Path Planning for Mobile Beacon Nodes in Localization for Wireless Sensor Networks

Lu Wang, Wusong Wen

1 Department of Mathematics and Information Engineering, Chongqing University of Education, China, tulang896@163.com
2 Department of Power Engineering, Chongqing Communication College, China

Abstract

A path planning for mobile beacon nodes is presented based on the node localization problem of WSN. The beacon nodes define the unknown node position by using ranging method of RSSI. By analyzing defects of a static trajectory, random trajectory, the beacon nodes move to the maximum coverage of unlocated nodes. The simulation result demonstrates that this algorithm obtains good localization performance and can be well adapted to the WSN node localization problem.

Keywords: Wireless Sensor Network, Path Planning Algorithm, Mobile Beacon Node

1. Introduction

Wireless sensor network (WSN, Wireless Sensor Networks) is a combination of wireless communication, sensing, microelectronics and embedded computing in many fields such as interdisciplinary technology [1], and is widely applied in military, industry, agriculture and other fields. WSN is the twenty-first century IT technology which has a significant impact on human life [2] (Figure 1 shows the WSN model). Network nodes localization [3-10] problem is one of the main study contents for wireless sensor network. The WSN localization problem is mainly divided into two parts: one method is based on the beacon node positioning and another is based on none beacon node positioning [3]. The method based on beacon node obtains adjacent node distance according to the received signal strength, the arrival time and the time difference, and calculates the unknown node position by using of the three side method. None beacon node positioning method forms a local coordinate according to the reference points, and calculates the unknown node position based on the relative node position.

At present, WSN node localization study mainly focuses on how to use fewer beacon nodes to locate the unknown node position. “Localization of wireless sensor networks with a mobile beacon” is introduced by Sichitiu and Ramadurai [4]. By using a plurality of beacon nodes moving freely in the network, the unknown node position can be located by calculating the distance to the beacon node, but as beacon nodes moving freely, this method consumes a lot of energy. “Static path planning for mobile beacons to localize sensor networks” is introduced in [5]. In that paper the mobile node planning method is presented, and takes round and S mobile path, but this method belongs to static planning, and does not apply to the uneven distribution WSN.
In this paper we present a beacon node adaptive path planning method and the node localization in WSN is achieved. In view of the above research, based on RSSI, the beacon nodes form a certain geometric shape, and determine the unknown node position by three boundary method in the covered area. By using the three edge measuring technique, unknown nodes position are located.

The rest of the paper is organized as follows. Section 2 presents some basic location theories. Section 3 presents the details of the mobile beacon node path planning. Section 4 presents the simulation results. Finally this paper concludes in Section 5.

2. Location theories

2.1. RSSI

According to the receive signal strength of the node, Received Signal Strength (RSSI) [11-16] ranging method calculates the signal energy consumption in the process of communication, and then determines the distance between nodes by comparing with the wireless signal propagation model. RSSI ranging method is simple, low cost, and nodes can usually provide the received signal strength values, therefore, RSSI is widely applied to the node localization problem in WSN.

2.2. Three edge measuring principle

Three edge measuring technique is one node location method that by using three non-collinear points to identify another one, and in three edge measuring technique, non-collinear points coordinates are known. Its principle is shown in Figure 2.

![Figure 2. Three Edge Measuring Principle](image)

Using the following formulas, we can determine the unknown point coordinate:

\[(x-x_a)^2 + (y-y_a)^2 = R_{a}^2 \quad (1)\]
\[(x-x_b)^2 + (y-y_b)^2 = R_{b}^2 \quad (2)\]
\[(x-x_c)^2 + (y-y_c)^2 = R_{c}^2 \quad (3)\]

3. Mobile beacon node path planning

3.1. Random path and Regular path

Random path algorithm [17] refers to the beacon nodes moving freely in the network, and unknown nodes determine their position according to the information between nodes. Different with random path,
regular path [8] refers to the beacon node moving in curve track, and beacon nodes broadcast its own position information continuously in the process of moving. The beacon node broadcasts a limited distance, and only when the unknown nodes in a certain range can receive the broadcast information. When the unknown node receives radio nodes more than the 3, its own position can be determined with three boundary method. Either random path method or regular path method do have errors, and sometimes errors will affect the correctness of the result (as shown in Figure 3.). This is because the broadcast information is periodically broadcast, and when the unknown node just receives broadcast information, the distance between nodes and beacon (\( R \)) is smaller than the beacon node broadcast radius (\( R \)) in fact. There has a distance error (\( \Delta R = R - R \)).

![Figure 3. Reasons for Error](image)

3.2. Adaptive beacon node movement path

Beacon node moving path has important effects on positioning accuracy and network coverage rate. Following factors must be considered when determining the beacon node moving path.

1. When the beacon nodes move, its coverage area includes the unknown nodes as much as possible.
2. The beacon nodes moving path includes the number of mobile as low as possible.
3. The total movement distance of beacon nodes as short as possible.

On this basis, a beacon node adaptive path planning method is presented in this paper, and does the following hypothesis:

1. 3 beacon nodes form triangular coverage area, and each beacon node has its own number (\( M_i, i = 1, 2, 3 \)), and triangle side length equals to the radius of the beacon node radio (as shown in Figure 4.).
2. 3 beacon nodes have the same broadcast radius.
3. 3 beacon nodes triangular area is much smaller than the network monitoring area.

![Figure 4. Beacon Node Location](image)
3.2.1. Unknown node localization in triangle coverage area

As shown in figure 3, three beacon nodes (\(M_i\) \((i=1,2,3)\)) form a regular triangle at this moment, and apparently unknown nodes are in the communication range of the three beacon nodes in the triangle area. Beacon node self-location (\(M_1(x_1,y_1), M_2(x_2,y_2), M_3(x_3,y_3)\)) is known. According to the RSSI values, the distance (\(d_{u1}, d_{u2}, d_{u3}\)) between unknown nodes and beacon node can be determined. By the following formulas can determine the unknown node position.

\[
(x-x_1)^2 + (y-y_1)^2 = d_{u1}^2
\]

\[
(x-x_2)^2 + (y-y_2)^2 = d_{u2}^2
\]

\[
(x-x_3)^2 + (y-y_3)^2 = d_{u3}^2
\]

3.2.2. Adaptive mobile path algorithm

Based on the random path and the regular path, analysis shows that the purpose is to reduce the mobile beacon node number and length, so that the energy consumption can be reduced, and survival time of the network can be improved. Based on this consideration this paper designs an adaptive path planning method for mobile beacon node: beacon node next moving direction is to cover more unknown nodes.

1. Three beacon nodes relative position don’t change, and the mobile process for three beacon nodes is just triangular translation.

2. The number of unknown nodes (\(n_{u1}, n_{u2}, n_{u3}\)) within communication range is calculated, and if the RSSI of unknown nodes is greater than a certain threshold, the node is in the beacon nodes communication range. When the unknown nodes define themselves in which beacon communication range, it will continue take part in decision for other beacon nodes, that is to say each beacon node communication range including the unknown node can be the same.

3. Related simulation results show that when the beacon node moving step is \(\sqrt{3}R\) [18, 20, 21], unknown node localization effect in WSN is best. In order to determine the beacon node moving direction, beacon nodes move towards the area including more unknown nodes, The moving mode as shown in Figure 5 (a).

(4) When the beacon nodes moving direction is determined, in order to make the new coverage area having more unknown nodes, equilateral triangle rotates around \(O_i\) with a certain angular velocity, and calculates the unknown nodes number in the new coverage area every once in a while. After rotating one cycle, the final measurement position which has the most unknown nodes number is determined (as in Figure 5 (b) shows).
(5) The beacon nodes in the new location repetitive 3.2.2 section contents, and the beacon node moving path is obtained. Figure 6 presents the adaptive routing algorithm flow chart.

4. Simulations

With Matlab, this paper analyzed the performance and effectiveness of the proposed algorithm and the comparative analysis of the proposed algorithm, the random algorithm and the regular algorithm are presented. This paper adopts signal transmission model as follows:

\[ PL(db) = PL(d_i) + 10 \cdot \eta \cdot \log_10 \left( \frac{d}{d_i} \right) + X_o \]  
\[ RSSI(d) = P_t - PL(db) \]

Table 1 gives the values of different parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_t )</td>
<td>-5dBm</td>
</tr>
<tr>
<td>( \eta )</td>
<td>4</td>
</tr>
<tr>
<td>( PL(d_i) )</td>
<td>55dBm</td>
</tr>
<tr>
<td>( E(X_o) )</td>
<td>0</td>
</tr>
<tr>
<td>( R )</td>
<td>6m</td>
</tr>
<tr>
<td>unknown nodes</td>
<td>100</td>
</tr>
<tr>
<td>( \sigma(X_o) )</td>
<td>5</td>
</tr>
<tr>
<td>Scale</td>
<td>100m x 100m</td>
</tr>
</tbody>
</table>

4.1. Algorithm performance

In the 100m x 100m monitoring area, randomly places 100 unknown node, and \( R = 6m \). In order to test the algorithm's accuracy, this paper uses the positioning error as performance index parameters, and by using random path and regular path, simulation is presented. Fig 7 shows the simulation results.
The graph 5 simulation results show that, the launch points [8] for adaptive path planning is 40, for random path is 85, for regular path is 60. For coverage rate, adaptive path planning can reach 90%, random path can reach above 95%, and regular path is 93%. The beacon node movement distance [19] on adaptive path planning is 140R, random path is 220R, and regular path is 190R. From the moving distance and the emission point number perspective, adaptive path planning algorithm is better than the other two algorithms. This is because the adaptive algorithm is always move to the area having more unknown nodes, and to a certain extent, this can save energy. In order to further determine the relationship between communication radius and positioning accuracy, this paper gives the positioning accuracy simulation results with different communication radius. The simulation results are shown in figure 8. From Figure 8 we can see that, positioning accuracy declines as communication radius increases, and that the adaptive path planning algorithm is superior to other algorithms in positioning accuracy, this is because the algorithm uses 3 beacon node, and the beacon nodes is always moving to the area having more unknown nodes.

4.2. Cost analysis

For the adaptive path planning algorithm and regular path algorithm, if the network has the same number of unknown nodes, the adaptive path planning algorithm and regular path algorithm path algorithm computational overhead is basically the same. Although communication costs will increase
slightly, but the hardware cost can be reduced greatly. Comparative analysis of the results is shown in table 2.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>hardware cost</th>
<th>Communication overhead</th>
<th>computational overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>adaptive path</td>
<td>low</td>
<td>moderate</td>
<td>low</td>
</tr>
<tr>
<td>regular path</td>
<td>high</td>
<td>low</td>
<td>moderate</td>
</tr>
</tbody>
</table>

The results show that, in the random distribution network, as adaptive path planning algorithm uses only 3 moving beacon nodes, and these beacons use adaptive moving path, so the different unknown nodes may not need the GPS to obtain their position but by calculation directly. At the same time assisted positioning RSSI ranging technology is the most inexpensive, this makes the adaptive path planning algorithm reduces the hardware cost of network.

In this paper, the beacon node number for the adaptive path planning algorithm is 3. In order to verify the relationship between the beacon node number and network coverage, an analysis about the relationship between beacon node number and network coverage is presented in this paper, and the simulation results is shown in figure 9. From the simulation results we can see that, with the increase of network nodes, network coverage rate increases, but when the number of nodes up to a certain number, coverage rates remains unchanged.

![Beacon nodes number and network coverage](image)

**Figure 9.** Beacon nodes number and network coverage

### 4.3. Stability analysis

In the simulation, as the entire network nodes are randomly distributed, this makes it possible to produce two kinds of forms of the network structure: one is a relatively dense and regular distribution of all nodes in the network; the other is a sparse nodes or irregular distribution network. In the irregular distribution network, it may appear that some unknown nodes are isolated or locate at the boundary of network.
This paper uses 20, 40, 60, 80, and 100 unknown nodes in the adaptive path planning algorithm stability experiment, which are distributed randomly in the designated area, and simulation experiments are carried out in regular and irregular distribution network. The simulation results as shown in figure 10 give the analysis about the relationship between unknown nodes and the average localization error.

The analysis results show that, based on adaptive path planning ideas the adaptive path planning algorithm can adopt adaptive adjustment method to irregular network node distribution, and can adjust the mobile beacon node movement route dynamically. This can not only improve the positioning information intensive degree, so that the average hop distance information in the error is not too large, but also makes the unknown node as much as possible to receive location information in the irregular distribution area, and to ensure the positioning stability.

5. Conclusions

Based on the wireless sensor network node localization problem, an adaptive path planning method for mobile beacon node is presented in this paper. The ranging principle, basic principle of RSSI measurement and the three edge ranging technology are introduced. On this basis, the beacon nodes form a certain geometric shape, and the unknown node location in coverage area is determined with the using of three boundary method. The whole wireless sensor network node localization problem is completed as beacon nodes move to area having more unknown nodes. Finally the algorithm performance is analyzed. The simulation results show that the algorithm has better performance in positioning accuracy and energy consumption, and can be well adapted to the WSN node localization problem.

6. Acknowledgement

This work was supported by the Natural Science Foundation of Chongqing of China under Grant (No.KJ121506).

7. Reference


[8] Li Ruixue, FANG Zhiyi, YI Tingting, "Improved DV-Hop Localization Algorithm Based On Regularly Moving Anchor (RMAN) and Received Signal Strength indicator (RSSI) and Its Performance Analysis", Journal of JiLin University (Engineering and Technology Edition), vol. 41, no.2, pp.435-441, 2011.


