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Deployment and reallocation in mobile survivability-heterogeneous wireless sensor networks for barrier coverage

Jie Tian*, Xiaoyuan Liang, Guiling Wang

Department of Computer Science, New Jersey Institute of Technology, United States

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ABSTRACT

Barrier coverage is a widely adopted coverage model for intruder surveillance application in wireless sensor networks. However, when sensor nodes are deployed outdoors, they are subject to environmental detriments and will be failed while operating in the rain. Thus, one barrier is not robust to provide barrier coverage under both sunny and rainy weather. In this paper, we study the barrier coverage problem in a mobile survivability-heterogeneous wireless sensor network, which is composed of sensor nodes with environmental survivabilities to make them robust to environmental conditions and with motion capabilities to repair the barrier when sensors are dead. Our goal is to keep field to be monitored continuously under both sunny and rainy weather and to prolong the network lifetime as much as possible. We propose a novel greedy barrier construction algorithm to solve the problem. The algorithm adopts weather forecast to direct the barrier construction under sunny and rainy weather, and the energy consumption of construction is minimized. Simulation results show that our algorithm efficiently solves the problem and outperforms other alternatives.

1. Introduction

Wireless sensor networks have been widely employed in many long-term surveillance applications such as field surveillance, critical infrastructure protection and country border control. Intruder detection as a very important long-term field surveillance application is extensively studied in the community [1–3]. In the application, sensors are deployed in the area to detect intruders. The intruder's objective is to traverse the monitored area. For example, in a battlefield, an enemy may try to traverse a protected area to conduct some malicious tasks, the successful detection of which before he passes through is important.

Among intruder surveillance applications, barrier coverage is a widely known coverage model to detect intruders. A barrier is a line of sensors across the entire field of interest. The sensing ranges of two neighbor sensors in the barrier are overlapped and thus the intruder are guaranteed to be detected. In the applications, the sensors are always deployed outdoors to achieve barrier coverage. However, as a tiny electronic device, an on-duty sensor node is vulnerable to many environmental attributes or detriments, such as rain or snow [4]. The sensor nodes may become unreliable and even dead under the rain, and thus the barrier coverage cannot be guaranteed. The environmental problem has been frequently cited as a vital reason to destroy the barrier coverage, but a very few research efforts have been dedicated to addressing the problem directly or fundamentally. Another problem in barrier construction outdoors is that it is almost impossible to construct an optimal barrier with sensors side by side along a straight line across the region, when

* Corresponding author: Tel.: +19735962869.
E-mail addresses: jt66@njit.edu (J. Tian), xl367@njit.edu (X. Liang), gwang@njit.edu (G. Wang).

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sensors cannot move and are randomly distributed in the network.

To increase the survivability of a sensor node outdoor, one way is to equip it with additional protection to make it for example water-proof [5]. However, to make all sensor nodes water-proof is not cost-effective. It may greatly increase the cost of sensor networks, making them less applicable [6]. Also, many environmental conditions that can do harm to sensor nodes only happen occasionally in an area. For example, in a given area, there is a low probability that it continuously rains for a long time. Hence, an effective solution is to construct a sensor network composed of both regular sensor nodes lacking of protection and nodes with additional environmentally robust features [7]. We call the latter environmentally robust nodes, or robust nodes for short. The term environmental survivability characterizes such heterogeneity, which is fundamentally different from the widely studied heterogeneity in terms of computational capacity, energy, communication range, and sensing range [8–11].

To efficiently construct barriers under a random sensor distribution, robust sensors with controlled mobility are employed in the network to guarantee the coverage. Since regular sensors can be damaged during the rain, it is not reasonable to add motor bases to make them move, which is costly. For robust sensors, adding motor bases can fully explore the better use of the robust feature when needed. After the initial deployment, the mobile robust sensors can move to certain locations and connect with other un-utilized sensors to form barriers under both sunny and rainy weather. This paper proposes a new kind of wireless sensor network, a mobile survivability-heterogeneous wireless sensor network composed of both static regular sensors without protection and mobile robust sensors with protection. It is important to exploit the moving strategy of mobile robust sensors to achieve barrier coverage under different weather conditions.

