Organizing Rescue Agents Using Ad-Hoc Networks

Toru Takahashi, Yasuhiko Kitamura, and Hiroyoshi Miwa

Abstract. When a disaster happens, rescue teams are organized. They firstly search for victims in the disaster area, then share information about the found victims among the members, and finally save them. Disasters often make conventional communication networks unusable, and we employ rescue agents using ad-hoc networks, which enable the agents to directly communicate with other agents in a short distance. A team of rescue agents have to deal with a trade-off issue between wide search activities and information sharing activities among the agents. We propose two organizational strategies for rescue agents using ad-hoc networks. In the Rendezvous Point Strategy, the wide search activities have priority over the information sharing activities. On the other hand, in the Serried Ranks Strategy, the information sharing activities have priority over the wide search activities. We evaluate them through agent-based simulations, comparing to a naïve and unorganized strategy named Random Walk Strategy. We confirm that Random Walk Strategy shows a poor performance because information sharing is difficult. We then reveal the two organizational strategies show better performance than Random Walk Strategy. Furthermore, the Rendezvous Point Strategy saves more victims in the early stages, but gradually the Serried Ranks Strategy outperforms it.

1 Introduction

When a disaster happens, rescue teams are immediately organized to save victims trapped in debris as soon as possible. They firstly search for victims in the disaster area and share information about the found victims. They then gather a necessary number of members required to save the victims. Disasters often damage conventional communication networks such as telephones, cell phones, and even the

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Internet seriously. Even they are alive, they often become useless because of heavy network congestions. It may be difficult to share information through conventional communication network when a disaster happens. As an alternative way, we employ rescue agents with ad-hoc networks to share information among them. A rescue agent can directly communicate with others in a short distance, and it may be able to communicate with even distant agents by transferring messages through mediator agents like a bucket brigade. If such mediator agents are not located properly among them, it is difficult to make them communicate with each other. Ad-hoc networks, therefore, do not guarantee stable communication because the range of message transmission is limited and the delay and/or disruption of messages occur frequently. We need new organizational schemes to share information among rescue agents using ad-hoc networks.

Rescue operations using ad-hoc networks are more difficult than those using conventional communication networks because it is not easy to share information among rescue agents through ad-hoc networks. This raises a trade-off issue between wide search activities and information sharing activities. If rescue agents disperse widely to search for victims in a disaster area, it is difficult for them to share information because they often are out of communication range. On the other hand, if rescue agents gather narrowly, they can share information easily through ad-hoc networks, but their search area is limited.

We have two strategies to organize rescue agents to deal with this issue. The Rendezvous Point Strategy makes rescue agents repeat to disperse widely to find victims and to get together at the rendezvous point to share information. The Serried Ranks Strategy makes rescue agents disperse only in a short range as far as they can communicate with each other to share information. The rescue agents move to find victims like serried ranks.

In this paper, we evaluate the organizational strategies by using agent based simulations (ABS). ABS is a powerful simulation technique that can represent rescue agents and their interactions [1, 2]. We first simulate a naïve and unorganized strategy named the Random Walk Strategy as the base line of our evaluation, and then evaluate two organizational strategies comparing with the base line.

The rest of this paper is organized as follows. We discuss related works in Section 2. We present our simulation testbed for rescue activities in Section 3. We then evaluate the Random Walk Strategy in Section 4 and the organizational strategies in Section 5. In Section 6, we conclude this paper with our future works.

2 Related Works

We have four important research issues to develop rescue agents with ad-hoc networks: 1) dynamic message routing protocols in ad-hoc networks; 2) saving battery power consumption; 3) strategies for rescue activities using ad-hoc networks; 4) remedies against communication failure.

- **Dynamic Message Routing Protocols:** Since rescue agents move around in the disaster area to save victims, the topology of ad-hoc networks dynamically changes. We must design message routing protocols to cope with it. Johansson et al. [3] discuss a comparison among three protocols; DSDV [4], AODV [5], and DSR [6]. Other dynamic routing protocols for ad-hoc networks have been proposed in [7, 8].

