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Barrier coverage in adjustable-orientation directional sensor networks: A learning automata approach☆

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ABSTRACT

Barrier coverage is one of the main applications of wireless sensor networks. There are two kinds of barrier coverage: weak and strong. While weak barrier coverage can only guarantee detecting intruders moving along predetermined or congruent paths, strong barrier coverage guarantees detecting all intruders regardless of their crossing paths. In this paper, we first present a centralized algorithm based on distributed learning automata to find strong barrier lines in adjustable-orientation directional sensor networks in which nodes can adjust their orientation in a non-overlapping form such as camera sensor networks. Then, we will present the distributed version of the proposed algorithm to be used in practical sensor networks. Moreover, the results of extensive simulations will be presented to compare the performance of proposed algorithms against the optimal algorithm, a greedy algorithm and a previously-proposed algorithm. The results confirm that the proposed algorithms achieve near-optimal results and outcome other algorithms completely.

1. Introduction

A *wireless sensor network* (WSN) consists of several small, low-cost, low-power sensor nodes which are deployed randomly in the *region of interest* (RoI) to monitor some aspects of the environment such as humidity, light, temperature, voice and video. Generally, a sensor node includes four components: 1) *a sensing unit* to acquire data from the environment 2) *a processing unit* to process raw data 3) *a transceiver unit* to send/receive the data and 4) *a power unit* to supply the required energy. However, some additional units could be added to sensor nodes depending on application requirements. WSNs could be used in a wide range of applications and environments such as monitoring battle field, forest, undersea, border, volcano and urban [1].

Barrier coverage is one of the main applications of sensor networks and is defined as detecting the intruders attempting to cross the RoI. There are two kinds of barrier coverage: weak and strong. While weak barrier coverage can only guarantee detecting intruders moving along predetermined and congruent paths, strong barrier coverage guarantees detecting all intruders regardless of their crossing paths.

Recently, directional sensor networks have received a great deal of attention due to their wide range of applications such as target detection and tracking. A directional sensor network consists of a number of directional sensors such as ultrasound,

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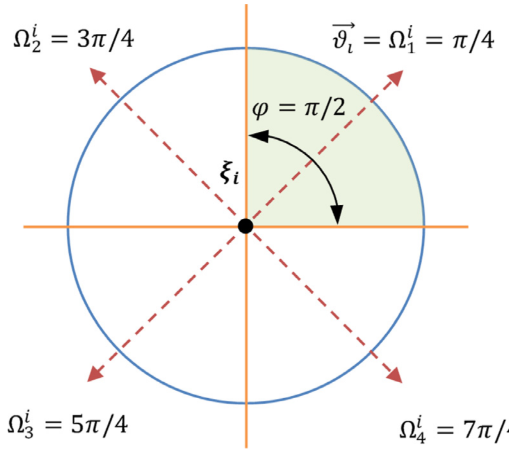

Fig. 1. The possible orientations of a typical directional sensor with $\varphi = \pi/2$ in non-overlapping form.

infrared and video sensors. The most important characteristics of directional sensors are their limitation in sensing (field-of-view) angle and sensing radius and also randomness of their orientation. Due to these unique characteristics, there are important differences between directional sensor networks and traditional omnidirectional sensor networks. The sensing region of a directional sensor is modelled by a circular sector while the sensing region of omnidirectional sensors is modeled by a disk. Moreover, rotation in some types of directional sensors allows them to adjust their orientation and cooperate with their adjacent nodes.

On the other hand, learning automata has been recognized as an efficient artificial intelligence tool that performs very well in dynamic environments such as wireless, ad hoc, and sensor networks. A cellular learning automata is defined as a graph in which each vertex represents a cell and is equipped with a learning automaton and each edge induces an adjacency relation between two cells (two automatons). The learning automaton residing in a cell determines its action according to its action probability vector and some internal rules. In recent years, cellular learning automata has been used to solve different problems of sensor networks such as congestion avoidance, data aggregation, backbone formation, barrier Coverage, deployment and scheduling [2].

In general, directional sensor networks could be classified to three classes based on type of their orientation: 1) *Aligned-orientation directional sensor networks* (ALODSNs) [3] in which orientation of sensors is identical and fixed, 2) *Fixed-orientation directional sensor networks* (FIODSNs) [4] in which orientation of sensors is fixed and distributed on $[0, 2\pi)$ uniformly and, 3) *Adjustable-orientation directional sensor networks* (ADODSNs) [5] in which the deployment of sensors is like FIODSNs but their orientation could be adjusted after deployment.

According to the above-mentioned classification, in this paper, we first present a centralized algorithm based on distributed learning automata to construct barrier lines in ADODSNs. Then, we will present the distributed version of the proposed algorithm. Afterwards, the results of extensive simulations will be presented. The simulations confirm that the proposed algorithms outcome similar algorithms completely and achieve near-optimal results.

The main contributions of the paper are two folds:

1. Introducing and modelling *adjustable-orientation directional sensor networks* (ADODSNs) with *directional barrier graph* (*DBG*) which could be used as a basis in other applications of ADODSNs.
2. Introducing two algorithms based on learning automata to find near-optimal number of strong barrier lines. Finding more barrier lines increases the network lifetime by activating one barrier in each round of the network. The simulations show that the proposed algorithms significantly improve the performance in comparison to other algorithms.

The remainder of this paper is organized as follows: Section 2 presents problem statement, Section 3 reviews the related works, Section 4 reviews the theory of automata, section 5 introduces our algorithms, Section 6 presents the simulation results and finally Section 7 concludes the paper.

2. Problem statement

In this paper, we consider a wireless sensor network with n stationary directional sensor nodes where all nodes are aware of their location. Our sensing model is similar to. Each node S_i has a directional sensor whose sensing region is a sector of a disk centered at ξ_i with a sensing radius of r and a field-of-view angle of φ. The orientation vector of a sensor is defined as the bisector of its sensing sector. In ADODSNs, a directional sensor has ability to change its orientation to any direction in a given set Ω.

Consider Fig. 1 as an example. In Fig. 1, $\varphi = \pi/2$, $\Omega = \{\pi/4, 3\pi/4, 5\pi/4, 7\pi/4\}$ and $\vec{\vartheta_i}$ is the orientation vector of the sensor. Therefore, this directional sensor has four possible orientations in non-overlapping form. The set of all possible