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Four-mobile-beacon assisted localization in three-dimensional wireless sensor networks ☆

Huanqing Cui [a,b,*], Yinglong Wang [b]

[a] College of Information Science and Engineering, Shandong University of Science and Technology, Qingdao, China
[b] Shandong Provincial Key Laboratory of Computer Network, Shandong Computer Science Center, Ji'nan, China

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ABSTRACT

Localization is one of key technologies of wireless sensor networks, and the mobile beacon assisted localization method is promising. For the three-dimensional sensor networks, this paper proposes a four-mobile-beacon assisted weighted centroid localization method. The four beacons form a regular tetrahedron while traversing the region and broadcast packets including their positions simultaneously. The ordinary sensor nodes estimate their locations using weighted centroid method. It also presents LAYERED-SCAN trajectory of mobile beacons which consists of several parallel layers of SCAN. This method can localize all the sensor nodes with appropriate parameters. Two sets of simulations are performed using Matlab to compare this method with other methods and evaluate tradeoffs between localization performance and different parameters. Simulation results show that the proposed method outperforms weighted centroid and multilateration methods using single mobile beacon.

1. Introduction

With the rapid development of wireless communications and electronics, wireless sensor networks (WSNs) are applied in many fields, such as object tracking, environment monitoring, vehicle navigation etc. In these applications, location information is critically essential and indispensable, because WSNs need associate sensed data with geographical information to make them meaningful. Moreover, the location information also supports many fundamental network services such as network routing, topology control, boundary detection etc. [1].

The problem of node localization is to determine locations of sensor nodes in a WSN. The easiest method is through manual configuration or global positioning system (GPS), which is often infeasible for large-scale and mobile WSNs. Hence, node localization has attracted lots of research efforts in recent years, and [1–3] presented surveys of these methods.

To localize a WSN in the global coordinate system, some special sensor nodes should be aware of their positions as a prior, which are called *beacons* or *anchors*. And the other sensor nodes, which are called *unknown nodes*, measure the distances or angles to beacons to estimate their positions. Generally, the locations of beacons are acquired through GPS receiver, so they are more expensive than unknown nodes [4]. The mobile-beacon assisted localization methods become promising. Most of these methods only use a single mobile beacon, which may lead to collinearity problem. This paper proposes a method utilizing four mobile beacons to localize unknown nodes in a three-dimensional space.

The rest of this paper is organized into five sections. Section 2 gives an overview of mobile beacon assisted localization methods. Section 3and 4 present the four-mobile-beacon assisted localization method and its moving trajectory, respectively. Section 5 describes the experiment setups and analyzes the simulation results. Finally, Section 6 concludes this paper.

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* Corresponding author. Address: Shandong University of Science and Technology, College of Information Science and Engineering, Economic and Technical Development Zone, 579 Qianwangang Road, Qingdao Shan-dong Province 266590, China. Tel.: +86 532 86057852.
E-mail address: cuihuanqing@gmail.com (H. Cui).

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2. Related work

The mobile beacon assisted localization methods utilize a beacon to traverse the region of interest (ROI) while broadcasting packets including its position, and unknown nodes estimate their positions based on the received packets. These methods can be categorized into *range-based* and *range-free*.

Range-based methods require that the absolute distance between sender and receiver can be measured by received signal strength (RSS), time of arrival (ToA) or time difference of arrival (TDoA). MAL (mobile-assisted localization) [5] utilizes TDoA to measure distances between node pairs until these distance constraints form a "globally rigid" structure that guarantees a unique localization. MBAL (mobile beacon-assisted localization) [6] is a novel range-based trilateration localization scheme involving a movement strategy of mobile beacon. Bahi et al. [7] proposed a range based method which uses Hilbert space filling curve as the trajectory of mobile beacon. MBL (ndc) (mobile beacon assisted localization based on network-density clustering) [8] combines node clustering, incremental localization and mobile beacon assistance together. Virtual ruler approach [9] employs a vehicle equipped with multiple ultrasound beacons to travel around ROI to measure distances between pairwise sensors.

