Neurocomputing 153 (2015) 11–19

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

A new learning automata-based approach for maximizing network lifetime in wireless sensor networks with adjustable sensing ranges

Hosein Mohamadi [a], Shaharuddin Salleh [a,*], Mohd Norsyarizad Razali [b], Sara Marouf [a]

[a] Center for Industrial and Applied Mathematics, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia
[b] Faculty of Science, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia

ARTICLE INFO

Article history:
Received 4 June 2014
Received in revised form
15 November 2014
Accepted 21 November 2014
Communicated by R. Tadeusiewicz
Available online 29 November 2014

Keywords:
Wireless sensor networks
Cover set formation
Learning automata

ABSTRACT

Recently, several algorithms have been proposed to solve the problem of target coverage in wireless sensor networks (WSNs). A conventional assumption is that sensors have a single power level (i.e., fixed sensing range); however, in real applications, sensors might have multiple power levels, which determines different sensing ranges and, consequently, different power consumptions. Accordingly, one of the most important problems in WSNs is to monitor all the targets in a specific area and, at the same time, maximize the network lifetime in a network in which sensors have multiple power levels. To solve the problem, this paper proposes a learning-automata based algorithm equipped with a pruning rule. The proposed algorithm attempts to select a number of sensor nodes with minimum energy consumption to monitor all the targets in the network. To investigate the efficiency of the proposed algorithm, several simulations were conducted, and the obtained results were compared with those of two greedy-based algorithms. The results showed that, compared to the greedy-based algorithms, the proposed learning automata-based algorithm was more successful in prolonging the network lifetime and constructing higher number of cover sets.

1. Introduction

In recent years, wireless sensor networks (WSNs) have been widely used in many applications such as national security, surveillance, and health care [2]. A WSN is composed of a number of low-power, low-cost sensor nodes equipped with components for sensing and processing data, as well as communicating with other sensor nodes [2]. One of the most challenging issues in WSNs is coverage that focuses on how well the sensors cover the monitoring region. In general, coverage problem can be classified into two main types: area coverage and target coverage. The area coverage addresses the problem of covering the whole points within the monitoring area. Whereas, the target coverage problem refers to covering only a set of fixed or moving targets within the sensor field [3].

This study addresses the problem of target coverage in cases in which sensors have multiple power levels with the aim of extending the network lifetime (i.e., the amount of time during which the monitoring activity can be performed). This problem, which is known as Maximum Network Lifetime with Adjustable Ranges (MNLAR) [1], is of a great importance because the energy of sensors is limited and their batteries cannot be easily recharged, especially in harsh environments. To overcome this problem, power saving mechanisms can be used to optimize sensor energy consumption. In general, these mechanisms are presented in the form of two different techniques: (i) scheduling the state of sensor nodes and (ii) adjusting the sensing range of sensor nodes. In the scheduling technique, an appropriate state (either active or passive) is chosen for each sensor node in order to save the limited energy of sensors during the network operation. In the adjusting technique, the most appropriate sensing range of each active sensor is chosen for monitoring the targets in such a way that the energy can be saved as much as possible. To solve the target coverage problem and prolong the network lifetime as far as possible, in this paper, we make use of advantages of both techniques. In other words, a scheduling algorithm is designed, in which only some of the sensors are active at any given time, whereas other sensors are switched to sleep state. Additionally, the algorithm attempts to find a minimum sensing range for the active sensors to meet the target coverage requirement.

To demonstrate the efficiency of the scheduling technique, an example network is given in Fig. 1, which is composed of three sensors and three targets. Let $S = s_1, s_2, s_3$ signify the set of sensors and $T = t_1, t_2, t_3$ show the set of targets. In this network, each sensor node has a single power level and can monitor a target if the target is positioned within its sensing range. For instance,

* Corresponding author. Tel.: +60 122130572.
E-mail address: ss@utm.my (S. Salleh).

http://dx.doi.org/10.1016/j.neucom.2014.11.056
0925-2312/

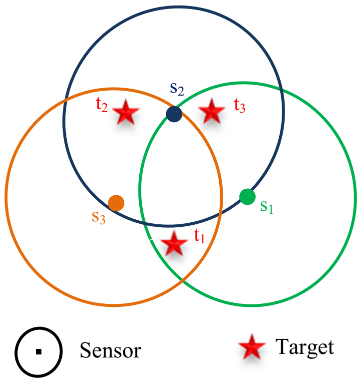

Fig. 1. Example network with three sensors and three targets.

