Weighted Centroid Localization Algorithm Based on Mobile Anchor Node for Wireless Sensor Networks

Jun-Ling Ma* Jung-Hyun Lee** Kee-Wook Rim*** Seung-Jin Han****

Abstract Localization of nodes is a key technology for application of wireless sensor network. Having a GPS receiver on every sensor node is costly. In the past, several approaches, including range-based and range-free, have been proposed to calculate positions for randomly deployed sensor nodes. Most of them use some special nodes, called anchor nodes, which are assumed to know their own locations. Other sensors compute their locations based on the information provided by these anchor nodes. This paper uses a single mobile anchor node to move in the sensing field and broadcast its current position periodically. We provide a weighted centroid localization algorithm that uses coefficients, which are decided by the influence of mobile anchor node to unknown nodes, to prompt localization accuracy. We also suggest a criterion which is used to select mobile anchor node which involve in computing the position of nodes for improving localization accuracy. Weighted centroid localization algorithm is simple, and no communication is needed while locating. The localization accuracy of weighted centroid localization algorithm is better than maximum likelihood estimation which is used very often. It can be applied to many applications.

Keywords : Wireless Sensor Networks, Localization, Mobile Anchor Node, Centroid Algorithm

1. Introduction

A sensor network is composed of a large number of sensor nodes that are densely deployed in a field. Each sensor performs a sensing task for detecting specific events. The sink, which is a particular node, is responsible for collecting sensing data reported from all the sensors, and finally transmits the data to a task manager. If the sensors can not directly communicate with the sink, some intermediate sensors have to forward the data [1].

There are several essential issues(e.g., localization, deployment, and coverage) in wireless sensor networks. Localization is one of the most important subjects for wireless sensor networks since many applications such as environment monitoring, vehicle tracking and mapping depend on knowing the locations of the sensor nodes [2]. In addition, with location-based routing protocols [3], both routing and data forwarding are determined based on the geographic location.

To solve the localization problem, it is natural to consider placing sensors manually or equipping each sensor with a GPS receiver. However, due to the large scale nature of sensor networks, those two methods become either inefficient or costly, so researchers propose to use a variety of localization approaches for sensor network localization.

These approaches can be classified as range-based and range-free. Firstly, the range-based approach uses an absolute node-to-node distance or angle between neighboring sensors to estimate locations. Common techniques for distance or angle estimation include received signal strength indicator(RSSI), time of arrival(TOA), time difference of arrival(TDOA), and angle of arrival(AOA). The approaches typically

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have higher location accuracy but require additional hardware to measure distances or angles. Secondly, the range-free approach does not need the distance or angle information for localization, and depends only on connectivity of the network and the contents of received messages. For example, Centroid method[4], APIT method[5], DV-HOP method[6], Convex hull[7], Bounding box[8] , and Amorphous algorithm[9] have been proposed. Although the range-free approach cannot accomplish as high precision as the range- based [10], they provide an economic approach. Due to the inherent characteristics(low power and cost) of wireless sensor networks, the range-free mechanism could be a better choice to localize a sensor's position, so we pay more attention to range-free approach in this paper.

This paper uses a single mobile anchor node as the reference node, which is required to move in the sensing field and broadcast its current position periodically. Sensor nodes receive the position information of the mobile node and localize themselves to the centroid of these positions by using the weighted centroid algorithm. The algorithm based on the Received Signal Strength Indication(RSSI). The results of simulations show that the method is a practical method that can be used in real-world system, and is also a method whose principle is simple, less computing and communication, is low cost, and provides flexible accuracy.

2. Related Work

In the past several years, extensive research has been done on localization for wireless sensor networks. A general survey is found in. Here we provide only a brief survey about range-free approaches and localization method, which involve mobile reference nodes.