Range-free algorithms always use area or borderline measurement techniques. The area measurement determines the intersection of all overlapping coverage regions and uses the centroid as the estimate location. Galstyan et al. [10] presented an online-distributed algorithm in which sensor nodes improve their location estimates by incorporating both connectivity constraints and constraints imposed by a moving target. Azimuthally defined area localization (ADAL) [11] utilizes a beacon with a rotary directional antenna to send message in a determined azimuth periodically, and an unknown node uses the centroid of intersection area of several beacon messages as its position. Arrival and departure overlap (ADO) [12] uses a possible area delimited by two circles with the same radius at different centers. Lee et al. [13] proposed a method based on geometric constraints utilizing three reference points, where two are used for obtaining the intersection area and the third is used further to delimit this area. The borderline measurement schemes determine some straight lines that pass through a sensor node and use the intersection point of these lines as its position. Ssu et al. [14] described a scheme using the geometry conjecture (perpendicular bisector of a chord), and perpendicular intersection (PI) [15] utilizes the geometric relationship of a perpendicular intersection to compute node positions.

There are some probabilistic approaches. Sichitiu et al. [4] proposed a mechanism using RSS to range and Bayesian inference to estimate locations. The parametric and non-parametric probabilistic estimation techniques presented in [16] utilize ToA to range. MBL (mobile beacon assisted localization) and A-MBL (adapting MBL) [17] adopt probabilistic methods to give an area where a sensor node might reside, along with the likelihood of such an estimate. A-MBL adopts an adapting mechanism to improve the efficiency and accuracy of MBL. SA-MBL (self-adapting MBL) [18] can judge the accuracy of MBL to reach the stable phase and be just related to the unknown nodes themselves, so it achieves more flexibility.

All of these methods utilize a single mobile beacon. Patro [19] proposed a method using four beacons to determine a square being the unknown node at the center, and the node takes square centroid as its position. Zhang et al. [20] presented a scheme using three beacons to move through ROI, and the sensor nodes determine beacon point set based on RSS to estimate positions.

The above methods are designed for two-dimensional ROI, but WSNs are often deployed in three-dimensional terrains in real applications, such as mountainous battlefield, aero space etc. Landscape-3D [21] treated the sensor localization as a functional dual to the target tracking problems. Yu et al. [22] proposed a method using a flying beacon to help unknown nodes to determine their locations. 3D-ADAL [23] is an extended version of ADAL [11]. Yadav et al. [24] proposed a method where unknown nodes calculate their positions based on the equation of sphere on receiving beacon messages. Caballero et al. [25] presented a method based on particle filtering for three-dimensional outdoor WSNs by using a single flying beacon on-board a helicopter. However, a single mobile beacon brings collinearity or coplanarity problem into localization, which decreases the accuracy. Hence, this paper proposes a method with four mobile beacons.

3. Four-mobile-beacon assisted localization method

Three problems should be answered during designing mobile beacon assisted localization method: (1) the strategy of estimating positions of unknown nodes; (2) the trajectory of mobile beacon; (3) the moments when beacon broadcasts its packets. This section determines the first problem, and the others are answered in Section 4.

3.1. Shape of four mobile beacons

In three-dimensional WSNs, an unknown node can estimate its position only when it knows more than three non-coplanar referencing positions. Therefore, the four beacons should not be coplanar. The simplest shape of polyhedron is a tetrahedron, so the four beacons constitute a regular tetrahedron, as illustrated in Fig. 1a.

Suppose the edge length of the tetrahedron equals to R, the transmission radii of beacons, and four beacons are $B_i (i = 1, 2, 3, 4)$. Let coordinates of B_1 and B_3 be $(0, 0, 0)$ and $(0, R, 0)$, respectively, then coordinates of B_2 and B_4 are:

$$B_2\left(\frac{\sqrt{3}R}{2}, \frac{R}{2}, 0\right); \quad B_4\left(\frac{\sqrt{3}R}{6}, \frac{R}{2}, \frac{\sqrt{6}R}{3}\right) \tag{1}$$