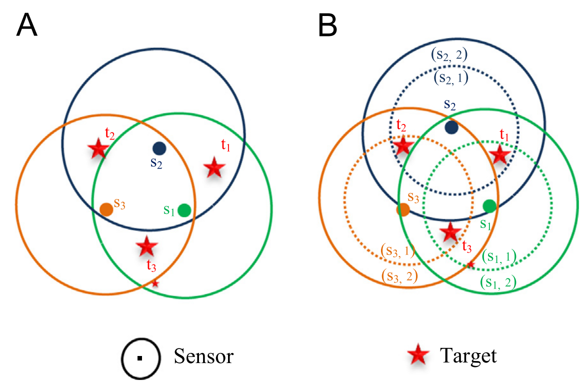

Fig. 2. Example network with three sensors, three targets and two power levels.

sensor s_3 can monitor target t_1 and t_2. In this network, the possible cover sets are $\{s_1, s_2\}$, $\{s_1, s_3\}$, and $\{s_2, s_3\}$. A cover set is a subset of sensors that monitor the whole targets. The classical assumption is that each sensor can be active for 1 unit of time. For example, by activating one of the above-mentioned cover sets, e.g., $\{s_1, s_2\}$ for the whole battery life of its sensors, the whole targets can be monitored for 1 unit of time. Therefore, the network lifetime cannot be further extended since only s_3 has residual lifetime and it is not able to monitor all the targets. While, by activating each of the three cover sets $\{s_1, s_2\}$, $\{s_1, s_3\}$, and $\{s_2, s_3\}$ for 0.5 units of time, the network lifetime is equal to 1.5 units of time. As can be concluded from this example, the scheduling technique can successfully extend the network lifetime.

To show the efficiency of the adjusting technique, an example network is depicted in Fig. 2, which consists of three sensors, three targets, and two power levels. Fig. 2A and B displays a network in which the sensors have a single power level and multiple power levels, respectively. In this paper, (s_i, a) refers to sensor s_i when activated at level a). Assume that the batteries can keep the sensors active for 1 unit of time at power level 1 and 0.5 unit at power level 2. If a single power level taken into account, there will be only one cover set (i.e., $(s_1, 1), (s_3, 1)$) and the total network lifetime will be equal to 1. Whereas, with multiple power levels, there will be more cover sets and the network lifetime is equal to 1.5 (for example, consider, $\{(s_1, 2), (s_2, 2)\}$, $\{(s_3, 2), (s_2, 2)\}$, and $\{(s_1, 2), (s_3, 2)\}$ are activated for 0.5 unit of time). In fact, the selection of sensors with appropriate sensing ranges can prolong considerably the network lifetime.

A number of studies have been recently conducted to solve the problem of MNLAR; however, learning automata (LA), which are modern heuristic methods, have not received adequate attention. This paper proposes an LA-based scheduling algorithm to find a near optimal solution to the MNLAR problem. In the proposed algorithm, network operation is divided into a number of rounds and the outcome of each round is a cover set. To generate a cover set, the algorithm explores a possible cover set of the network. The cover set is rewarded if the amount of energy consumed by the adjusted sensors in the cover set is less than that of the best cover set found so far. As the proposed algorithm goes on, the automata learn how to choose the best actions (the adjusted sensors with appropriate sensing ranges) to find an optimal cover set of the network among all cover sets. The process of generating cover sets continues until all the targets are under full coverage of the sensors. The performance of the proposed algorithm was evaluated through conducting several experiments in terms of the network lifetime, and the obtained results were compared with those of two greedy-based algorithms. The results demonstrated that the proposed algorithm could contribute more successfully to extending the network lifetime and number of constructed cover sets.

Generally, this paper has the following contributions: (1) designing an LA-based algorithm to solve the MNLAR problem; (2) proposing a pruning rule to improve the performance of the proposed algorithm; and (3) evaluating the performance of the algorithm through several experiments.

The remainder of this paper is organized as follows. In Section 2, the related studies on prolonging the network lifetime are presented. In Section 3, the problem of MNLAR is presented. In Section 4, LA and variable action-set LA are introduced. In Section 5, a new scheduling algorithm is proposed for solving the problem. In Section 6, the performance of the proposed algorithm is evaluated through the simulation experiments. Finally, Section 7 concludes the paper.

2. Related work

One of the most important challenges in WSNs is increasing the network lifetime. In this condition, energy efficiency is an important issue in WSNs where the battery of sensors cannot be changed or recharged. Recently, most of the studies conducted on extending the network lifetime have been focused on the management of energy consumption. One of the methods commonly used for increasing the network lifetime is scheduling the nodes' activity. In this method, the network operation falls into several rounds. In each round, the sensors of one cover set are activated to perform the network operation and the other sensors are switched to inactive state for saving energy. This strategy has an important contribution to prolonging the network lifetime because of two reasons. First, inactive sensors consume a negligible amount of energy. Second, if the battery of sensors is frequently switched between active and inactive states, it can last for a longer time. The scheduling technique is applied to cases where sensors are deployed redundantly. The adjusting technique enables sensors to save energy when they are covering targets positioned in their vicinity since the power consumption of sensors depends on the distance between sensors and targets. This technique is applied to the networks where sensors have multiple sensing ranges [23]. This paper attempts to find a solution to the target coverage problem and, simultaneously, extend the network lifetime by means of both techniques of power saving (i.e., scheduling sensors and adjusting sensing ranges). In the following, some outstanding studies are presented.

In the literature, several studies can be found, which have used the scheduling technique for solving the target coverage problem in WSNs (see [5–12]). For the first time, Cardei and Du [5] addressed the problem of target coverage and proved its NP-completeness. They modeled the problem as disjoint cover sets each of which could monitor the whole targets. In [6], non-disjoint cover sets were introduced, in which each sensor could take part in more than one cover set. The authors demonstrated that