Task Allocation for the Police Force Agents in RoboCupRescue Simulation

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Abstract. In this paper, three mechanisms for task allocation among police force agents in the rescue simulation environment are presented. Three different approaches namely full auction-based, partitioning-based and hybrid approaches are briefly described. The empirical results of using the hybrid approach show a significant improvement in performance over the other two approaches. By using the hybrid mechanism for the police forces, our agents together with other types agents ranked third in the RoboCupRescue 2004 simulation competitions.

1 Introduction

The rescue simulation environment is a multi-agent environment in which fire brigades, ambulance teams and police forces work together to mitigate a simulated disaster [1][2][3]. Extinguishing a spreading fire, saving civilians lives, and clearing blocked roads are the responsibilities of these agents respectively. In this paper we investigate the use of task allocation algorithms in this domain. In a disaster mitigation problem, agents are not aware of the tasks in advance and the priority of tasks change over time. Agents of each type are responsible for their own duties. The problem is then how to assign agents to these tasks dynamically. We have introduced three approaches namely full auction-based mechanism [4][5][6][7], partitioning-based mechanism, and a hybrid mechanism which merges the benefit of the other two approaches. The auction-based mechanism has been used by Caspian 2004 Rescue Simulation team during the German Open 2004 competitions in which we ranked fourth. The hybrid mechanism also was exploited during RoboCupRescue 2004 simulation competition where we won the third place.

In the next section the characteristics of the rescue simulation environment is briefly described. Section three describes the usage of task allocation mechanisms in this domain. In the first part of section three, the fully auction-based mechanism is introduced followed by the partitioning-based approach. After that, in the third part, our hybrid approach is presented. The fourth section is devoted to empirical results of using these approaches, and makes a comparison between them.

2 The Rescue Simulation Environment

The rescue simulation environment is a multi-agent environment in which three types of agents are defined to cooperate with each other with the goal of mitigating a

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simulated disaster. Fire Brigades are responsible for extinguishing a spreading fire. Ambulance Teams are responsible for saving the lives of the civilians who need help and Police Forces are in charge of clearing blocked roads. Fire Station, Ambulance Center, and Police Office help corresponding agents accomplish their tasks. In such an environment the problem of disaster mitigation can be considered as a task allocation problem, where each type of agent is responsible for its own defined duties. The agents are not aware of the tasks in advance. Indeed, as the simulation continues new tasks emerge, and the fact that the priority of tasks change over time, makes the situation even worse. Sometimes there's a need to explore the world for accomplishing a task (e.g. finding civilians who need help), and sometimes the tasks are reported by other agents who faced them (e.g. clearing a road through which another agent needs to pass). The problem is then how to assign agents to these tasks dynamically.

3 Task Allocation

The focus of this research is on the development of a dynamic task-allocation algorithm for the Police Force Agents. Police Forces are the agents that help other agents accomplish their tasks better. These agents will be informed about new tasks either by themselves exploring the world or by other agents who faced the obstacles. To address the problem of dynamic task allocation among police forces we have developed three approaches which will be explained in later sections in more detail.

3.1 Full Auction-Based Mechanism

Auction mechanism is a market-based paradigm which consists of an auctioneer (seller) and potential bidders (buyers) in which items are sold to a buyer who suggested the highest (or lowest) price [6][7]. Once the auctioneer wants to sell an item, he will notify the bidders of the item. The auctioneer receives all the bids and determines the best suggestion, and notifies the bidders about the winner. One of the main advantages of auction-based mechanisms is that they are distributed in the sense that each agent performs a local computation regarding its own bidding strategy.

In our approach, the police office takes on the role of an auctioneer, and the police forces take on the roles of the bidders. The items that are bid for are the tasks or, in this environment, the blocked roads. In an auction algorithm, both single and combinatorial mechanisms can be used. In our approach we used a single method. The following scenario is applied:

1. Fire brigades and ambulances send a request for clearing the obstacles in a blocked road to the fire station or the ambulance center respectively.
2. Fire station and ambulance center collect the received requests and send a request to the police office.
3. The police office notifies police forces about the received requests. The real auction starts here.
4. Police forces receive the requests and make bids on them, and send their bids to the police office.

5. The police office collects all the bids and determines the winner.
6. All the police forces will be notified about the winner by the police office.
7. After accomplishing the task, the police force who won the auction will notify the center that he is free, so that he can participate in coming auctions.

In addition to the above scenario, at the beginning of each cycle the police forces bid for the tasks which are remained unassigned yet. To complete our discussion, more detail about the bidding strategy and winner determination is given below.