In a sensor network, some nodes are equipped with special positioning devices that are aware of their locations. These nodes are called anchor nodes or reference nodes. Other nodes that do not initially know their locations are called unknown nodes or sensor nodes. Generally, an unknown node can estimate its location by range-based or range-free methods if three or more anchors are available in its coverage field. Obviously, the number and position of anchor nodes have a noticeable influence on the localization precision. Researchers showed that the precision of the localization increases with the increasing of the anchors' number. The main problem with an increased number of anchors is that they are far more expensive than the rest of the sensors, even if only 10% of the nodes are anchors; the price of the whole network will increase about tenfold. Another observation is that after the(stationary) unknown nodes have been localized, the anchors become useless. The reasoning mentioned above leads us to consider using a single mobile anchor to localize the sensor network.

The main idea of localization with a mobile anchor node is as follows: After sensor deployment, a mobile anchor node traverses the sensor network while broadcasting anchor packets, which contain the coordinates of the anchor node. Sensor nodes receiving anchor packets could infer their distance from a mobile anchor node and use these measurements as constraints to construct and maintain position estimates. These methods have a common feature: they use range-based approaches. Though they can reach fine resolution, either the required hardware is expensive(ultrasound devices for TDOA, antenna arrays for AOA) [11] or the results depend on other unrealistic assumptions about signal propagation(for example, the actual received signal strengths of radio signals can vary when the surrounding environment changes).

Due to the hardware limitations of sensor devices, range-free approaches are a cost effective alternative to a more expensive range-based approach. A simple algorithm proposed, computes location as the centroid of its proximate anchor nodes. An alternate solution, DV-Hop, extends the single hop broadcast to multiple-hop flooding, so that sensors can find their distance from the anchors in terms of hop counts. An amorphous positioning scheme adopts a similar strategy as DV-Hop; the major difference is that Amorphous improves location estimates using offline hop-distance estimations through neighbor information exchange. Another existing range-free scheme is an APIT algorithm. APIT [12-13] resolves the localization problem by isolating the environment into triangular regions between anchor nodes. A node uses the point-in-triangle test to determine its relative location with triangles formed by anchors and thus narrows down the area in which it probably resides. APIT defines the center of gravity of the intersection of all triangles that a node resides in as the estimated node location. [14-17]Based on these analyses, localization using a single mobile anchor node would be more economical. In addition, considering the constraints in computing and memory power of sensors, we adopted the weighted centroid method with a single mobile anchor to locate sensors in wireless sensor networks.

3. Method of Localization

This method can be used in large-scale field environment. Figure 1 illustrates the system environment where a sensor network consists of a mobile anchor node and unknown nodes that could be scattered from a plane or from a mortar shell. The mobile anchor is a human operator or an unmanned vehicle deployed with the sensor network. If the network is deployed by plane scattering, this anchor can be even the plane itself. The unknown nodes are the nodes of initially unknown positions. Once the nodes are deployed, they will stay at their locations to conduct the sensing task. The mobile anchor, which is a node aware of its location(e.g. equipped with GPS), and is able to traverse for assisting the sensors to determine other node locations.[18-21] The mobile anchor node needs to traverse over the entire region in order to cover all sensor nodes. This can be done by driving the mobile anchor node to move in a spiral trajectory. Obviously there are many other options to moving trajectory. Finding an optimal trajectory to cover all sensor nodes can be a research topic for our future work. No matter which trajectory is used, the location of the mobile anchor node on the trajectory should be known. At the same time, we assume that the mobile anchor has sufficient energy for moving and broadcasting its information during the localization process. The speed of the mobile anchor is adjustable and unrestricted, but uniform in the process of location.

We used an idealized radio model for wireless communication because it was simple and easy to reason mathematically. We assumed that our idealized model is perfect spherical radio propagation and has identical transmission range(power) for all radio positions as shown in Figure 1. It is a sphere with the anchor as its center and the broadcasting radius R as its radius. Only the sensors within the range are assumed capable of receiving the information sent by the anchor.

