Dynamic Point Coverage in Wireless Sensor Networks: A Learning Automata Approach

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Abstract. Dynamic Point coverage in wireless sensor networks is the problem of detecting some moving target points in the area of the network using as little sensor nodes as possible. This can be accomplished by designing a dynamic schedule for making nodes on and off in such a way that in each slice of time, only nodes which can sense the target points in that period are on. In this paper, we propose a novel method for this problem using learning automata. Each node is equipped with a learning automaton which will learn (schedule) the proper on and off times of that node based on the movement nature of a single moving target.

Keywords: Dynamic Point Coverage, Wireless Sensor Network, Learning Automata, Scheduling

1 Introduction

Point coverage in wireless sensor networks is the problem of detecting some stationary or moving target points in the area of sensor network using as little sensor nodes as possible. This problem can be addressed in many different ways such as designing a deployment strategy which can best address the criterion of minimum number of required nodes [1, 2, 3], rearrangement of nodes assuming movement ability for them [4, 5, 6] and designing a suitable scheduling strategy for making nodes on and off in such a way that in each slice of time (period), only nodes which can sense the target points in that period are on [7, 8, 9]. The last solution is superior to other ones since it can deal with changes occurred in the topology of the network and also prolong the lifetime of the network by allowing only a portion of nodes to be in on state at each slice of time. To our best knowledge, in all decentralized approaches for scheduling, some sort of notification messages are exchanged between nodes in on and off states. Such solutions have two drawbacks; one is the overhead of these notification messages and the other is that nodes in off state should have the ability to receive these messages, and hence they cannot power off their receiving antenna. This leads to high energy consumption even in off periods according to [12].

In this paper, we propose a novel method for addressing the problem of dynamic point coverage in wireless sensor networks using learning automata. This solution can address the two shortcomings of scheduling methods mentioned earlier. This is because in this method, each node (or better the automaton of each node) learns its best on and off schedules using only the information of the moving targets passing through its sensing area, and hence no notification messages exchanged between on and off nodes.

The rest of this paper is organized as follows. The problem statement is given in section 2. In section 3 the proposed method is presented. Simulation results are given in section 4. Section 5 is the conclusion.

2 Problem Statement

We are interested in the dynamic point coverage problem in which a single target point is moving throughout the area of the sensor network and should be detected by nodes which are close enough to it. The problem is to determine the precise times of going to off state and coming back to on for each node based on the movement strategy of the target point. We assume that only one 'on period' and one 'off period' are sufficient for scheduling of each node. More specifically, the target passes the sensing area of node *i* every T_{i1} slices of time for a duration of T_{i2} slices, and the problem at hand is to determine these two time slices for each node in the network. Determination of going to off state is not so complicated. On the other hand, finding the precise time of coming back to on state is more challenging if T_{i1} and T_{i2} change throughout the lifetime of the network.

3 Proposed Method

Each node *i* in the network is equipped with a learning automaton and starts the algorithm with off state period set to 1 time slice. Learning automaton of each node has three actions; *extending* or *shortening* the off state period, and *no change* action. At the beginning, *extending* action has the probability very near to 1 and *shortening* and *no change* actions both have the probability very near to 0. As the algorithm goes on, the off period gradually increases and gets closed to T_{i1}, and hence the probability of *extending* action should decrease to near 0 whereas the probability of *no change* action increases to near 1.

The proposed algorithm is as follows: Each node starts in on state, sensing its surrounding area to determine whether it can sense the target or not. If target cannot be sensed, the node continues in on state until it can sense the target. When the target can be sensed, the node continues in on state, keep on monitoring the target positions. Whenever the node cannot sense the target anymore, it switches to off state, but before that, it determines its off duration using its learning automaton. Learning automaton of the node, selects one of its actions. Based on the selected action, previous off duration will be extended, shortened or remained unchanged. Node goes off for the specified duration and then becomes on. Coming into on state, the node checks for presence of the target for some short duration (*CHECKING_PERIOD*) and based on the result of this checking, rewards or penalizes its learning automaton:

- If the target cannot be sensed, *extending* action is rewarded.
- If the target is sensed right after the node becomes on, *shortening* is rewarded.

