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Auction-based adaptive sensor activation algorithm for target tracking in wireless sensor networks

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HIGHLIGHTS

- We present an auction mechanism for the problem of target tracking in WSNs.
- We propose an adaptive sensor activation algorithm for the target tracking.
- We improve prior trilateration algorithm for low target localization errors.
- The proposed algorithms provide high energy-efficiency and tracking quality.

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ABSTRACT

Due to the severe resource constraints in wireless sensor networks (WSNs), designing an efficient target tracking algorithm for WSNs in terms of energy efficiency and high tracking quality becomes a challenging issue. WSNs usually provide centralized information, e.g., the locations and directions of a target, choosing sensors around the target, etc. However, some ready strategies may not be used directly because of high communication costs to get the responses for tracking tasks from a central server and low quality of tracking. In this paper, we propose a fully distributed algorithm, an auction-based adaptive sensor activation algorithm (AASA), for target tracking in WSNs. Clusters are formed ahead of the target movements in an interesting way where the process of cluster formation is due to a predicted region (PR) and cluster members are chosen from the PR via an auction mechanism. On the basis of PR calculation, only the nodes in the PR are activated and the rest of the nodes remain in the sleeping state. To make a trade-off between energy efficiency and tracking quality, the radius of PR and the number of nodes are adaptively adjusted according to current tracking quality. Instead of fixed interval (usually used in existing work), tracking interval is also dynamically adapted. Extensive simulation results, compared to existing work, show that AASA achieves high performance in terms of quality of tracking, energy efficiency, and network lifetime.

1. Introduction

The rapid development in low-power micro-electro-mechanical system (MEMS) technology, microprocessors, and wireless communications has brought tremendous attention to the research in wireless sensor networks (WSNs). WSNs consist of hundreds of low-cost, low-power, multi-functional micro-sensor nodes with the capabilities of sensing, processing, and wireless communications [1,2]. Sensor nodes have been deployed to play significant roles in traffic control, battlefield, habitat monitoring, and intruder tracking in recent years [1–6].

Target tracking with WSNs has gained much attention in recent years. The main aim of target tracking is to find out the location, velocity, and direction of a target instantaneously. Accurate location is the most important information for a target tracking system. For example, we can monitor and track a target like a person or a vehicle that is moving under the radio coverage of a WSN, and sensor nodes report the location information of the target to a control center (or the sink node) periodically. Here, the sink is the node that collects the information from the nodes and processes them, and makes an aggregated tracking information for end users. However, there are difficulties in achieving such information from WSNs as WSNs have inherent limitations, e.g., the unattended sensor nodes, the strict power constraint, and the limited computational capability of sensor nodes [3]. Energy depletion of sensor nodes in a region of interest causes the emergence of the connectivity and coverage holes, which finally leads to the network failure. Therefore, designing an efficient target tracking algorithm with energy efficiency, high tracking quality, and low computational complexity becomes a highly challenging problem.

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Various target tracking algorithms for WSNs have been proposed recently [1,2,7–13]. The sensor activation problem as a research area has received considerable attention in recent years. Some prior algorithms have been shown to outperform other solutions for the problem, namely, SARA (sensor activation and radius adaptation), DLM (distributed lifetime maximization), VRCSC (variable radii connected sensor cover), DSA (distributed sensor activation algorithm) [14–17]. For a specific application, such as target tracking in WSNs, sensor activation in a region of interest of a WSN is a critical task. On the one hand, some of the existing sensor activation algorithms have high computation complexity and high communication costs to get responses for tracking tasks from the sink, such as filter based tracking algorithms [18,19,11], while others have crucial requirements on the capabilities of sensors or the settings of the WSN, such as the algorithms presented in [20–22]. On the other hand, a set of algorithms (e.g., [23]) activates a large number of sensors for tracking, which is also not efficient for a tracking system. Overall, the quality of tracking is not sufficient in these algorithms. To make every step of tracking operation energy-efficient while ensuring the quality of tracking, the following concerns should be addressed adequately:

(Q1) Which subset of sensor nodes should be activated to form a cluster before the target moving toward the nodes?
(Q2) How is a target located when considering practical deployment issues, such as measurement noises or obstacles?
(Q3) How are sensor nodes scheduled in an energy-efficient manner, while guaranteeing the tracking quality?

