Path Planning for Mobile Anchor Node in Localization based on Ad-Hoc Localization Algorithm

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Abstract.
For mobile anchor node static path planning cannot accord the actual distribution of node for dynamic adjustment which result in incomplete coverage and lack of flexibility. We take advantage of the high localization accuracy and low computational complexity of AHLos algorithm. This article introduces mobile anchor nodes instead of the traditional fixed anchor nodes to improve the algorithm. Firstly, the high connectivity nodes are chosen in the network as AHLos algorithm initial anchor nodes. The initial anchor nodes are located through the method of approximate location. The mobile anchor nodes traverse all the initial nodes. The residual nodes in the network will be located by AHLos location algorithm. In addition, not every two initial anchor nodes are neighbor nodes in the process of traverse. The minimum hop path from one initial anchor node to the next one is defined as the transition path. The mobile anchor node use the transition path between two non-neighboring initial nodes to induction the next initial node. At the same time, the GPS can be shut down along the transition path. The mobile anchor nodes adjust its direction as soon as possible, once the signal of the next node is perceived. This method could both avoid the energy consumption of GPS and greatly reduce the actual distance of the mobile anchor node. The result shows that, through introduce the mobile anchor node, we can configure the information of initial anchor nodes more flexible. Meanwhile, with the use of the approximate location and the transition path, the distance and energy consumption of the mobile anchor node is greatly reduced.

Keywords: Mobile anchor node, Path planning, AHLos, approximate location, Transition path

1. INTRODUCTION

WSN is an emerging technology for monitoring the physical world with a densely deployed network of sensor nodes. It can be used in a variety of applications such as environment monitoring, military surveillance, etc.\(^{[1]}\) Node self localization is a fundamental problem in WSN, e.g. sensor nodes have to be aware of their locations to be able to specify the place where an event takes place\(^{[2]}\). However, it is an infeasible solution if all the nodes equip with a GPS considering the costs and the energy factors. It is also unlikely that the position of each node can be predetermined by a network of thousands of nodes\(^{[3]}\).

The location of the anchor nodes can be acquired in advance. We usually installed GPS on the node, or arranged in advance. The localization algorithm is based on the location of the anchor nodes to determine the unknown nodes\(^{[4]}\). If there are a lot of anchor nodes in the localization algorithm, it will increase the cost of WSN. This is inconsistent with the characteristics of WSN applications. In this case, in order to reduce the construction cost of WSN, a number of mobile sensor nodes can be equipped with GPS. This method has a high practical significance: mobile anchor node can reach a larger range and higher positioning accuracy; the mobile node can use a mobile robot platform, it is easily to configure the position of anchor node. In order to improve the accuracy of positioning and the efficiency of positioning, the path planning of mobile anchor node become a basic research question. In this paper, we use only one GPS-equipped mobile anchor node in the WSN, which cooperate with AHLos positioning algorithm to locate all nodes in the network. The primary literature which use mobile anchor node path planning in wireless sensor network is\(^{[5-7]}\), etc. In these literatures, the mobile anchor nodes are all moving randomly. The path planning problem of mobile anchor node is studied by Koutsonilas, Rui Huang, etc. Koutsonilas proposed SCAN, DOUBLE SCAN, and HILBERT path planning method; Rui Huang proposed round and S-shaped path planning method. They are all static path planning, no matter how WSN nodes are distributed. The mobile anchor node is according to the path which is planned beforehand. The location accuracy is high when the sensor nodes are close to the planning path of mobile anchor node. The location accuracy is low when the sensor nodes are far away from the path, even it cannot receive messages from mobile anchor nodes. Literature\(^{[7]}\) discussed the optimal path planning of...
the mobile anchor node. But there are many factors affecting the problem. Only several principles are given.

This paper researches the path planning problem of mobile anchor node in the localization of wireless sensor network. AHLos (Ad-Hoc Localization System) Localization algorithm demands a high density of anchor nodes, and error accumulation is existed in the iterative process. The introduction of the mobile anchor node to instead the fixed anchor nodes in AHLos algorithm, which could ensure the accuracy, improve the efficiency of the anchor nodes in the algorithm and reduce the costs of positioning. The mobile anchor node moves within the whole area, and provide enough information of localization. In this process, the path of mobile anchor node is called AHLos path planning.