- **Saving Battery Power Consumption:** Since each node in ad-hoc networks is battery driven, power-aware metrics are important to evaluate rescue activities as discussed in [9, 10]. Toh [11] proposed power-aware message routing protocols for a disaster case.
- **Strategies for Rescue Activity:** Rescue strategies to save victims are an important research issue, but there are few works on strategies for rescue activities using ad-hoc networks. Most of models are based on random-based movement [6, 12] of agents or nodes. Aschenbruck et al.[13] presented significant differences of performance between using conventional random-based movement and realistic scenario-based movement in simulations. In this paper, we propose organizational strategies for rescue agents and evaluate them contrasting a random-based strategy.
- **Remedies against Communication Failure:** Since obstacles such as thick concrete shielding often make rescue agents difficult to maintain their ad-hoc communication in real environments, we need remedies to overcome this problem. [14, 15] discuss methods to maintain a communication path between human operators and exploring robots. Ulam[16] discusses a method to recover from communication failures. Since we focus on strategies for information sharing and searching for victims, this paper does not deal with this issue.

3 Simulation Testbed

Our simulation consists of victims that are scattered in a disaster area and rescue agents that search for them. If an agent finds a victim, we assume it needs to gather a necessary number of other rescue agents to save the victim because victims are trapped under debris and more than one agent are required to save a victim. Rescue agents can share information about the victim through ad-hoc networks to gather other agents. The rescue agent can send messages to its neighbors located in the communication range and the neighbors also can pass the messages to their neighbors recursively to share information among rescue agents in the communication range.

We deal with three strategies in this simulation. They are the Random Walk Strategy, the Rendezvous Point Strategy and the Serried Ranks Strategy. The Random Walk Strategy is a non-organizational strategy in which agents move randomly keeping an interval to other agents. The Rendezvous Point Strategy aims to distribute rescue agents widely. It enables them to search for victims in a wide disaster area. We set a rendezvous point where rescue agents return to share their information about victims and to gather other rescue agents. The Serried Ranks Strategy makes rescue agents form serried ranks to keep them share information. They can communicate with each other at any time because all of them are located in the communication range, so it is easy for them to gather other rescue agents to save victims as soon as one of them finds a victim. Since the agents always stay in the communication range, their search activities also are limited in the area. We show the details of simulation below.

The simulator represents the disaster area as a two-dimensional cell model where the distance between two points is defined as the Manhattan distance. Rescue agents and victims are located in the disaster area.

Rescue agent, $A_i(i=1,\cdots,n)$ can stay or move to a neighboring cell in a simulation step following its strategy ($Strategy_i$). All the agents start from the start cell. At every step, the agent can send a message to others in the communication range (r_i) of ad-hoc networks. The message contains the current location of the agent, the location and the rescue cost of victims, and the number necessary of rescue agents if it has found one or more victims.

Victim $R_j(j=1,\cdots,m)$ is located in the disaster area. In order to save a victim, a rescue agent needs to find him/her and to gather a necessary numbers of agents. If a rescue agent and a victim is located in a same cell, the agent can find the victim with probability p. Victim R_j has two parameters; rescue cost c_j and the necessary number of rescue agents t_j where c_j / t_j simulation steps are required to save the victim if the number of rescue agents located at the cell is t_j. Otherwise, they cannot start the saving activity.

3.1 Strategy of Rescue Agents

Random Walk Strategy makes rescue agents move randomly searching for victims. If an agent is located within the distance $interval_i$ from other agents, the agent moves to or stay at a cell where it keeps the longest interval from others.

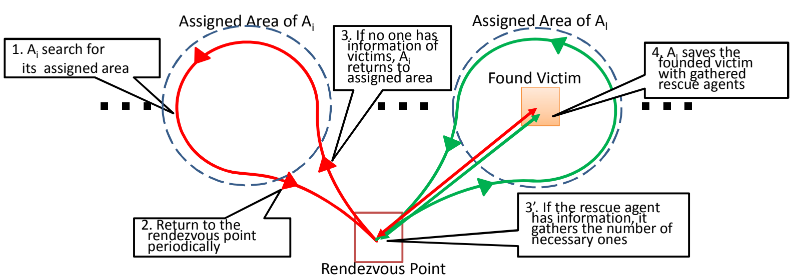

Fig. 1 Rendezvous Point Strategy.