- **Bidding Strategy:** Once a free police force is informed about a new task he will make a bid for it. To this end, the agent uses a cost function to calculate the cost of performing that special task. This cost depends on some parameters, like the distance to the destination route, distance of the destination from the refuges, the distance of the destination from fiery buildings, and some other parameters. In an auction-based mechanism an agent can use any kind of bidding strategy for calculating the cost of accomplishing a special task. It does not matter what the strategy exactly is while it is proportional among other agents. For these reasons we do not discuss the bidding strategy in more detail here.

  As another point, we assume that each task is performed by a single agent. Considering that removing a blockade is not too costly, this assumption does not affect the whole problem.
- **Winner Determination:** The police office receives all the bids and determines the least costly proposal as the winner. Since we assume that each free agent makes bids on all tasks, the winner determination procedure is straightforward. The auctioneer assigns the first task to the agent who made the least costly bid for it. Then the agent and the other bids it had made are removed from the list of suggested bids. The auctioneer continues his work by finding the next least costly bid and so on. This means that in this approach the least costly bid is preferred over the others.

Empirical results show that using full auction-based mechanism has the following advantages:

- **Different Bidding Strategies:** Bidders are allowed to implement different bidding strategy, which leads to a more flexible structure. We can assume different responsibilities for police forces, for example consider a police force which is more inclined to help fire brigades or ambulances. Therefore it is possible to assign different responsibilities in this level. However note that the final task-allocation is made by the police office and all the received bids are assumed to be made by identical agents, and the least costly bidder will win the auction.
- **Efficient Task Allocation:** Auction-based task allocation ensures that each request (task) will be assigned to a bidder (police force). This leads to the fact that no tasks remain unassigned.

Besides the mentioned advantages, there are several shortcomings:

- **Large Number of Communicated Messages:** In the auction-based mechanism, it is necessary to transmit a number of messages to set up an auction. In our approach, the first message is an announcement of a new task. The second type of message is the bids that agents send to the police office. The third message is the winner notification. All of the above messages should be transmitted in order to assign one task to an agent. Considering that in a typical disaster situation the number of police forces involved in the environment varies from 10 to 15, and all of the free agents bid on a task, the number of communicated messages is too large. Event if we encapsulate information in one message, the number of communicated messages would be still significant.
- **Delay in Task Execution:** As mentioned above three types of messages should be transmitted in order to assign a task to an agent. It will take at least 3 cycles for a task that is requested to the police office to be assigned to a police force (actually this is because of the limitations in the simulated environment). However, by using a proper algorithm, the police force can remove the obstacle in fewer cycles.

To address the above shortcomings, we have mixed the auction algorithm, with a partitioning-based task allocation mechanism to build a hybrid approach. The basis of the partitioning-based approach is given in the following section, and the hybrid approach is introduced later.

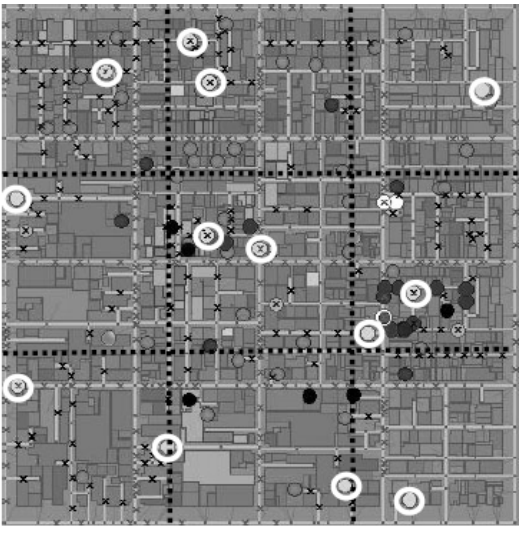

Fig. 1. The partitions made and the assigned police forces to each partition. White circles represent police forces.

3.2 Partitioning-Based Task Allocation

Partitioning-based approach is another way of simply allocating tasks between the police force agents. In this way the map of the city is partitioned into several regions, resembling a grid. Note that the number of partitions is less than the number of police

force agents. The police office is responsible for partitioning the disaster space and assigning the police forces to these partitions. Also there might be a need to change the activity region of an agent from one partition to another.