2. INTRODUCTION OF RELEVANT ALGORITHMS

2.1. AHLos algorithm

This algorithm operates on an ad-hoc network of sensor nodes where a small percentage of the nodes are aware of their positions either through manual configuration or using GPS [10]. We refer to the nodes with known positions as anchor nodes and those with unknown positions as unknown nodes. Our goal is to estimate the positions of as many unknown nodes as possible in a fully distributed fashion. The proposed location discovery algorithms follow an iterative process. After the sensor network is deployed, the anchor nodes broadcast their locations to their neighbors. Neighboring unknown nodes measure their separation from their neighbors and use the broadcasted anchor positions to estimate their own positions. Once an unknown node estimates its position, it becomes an anchor and broadcasts its estimated position to other nearby unknown nodes, enabling them to estimate their positions. This process repeats until all the unknown nodes that satisfy the requirements for multilateration obtain an estimate of their position [11]. This process is defined as iterative multilateration which uses atomic multilateration as its main primitive. Furthermore, we describe collaborative multilateration as an additional enhanced primitive for iterative multilateration.

Atomic multilateration makes up the basic case where an unknown node can estimate its location if it is within range of at least three beacons. Figure 1 illustrates a topology for which atomic multilateration can be applied.

Given that an adequate number of anchor nodes are available, a Maximum Likelihood estimate of the node's position can be obtained by taking the minimum mean square estimate.

In an ad-hoc deployment with random distribution of anchors, it is highly possible that at some nodes, the conditions for atomic multilateration will not be met: i.e. an unknown node may never have three neighboring beacon nodes therefore it will not be able to estimate its position using atomic multilateration. When this occurs, a node may attempt to estimate its position by considering use of location information over multiple hops in a process we refer to as collaborative multilateration. If sufficient information is available to form an over-determined system of equations with a unique solution set, a node can estimate its position and the position of one or more additional unknown nodes by solving a set of simultaneous quadratic equations. Figure 2 illustrates one of the most basic topologies for which collaborative multilateration can be applied.

The iterative multilateration algorithm uses atomic multilateration as its main primitive to estimate node locations in an ad-hoc network [12]. When an unknown node estimates its location, it becomes a beacon. This process repeats until the positions of all the nodes that eventually can have three or more beacons are estimated.

2.2. The initial selection of anchor nodes

Analysis shows that the localization of AHLos algorithm has relationship with the nodes connectivity. When the nodes connectivity is higher, the available information for the node is more. The effect of localization will be better. Therefore, the initial of the algorithm, some nodes need to be picked as the initial anchor nodes. These initial anchor nodes should be located by the mobile anchor node at first. So that we can achieve maximize efficiency of the mobile anchor node. At the same time, enough anchor nodes
information are provided to locate other unknown nodes by AHLos algorithm.

The select of initialize anchor nodes are divided into three steps:

(1) Wireless sensor networks self-organize into networks. The nodes get the connectivity information and the distance information with neighbor nodes.

(2) According to the proportion and the number of the nodes. Identify the set of initial anchor nodes which have higher connectivity.

(3) If the number of the anchor nodes is greater than the number of requirement, we can choose from the anchor nodes repeatedly, and then calculate the length of AHLos path. At last, determine the set of nodes which have the shortest path.

2.3. The approximation localization of initial node and the error analysis

In AHLos path planning, the initial anchor nodes are located by the mobile anchor node through approximate, instead of the general three-point positioning method. We set a critical distance $\varphi$ which is close to 0, once the distance between mobile anchor node and the initial anchor nodes is lower than $\varphi$, we can think that the position of the mobile anchor node is the position of initial anchor node. So the initial anchor nodes are located.

In AHLos path planning, the mobile anchor node only needs to approach the initial anchor nodes. The accuracy of approximate location is higher than the traditional three-point location. The positioning error $e$ depends on the distance measurement error $e_m$, critical distance $\varphi$ and anchor nodes measurement error $e_a$ [14].

$$e = e_m + e_a + \varphi$$

(1)

Three-point positioning error equals calculation error $e_c$. The calculation error is mainly from the ranging error $e_{mf}$ and anchor nodes self-measurement location error $e_{af}$.

$$e_f = e_c = e_{mf} + e_{af}$$

(2)

First of all, there is much error in distance measure between the nodes. But when the distances get closer, the measure error will get smaller. Relative to the three-point positioning, approximate location affected by the ranging error is much smaller, so $e_m < e_{mf}$, and the three-point positioning requires three times measurements, the ranging error is greater. The second, critical distance $\varphi$ is a constant value. Because the size of the sensor node is small, when the ranging measure is precision, $\varphi$ could set close to 0. So the increased $\varphi$ cannot significantly increase the positioning error.