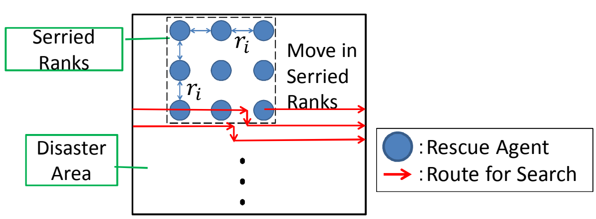

Fig. 2 Serried Ranks Strategy.

As we increase $interval_i$ rescue agents are located sparsely. If a rescue agent receives information about victims, it moves to save the nearest victim regardless of the distance to the other agents. When it arrives to a cell with a victim, it waits to save the victim until the necessary number of rescue agents arrive at the cell.

Rendezvous point strategy is an organizational strategy as shown in Figure 1. In this strategy, we assign a search area to each rescue agent without overlapping and set the rendezvous point to share information among agents. Rescue agents repeat to search the assigned areas for victims and to return to the rendezvous point. If an agent returns to the rendezvous point with information about a victim, it waits there to gather the necessary number of other rescue agents. If the agents gather, they move to save the victim.

In the Serried Ranks Strategy, we deploy rescue agents in a rectangle shape, which we call “serried ranks”, as shown in Figure 2. They maintain an interval, which is equal to the communication range r_i, among them. They move with keeping the serried ranks to search for victims. The agents move horizontally until the end of the disaster area, then move a step vertically, and move horizontally again.

If a rescue agent finds a victim, it sends the information to rescue agents around it. The necessary number of agent move to save the victim departing from the position in the serried ranks. The rest of agents continue to search for victims keeping their position in the serried ranks. Completing to save the victim, the agents return to the position in the ranks. They can catch up with the serried ranks because the speed of the serried ranks is set to one half of rescue agents.

4 Evaluation of Random Walk Strategy

We evaluate the Random Walk Strategy, especially the performance depending on the distribution of agents defined by $interval_i$ and the necessary number of rescue agents. In this simulation, we set the parameters as follows: The number of rescue agents (n) = 20, the number of victims (m) = 20, the probability to find a victim (p) = 0.10, the rescue cost (c_j)=100, and the communication range (r_i)=5. We change $interval_i$ from 0 to 5. We set the necessary number of rescue agents to 2 or 5. In the Random Walk Strategy, a rescue agent waits for necessary number of rescue agents at a cell with a victim. When all the rescue agents keep waiting, we define this case as a failure.

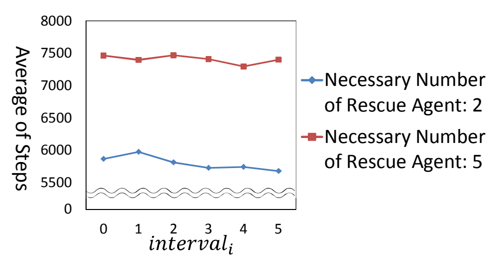

Fig. 3 Steps required to save all the victims without failure using the Random Walk Strategy.

Table 1 Failure rate when the necessary number of rescue agents is 5

$interval_i$	0	1	2	3	4	5
Failure rate(%)	11.1	11.7	11.6	11.5	11.8	15.1

Figure 3 shows the average performance of 1000 simulations, which is simulation steps required to save all the victims without failures. The x-axis represents $interval_i$. Table 1 shows the rate of failures when the necessary number of rescue agents is 5. When the necessary number is 2, we have no failure.

The performance of the Random Walk Strategy is affected by the necessary number of rescue agents. Even if a rescue agent finds a victim, it often cannot gather the necessary number of rescue agents because it is difficult for them to share information about the found victim among the rescue agents through ad-hoc networks.

When the necessary number of rescue agents is 2, the large interval shows a better performance than the small one. When the number is 5, the difference is little but the failure rate increases as the interval does. These results suggest when the necessary number of rescue agents is small, the wide distribution of agents leads to a better performance than narrow distributions. On the other hand when the necessary number of rescue agents is large, the wide distribution of agents leads to a poor performance because it is difficult to gather them through ad-hoc networks.

