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An Improved DV-Hop Localization Algorithm Based on Hop Distance and Hops Correction

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Abstract

In order to solve the problem that the DV-Hop algorithm has large error in the network topology environment of random distribution of nodes, this paper proposes a WSN localization algorithm based on hop distance correction. The algorithm uses the method of multi communication radius to correct the hop number within 1 hops, which makes it more consistent with the real situation; Then, the weighted factor is obtained by error of the average distance per hop of anchor node; Finally, the total least squares method is used to calculate the coordinates of the unknown nodes to improve the positioning accuracy of DV-Hop positioning algorithm. The simulation results show that the improved algorithm has a better accuracy and stability than the original DV-Hop algorithm.

***Keywords**: WSN, DV-Hop algorithm, hops, average distance per hop, total least square method*

1. Introduction

In applications of Wireless Sensor Network (WSN), node localization is the precondition and foundation, so it is a hot issue in current research [1]. At present, the two kinds of positioning technology are range-based and range-free [2]. There are some range-based localization algorithms such as TOA, TDOA, RSSI, AOA, and so on, all of which has higher accuracy, but need extra hardware and the cost is higher. There are some range-free localization algorithms such as DV-Hop, Amorphous, and APIT and so on, all of which has low accuracy, no additional hardware support and the cost is lower.

Due to the limited energy, range-free localization algorithms have wide range of applications in wireless sensor networks, among them, the DV-Hop algorithm is one of the most widely used localization algorithms [3-4]. However, the algorithm has a low accuracy in large scale, so many scholars have improved the algorithm [5-9]. The positioning accuracy of these improved algorithms are improved at different degree, but all of them improved the average distance per hop of unknown nodes only from a single aspect, while it is influenced by many factors. Therefore, the average distance per hop of unknown nodes are improved by the errors of the average distance per hop of anchor nodes and the number of hops in this paper to make it more close to the real value, and thus further improve the accuracy of the positioning. Simulation results show the effectiveness of the proposed algorithm.

2. DV-Hop Localization Algorithm

2.1. Positioning Process

DV-Hop algorithm, proposed by Niculescu *et al.* [10-11], obtains the estimated distance between the anchor nodes and unknown nodes by the hops timing the average

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distance per hop. Then the coordinates of the unknown nodes are estimated by using the three edge measurement method. The positioning process is as follows:

(1) The anchor node broadcasts a packet $\{id_i, x_i, y_i, hop\}$ containing node ID, node location, and hop count. Neighbor nodes record the node ID of each node, the coordinate values, and the smallest hops. Forward packet after hop is plus 1. In this way, all nodes obtain from the minimum number of hops of each anchor node.

(2) The average distance per hop of each anchor node is calculated by using the formula (1).

$$HS_i = \sum_{j \neq i} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \,/ \sum_{j \neq i} hop_j \quad (1)$$

Among them, (x_i, y_i), (x_j, y_j), hop_j is the location of the beacon node i and j, the minimum hop count of the two, respectively. The unknown node estimates the distance between the anchor nodes by the average distance per hop of the nearest anchor node timing the minimum hops.

(3) Unknown nodes use distance of 3 or more anchor nodes to estimate their coordinates.

2.2. Error Analysis

(1) Error caused by minimum hops

From the first step of DV-HOP localization process, it can be seen that no matter how far the actual distance between the two neighbor nodes is, as long as the node receives the information from the neighbor nodes, the number of hops is 1. However, the layout of the nodes in the actual network environment is random, so there will not be a large number of regular nodes, and the path of the twists and turns. The minimum hop count obtained in this case is used to continue the positioning process and there will be a big error, as shown in Figure 1.