2.4. Movement on the transition path

Based on the position method of Approximation location, mobile anchor node only needs to follow a specific path traverse all initialized anchor nodes. When two initial anchor nodes are neighbors, after mobile anchor node approach to one of the initial anchor node, it could perception the direction of the next one. But when two initial anchor nodes are not neighbors, the mobile anchor node is unable to determine the direction that it should move. Here, the transitioning through intermediate nodes is proposed. Transition once called ‘one-hop’, through the ‘multi-hop’ of the intermediate nodes, the next initial anchor node can be located by approximation method. The multi-hop path is called ‘transition path’. In the transition path, the next node must be its neighbor. The mobile anchor node moves along this transition path from one initial anchor node to the intermediate nodes, until approaching another initial anchor node. It should be pointed out that the intermediate nodes do not need to be located along the transition path during the movement. They merely played the role of a bridge. Otherwise AHLos localization algorithm will meaningless. Therefore, the GPS can be temporarily turned off when passing through the intermediate nodes. This method can save a lot of energy. In addition, it is not necessary to move close to the critical distance $\varphi$ toward intermediate nodes. As long as the mobile anchor node access into the next communication radius. Once the mobile anchor node detects the next node, it could adjust the direction immediately. This method could greatly shorten the displacement distance.

![Fig.3 approximate location](image-url)
The specific mobile process is shown in figure 3. Firstly, put the mobile anchor node in the initial position A, it find the nearest initial anchor node 1, then move to the direction of node 1, it arrive at the position B (Keep critical distance $\phi$ with node 1). The initial anchor node 1 is located by approximation method. The next goal of the mobile anchor node is the initial anchor node 3. But nodes 1 and 3 are not neighbors; the mobile anchor node cannot search the node 3 directly. We find a transition path between nodes 1, 3 ($1 \rightarrow 2 \rightarrow 3$) as a Bridge. The mobile anchor node moves toward the intermediate node 2, then from the node 2 approximate the node 3. Finally, the initial anchor node 3 could be located. It should be noted that the mobile anchor node from the position B towards to the intermediate node 2, When it reached position C, the node 3 will enter its communication radius, the mobile anchor nodes do not need to continue move to the node 2, it could adjust direction toward to node 3 immediately. The position of D is the position of node 3. The distance of the mobile anchor node has run is greatly reduced. This is shorter than use transition path directly.

3. AHLOS PATH PLANNING

3.1. The choice of transition path

The path length of the mobile anchor node is the sum of transition path length between initial anchor nodes. In order to find the optimal path, the distance between every two initial node needs to be obtained in advance. But it will not be neighbor between every two nodes; we should pre-calculate the distance according to the movement of the mobile anchor node.

The shortest path between each two initial nodes should be determined in advance. Each initialized nodes in the network broadcast a packet to its neighbor nodes. The packet include the ID of the node, meanwhile the initial distance parameter is set to 0. After the neighbor nodes receive this packet, it should add the distance between the two nodes on the distance parameter, and record the transmission sequence of the packet. Then the neighbor broadcast the packet to its neighbors. Each node receives the packet do the same operation. At last, every two initial nodes can establish multiple routes. The shortest path is selected as the path between the initial anchor nodes.

3.2. Traveling salesman problem

After the transition path between every two nodes are determinate. The global optimal path is the shortest path that the mobile anchor node traverses all initial anchor nodes. The mobile anchor node path planning is abstracted as the traveling salesman problem.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>the Contrast between Path Planning of Mobile Node and TSP</th>
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</thead>
<tbody>
<tr>
<td>The mobile anchor node path planning</td>
<td>Traveling salesman problem</td>
</tr>
<tr>
<td>Mobile anchor node Initial nodes</td>
<td>salesman cities</td>
</tr>
<tr>
<td>Distance between the initial nodes</td>
<td>Distance between the cities</td>
</tr>
<tr>
<td>Search the shortest length traversal all initialized nodes</td>
<td>Search the shortest length traversal all cities</td>
</tr>
</tbody>
</table>

\[
\min \sum_{i \neq j} d_{ij} x_{ij} 
\]

\[s.t \sum_{i=1}^{n} x_{ij} = 1 \]  \hspace{1cm} (3)

\[\sum_{j=1}^{n} x_{ij} = 1 \]  \hspace{1cm} (4)

\[\sum_{i,j \in S} x_{ij} \leq |S| - 1 \hspace{1cm} 2 \leq |S| \leq n - 2, S \subset \{1,2,...,n\} \]  \hspace{1cm} (5)

\[x_{ij} \in \{0,1\} \hspace{1cm} i, j = 1,2,...,n \hspace{1cm} i \neq j \]  \hspace{1cm} (6)

