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Distributed wireless sensor network localization based on weighted search☆

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ABSTRACT

Node localization is one of the key technologies of WSN applications. In this paper, we propose a distributed weighted search-based localization algorithm (WSLA) and its refinement algorithm (WSRA) for wireless sensor network (WSN). In real applications, WSLA + WSRA need to run iteratively to achieve localization and position refinement of nodes. In each iteration of WSLA, every node obtains the coordinate and distance information of its 1-hop neighbors, and then employs weighted two-dimensional logarithmic search to compute its best estimated position; finally, every node estimates its coordinate and type according to the distribution of its best estimated positions. By analyzing experiment results of WSLA, we found some errors, and eventually propose WSRA that is based on geometrical relationship of neighbors. Finally, we compare the localization performance and complexity of WSLA + WSRA with those of MLE, RSOCP + NCSG and PSO, which are three state-of-the-art range-based localization algorithms, in different network scenarios (e.g., uniform topology, irregular C-shaped network and fading environment). The simulation results show that WSLA + WSRA have relatively high localization accuracy and low computational complexity compared with MLE, RSOCP + NCSG and PSO.

1. Introduction

Wireless sensor network (WSN) is a kind of self-organized wireless communication network. It is composed of a large number of tiny, battery-powered sensor nodes with limited processing, storage and communication capabilities [1]. Sensor nodes need to know their positions [2] in many WSN applications, such as forest-fire prevention, environmental monitoring, target detection and tracking. Therefore, node localization is one of the key technologies of WSN. In general, sensor nodes use two methods to estimate their positions. The first method utilizes dedicated localization hardware (e.g., GPS) or deploys the nodes in known positions; this method is simple and highly accurate, but the hardware costs and energy consumption are intolerable in large-scale networks. Therefore, only a few nodes, which are called anchor nodes, adopt this method. The second method utilizes software localization technology, which comes with lower hardware costs and less energy consumption than the first method. Although its localization accuracy is a little worse than that of the first method, it could meet the requirement of most applications. The second method is adopted by most nodes, which are called ordinary nodes in practice.

WSN localization schemes include range-based localization, range-free localization and event-driven localization [3–5]. The range-based localization assumes that the node is able to measure the distances or angles from its neighbors; the measuring methods include received signal strength indicator (RSSI), time-of-arrival (TOA), time difference of

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arrival (TDOA) and angle-of-arrival (AOA) [6,7]. The range-free localization, which includes centroid localization, DV-Hop algorithm and LAEP [8–12], assumes that the node has no ability to measure the distances or angles from its neighbors and uses connectivity or hop-count information to estimate the positions of nodes. The range-based localization can provide higher accuracy than range-free localization, but the latter does not need extra hardware for measurement. The event-driven localization, such as spotlight, uses the spatio-temporal properties of artificial events in the network (e.g., light) to obtain the positions of nodes [13–15]. So far, artificial events that are generated and propagate across the network area include well-controlled events and uncontrolled events.

Localization algorithms include centralized algorithms and distributed algorithms in terms of the place where the most computation processing is executed [5,16]. The centralized algorithms require that each node transmit its measurement result or connectivity information to the sink node, which will return the estimated positions to all the nodes after computing. The centralized algorithms provide higher accuracy than the distributed ones, but they require more communications, which result in a large consumption of energy and bandwidth. The distributed algorithms utilize local information to achieve localization, and they can save more energy and bandwidth compared with the centralized ones. Also, they are more scalable to the size of networks.

In this paper, we propose a range-based distributed WSN localization scheme based on weighted search, which includes weighted search-based localization algorithm (WSLA) and weighted search-based refinement algorithm (WSRA). WSLA employs two-dimensional logarithmic search-based algorithm (TDLS) to search the best estimated point (BEP) and WSRA utilizes geometrical relationship to improve localization accuracy. To the best of our knowledge, the contributions of this paper include:

(1) Weighted TDLS (W-TDLS) is proposed to search the BEPs of nodes, which is a deterministic search process.
(2) A FIFO-based mechanism for WSLA is proposed to estimate the localization accuracy of nodes.
(3) WSRA is proposed to improve localization accuracy according to geometrical relationship (e.g., distance-hop contradiction).
(4) Some methods are proposed in WSLA + WSRA, which can achieve an acceptable localization accuracy for the node with only 1 or 2 neighbors (e.g., lonely node).

The remainder of this paper is organized as follows. Section 2 provides an outline of related work in range-based localization. Section 3 describes the mathematical model of range-based localization. In Section 4, we present W-TDLS to search the BEP and a FIFO-based mechanism to update the type of node, and then WSLA is proposed. In Section 5, based on geometrical relationship, we propose WSRA to improve the localization accuracy of WSLA. The simulation results are shown in Section 6, and we conclude this paper in Section 7.

2. Related works

Range-based localization of WSN is often modeled as an optimization problem with an objective function that depends on the distances and positions of the nodes. The main difficulty is that [17], even in the absence of distance measurement errors, it is a nonconvex optimization problem with many local minima. Nowadays, the solution methods of localization optimization problems can be roughly divided into two categories: one is based on mathematical optimization theories and the other is based on intelligent search methods.

Maximum likelihood estimation (MLE) is one of the simple methods for computing extreme value of objective functions with limited computational complexity. Therefore, MLE and its improvement versions are the grounded estimation approach for node localization [18]. The localization accuracy of MLE-based localization is very good in the absence of distance ranging errors. However, its localization performance deteriorates rapidly with increasing distance ranging errors. Multi-dimensional scaling (MDS) is another kind of classic range-based algorithm, and a set of localization algorithms based on MDS are proposed. Costa et al. have proposed distributed weighted-multidimensional scaling for localization in [19], which adopts a weighted cost function, an adaptive neighbor selection method and a majorization method to achieve node localization. Shang et al. proposed MDS-MAP in [20], which achieves localization by building a global map using classical MDS.

Recently, a number of approaches have been proposed to relax the original non-convex problem to a convex problem. After relaxation, the convex problem can be efficiently solved by some available optimization techniques such as the interior point method. Two kinds of convex relaxation techniques—semi-definite programming (SDP) relaxation in [21–24], and second-order cone programming (SOCP) relaxation in [5] and [25–28]—are representations of these approaches. The traditional SDP-based algorithms are computationally expensive for large-scale networks (more than several hundred nodes) and require centralized computation due to their complex structures. To reduce the computational complexity, distributed SDP localization algorithm is proposed in [23]. Compared with the SDP relaxation, the SOCP relaxation is weaker and thus less accurate, but it has a simpler structure and allows efficient distributed implementation. The drawback with the relaxation methods is that even when the original problem is uniquely localizable, the relaxed problem may not be [17]. In addition, both SDP and SOCP rely on a sophisticated optimization package that cannot be easily achieved on a sensor node with limited resources.

Intelligent search-based algorithm is another kind of WSN localization method; this kind of algorithm may achieve relatively high accuracy with relatively low complexity. Zhang et al. achieve localization with a genetic algorithm (GA) in [29], which can work well not only in dense and uniform topologies but also in sparse and irregular networks. Low et al., Kulkarni and Venayagamoorthy proposed a particle swarm optimization (PSO) approach for localization in [30,31]. Shekofteh et al. proposed a localization algorithm based on tabu search (TS) and simulated annealing (SA) in [32], where TS is a dynamic neighborhood search technique that drives the search by escaping from local optima and avoiding the cycling. Wang et al. proposed a sequence search (SS) based algorithm in [33]; the SS can improve the localization accuracy by optimizing the localization sequence. Geem