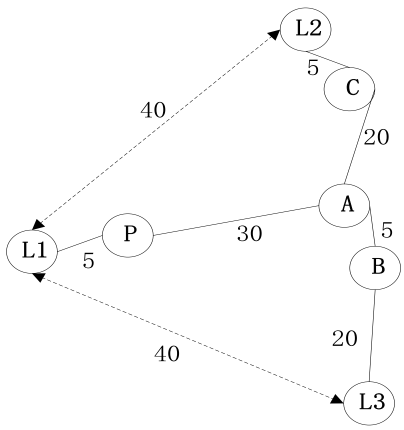

Figure 1. Error Analysis

In Figure 1, P is an unknown node, L1, L2, L3 are the beacon nodes. From Figure 1, it can be seen that the distance between nodes L1 to node P is much smaller than the distance from node P to node A. However, in the traditional DV-Hop positioning process, the hop between L1 and P is 1, and the hop between P and A is also 1. Obviously, error of minimum hop is large.

(2) The error caused by the average distance per hop

In the second step of DV-Hop, the anchor node calculates the average distance per hop based on the minimum hops. The unknown node uses the average distance per hop of its nearest anchor node timing the hops to estimate the distance between each anchor node.

In Figure 1, according to DV-Hop positioning process, the average distance per hop of L1 is$(40+40)/(4+4)=10$. The unknown node receives the average distance per hop of L1 and makes it as its average distance per hop, then estimates the distance between L1 is $10\times 1=10$. And the actual distance between two nodes is 5, the distance error between the calculated distance and the actual value is relatively large.

3. The Improved Localization Algorithm

Aiming at the error caused by the minimum hop number and the average distance per hop, the DV-Hop algorithm is improved from these two aspects in the paper.

3.1. Correct the Minimum Hop Trust

The principle of DV-Hop algorithm is: nodes only accept the smallest hop in the network. Experimental results show that the error of most of the nodes is relatively large when the hops=1 [12]. So the improved algorithm amends the minimum hop when hops=1. For the hop number greater than 1, it does not amend.

In this paper, we introduce four communication radius to each node, it is R, 3R/4, R/2 and R/4, respectively. When the nodes broadcast package with communication radius R, 3R/4, R/2 and R/4, all nodes capable of receiving broadcast are divided into adjacent node group 1, adjacent node group 2, adjacent node group 3 and adjacent node group 4. Obviously, the adjacent node group 1 includes adjacent node group 2, 3 and 4, the adjacent node group 2 includes adjacent node group 3 and 4, the adjacent node group 3 includes adjacent node group 4. In the broadcast process, nodes in the adjacent node group 2, 3 and 4 are removed from the adjacent node group 1, and the remaining nodes record the hops to the neighbor node as 1. Nodes in the adjacent node group 3 and 4 are removed from the adjacent node group 2, and the remaining nodes record the hops to the neighbor node as 3/4. Nodes in the adjacent node group 4 are removed from the adjacent node group 3, and the remaining nodes record the hops to the neighbor node as 1/2. Nodes in the adjacent node group 4 record the hops to the neighbor node as 1/4. On this basis, the anchor nodes broadcast with the communication radius of R, and all nodes receive data and transmit it with the flood way. At the end of the flooding, the minimum number of hops is reserved for each node.

The specific process is as follows:

(1) All nodes first broadcast information $\{id_i, x_i, y_i, hop_i\}$ with the communication radius of R/4 in the network start up. All the receiving nodes record the packet information, and the minimum number of hops between the nodes and the transmitting nodes is denoted as 1/4. In order to reduce the communication overhead, the receiving node does not forward the first broadcast message.

(2) After time T, all nodes broadcast information $\{id_i, x_i, y_i, hop_i\}$ with the communication radius of R/2. Received nodes see whether there is information of id_i in the record table. If it does not exist, they record the packet information and the minimum number of hops between the nodes and the transmitting nodes is denoted as 1/2. If it exists, they do not for any processing. The receiving node does not forward the second broadcast message.

(3) After time T, all nodes broadcast information $\{id_i, x_i, y_i, hop_i\}$ with the communication radius of 3R/4. Received nodes see whether there is information of id_i in the record table. If it does not exist, they record the packet information and the minimum number of hops between the nodes and the transmitting nodes is denoted as 3/4. If it exists, they do not for any processing. The receiving node does not forward the third broadcast message.

