interval-based approach to reflect the uncertainty in the agents' decision-making

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during the task allocation. In the present study, the uncertainties of task allocation in disaster environments are identified and the task allocation is performed by the proposed approach derived from the contract net protocol (CNP) and the interval VIKOR method. The main innovation of this study is improving SAR operations by providing an approach for the reflection, at intervals, of the uncertainty in disaster environments. The uncertainty affecting the information directly affects the decision-making procedure in SAR. This initiative is appropriate for working with interval data and improving the task allocation in agent-based groups by reflecting the nature of disaster environments.

In Section 2, predominant task allocation approaches and methods considering the uncertainty are discussed. In this section, we review the previous studies and also discuss the main reasons for the choice of applied methods and approaches. In Section 3, the research scenario is stated. Then, in Section 4, the proposed method is described in four substeps: ordering the tasks, finding the coordinating agent, the auction phase, and observation of the real environment by the agent. In Section 8, some tests are developed to validate the proposed model and the algorithm's functionality. In Section 9, the final results of this study are presented.

2. Task allocation

Since early 1990, multi-robot task allocation has received attention as a method for deciding which mobile robot should perform each task [19–21]. This method of task allocation is designed to find the assignment that maximizes overall optimization [22]. Increasing the complexity and scale of the system under study makes the issue more important [2,23]. In most cases, completing all the tasks in the environment is not possible, due to short supply. This situation emphasizes the importance of an efficient allocation of tasks to obtain the desired performance of the system [24]. The task allocation problem is known as NP-complete [25].

2.1. Task allocation approaches

There are various categories for task allocation. In terms of the central controller approach, it is divided into three categories: centralized, decentralized, and a combination of both of them [22]. In the centralized approach, which leads to optimum (or near-optimum) results [26], the central controller is in charge of the task allocation [23,25]. However, this approach encounters some problems, due to limited scalability, lack of full visibility in the environment, and the loss of the central control point [11,22]. The method is used in environments where information is readily available, such as parallel planning in factories [21]. The decentralized approach increases the mission scope and eliminates the possibility of damage to the central server [11], although it is highly complicated [21] and raises the communication overhead among the agents [27]. This approach is used in the task allocation management of forest fire scenarios [28] and stabilization of the energy generated in power plants [26]. In some studies, a combination of both centralized and decentralized methods is used [22]. The benefits of the approach, applied in supply chain management, include simultaneously using centralized comprehensive information, having flexibility and having no point of failure [9]. In some categories, only two centralized and decentralized approaches are used for task allocation [11,21,25]. The centralized approach is more suitable for cases with mild or definite changes [29]. Due to the complexity of crisis management systems, the centralized approach does not meet all the needs in order to control these systems; therefore, a decentralized approach is more efficient because of the inherent distributed nature of SAR systems and the agents' local sight [30,31]. The main problem related to such approaches is the lack of the optimal result in the allocation process. In this study, given the uncertain nature of disaster environments and in order to enjoy the advantages of both approaches, we used the centralized approach, in which the concepts of the decentralized approach are used to reduce communication overhead. Another classification is the task allocation in terms of the level of cooperation among the agents, including the coordinated agents and self-interested agents (the agents each pursue their own goals) [7]. In the present study, agents are the coordinated ones, who cooperate to search for and rescue the victims.

Various methods are proposed for the task allocation. Common approaches are auction -based, consensus-based and optimization-based methods.

2.1.1. Auction-based approaches

In these approaches, each agent submits his offer to the work auctioneer. After reviewing the offers, the auctioneer entrusts the work to the winning bidder [32]. Auction-based approaches are applied to environments in which gathering accurate instant information is difficult [21]. Auction-based approaches are the most popular solutions for task allocation problems [32] and have been tested more than other approaches [1]. Extensions to the auction-based approaches have frequently been proposed [33,34]. Contract net protocol (CNP) is one of the main auction-based approaches. According to CNP, norm-based CNP was developed based on the social, organizational and operational norms [34]. Other protocols such as M+ were introduced based on a local, decentralized planning and a multi-layer decision-making process for the task allocation [33]. The auction-based methods were used in various studies, including assigning tasks to a group of firefighters [35] and in the rational distribution of the SAR agents [3,36].

2.1.2. Consensus-based approaches

Consensus-based approaches enable a number of agents to converge in situational awareness and make task allocation possible in different network topologies. The consensus-based action algorithm (CBAA) and consensus-based bundle algorithm (CBBA), which are resistant to changes in communication network topology, use the auction-based decision-making strategy and consensus-based approach for decentralized selection of actions and resolving paradoxes, respectively [11]. The heterogeneous robots consensus-based allocation (HRCA), which removes the limits on the maximum number of tasks, can be assigned to each robot in the CBBA [37], and the decentralized assignment algorithm (DAA), which ensures the critical task allocation as well as the resources heterogeneity and constraints [30], are placed in this category.

2.1.3. Optimization-based approaches

The allocation of tasks among the robots can be introduced as an optimal allocation problem (OAP) [24,30], for which the Hungarian algorithm is a viable solution [2]. Most of these methods are appropriate for solving single-robot task allocation for single-task robots, although they are not applied to those tasks requiring several robots to cooperate [32]. These methods, however, retain the overall optimum solutions, in spite of poor scalability [29]. Other optimization approaches, such as methods based on swarm intelligence, are used in task allocation [32]. In most cases, optimal solutions are identified through heuristic solutions [17]. The optimization methods in task allocation include the genetic algorithm [38], ant colony algorithm [19,32], taboo random search method [39] and particle swarm optimization [40]. The swarm intelligence methods have high stability and scalability, and are appropriate for allocated multi-robot systems [32]. These methods produce satisfactory but potentially suboptimal solutions [17]. The main problem of adaptive algorithms designed to deal with various dynamic issues is the lack of a standard method to assess their performance [41].

Coalition-based [42], learning-based [43], blackboard method [44] and dynamic weighted task allocation [31] are among the task allocation methods for disaster environments.

Various methods were developed for the task allocation of the agents, each of which has advantages and disadvantages. Scientific