More details about these steps are given below:

- **Partitioning the Disaster Space:** Efficient partitioning the disaster space is one of the open challenges in the rescue simulation domain. In our approach the disaster space is statically partitioned into a number of regions. This was carried out in the beginning of the simulation and did not change till the end. The number of partitions must be less than the number of police force agents. A better solution to this problem is to dynamically partition the disaster space with respect to the density of the blockades in different parts of the city, and the degree to which other types of agents are busy in a special region. However, this is yet an open issue in this approach needing further research.
- **Assigning Police Forces to the Partitions:** Assigning police forces to different partitions is carried out both statically and dynamically. Meaning that in the beginning of the simulation one police force is assigned to each partition. Since the number of partitions is less than the number of police forces, there are always some free police forces available that can be assigned to more busy regions with more requests dynamically.
- **Changing the Activity Region of a Police Force:** The disaster space is a dynamic space, in which no preliminary information about the potential tasks of an agent is available. This makes it impossible to define a planning for clearing the roads in advance. The change in activity area of the fire brigades and the ambulances makes the need for clearing the roads in different parts of the disaster space change over time. It may be necessary to assign more police forces to a special region than the usual number. To this end the police office changes the activity region of one or more police forces according to the rate of requests in different regions. Note that after all the roads of a partition are cleared, the police forces assigned to that region are considered as free agents.

In contrast with the fully auction-based mechanism, the advantages of this approach are:

- **Faster Task Assignment:** In the fully auction-based approach it took 3 simulation steps for the police office to assign a task to a police force. But in this approach each task that arises in a region is immediately added to the agent's list of tasks. In some situations (not all) this leads to a better performance for the police team.
- **No Permanent Need to the Police Office:** One of the fundamental capabilities of a rescue team should be its ability to operate well in absence (failure) of the decision-making centers. In this approach since the disaster space is partitioned into several regions, in the case of police office failure, the police forces will explore the whole area and find and remove the obstacles on their way. Although it is inefficient, the police office failure does not cause the

police forces to cease operating, which was not possible in the full-auction model.

- **Less Communication Messages:** The communication messages in this approach are reduced to the messages through which the police office notifies the police forces about the tasks. This is much less than what was seen in the auction-based approach.

Besides the aforementioned advantages this approach has several disadvantages. The most important shortcoming of this approach is that the agents perform the tasks inefficiently – just contrary to the auction approach. In this approach all the tasks in a partition are considered altogether, and the agent(s) assigned to that region are responsible for carrying them out. If the agents are busy, there's a possibility that a task be carried out too late.

3.3 Hybrid-Method for Task Allocation

In the hybrid approach we have tried to combine the benefits of the two methods, and avoid common shortcomings as far as possible. For this method, two types of requests have been defined; one the urgent requests that must be dealt with as soon as possible, and the other the normal requests, for which there's no emergency in handling them. The urgent requests are made by the other types agents when thy need an obstacle to be removed as soon as possible. Examples are, when the only path to the fire refuge is blocked, or an agent is trapped in a road that is blocked on both heads. In the beginning of the simulation the police office partitions the disaster space and assigns one or more police forces to each partition. The agents operate and react to the normal requests in the same way as the second approach. When there's an urgent request made, the police office holds an auction for it. All the police forces in all parts of the disaster space participate in the auction, and bid for the urgent task. It does not matter which region the task belongs to, any agent belonging to any region may win the auction. After accomplishing the task, the winning agent returns to the partition to which he was originally assigned to.

The advantage of this hybrid approach is that the police forces operate in the whole disaster space, while some of them are dealing with urgent tasks. In this way fire brigades and ambulances can change their activity area with less performance loss.

4 Empirical Results

In order to measure the performance of the three methods discussed above, we conducted 5 sets of experiments. The different setups used to perform the experiments are as follows:

1. Full auction mechanism is used for the police force agents.
2. The partitioning-based method is used for the police force agents.
3. The hybrid method is used for the police force agents.
4. While using the hybrid approach the police office is not running.
5. The blockade simulator is not running.

Note that other types of agents are identical in our experiments. For all the experiments the score of the whole rescue team is used to measure the performance. Although the score is achieved by all types of agents involved in the simulation (not the police forces alone), the difference in the score helps evaluate the different methods used for the police forces. The 5 sets of experiments were performed using 4 different maps, which were used in the RoboCup 2004 final round, namely Kobe, VC, Random Map, and Foligno. Each experiment was performed 10 times, and the average of the scores gained is presented.