(4) After time T, all nodes broadcast information $\{id_i, x_i, y_i, hop_i\}$ with the communication radius of R. Received nodes see whether there is information of id_i in the record table. If it does not exist, they record the packet information and the minimum

number of hops between the nodes and the transmitting nodes is denoted as 1. If it exists, the hop is not changed, and the broadcast information with node ID and hops is transmitted.

(5) The node that receives the forwarding information is first to inquire whether there is a record of the hop with the anchor node. If no, hops between the nodes and the anchor nodes is recorded as the sum of hops recorded in forwarding nodes and hops between the node and the forwarding node. If exist, compare the recorded hops to hops between the anchor nodes and take the minimum hops. Such continuous forwarding, so that all nodes can get the minimum hops between each node.

3.2. Correct the Average Distance per Hop

In the traditional DV-Hop algorithm, the same average distance per hop is used to calculate distance, which increases the error, so how to amend the average distance per hop plays an important role on improving the positioning accuracy. As the smaller error of the average distance per hop is and the smaller distance is, the effect of the average distance per hop of the unknown node is greater. Therefore, in the improved localization algorithm, all the anchor nodes in the network need to calculate their error of average distance per hop. And then the packet with the average distance per hop and the error of average distance per hop is broadcast to the network. The unknown node in the network only receives the broadcast packet information from its nearest anchor node. The average distance per hop of the unknown node is amended by weighted average distance per hop of the nearest anchor node and the average distance per hop of the whole network.

Specific steps are as follows:

(1) According to the minimum hops obtained through 2.1, using the formula (1) to calculate the average distance per hop of anchor nodes;

(2) Using the position information in the record table, the anchor node calculates the actual distance between the other anchor nodes by the formula (2).

$$d_{tij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{2}$$

Where $(x_i, y_i), (x_j, y_j)$the true is coordinates of the position of the anchor node i, j, respectively.

(3) Estimate distance between anchor nodes is calculated by formula (3).

$$d_{eij} = HS_i \times hop_{ij} \tag{3}$$

Where HS_i is the average distance per hop of anchor node i. hop_{ij} is the minimum hop between anchor node i and node j.

(4) Calculate error of average distance per hop of anchor nodes.

$$\varepsilon_i = \frac{\sum_{i=1}^{N} |d_{tij} - d_{eij}| / hop_{ij}}{N-1} \tag{4}$$

Where N is the number of anchor nodes.

(5) Anchor nodes in the network broadcast packets $\{id_i, HS_i, \varepsilon_i\}$ in the network ;

(6) The unknown node uses the type (5) to calculate the distance between the anchor nodes according to the information recorded in the table.

$$d_i = HS_{near} \times hop_i \tag{5}$$

Where HS_{near} is the average distance per hop of the nearest anchor node from the unknown node. hop_i is minimum hops between unknown nodes and anchor nodes.

(7) Unknown nodes calculate weighted factor by formula (6).

$$\gamma_i = \frac{1}{\varepsilon_i} + \frac{1}{d_i} \tag{6}$$

(8) The unknown node calculates the average distance per hop of the whole network according to the received data packets.

$$HS_{avg} = \frac{\sum_{i=1}^{N} HS_i}{N} \tag{7}$$

(9) Calculate the average distance per hop of unknown node by formula (8).

$$HS_{un} = (1-\gamma) \times HS_{avg} + \gamma \times HS_{near} \tag{8}$$

3.3. Use the Total Least Squares Method to Calculate the Coordinates of Unknown Nodes

The total least squares method takes full account of the position error of the anchor node and the distance error caused by the position error caused by the GPS self-localization. It can reflect the influence of the two kinds of errors and improve the accuracy of unknown nodes.

When the unknown nodes get more than three d_{pi}, different from DV-Hop algorithm, the total least squares method described by [13-14] is used to calculate the coordinates of unknown nodes.

3.4. Algorithm Flow

Aiming at the problem that the DV-Hop algorithm has large error, this paper proposes an improved algorithm and its flow is shown in Figure 2.

