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Path planning algorithms for mobile anchors towards range-free localization

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HIGHLIGHTS

- Proposed a distributed range-free movement strategy for mobile anchor to localization sensors in a connected network.
- Improvements in terms of both path length and localization accuracy are shown.
- Proposed another movement strategy for mobile anchor, localizes all the sensors lying in a rectangular region.
- Improvement of path length is shown theoretically compared to the existing methods.

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ABSTRACT

The objective of path planning for a mobile anchor is to find the path of minimum length that the anchor traverses to localize all sensors. The challenge is to design a movement strategy which reduces path length while meeting the requirements of a good range-free localization technique. A novel deterministic movement strategy is proposed in this paper that reduces path length and uses an existing range-free localization scheme which yields good positional accuracy. The mobile anchor moves in a hexagonal pattern to localize all the sensors which form a connected network. We compare performance of our algorithm with an existing path planning algorithm in terms of both path length and localization accuracy. Simulation results show that even in presence of irregular radio propagation, our algorithm achieves full localization. We have proposed another movement strategy for a mobile anchor using same hexagonal pattern to localize all the sensors lying in a rectangular region. Improvement in path length is shown theoretically compared to existing path planning schemes.

1. Introduction

A wireless sensor network (WSN) consists of autonomous sensors distributed over a region which monitor physical or environmental conditions and cooperatively send data through the network to a sink. Localization of wireless sensors with high degree of accuracy is required for many WSNs applications [4,5], such as security and surveillance, object tracking, geographic routing [12], etc. GPS is one of the widely used techniques for location discovery in outdoor networks [21], but it is not always practical to equip each sensor with a GPS receiver due to cost and energy consumption.

Usually localization techniques use some sensors with known positions; called anchors. Usually anchors are GPS enabled sensors. Based on beacons transmitted by anchors, the sensors are localized. Many localization algorithms [3,6,7,10,13,14,11,17,25,29,31–33] are proposed for WSNs. These schemes can be viewed as range-based or range-free. In range-based schemes, the sensor locations are computed using distance and/or angle information between sensors [8]. On the other hand, connectivity constraints such as hop-count, anchor beacons, etc. are used in range-free schemes. Although positioning error always occurs during localization [16], usually range-based schemes are more accurate than range-free schemes. But range estimation techniques in range-based schemes are erroneous as well as costly due to requirement of special hardware. This encouraged researchers to design range-free schemes for sensor localization. Also number of static anchors are needed in the localization schemes like [3,7,10,13,14,11,29,33]. To minimize the number of static anchors and to avoid range measurements, range-free localization schemes [25,31,32] using mobile anchor

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are proposed. One mobile anchor with a suitable path planning is equivalent to many static anchors. By a single mobile anchor, we can save large number of static anchors with deployment cost in the expense of the mobility of the mobile anchor. Therefore, reducing path length of the mobile anchor becomes an important issue in the area of localization. In most of the existing works [23,27,26] where path planning is proposed for connected network, ranging techniques are used. Our aim is to propose a path planning using only connectivity information such that the mobile anchor can use an existing range-free localization scheme for better accuracy. In this paper we propose two different movement strategies for mobile anchor. Localization scheme proposed by Lee et al. [25] is used for localization during movement. One movement strategy is proposed for any arbitrary connected network. The anchor localizes every sensor of the network with connectivity guided movement. The other movement strategy is proposed to localize sensors over a bounded rectangular region where the anchor has to cover the whole rectangle to ensure localization of all sensors. In this strategy, only boundary information is used to localize all the sensors irrespective of deployment and underlying network topology.

Problem statement: We consider two different kinds of path planning problems.

- Static sensors are randomly deployed on a two dimensional plane such that a connected network is formed. A mobile anchor moves along the network to localize the sensors. Sensors and the anchor have equal communication range. The problem is to propose a distributed range-free path planning algorithm for the mobile anchor that guarantees full localization and able to use some localization scheme which yields good positional accuracy while reducing path length.
- Static sensors are randomly deployed in a rectangular region with known boundary information. The problem is to propose a movement strategy for a mobile anchor such that path length can be reduced while maintaining good localization accuracy.