5 Evaluation of Organizational Strategies

We evaluate two organizational strategies; the Rendezvous Point Strategy and the Serried Ranks Strategy. The Rendezvous Point Strategy emphasizes the wide search activities and The Serried Ranks Strategy emphasizes the information sharing activities.

The setting of parameters is the same to the simulation in the previous section except the communication range. In the Rendezvous Point Strategy, the communication range r_i is set to 0 and the rescue agents can share information only at the rendezvous point. In the Serried Ranks Strategy, we change r_i from 0 to 10.

Figures 4 and 5 show the result of the average performance of 1000 simulations. Figure 4 shows that how many steps the Rendezvous Point Strategy and the Serried Ranks Strategy take to save all the victims. Figure 4 shows the cumulative number of saved victims at each step when the necessary number of rescue agents is 5 and the communication range is 5.

The necessary number of rescue agents makes little difference in both of the Rendezvous Point Strategy and the Serried Ranks Strategy. It means that these strategies enable rescue agents to share information more effectively among them than the Random Walk Strategy.

In the Serried Ranks Strategy, the large communication range improves the performance. The performance of the Rendezvous Point Strategy is close to that of

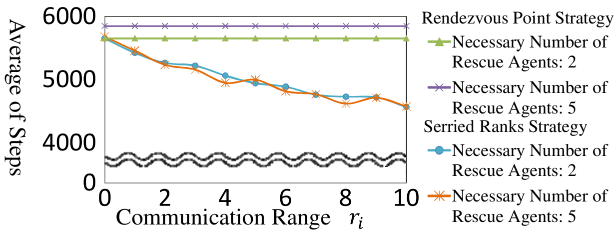

Fig. 4 Steps to save all the victims with the Rendezvous Point and the Serried Ranks Strategy.

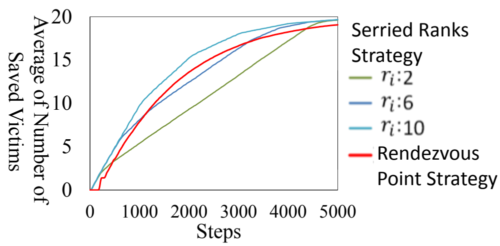

Fig. 5 Cumulative number of saved victims at each step.

the Serried Ranks Strategy when the communication range is 0, but generally speaking, the performance of the Serried Ranks Strategy is better than that of the Rendezvous Point Strategy. In the Serried Ranks Strategy, rescue agents search the narrow area exhaustively and they rarely overlook victims.

Figure 5 shows that the Rendezvous Point Strategy saves more victims than the Serried Ranks Strategy in the middle stage when r_i is less than 6. The Rendezvous Point Strategy can search the disaster area widely in a short time, and the Serried Ranks Strategy searches the area exhaustively but it takes a long time. These results suggest combining two strategies may lead a better performance.

6 Conclusion

We propose organizational strategies for rescue agents using ad-hoc networks in a disaster area. We have a trade-off issue between wide search activities and information sharing activities because the range of ad-hoc communication is limited. If rescue agents disperse widely, they can search a large disaster area, but it is difficult for them to share information, because they often are out of communication range. On the other hand, if rescue agents gather narrowly, they can always share information through ad-hoc networks, but they can search only a narrow area. We propose two organization strategies for rescue and relief operations based on ad-hoc networks. The Rendezvous Point Strategy emphasizes wide search activities and the Serried Ranks Strategy emphasizes information sharing activities.

We first simulate random walking agents and evaluate the effect of the necessary number of rescue agents and the degree of distribution. As a result, we confirm that it is difficult to share information among many agents, especially when they disperse widely.

We then simulate two organizational strategies; the Rendezvous Point Strategy and the Serried Ranks Strategy. As a result, these strategies enable them to share information better than the random walk agents. While the Rendezvous Point Strategy is better in term of saving victims in a short time, the Serried Ranks Strategy is better in term of saving all the victims.

As our further works, we propose a new organizational strategy which combines the advantages of two strategies for rescue agents with ad-hoc networks.

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