In the first set of experiments the full auction mechanism was used. This method was used by the police agents in the Caspian rescue simulation team during German-Open 2004 competitions. The second set shows the scores gained while using the partitioning-based approach. In the third set of experiments the hybrid-method which makes use of the advantages of the other two methods is tested. This method was used by the Caspian rescue simulation team during the RoboCup 2004 competitions. In the set of experiments in which the police office is not running, there's no auction, and no clearing requests will be sent to the police forces either. The police forces discover the tasks by themselves. The result of the experiment in which the blockade simulator is not running shows the overall score of the rescue team in absence of the blockades. This helps to take into consideration the maximum possible score of the rescue team.

Comparing the auction mechanism to the hybrid-method shows that in the beginning of the simulation the police forces using the auction mechanism scored better than those using the hybrid-method. But the situation changes over time, and the hybrid-method ends with a higher score. That is because in the auction- mechanism the

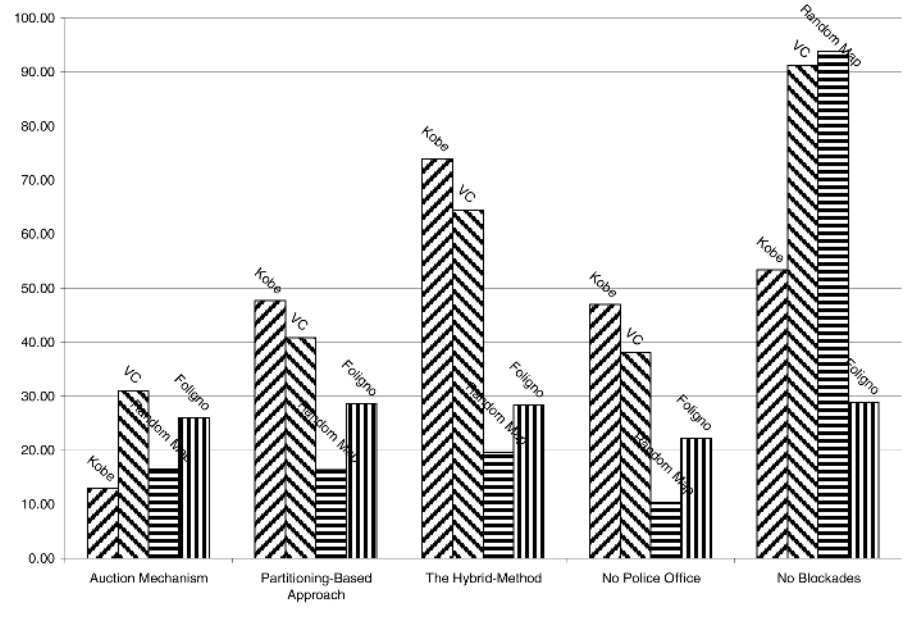

Fig. 2. The average scores of the experiments using the 3 methods in 4 different maps

police forces deal with the blockades in the region of the fire brigades and ambulances focus. As the simulation continues, these agents need to change their activity area, but other parts of the city are remained full of blockades. In the hybrid-method one or more police forces are assigned to each partition, and other police forces deal with the urgent requests. That causes the city be cleared from blockades, while the urgent requests by the fire brigades and ambulances are handled.

The scores gained through the experiments are illustrated in figure 2. In this figure it is shown that the hybrid-method had a higher performance over other methods in all the maps used. Police forces using the partitioning-based mechanism scored higher than those using the auction mechanism. One point to be clarified in fig. 2, is that the team scored less in the Kobe map when no blockades were running, with respect to the situation where the hybrid-method was used. The reason behind such facts is that the score of the team is highly dependant to the map configuration, and special situations happening in each run, and facts such as which fire do the fire brigades choose to extinguish first.

5 Conclusion and Future Work

In this paper, the usage of task allocation mechanisms for police force agents in the disaster mitigation environments has been described. Three different approaches have been presented. The empirical results of using these approaches show that the fully auction-based mechanism looks promising in situations where there is an urgent need to reply. However, in rescue simulation domain where the agents change their working area rapidly, using this approach will lead to a significant performance loss, because other parts of the disaster space were not considered. By using the second method, partitioning-based approach, we have noticed that all parts of the disaster space are cleared simultaneously, but the urgent requests are handled too late. The third method combines the advantages of the other two. In this method the urgent requests are handled as fast as possible, while other agents are distributed in other partitions and serve other parts of the city monotonically.

By using the hybrid method in the Caspian 2004 Rescue simulation team, our agents together with other type agents succeeded to rank third.

In our research work we are going to enhance the performance of the system by adding the ability for the fire fighters and ambulance teams to report the priority of their requests. Partitioning the disaster space dynamically based on the observed priority of each region, is another work to do.

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