Our contribution: In this paper we introduce a hexagonal movement strategy for mobile anchor. Our proposed distributed range-free movement strategy localizes all sensors in a connected network. To the best of our knowledge, this is the first work where localization and path planning both are done using connectivity of the network and without any range estimation. Simulation results show improvement over existing work [26] in terms of both path length and localization accuracy. Full localization is guaranteed when radio propagation is regular. Simulation results show, also in presence of radio irregularity, all the sensors are being localized using proposed movement strategy.

Then we use hexagonal tiling to cover a rectangular region with known boundary information to propose a movement strategy for mobile anchor. The anchor localizes all the sensors lying within the region. We show theoretically that the length of the path traversed by the anchor is lesser in the proposed strategy compared to other existing path planning methods [18,22,24,28]. Results show 7.35%–27.74% improvement of our scheme over different schemes in terms of path length. Good localization accuracy is also observed in simulation.

The organization of the remaining part of the paper is as follows. In Section 2, we discuss about related works. The theoretical results of our proposed path planning on a connected network are explained in Section 3. The algorithm along with system model is given in Section 4. Effect of irregular radio propagation is discussed in Section 5. Theoretical analysis of movement strategy for a mobile anchor in a rectangular region is discussed in Section 6. The simulation results are presented in Section 7. We conclude in Section 8.

2. Related works

Path planning algorithms design path for mobile anchor in the network along which the anchor moves while localizing all sensors. First we look at a brief overview of the existing range-free localization schemes which provide good accuracy. Based on DV-Hop, Boukerche et al. [7] proposed DV-Loc which uses static anchors. DV-Loc improves scalability and positioning accuracy over DV-Hop using lower processing resources. Ssu et al. [31] proposed a localization scheme using mobile anchor where the sensor's position is estimated as the intersection of perpendicular bisector of two calculated chords. However this scheme suffers from short chord length problem i.e., localization errors become large if length of the approximate chords is short. Xiao et al. [32] improved over that scheme using pre-arrival and post-departure points along with the beacon points to localize a sensor. Later Lee et al. [25] used beacon distance effectively as another geometric constraint and proposed a more accurate localization scheme. Now we look onto the existing path planning algorithms.

The path planning problem can be classified in two different classes depending on the knowledge of the area of sensor deployment and the underlying topology formed by the sensors. Topology-based path planning can be viewed as a graph traversal problem. Sensors have information about their neighbors which they send to the mobile anchor for determining the path. The authors in [27] proposed two algorithms namely breadth first and backtracking greedy algorithms. Li et al. [26] proposed a depth first traversal scheme *DREAMS* to localize the sensors. Both these works need range estimations. In *DREAMS*, mobile anchor first visits a sensor using random movement before performing depth-first traversal on the network. An already visited localized sensor provides information to the anchor about its next destination. Algorithm stops when anchor returns to the first sensor. During depth-first traversal, anchor performs distance-based heuristic movement using received signal strength from sensors. Kim et al. [23] proposed a path planning for randomly deployed sensors using trilateration method for localization. An already localized sensor becomes a reference point to help other sensors to find their positions which reduces path length but localization error may propagate. Chang et al. [9] proposed another path planning algorithm of the mobile anchor where localization is done using the scheme proposed by Galstyan et al. [15] and mobile sensor calculates its trajectory by moving around already localized sensors. Our aim is to propose a path planning algorithm which can decide its trajectory without using any range estimation in a connected network. Using connectivity of the network, we discover neighbors of a sensor as well as localize them by the scheme [25].

The other class of path planning problem aims to cover a rectangular area where all the sensors are deployed. *Scan*, *Doublescan* and *Hilbert* schemes are proposed by Koutsonikolas et al. in [24]. They used the localization scheme proposed in [30]. *Scan* covers the whole area uniformly where the mobile anchor travels in line segments along X-axis (or Y-axis) keeping a fixed distance between two line segments. In *Doublescan*, anchor moves in the direction of both X-axis and Y-axis, which improves localization accuracy in the expense of traveled distance. *Hilbert* reduces both error and path length in comparison to these two. Huang et al. proposed two path planning schemes namely *Circles* and *S-curves* [22]. Simulation results show that *S-curves* produce similar results like those discussed above. Based on trilateration, Han et al. proposed a path planning scheme *LMAT* [19] for a mobile anchor. Using received signal strength indicator (RSSI) technique, sensor measures distances from three different non collinear points and finds its position. Chia-Ho Ou et al. proposed a movement strategy [28] of the anchor which helps sensors to localize themselves with good accuracy by reducing the short