In response to the similar concerns above, cluster-based tracking algorithms normally used [24,25]. In a target tracking application, both cluster member nodes and cluster head (CH) node can detect the target. The burden on the CH is much heavier than on the cluster member nodes, for example, the CH has to collect the data from the members and finish the data fusion and communicates with the sink. Thus, the CH consumes more energy than the member nodes. Selections of CH and cluster members have important effects on both the quality of tracking and the network lifetime. In prior work, clusters are either formed at the network initialization or at the time of tracking. Both have effects in tracking quality, e.g., the cluster may not be exactly found as it was formed at the initialization, there can be delays caused by cluster formation as a target is detected.

To address those concerns above to a great extent, specifically, energy-efficiency and tracking quality, we come up with the following ideas and algorithms.

(a) We introduce an "auction mechanism" to form a cluster ahead of a target as it moves. The auction mechanism is employed to form a cluster ahead of the target moving toward the cluster. In each iteration of tracking, a CH in the current cluster compute a predicted region (PR) using a prediction method, where the target is likely to move based on the current and previous movement information of the target. At the end of each iteration, the current CH broadcasts an auction message to activate the nodes in the PR. Then, the CH acts as the auctioneer and the nodes in the PR act as bidders. Each bidder evaluates the tracking task and responds the CH by a *bid*. The CH ranks the *bids* to choose appropriate sensor nodes for tracking. The sensor node with the highest *bid* is selected as the next CH, and the other appropriate sensor nodes are chosen to be the members of predicted cluster. Our proposed auction mechanism requires few computations and reduces communications between the nodes in the PR. The nodes with a lower *bid* do not need to participate in tracking. This mechanism does not consume significant energy of the network compared to many existing clustering mechanisms, such as LEACH [26], TopDisc [27], and GAF [28].
(b) We propose an auction-based adaptive sensor activation algorithm (AASA) to make a trade-off between energy efficiency and tracking quality. The algorithm is composed of two parts: (1) the adaptive radius of the PR and the number of members in a cluster; (2) the adaptive tracking time interval. In part (1), both the radius and the number of members are adaptive, which are dynamically adjusted, according to the current tracking quality. This implies that the number of sensors that should be activated for achieving high quality of tracking can be adapted according to the system user. In this paper, we use prediction error as the metric for assessing *tracking quality*. In part (2), the tracking interval is an important setting to a tracking system. Although the tracking interval is fixed in most of the existing tracking algorithms, we strongly believe that the tracking interval should be related to the velocity of the target considering for energy saving in a WSN. Because a high velocity of the target requires a short interval to capture the target and a low velocity allows a long interval. We found that tracking quality is also greatly affected in those algorithms by the fixed interval. In AASA, the tracking interval is dynamically adapted based on the instantaneous velocity of the target, which saves more energy and keeps the required tracking quality.
(c) In order to locate the target in the current region and compute the PR, we propose an improved trilateration algorithm to locate the target approximately. An original trilateration algorithm is available in the ideal sensor network that does not handle the detection errors occurred in the localizations, caused by node unavailability. In a practical deployment, sensing noises and obstacles are inevitable. As a result, using the trilateration algorithm directly in tracking operation is infeasible. Our improved trilateration algorithm takes the detection errors into account.
In summary, the contributions of this paper are as follows.
(1) We present an auction mechanism to form a cluster in a predicted region before the target arrives in the region.
(2) We propose an adaptive sensor activation algorithm (AASA) to activate a subset of appropriate sensors in the predicted region.
(3) We improve an existing trilateration algorithm to provide target localization with low detection errors.
(4) We conduct extensive simulations to evaluate our tracking algorithm. Compared to existing work [7,23], our algorithm shows that it is energy efficient and provides prolonged lifetime and high tracking quality.

The rest of this paper is organized as follows. Section 2 reviews the related work. Preliminaries of the approach is given in Section 3. The auction mechanism and the localization algorithm are presented in Section 4. The proposed AASA algorithm is proposed in Section 5. Section 6 discusses the simulation studies. Section 7 concludes this paper.

2. Related work

The research of target tracking using WSNs has been gaining a lot of attention in recent years [1,2,7–13]. Various tracking algorithms have been presented in the literature that can be classified into five categories of schemes, which are tree-based tracking, cluster-based tracking, prediction-based tracking, mobicast message-based tracking, and hybrid methods [29,25]. In this paper, we concentrate on a sensor activation algorithm (based on an auction mechanism) for tracking, for which we need to discuss both the cluster-based and prediction-based methods. More specifically, we need to find a combination of both methods in sensor activation as accurately as possible and in an energy-efficient manner.

2.1. Cluster-based and prediction-based target tracking

A prediction-based clustering algorithm (PBCA) is presented in [7]. In this algorithm, two parameters, distance from predicted