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Heuristic methods to maximize network lifetime in directional sensor networks with adjustable sensing ranges

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ABSTRACT

During recent years, several efficient algorithms have been designed for solving the target coverage problem in directional sensor networks (DSNs). Conventionally, it is assumed that sensors have a single power level. Though, it is clear that, in real applications, sensors may have multiple power levels that determine different sensing ranges and power consumptions. One of the most significant challenges associated with the DSNs is monitoring all the targets in a given area and, at the same time, maximizing the network lifetime. In this paper, this issue is known as Maximum Network Lifetime with Adjustable Ranges (MNLAR) which has not been already studied in the DSNs. In this paper, we propose two heuristic algorithms (Algorithms 1 and 2) to solve the problem. In order to evaluate the performance of the proposed algorithms, extensive experiments were conducted. The obtained results were compared to a theoretical upper bound in order to measure the quality of the solutions provided by the proposed algorithms. The results demonstrated that Algorithm 2 was more successful than Algorithm 1 in terms of extending the network lifetime.

1. Introduction

Wireless sensor networks (WSNs) have received a great deal of interest in recent years due to their vast and significant applications such as national security, military, and environmental monitoring (Cerulli et al., 2012). A WSN is composed of a large number of low-cost, low-power sensor nodes that are equipped with sensing, data processing, and communication components (Yick et al., 2008). Conventionally, in sensor networks, it is often assumed that sensors have a disk-like sensing range. Though, in real world, because of equipment constraints or environmental impairments, sensor nodes might be limited in their sensing angle and they facilitate a sector-like sensing range (Amac Guvensan and Gokhan Yavuz, 2011; Ai and Abouzeid, 2006). These types of sensors are referred to as directional sensors (e.g., ultrasound, infrared, and video sensors). Each directional sensor can adopt several directions, but at a specific point of time, it can sense only one direction. Directional sensors are able to collect information about certain subregions of the whole space and they can coordinate to perform collectively a complex sensing task (Sung and Yang, 2014).

In this study, we tackle the problem of target coverage in cases in which sensors have multiple power levels (i.e., multiple sensing ranges) with the aim of extending network lifetime. The network lifetime refers to the amount of time in which the monitoring activity can be performed. There are several challenges that arise in solving this problem in a directional sensor network (DSN). First, due to the limited sensing angle of directional sensors, they cannot sense a circular region completely; it makes the problem more difficult compared to the WSNs (Ai and Abouzeid, 2006). Second, the energy of sensors is limited, and their batteries could not be easily recharged, especially in harsh environments (Ai and Abouzeid, 2006; Cai et al., 2009). Therefore, power saving mechanisms that optimize sensor energy utilization have a great impact on extending the network lifetime. Generally, these mechanisms can be divided into two techniques: (i) scheduling in which the sensor nodes are switched between active and sleep modes, and (ii) adjusting the sensing range of the sensor nodes (Cardei et al., 2006). In recent years, several efficient scheduling algorithms have been proposed to solve the problem in cases where sensors have a single power level (i.e., sensing ranges are not adjustable); whereas the technique of adjusting the sensing range of the sensor nodes (in cases where sensors have multiple power levels) has not received an adequate attention. In this study, we combine both techniques in order to maximize the network lifetime as far as possible.

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The problem of maximization of network lifetime in DSNs, which we denote as MNLAR (Maximum Network Lifetime with Adjustable Ranges), can be formally described as follows. Suppose m targets with known locations and n directional sensors with adjustable sensing ranges are deployed randomly in the vicinity of the targets to monitor them. Initially, sensors have a certain battery lifetime. Each sensor can be in either active or inactive mode. Each active sensor can monitor targets located in one of its non-overlapping directions at any given time. When a sensor is in active mode, its power consumption is dependent on its sensing range. On the other hand, inactive sensors do not monitor any target and their power consumption is negligible. The MNLAR problem deals with scheduling sensors' activity in a way to maximize the network lifetime concerning the restriction that throughout the network lifetime, each target must be monitored by the work direction of at least one active sensor.

Despite several studies recently conducted for solving the target coverage problem in DSNs, the problem of MNLAS has not received the adequate attention. In this paper, we propose two scheduling algorithms to solve this problem. In these algorithms, we not only select the sensor directions of each cover set but also determine their sensing ranges. The goal is to use a minimum sensing range to minimize the energy consumption and, at the same time, to meet the target coverage requirement. Extensive experiments were conducted to examine the performance of the proposed algorithms and explore the effect of different parameters on the network lifetime. The obtained results were compared to a theoretical upper bound.

Our contributions: In this paper, we introduce the problem of maximum network lifetime with adjustable ranges in a DSN. We design two efficient heuristics using greedy technique to solve the problem. We evaluate the performance of the algorithms through several simulations.

