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Crisis management using MAS-based wireless sensor networks

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ABSTRACT

Wireless communication is increasingly used to manage large-scale crises (e.g., natural disasters or a large-scale city fire). Communication has traditionally been based on cellular networks. However, real-life experience has proven that the base stations of these networks may collapse or become unreachable during a crisis. An incident commander must also know as much information as possible about the occurring events to control them quickly and efficiently. This paper thus proposes a crisis management approach that overcomes the problems encountered by the base stations and insures relevant, rich and real-time information about events. This approach is based on wireless sensor networks, which are distributed in nature with no need for infrastructure and could be deployed in dangerous and inaccessible zones to gather information. Our proposal uses a multi-agent system as a software layer. The multi-agent system aims to improve the wireless sensor network performance by allowing cooperation between sensor nodes, offering better lifetime management and virtualizing the application layer. This virtualization supports several required applications simultaneously, including event monitoring and object tracking. Through successive simulations, we prove the importance of our approach in crisis management using several criteria to estimate the position's error in object tracking, end-to-end delay and wireless sensor network lifetime management.

1. Introduction

Several works [1–6] propose using wireless communication as a main contributor in managing large-scale crises, including large-scale city fires and forest, industrial and natural disasters. These works focus mainly on using cellular and ad hoc networks. However, two problems have appeared when using these wireless networks. First, experience has shown that cellular network base stations might collapse or become unreachable during a crisis, e.g., in 1995 and 1999, the base stations were unreachable during the earthquakes in Japan. The second problem concerns the type of information exchanged on these networks. Ad-hoc and cellular networks allow inter-rescue person communication as well as communication between the incident commander and rescue people. However, the crisis information is limited to what the rescue people see, while the risk might come from inaccessible zones or zones that are not considered by rescue people.

To handle these issues, we propose a crisis management solution based on using wireless sensor networks (WSNs). Such networks are distributed and rely on neither an infrastructure nor a base station that may collapse. The sensor nodes (SNs) can also be deployed in hostile and inaccessible zones. WSNs can thus gather relevant, rich and real-time information about the occurring event. Our proposal aims to simultaneously manage several vital applications

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during such events, including the events' data aggregation, e.g., fire evolution, safe zones and gas diffusion, and the orientation and tracking of rescue people and intervention robots. To manage several applications over the same WSN and optimize its lifetime and performance, our proposal is also based on a multi-agent system that serves as a software layer. The implemented multi-agent system (MAS) can empower the SNs to make decisions autonomously and according to a local/partial network view, which seems to be more appropriate in such a distributed and dynamic context. Part of this work appeared in IEEE Globecom' 2010 [7].

This paper is organized as follows. We first discuss related work and motivate the need for our proposed scheme in Section 2. Section 3 presents the problem statement. Section 4 discusses the proposed data aggregation, rescuer orientation and tracking schemes, as well as how to manage several applications simultaneously. Section 5 then presents the simulation setup with the related developed models (routing, node distribution, energy consumption and traffic). Section 6 gives a performance evaluation. Finally, Section 7 provides conclusions and offers some perspectives.

2. Related works

Crisis management solutions are generally tackled using tailored solutions and data aggregation methods. This section is divided into two parts. The first part gives an overview of existing management solutions, and the second highlights research works on data aggregation.

2.1. Existing crisis management solutions

Saha and Matsumoto [8] have proposed a hybrid solution based on WSNs, ad hoc networks and cellular networks that considers the deficiencies of cellular networks. Their goal is to offer a data collection framework during a disaster. They thus consider dividing a network into cells, with a base station in the center of each cell and static ad hoc relay stations (ARSs) on the seeds. The SNs of each cell gather their cell information and send it to the incident commander through the base station of the cell. Conversely, if the base station fails, the ARSs replace it. However, a network divided into cells is not always realistic in disaster situations. Placing ARSs at precise locations could also be infeasible in some disasters where human intervention is dangerous and robot routes are collapsed.

A previous study [3] has proposed a WSN architecture for military and crisis management. The authors mainly address clock synchronization in audio and video communications over a WSN to manage the security problem, as they assume a military application. Due to the importance of security in the proposal, the authors have not clearly considered the problems of incident field information aggregation and communication with the incident commander.

Another study [2] has examined the problem of team coordination among a set of vehicles (or robots) during an incident. The main role of the vehicles is to penetrate dangerous areas, gather information and send it to the incident commander. The incident commander remotely controls the vehicle's team leader, and each team member coordinates with the leader to define its orientation and speed. This proposal saves rescue people's lives and could be useful for quick intervention. However, continuous real-time information gathering remains important to monitor and control the evolution of the incident.

Considering the deficiencies in cellular networks and the placement problem when using hybrid proposals, information aggregation and continuous vital sign gathering, this paper proposes a multi-agent system-based WSN for crisis management. This proposal tends to simultaneously manage several vital applications during a crisis, including incident information aggregation (e.g., fire evolution, safe zones discovery and gas diffusion) and the tracking and orientation of rescue people and intervention robots.

In our previous paper [7], we have proposed a crisis management model based on sensor networks. The proposed model aims to handle crisis events through sensor nodes without any infrastructure. However, the proposed model has several limitations. First, it does not explicitly address the handling of several applications running simultaneously. Second, the rescuer orientation model is outside the paper scope. Third, the tracking model does not include a clear relationship with our agent model. The tracking is based on the sensor's RSSI measurement without considering the information relevance. Fourth, our previous work does not address the routing issue, which is important to ensure network connectivity and information communication. Furthermore, the paper does not address node deployment, traffic and energy consumption modeling. In this paper, we address these limitations to create a more powerful approach. We start by detailing and completing our data aggregation model, the criteria for the cooperation decision mechanism and how the agent manages the applications running simultaneously. We propose a rescuer orientation method to control a crisis situation faster. We explicitly include multi-object tracking in our agent model and propose using information relevance measurement and transmission power consumption instead of RSSI. To cover the routing issue, we propose a lightweight routing protocol (Section 5.2) to ensure connectivity, fast convergence, and low maintenance costs (in terms or power). Finally, we address related issues, including required node deployment, traffic, and node power consumption modeling.

Some data aggregation methods in WSNs are also seen as possible crisis management tools. A state-of-the-art existing data aggregation proposal is thus given in the next section.

2.2. Data aggregation

The data aggregation mechanism in WSNs can be classified into two categories. The first category is structure-free and handles the random SN distribution. This mechanism type does not require power consumption to organize the network. This category ensures high data