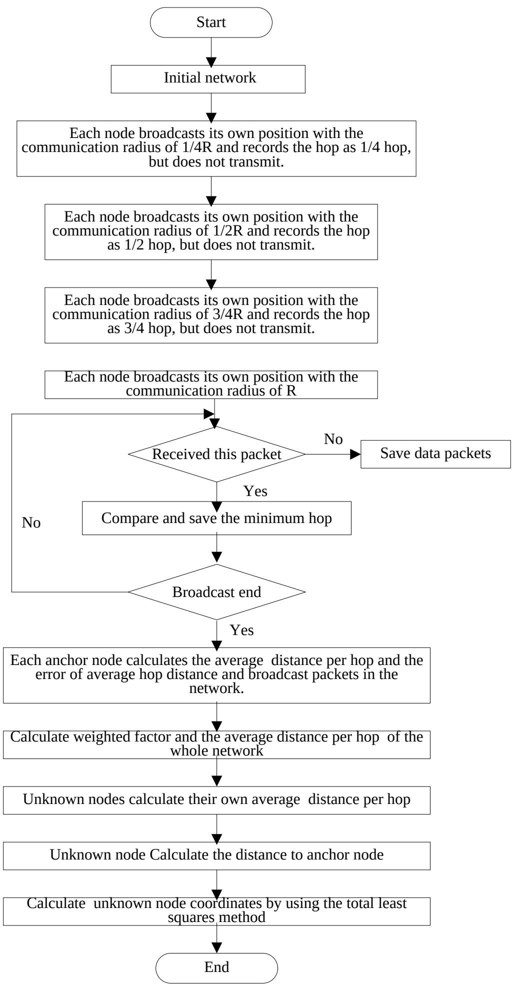

Figure 2. Flow of the Improved Algorithm

In this paper, MATLAB7.0 is used to simulate the algorithm. In the simulation environment, the anchor nodes and unknown nodes are randomly distributed and the area is [0,150]×[0,150]. Algorithm accuracy is the most important measure of the algorithm.

The performance of the proposed algorithm is verified by comparing the localization error of DV-Hop localization algorithm and the improved algorithm. The positioning error is calculated by using formula (9).

$$\delta_i = 100\% \times \sqrt{(x_t - x_e)^2 + (y_t - y_e{}^2} / R \tag{9}$$

Where (x_t, y_t) , (x_e, y_e) is the true position of the node and the estimated position, respectively. R is communication radius of nodes. The experimental scene is executed many times and the results are averaged, which makes the experimental data more objective.

4. Result Analysis

(1) Proportion of anchor node is different

In the network area, 200 nodes are randomly distributed and the total number of nodes is constant. The proportion of anchor nodes is gradually increased from 5% to 40% and the communication radius is R=10m. The positioning error of the two algorithms is compared. The simulation results are shown in Figure 3.

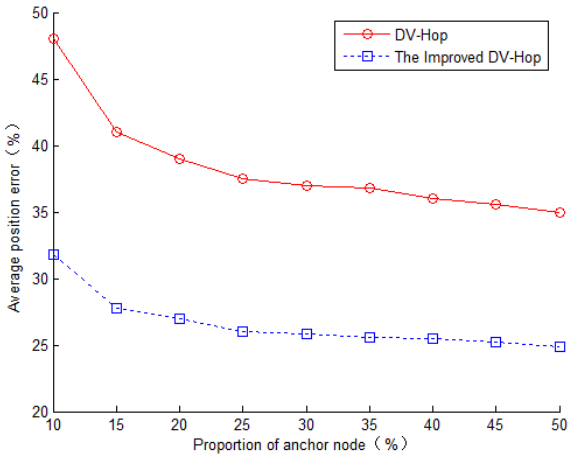

Figure 3. Comparison of Position Error with Different Proportion of Anchor Node

As can be seen from Figure 3, when the proportion of anchor nodes is small, positioning error of the improved algorithm is less than that of the traditional DV-Hop algorithm, but the difference is not great. With the increase of anchor nodes, the average position error of the two algorithms is gradually reduced. Because the improved algorithm amends the minimum hop and weights the average distance per hop of the unknown nodes, which reduces the error caused by the minimum hop c and the average distance per hop and the estimated distance between the unknown node and the anchor node is more close to the actual distance. So the performance of the improved algorithm is more significant than that of DV-HOP algorithm. Obviously, the performance of the improved algorithm is obviously better than the traditional DV-HOP algorithm. Compared with the traditional DV-HOP algorithm, the positioning error of the improved algorithm is reduced by 15%

(2) The number of nodes is different

In the network area, 200 nodes are randomly distributed, and the communication radius is R=10m, proportion of anchor node is 10%. By changing the number of nodes, the ratio of anchor nodes is constant. The performance of the two algorithms is compared. The simulation results are shown in Figure 4.