The remainder of this paper is organized as follows. In Section 2, both background and related studies conducted on prolonging the network lifetime are presented. In Section 3, the problem of MNLAS is introduced. In Section 4, two new scheduling algorithms are proposed for solving the problem. In Section 5, upper bound is introduced. In Section 6, the performance of the proposed algorithms is evaluated through the simulations. Finally, Section 7 concludes the paper.

2. Related work

One of the basic problems in sensor networks is coverage that refers to collecting different types of data from the environment. Coverage problem can be classified into two main subcategories: area coverage and target coverage (Amac Guvensan and Gokhan Yavuz, 2011; Zhu et al., 2012). The aim of the area coverage is that each point in the area of interest can be continuously monitored by at least one active sensor node. However, in some applications, only some crucial targets in the field are required to be continuously monitored. This study focuses on solving the target coverage problem using both techniques of power saving, i.e., scheduling the sensors and adjusting sensing ranges. In this section, we first present a background to convey the significance of using these two techniques in extending the network lifetime. Second, we present some outstanding studies conducted to solve target coverage problem by applying these techniques to WSNs and DSNs.

2.1. Background

One of the main uses of sensor networks is collecting data in inhospitable or remote environments such as fire monitoring in forests, battlefield surveillance, and tsunami monitoring in deep sea. Since accurate placement of sensors is ruled out by cost and/or risks considerations, under such environments, sensors are commonly deployed in a random way. To compensate the lack of accuracy in such random deployment, more sensors than actually required are distributed in the field. This over deployment causes WSNs to be more resilient to faults because some targets are redundantly monitored by multiple sensors. Each sensor is provided with a limited-lifetime battery that cannot be easily recharged or replaced in harsh environments. Therefore, the use of power saving mechanisms for extending the network lifetime is of a great importance in the design of WSNs. Generally, these mechanisms can be divided into two techniques: (i) scheduling sensor nodes' activity, and (ii) adjusting the sensing range of sensor nodes (Cardei et al., 2006).

The technique of scheduling sensor nodes' activity takes the advantage of redundancy in sensor deployment. It organizes sensors into a number of cover sets each of which can monitor all the targets. Additionally, it determines the amount of time each cover set can be activated. Afterwards, the cover sets are activated successively for a pre-determined duration. When a cover set is active, the sensors belonging to other cover sets are in inactive mode. This significantly increases the network lifetime due to the following reasons. First, inactive sensors consume considerably less energy than the active ones. Second, if the battery of a sensor frequently oscillates between active and inactive modes, it lasts for a longer duration (Singh and Rossi, 2013).

To show the efficiency of scheduling technique, we consider the example network depicted in Fig. 1 in which there are three directional sensors and three targets. Let $s_n (1 \le n \le 3)$ denote the set of directional sensors and $t_m (1 \le m \le 3)$ represent the set of targets. The figure also shows that each directional sensor has three directions and $d_{i,j} (1 \le j \le 3)$ indicates the directions of sensor s_i. In this example, a single power level is considered for each sensor. A target can be monitored when it is within both the sensing region and the sensing range of at least one active sensor direction. For example, target t_2 is monitored by $d_{2,2}$ and $d_{3,1}$ simultaneously. The possible cover sets for all targets are $\{d_{1,3}, d_{3,1}\}$, $\{d_{1,3}, d_{2,2}\}$ and $\{d_{2,1}, d_{3,1}\}$. A cover set is a subset of sensors that can monitor the whole targets. Assume that the battery of each sensor keeps the sensor active for 1 unit of time (classical assumption). By considering one of the above-mentioned cover sets, e.g., $\{d_{1,3}, d_{3,1}\}$ and activating it for the whole battery life of the sensor, all the targets can be monitored for 1 unit of time. As a result, the network lifetime cannot be further extended because only s_2 has residual lifetime and it is not able to monitor all the targets alone. Whereas, by considering three cover sets (i.e., $\{d_{1,3}, d_{3,1}\}$, $\{d_{1,3}, d_{2,2}\}$, and $\{d_{2,1}, d_{3,1}\}$) and activating each of them for 0.5 units of time, the network lifetime equals 1.5 units of time. It can be concluded that this strategy outperforms the previous one.

Another technique for prolonging the network lifetime is adjusting the sensing range of sensor nodes. This technique helps

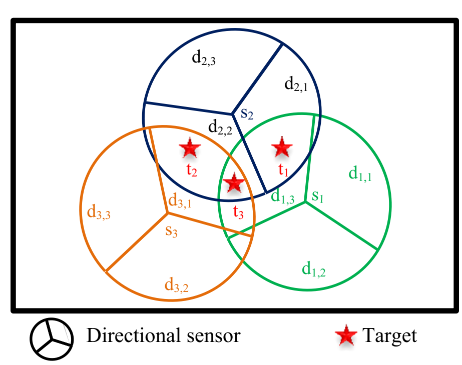

Fig. 1. Example network with three directional sensors and three targets.