To tackle the problem, we leverage the mix deployment of static regular sensors and mobile robust sensors to construct barriers under different weather conditions. Our objective is to construct one barrier with minimum sensing overlaps to detect intruders as long as possible under both sunny and rainy weather. Note that static regular sensors cannot work under the rain; otherwise they will be damaged permanently and cannot work any more though they still have energy left. Mobile robust sensors need to conserve their energy consumption such that they still have enough energy to move and thus to form a working barrier when there comes rain. Since the energy consumption of movement in mobile robust sensors is much higher than energy consumption of sensing and communication, the aim of this paper is to minimize the total energy consumption of movement of robust sensors to construct barriers under different weather conditions such that the network lifetime is prolonged as much as possible.

Because of the additional dimension of complexity in barrier construction incurred by weather, previous works [1,2,12–14] in studying barrier construction to achieve guaranteed barrier coverage cannot be directly employed here. If all static regular sensors are used to construct the barrier under the sunny weather, a large amount of mobile robust sensors need to be moved to form a new barrier when rain comes and thus a lot of energy is consumed. For example, in [13], a lot of mobile sensors need to move to the predefined line under the rainy weather to form a new barrier. If all mobile robust sensors are used to construct the barrier at the beginning, they will work for a long time and will not have enough energy to work during rainy weather. Thus, our idea is to use both static regular sensors and mobile robust sensors to construct a barrier with the least energy consumption under sunny weather and then to reallocate mobile robust sensors to construct a new barrier with the least energy consumption in robust sensors' movement under rainy weather.

In the paper, we propose a greedy barrier construction algorithm to solve the problem. Given a long-belt shaped area, a barrier is first constructed in a centralized manner without moving any robust sensors. When rain comes, a new barrier is constructed locally to save energy consumption of communication. The long-belt area is divided into several grids based on the positions of mobile robust sensors in the barrier. In each grid, a coordinator is selected to direct the movement of mobile robust sensors to construct a new barrier. If there are not enough mobile robust sensors to reconstruct the barrier, the grid merges itself with one of its neighbor grids to form a bigger grid to make the reconstruction. To increase the network lifetime, minimizing energy consumption of moving robust sensors in each grid is considered by each coordinator to make the decision.

To summarize, our contribution in this paper is three-fold:

- We for the first time propose a new mobile survivability-heterogeneous sensor networks composed of both static sensors nodes without protection and mobile sensors nodes with environmentally robust features.
- We for the first time study the barrier coverage problem in such heterogeneous WSN considering different weather conditions.
- A greedy algorithm is proposed to achieve efficient and effective barrier coverage under both rainy and sunny weather.

The remainder of the paper is organized as follows. Related work is discussed in Section 2. We present the assumptions and models in Section 3. Section 4 describes the greedy algorithm. Section 5 reports simulation results. Finally, we conclude the paper in Section 6.

2. Related work

Barrier coverage for intruder detection has been studied extensively. Theoretical foundations of designing barriers using wireless sensors in WSNs are developed in [15]. According to [15], the barrier coverage problem is very difficult to solve in a decentralized way due to its globalized nature. Chen et al. address this challenge by introducing the concept of local barrier coverage in [16]. In [17], Liu et al. propose a distributed algorithm to construct multiple disjoint barriers for strong barrier coverage when sensors are distributed following a Poisson distribution. In [18], Saipulla et al. study the barrier coverage problem when sensors are deployed along a line. To further utilize the barrier concepts in wireless sensor networks, Kumar et al. develop solutions for the case when sensors are deployed to form an impenetrable barrier for detecting movements in [19]. In [20], Chen et al. introduce a