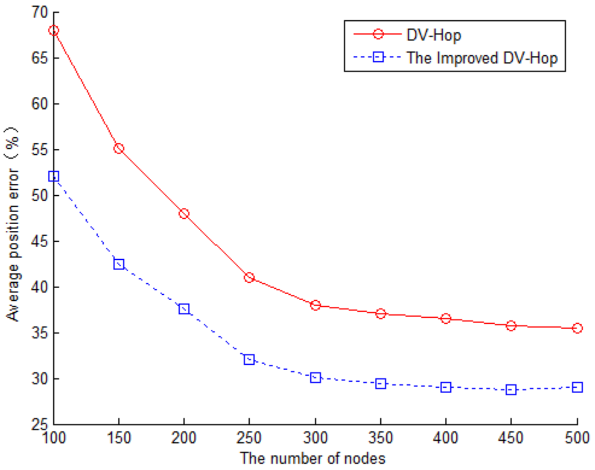

Figure 4. Comparison of Position Error with Different Number of Nodes

From Figure 4, it can be seen that, with the increase of the number of nodes, the positioning error of the two algorithms is reduced. When the total number of nodes is 300, the error tends to be stable and the change is not big. However, positioning accuracy of the improved algorithm is significantly better than that of the traditional DV-Hop algorithm. Compared with the traditional DV-Hop algorithm, the positioning accuracy of the improved algorithm is reduced by 16%.

(1) Communication radius is different

The total number of nodes in the network is 100 and the communication radius is changed. The DV-Hop algorithm and the improved algorithm are simulated under different communication radius, and the coordinates of unknown nodes are obtained by repeat run location algorithm. The error of each location is calculated by using the formula (9), and the simulation results are shown in Figure 5 (a-d).