- If target can be detected during *CHECKING_PERIOD*, but not immediately when the node comes back to on state, *no change* action is rewarded.

After the above procedure is done, if the target is detected, node continues in on state until the target cannot be sensed anymore and at this time, above procedure is repeated. If the target isn't found in *CHECKING_PERIOD*, node goes off for a very short period and comes back to on state after that, checking for the presence of the target. Going off and coming back to on state is repeated until the target can be detected by the node. At this time, node continues in on state until the target cannot be sensed anymore, then next off period is determined using learning automaton of the node as explained before.

4 Experimental Results

To evaluate the performance of the proposed method several experiments have been conducted and the proposed method is compared with methods given in [7] and [8]. For simulations, a scenario very similar to [9] is used. Assume a road in which target enters from one end and exits from the other end periodically. This is depicted in figure 1. Communication energy estimation is done using the radio model described in [11], and based on the specifications of MEDUSA II sensor node. Binary detection model [10] is assumed for all sensor nodes.

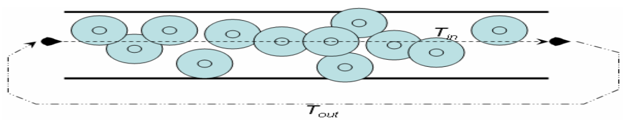

Fig. 1. Simulation scenario: Sensor nodes are scattered randomly through the area of a road and target enters the road from left and exits from right. This sequence is repeated every T_{out} (ms)

Detection rate, off period rate and energy consumption of nodes are studied for constant and randomly selected speed of the target. Figure 2 gives the results for constant speed and figure 3 gives the results for randomly selected speed.

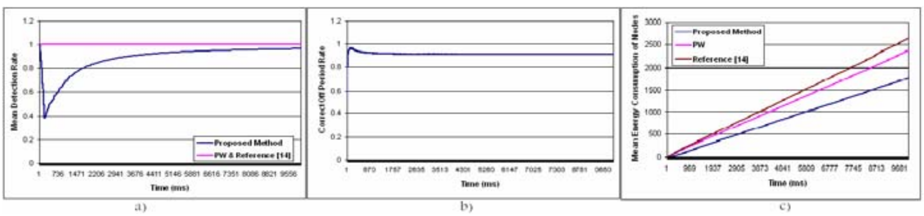

Fig. 2. Detection rate (a), off period rate (b) and consumed energy (c); target speed is constant

5 Conclusion

In this paper, we propose a completely different and novel solution to the problem of dynamic point coverage in sensor networks. Previous works in this area use some sort of notification messages which should be exchanged between nodes in on state and nodes in off state. This requires the nodes in off state to have their receiving units on which leads to high energy consumption. In contrast, the proposed method makes use of a learning automaton in each node to make it capable of learning it's off and on periods based on the target path. No notification messages will be required, and hence nodes which are in off state can completely switch their receiving units off. Experimental results show that our method can save much more energy and better prolong the lifetime of the network than other similar methods in the expense of a bit less precision in the detection of the target.

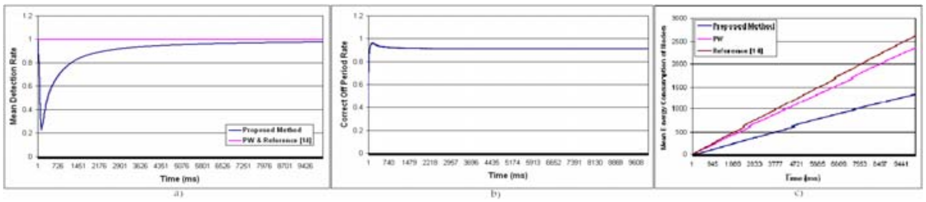

Fig. 3. Detection rate (a), off period rate (b) and consumed energy (c); target speed is random

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