In this paper, we proposed the location of mobile anchor node influence: In the localization algorithm, location of mobile anchor node has influence to the unknown nodes, RSSI bigger location, and the greater influence on the location of sensor nodes. When Unknown node received multiple mobile anchor node position signal Then unknown node by the impact of these locations. Location of largest RSSI has the

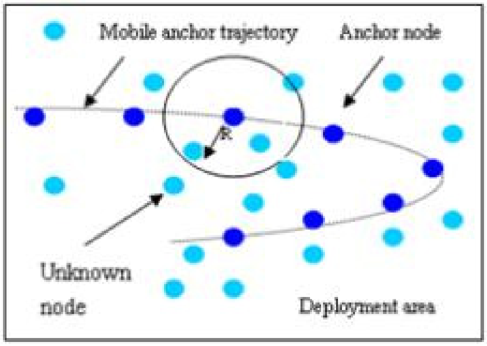

Fig. 1. System Environment with a Mobile Anchor Node

greatest power to decide to the position of sensor node.

Signal selection principle: An unknown node may receive multiple signals of positions from the mobile anchor node.

RSSI value should be the largest of several signals position calculation. Location computed to ensure that the signals involved in more than three. Will be distances of more than R the location of mobile anchor node removed, so as to avoid the expansion of the positioning error. Behind the simulation proves this point.

4. Weighted Centroid Localization Algorithm

Through the front of the Analysis, can find common centroid algorithm, did not reflect the mobile anchor node's influence, affecting the localization accuracy. To enhance the localization accuracy, in this paper we used the weighted centroid localization algorithm. Its main idea: In the algorithm, mobile anchor node confronts the right to decide the location of the centroid through weighted factor to reflect. The use of weighted factor reflected the intrinsic relationship between them.

We embody this relationship through the formula of the weighted factor:

$$X = (X_1/d_1 + X_2/d_2 + X_3/d_3)/(1/d_1 + 1/d_2 + 1/d_3)$$
$$Y = (Y_1/d_1 + Y_2/d_2 + Y_3/d_3)/(1/d_1 + 1/d_2 + 1/d_3)$$

Figure 2 illustrates Known 3 mobile anchor nodes coordinate (X_1, Y_1), (X_2, Y_2), (X_3, Y_3), unknown node to anchor nodes distance d_1, d_2, d_3. According to the formula can be calculated unknown node coordinates(X, Y). Compared to ordinary centroid algorithm, $1/d_1$, $1/d_2$, $1/d_3$ is weighted factor. The factor $1/d_1$, $1/d_2$, $1/d_3$ indicates that mobile anchor node with a shorter distance to unknown nodes has a larger infect its coordinates. We can improve the localization accuracy from these inner relations.

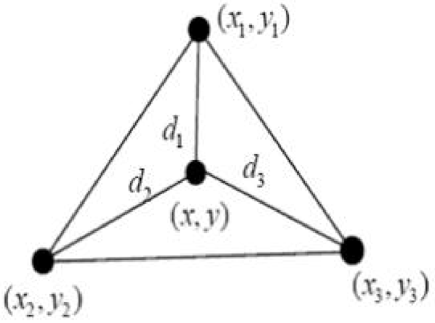

Fig. 2. Weighted Centroid Localization Algorithm

Weighted centroid localization algorithm process :

(1) The mobile anchor node periodically sends its own information.

(2) Unknown node received information, only records the same location of the mobile anchor node average RSSI.

(3) Unknown node received over threshold m in the position information then RSSI value in accordance with the smallest sort of mobile anchor node location .And to establish the mapping between RSSI value and the distance from unknown node to the mobile anchor node. The establishment of three sets: mobile anchor node_set={a_1, a_2, ⋯,a_m} ; Distance_set={d_1, d_2, ⋯, d_m} $d_1<d_2$ ⋯.$<d_m$; Mobile anchor node position_set={(X_1, Y_1), (X_2, Y_2), ⋯, (X_m, Y_m)};

(4) RSSI value with the first few large location of mobile anchor node of the calculation:
Based on the preceding analysis, in the mobile anchor node_set Select RSSI value of large node location then the composition of the triangle set. This is very important. Triangle_set={(a_1 , a_2, a_3), (a_1, a_2 , a_4), ⋯(a_1, a_3 , a_4), (a_1, a_3 , a_5) ⋯ };

(5) n location of mobile anchor nodes can be composed of C_n^3 triangles. The use formula(1) calculates C_n^3 coordinate.

(6) Calculates the mean value(X,Y) of C_n^3 coordinate. The(X, Y) is Unknown node coordinate.