4. THE SIMULATION AND ANALYSIS

4.1. The steps of the algorithm

The main steps of the algorithm: firstly, a number of nodes are random spread in the region. These nodes form an ad-hoc network. Each node measure the distance with their neighbor nodes through ranging module. The distance information is obtained. Those who have the largest number of neighbor nodes are chosen from all nodes (Typically 10% of all the nodes can be selected) as the initial anchor nodes. The shortest transition path between every two nodes is determined by broadcast the packet, and the distance between initial anchor nodes can be obtained at the same time. Then, the shortest path traversing all initialized anchor nodes is searched by genetic algorithm. At first, the mobile anchor node is placed to the starting node of the traverse path. The mobile anchor node will traverse all the initial anchor nodes.
according to the sequence. In this process, GPS is opened when the mobile anchor node approximate to the initialization anchor node. While walking along the transition path, the GPS should be closed temporarily. Once the mobile anchor node detects the signal of the next node, the mobile anchor nodes adjust the direction immediately. This can greatly shorten the distance of actual movement.

When all initial nodes are located, the remaining of the unknown node could be location by AHLos algorithm.

4.2. Comparison and analysis of simulation results

The simulation area is a 100*100 square, 100 sensor nodes are randomly deployed. The communication range of the sensor node is 20m. The proportion of initial anchor nodes is 10%. At the beginning, the mobile anchor node is deployed within the communication radius of any initial anchor nodes. So the mobile anchor nodes can traverse all the initial anchor nodes successfully.

4.2.1 Path planning of different amount of initial nodes

In this paper, the simulation is used 10, 20, 30, 40, 50 initial anchor nodes, corresponding to the total number of 100, 200, 300, 400, 500 sensors. They are deployed in 100*100 square areas. Based on the AHLos path, mobile anchor nodes traverse all initial anchor nodes.

Table.2 The length of the optimal path of nodes with different number in the path planning

<table>
<thead>
<tr>
<th>The number of initial nodes</th>
<th>The length of optimal path</th>
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<tbody>
<tr>
<td>10</td>
<td>145</td>
</tr>
<tr>
<td>20</td>
<td>160</td>
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<tr>
<td>30</td>
<td>202</td>
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<tr>
<td>40</td>
<td>251</td>
</tr>
<tr>
<td>50</td>
<td>333</td>
</tr>
</tbody>
</table>

We can see from the simulation data, AHLos path planning can complete the traverse of different numbers initial anchor nodes, and in the case of the nodes increasing, path length increase smoothly instead of rapidly. It has a high stability.

4.2.2 Comparative analysis of different path planning methods

In order to judge the performance of AHLos path planning comprehensively, the AHLos path planning is compared with SCAN, DOUBLE SCAN, HILBERT path planning.

![Fig.4 Comparison of different path planning methods under different number of initialization nodes](image)

![Fig.5 Comparison of different path planning methods under different node communication radius](image)

![Fig.6 Comparison of different path planning methods under different area](image)
From Figure 4, we can see that the path length of AHLos path planning increase slowly follow the increase of the initial anchor nodes. The SCAN, DOUBLE SCAN, HILBERT are static path, so the path length dose not changed when the area and communicate radius not changed. From Figure 5, 200 nodes are deployed, and 40 initial anchor nodes are selected. We can see the change of all kinds of path planning along with the change of communication radius. For AHLos path planning, the increase of communication radius makes the transition path between the two initial anchor nodes shorter. Thereby the mobile anchor node could percept the next intermediate node earlier. The travel distance is reduced. From Figure 6, the communicate radius is 20m. We can see the changes of the path length that 40 initial anchor nodes are deployed in different area. With the increase of area, the path length of SCAN, DOUBLE SCAN, HILBERT are significantly increased. For AHLos path planning, the path increases slowly.

5. Conclusion

From the above three experiments, it can be concluded that under the condition of low node density, the advantages of AHLos path planning are obvious. Along with the rising of the node density, the gap between AHLos and other kinds get narrow; under the condition of high node density, the path of AHLos compare with others is almost the same. But based on the characteristics of AHLos localization algorithm, under the condition of high node density, every node has lots of neighbors, the requirement of initialization node ratio get less, and so the AHLos path can be shortened. This algorithm is dynamically adjusted with AHLos, which is not available in other path planning. Meanwhile, the problem of collineations will not take place in the algorithm; the location accuracy is guaranteed.

Above all, AHLos path planning is rational to use the mobile anchor node information; the path is also superior to the general static path planning.

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REFERENCES: