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Stochastic barrier coverage in wireless sensor networks based on distributed learning automata

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A R T I C L E   I N F O

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A B S T R A C T

Barrier coverage is one of the most important applications of wireless sensor networks. It is used to detect mobile objects are entering into the boundary of a sensor network field. Energy efficiency is one of the main concerns in barrier coverage for wireless sensor networks and its solution can be widely used in sensor barrier applications, such as intrusion detectors and border security. In this work, we take the energy efficiency as objectives of the study on barrier coverage. The cost in the present paper can be any performance measurement and normally is defined as any resource which is consumed by sensor barrier. In this paper, barrier coverage problem is modeled based on stochastic coverage graph first. Then, a distributed learning automata-based method is proposed to find a near optimal solution to the stochastic barrier coverage problem. The stochastic barrier coverage problem seeks to find minimum required number of sensor nodes to construct sensor barrier path. To study the performance of the proposed method, computer simulations are conducted. The simulation results show that the proposed algorithm significantly outperforms the greedy based algorithm and optimal method in terms of number of network barrier paths.

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1. Introduction

Nowadays, wireless sensor networks are implemented in a wide range of applications such as border surveillance and intrusion detection. Coverage is one the adapted metrics to measure the quality of service (surveillance) in networks [2]. For instance, sensor nodes can be deployed in borders of a country to detect intrusion, around forests to detect fire, both sides of gas and oil pipe lines to detect potential sabotage, around chemical factories to detect leakage and emission of chemical gases, and etc. The main goal of these applications is to detect any kind of intruders when they enter or penetrate into the network region [3]. The problem, which is referred to as barrier coverage problem, arises from the fact that sensors tend to unnecessarily cover the whole area in the network, rather than detecting only those intruders that enter or exit a network.

Basically, barrier coverage can be categorized into two classifications: weak barrier coverage and strong barrier coverage [4]. In weak barrier coverage, we only need to detect intruders moving along congruent crossing paths; and in strong barrier coverage, we need to detect intruders with arbitrary moving paths. In most of the studies in coverage problem of wireless sensor networks, sensors are supposed to have an omnidirectional sensing model, in which the sensing range of a sensor is mostly a disk model and an object can be covered or detected by a sensor if it is within the sensing range of the sensor [5,6].

Fig. 1 shows a network which can support 2-barrier coverage. It can be seen in the figure that any intruders can be detected by deployed sensor nodes. For instance, two intruders penetrating into the network can be seen in this network. We require that, in order to cover them, every crossing path be covered by deployed sensor nodes in networks. A path is a crossing path if it crosses from top to bottom [2]. In real implementation of wireless sensor networks, intruders are highly unlikely to follow such paths; a short path across the belt region is more likely to be taken.

A wireless sensor network consists of tiny nodes. Each node in network has a low computation power, battery capability, transmission power, etc. Thus, energy consumption is one of the critical issues in this kind of network. Scheduling algorithms try to schedule sensor nodes into proper status to save restricted resources in network. In barrier coverage, also most of the approaches select appropriate nodes to guarantee detection of intruders to network borders.

In this work, we model barrier coverage problem with stochastic edge-weighted graph, called it stochastic barrier coverage, and propose a novel method based on distributed learning automata

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to address the problem of stochastic barrier coverage in wireless sensor networks. In the proposed algorithm which is called DLASBC, each node in the network is equipped with a learning automaton which learns (schedules) best node to cover barrier path based on distributed learning automata structure. The DLASBC is developed around the modeling tool of distributed learning automata. It is established that the number of barriers in a network, gained by DLASBC, is better than that of other similar schemes. Our main purpose is to increase network barriers.

The main contributions of this paper are as following:

- Proposing a new approach to barrier coverage in wireless sensor network.
- Modeling barrier coverage with stochastic edge-weighted graph.
- Finding an optimal solution for the network stochastic edge-weighted coverage graph.
- Comparing the performance of the proposed method with the greedy and optimal methods.

The rest of the paper is organized as following. Section 2 briefly surveys related works. Problem statement is given in Section 3. In Section 4, we overview the learning automata and distributed learning automata. The proposed method is given in Section 5. Section 6 reports the performance of our proposed network barrier monitoring scheme. Finally, Section 7 concludes the paper.

2. Related Work

One of the most important issues in wireless sensor networks is coverage problem. This problem relates to the ability of a wireless network to monitor a certain area or some certain events. Coverage problem is classified into three main different types [7]; area coverage, point coverage, and barrier coverage. Area coverage: the main objective of area coverage is to monitor the whole area of the network with minimum number of sensors providing desired coverage level during the maximum lifetime of the network. Point coverage (target): the objective of point coverage is to cover a set of stationary or moving points.

Barrier coverage: barrier coverage can be considered as the coverage with the goal of minimizing the probability of undetected penetration through the barrier (sensor network). This type of coverage problem needs less number of sensors than full coverage problem.

He and Shi [32] studied sensor barriers with minimum cost in wireless sensor networks. They proposed a distributed algorithm to find maximum number of barrier coverage in wireless sensor networks. Their method works for any size of sensor nodes and any shape of field in networks, and no single node necessarily knows its exact location and only needs to communicate with its neighbors. Their proposed approach complexity is in order of $O(n^2)$ where "n" is the number of deployment nodes in the network. Yang and Qiao [8] studied the barrier information coverage problem. They proposed an energy efficient method based on collaborations and information fusion between neighboring sensors to decrease the number of active nodes. However, the proposed heuristic algorithm requires the location information for all sensors and barriers, and also it may not find the optimal sensor barrier with minimum cost.

Kumar et al. [9] proposed a centralized wakeup/sleep scheme for optimally solve the problem of barrier coverage in WSNs. Mostafaei and Meybodi [10] proposed an energy efficient scheduling method based on learning automata, in which each node is equipped with a learning automaton, which helps the node to select best node to guarantee barrier coverage, at any given time. They initially executed Dijkstra's algorithm on the static coverage graph snapshot and then proposed a learning automata based to find near optimal method find barrier paths in deployed network.

Barrier coverage with mobile sensor nodes is another type of this problem. Ban et al. [11] concentrated on the problem of how to relocate mobile sensors to construct k sensor barriers with minimum energy consumption. They modeled the problem as integer linear programming (ILP) and proved this problem is NP-Hard. Then proposed an approximation algorithm AHGB to construct one energy-efficient sensor barrier. Based on AHGB, a Divide-and-Conquer algorithm was proposed to achieve k-barrier coverage for large sensor networks. Saipulla et al. [12] studied how to efficiently improve barrier coverage using mobile sensors with limited mobility. They explored the fundamental limits of sensor mobility on barrier coverage and proposed a sensor mobility scheme that constructs the maximum number of barriers with minimum sensor moving distance. Wang et al. [13] studied how to efficiently use mobile sensors to achieve k-barrier coverage. They studied two problems under two scenarios. First, when only the stationary sensors have been deployed, what is the minimum number of mobile sensors required to form k-barrier coverage? Second, when both the stationary and mobile sensors have been pre-deployed. They introduced a novel concept of weighted barrier graph (WBG) and proved that determining the minimum number of mobile sensors required to form k-barrier coverage is related with finding k vertex-disjoint paths with the minimum total length on the WBG.

In [14] authors tried to achieve barrier coverage in sensor scarcity case by dynamic sensor patrolling. They designed a periodic monitoring scheduling (PMS) algorithm in which each point along the barrier line is monitored periodically by mobile sensors. Based on the insight from PMS, they proposed a coordinated sensor patrolling (CSP) algorithm to further improve the barrier coverage, where each

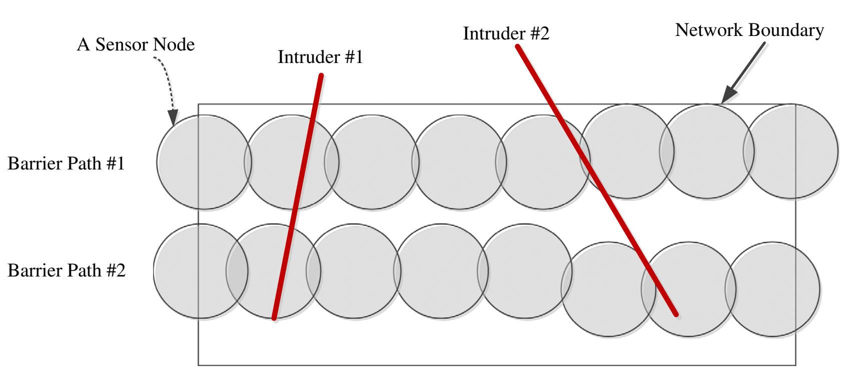

Fig. 1. An illustration of strong 2-barrier coverage: any crossing path from the top of the region to the bottom is covered by at least one sensor.

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