Information Sciences 292 (2015) 95–110

Contents lists available at ScienceDirect

Information Sciences

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

Probabilistic coverage based sensor scheduling for target tracking sensor networks

Ke Shi *, Hongsheng Chen, Yao Lin

School of Computer Science and Technology, Huazhong University of Science & Technology, Wuhan 430074, China

ARTICLE INFO

Article history:
Received 27 February 2014
Received in revised form 12 August 2014
Accepted 29 August 2014
Available online 6 September 2014

Keywords:
Probabilistic coverage
Sensor scheduling
Target tracking
Wireless sensor networks

ABSTRACT

In target tracking sensor networks, tracking quality and network lifetime are two conflicting optimization goals due to the limited battery power of the sensor nodes. During the movement of a target, how to select an optimal subset of sensors to wake up is of critical importance both for extending network lifetime and guaranteeing tracking quality. In this paper, we first propose a probabilistic-based dynamic non-complete k-coverage method, α–k-coverage, which can guarantee that target moving area is covered by at least k sensors under at least α probability. Then, we propose an energy-efficient sensor scheduling scheme, Optimal Cooperation Scheduling Algorithm (OCSA), to balance tracking quality and network lifetime under α–k-coverage condition. The effectiveness of the proposed scheme is validated through extensive simulation experiments.

1. Introduction

Wireless sensor networks (WSNs) are an emerging technology that has many applications. These networks are composed of hundreds, and potentially thousands of tiny sensor nodes, functioning autonomously, and serving different purposes. They are typically battery powered with limited communication and computation abilities. Each node is equipped with a variety of sensing modalities, such as acoustic, seismic, and infrared. Applications of WSNs include battlefield surveillance, environment monitoring, biological detection, home appliance and inventory tracking. In this paper, we focus on target tracking application.

Target tracking is an important application of wireless sensor networks, such as vehicle tracking in military surveillance [32] and wild animal tracking in habitat monitoring [7,20]. In these applications, tracking quality and network lifetime are two conflicting requirements due to the limited battery power of the sensor nodes. With unlimited power supply, a given area can be monitored perfectly with a set of sensor nodes that cover the entire area in terms of sensing. However, since the sensor nodes have limited power, the quality of monitoring becomes inversely proportional to the life time of the network. Thus, during the movement of a target, how to select an optimal subset of sensors to wake up is of critical importance both for extending network lifetime and guaranteeing tracking quality [11,38]. It is a challenge task to design an energy-efficient tracking algorithm for target tracking application due to the limited battery power of the sensor node, which aims at increasing the network lifetime.

Most works recently in target tracking application focus on the deployment phase of wireless sensor networks. How to schedule sensors dynamically and timely by taking into account of both the energy consumption and tracking quality is still

* Corresponding author.
E-mail addresses: keshi@mail.hust.edu.cn (K. Shi), chenhs1981@163.com (H. Chen), catherinelin0755@qq.com (Y. Lin).

http://dx.doi.org/10.1016/j.ins.2014.08.067
0020-0255/

a challenge during the target's movement. As power is always a valuable and limited resource in sensor networks, it has been advocated that only a small subset of sensor nodes is powered on for the purpose of surveillance and tracking, in which node activation is based on trajectory prediction. However, corresponding performance highly depends on the accuracy of mobility prediction algorithms. In fact, the prediction of the next location of target may not be always accurate. A wrong prediction may cause a wrong sensor scheduling.

Though we cannot predict the next location of target accurately, we can predict the possible moving area of target at next time point, that is, we can predict the approximation bound of the next location of target. In this paper, we propose a dynamic moving area prediction method and a probabilistic-based dynamic non-complete k-coverage method, α–k-coverage, which can guarantee that target moving area is covered by at least k sensors under at least α probability. Thus, a candidate sensor set can be selected using α–k-coverage algorithm. Then, we propose a novel sensor selection algorithm, Optimal Cooperation Scheduling Algorithm (OCSA), to select a suitable sensor subset from the candidate set by both taking into account of minimizing communication cost (minimizing the transmission energy) and sensor's availability. The goal is to find the suitable subset of sensors which will be waked up in next tracking period, in order to not only minimize the transmission energy but also provide certain tracking quality guarantee.

This study is a combination of theoretical analysis and simulated evaluations, the correctness of our tracking algorithm and the effectiveness of the proposed scheduling scheme are validated through theoretical proofs and extensive simulation experiments. The contributions of this paper are the following:

(1) Taking account into tracking quality and network lifetime in target tracking sensor networks.
(2) Proposing the concept of α–k-coverage, a probabilistic-based dynamic non-complete k-coverage method for target tracking application. The candidate sensor set which may be activated at next tracking period can be selected by α–k-coverage.
(3) Designing a novel energy-efficient sensor scheduling algorithm to select a suitable subset from the candidate sensor set.
(4) Analyzing the performance of our approach through simulation.

The rest of the paper is organized as follows. In Section 2, we categorize the related research works in current literature. The system model of target tracking sensor network including the energy consumption model is given the Section 3. The problem definition is also given in Section 3. In Section 4, we propose a probabilistic-based dynamic area coverage algorithm to determine the candidate tracking sensor set. An energy-efficient sensor selection algorithm to balancing the tracking quality and energy consumption by selecting a suitable subset from the candidate sensor set is presented in Section 5. The detailed results of performance evaluation study are presented in Section 6. Finally, we conclude the paper and point out some future works related to this topic.

2. Related works

Tracking moving targets in large scale sensor networks has gained extensive attention recently. Aslam et al. [4] and Mechitov et al. [22] propose several tracking schemes based on the minimalist binary sensor model, in which each sensor's value is converted reliably to one bit of information. This bit indicates that whether the object is moving toward the sensor or away from the sensor. The tracking scheme is then designed based on the area overlapping. However, this binary model cannot measure the distance, and the area overlapping requires large amount of nodes to determine the target's location accurately. It causes heavy energy consumption.

A novel target tracking protocol [31] is proposed by using sensor networks for mobile users. It is assumed that a mobile target may move in any way, so in all the ways the sensor nodes need to be active, thus it consumes too much energy. To save the energy, the number of nodes that actively track the target should be minimized. Most nodes should be in sleeping mode. To guarantee the tracking quality, the nodes around the current location of target should be waked up in time. Information-driven target tracking schemes are proposed by Chu et al. [10] and Zhao et al. [42]. The information utility is computed based on the cost of communication and computation to decide which nodes should actively participate the tracking. The leader is selected to perform this computing. However, it is a one-to-one based handoff scheme. The leader is heavily loaded.

Wang et al. [35], Chen et al. [9], and Yang and Sikdar [37] propose cluster-based tracking schemes. In these schemes, sensor nodes are grouped into clusters either statically or dynamically in the vicinity of target. This cluster is in charge of tracking. The trilateration technique [9], the Voronoi diagram-based approach [35] and KF/MLE based approach [34] are utilized to locate the target. A cluster head coordinated the tracking activities of nodes in this cluster. The key of these schemes is to predict the target's location accurately and construct corresponding cluster based on predicted location.

Zhang and Cao [40,41] introduce a tree-based tracking approach (DCTC). They define a dynamic convoy tree-based collaboration tracking mechanism and formalize the tracking problem as a multiple objective optimization problem. The solution to the problem is a convoy tree sequence with high tree coverage and low energy consumption. However, global network information that is not available in largest sensor network is required for constructing such a convoy tree sequence. Re-configuration and maintenance of a convoy tree incurs considerable computational and communication overhead. And building such a tree also depends on trajectory prediction.