5. Simulation

The key metric for evaluating a localization technique is the accuracy of the location estimates versus the communication and deployment cost. Increasing the density of anchors or the frequency of location broadcasting should improve accuracy, but a tradeoff needs to be made to determine appropriate deployment parameters. To evaluate this proposed method we use UNIX, programs with the C language. We have carried on the computer simulation to the above algorithm. Simulation condition: The mobile anchor node reference MICA2 mote; Uses outdoor launches the radius 200 to 300m; Deployment area is 200*200㎡ .The unknown node arranges stochastically; the unknown node is 220. The mobile anchor node has 6 kinds of situations: 9, 12, 16, 20, 25, and 30 positions. The simulation uses weighted centroid localization algorithm and maximum likelihood estimation method. Localization accuracy mainly depends on the numbers of the mobile anchor node broadcasting its positions or the anchor density. It is very easy for our method to change anchor density by adjusting the interval time or the moving length of the mobile anchor node broadcasting its positions or by changing the moving interval of spiral line. In comparison with other methods, this is one of the advantages with our method, and it does not require additional hardware. Figure 3 and Figure 4 show the simulation result. In the figure 3 error of weighted centroid localization algorithm is 16.2m and error of maximum likelihood estimation is 24.2m when mobile anchor node is 9. Error of weighted centroid localization algorithm is 14.4m and error of maximum likelihood estimation is 18.9m when mobile anchor node is 12. In the figure 4 error of weighted centroid localization algorithm is 48m and error of maximum likelihood estimation is 73m when mobile anchor node is 9. Error of weighted centroid localization algorithm is 38m and error of maximum likelihood estimation is 67m when mobile anchor node is 12. .As can be seen from the figure weighted centroid localization algorithm has better localization accuracy. Has the obvious superiority, if the anchor density is low. Weighted centroid localization algorithm is simple, and no communication is needed while locating. It does not require additional hardware. The mobile anchor node can be used many times. So it is very inexpensive.

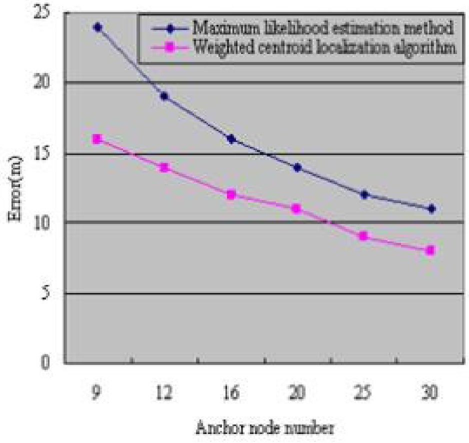

Fig. 3. Average Error

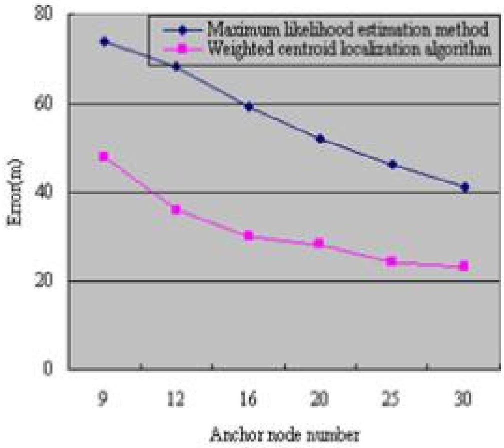

Fig. 4. Maximum Error

6. Conclusion and Future Works

Many wireless sensor network applications depend on nodes being able to accurately determine their locations. This is the first work to study range-free localization in the presence of mobility. One of our ideas is that a mobile anchor can improve the localization accuracy and coverage because it can move to every point of wireless sensor networks. Another factor is that range-free requires no extra hardware or data communication and reduces the costs of localization. Our simulation experiments reveal that our method can provide accurate localization even when memory limits are severe, the seed density is low, and network transmissions are highly irregular.

Many issues remain to be explored in future work including how to select a moving path to improve the locating performance, how to apply this to real-world sensor networks and how to expend our method to other applications.

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