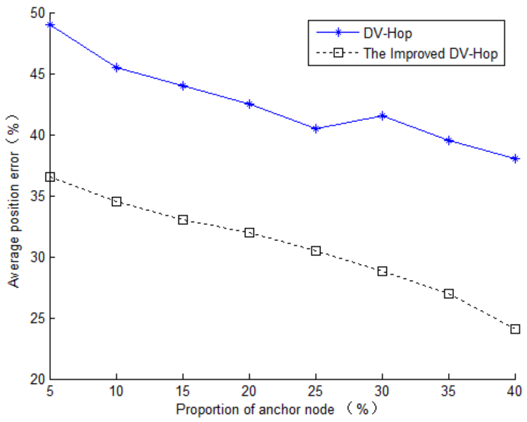

Figure 5 (a). The Average Positioning Error Chart When R=15m

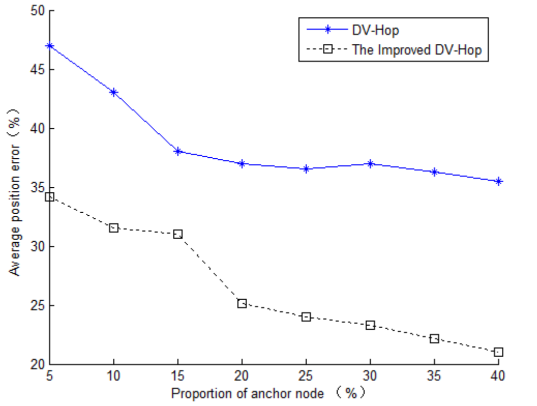

Figure 5 (b). The Average Positioning Error Chart When R=20m

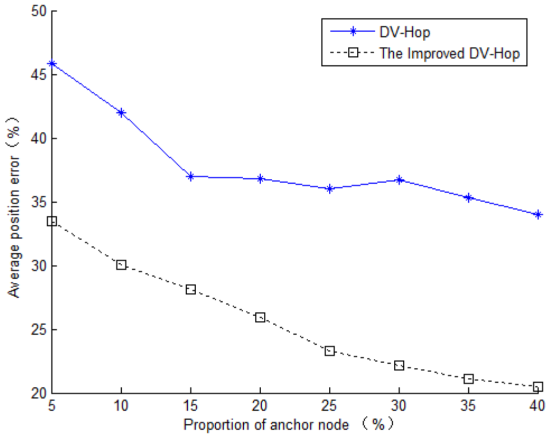

Figure 5 (c). The Average Positioning Error Chart When R=25m

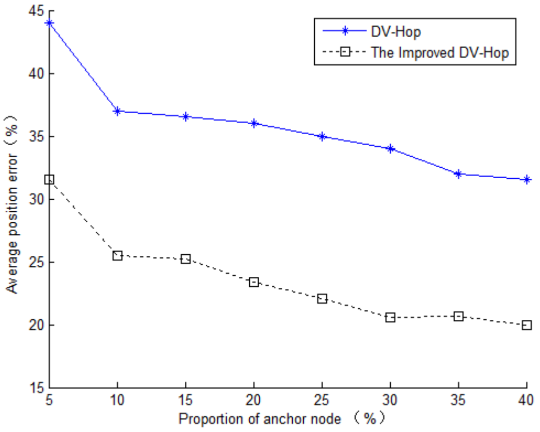

Figure 5 (d). The Average Positioning Error Chart When R=30m

Figure 5 shows that with the increase of the proportion of the anchor nodes, the average positioning error is reduced. In the same communication radius and the ratio of anchor nodes is the same. The error of the traditional DV-Hop algorithm is relatively large, and the error of the improved algorithm is small. Other conditions are the same, the communication radius becomes large, and the positioning error can be reduced. Positioning accuracy of the improved algorithm is improved about 23% ~31% than that of the traditional DV-Hop algorithm.

(5) Comparison of energy utilization efficiency of the algorithm

When the simulation times are same, comparison of the network total energy consumption of the two algorithms is shown in Figure 6. As can be seen from Figure 6, the energy consumption of the improved algorithm is slightly higher than that of the DV-Hop, but it is not very obvious. Because in the process of localization, the improved algorithm is more than the DV-Hop algorithm to broadcast the 3 data packets to get the minimum hops, but the first 3 broadcasts are not forwarded, so the consumption of energy increasing is not obvious, which is basically the same as DV-Hop.

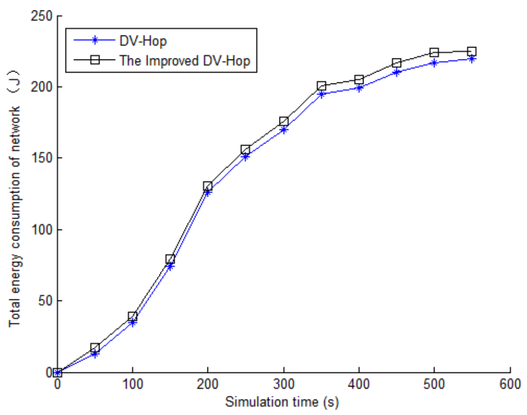

Figure 6. Comparison of Energy Utilization Efficiency of the Algorithms

5. Conclusion

Traditional DV-Hop positioning algorithm is widely used in wireless sensor networks because of its simplicity, low cost but its positioning accuracy is low. When hop is 1, it does maximum impact on node localization. The number of hops is to be classified in this paper by the improved DV-Hop algorithm, which makes it more close to the actual jump values. Then weighted the unknown node's average distance per hop, so that the estimated distance between the anchor node and the unknown node is closer to the true value, which effectively improve the algorithm's positioning accuracy. Moreover, the improved algorithm does not increase the extra hardware, without increasing the amount of computation. It is a kind of applicable localization algorithm to meet the limits of cost and energy of nodes in wireless sensor networks.

Acknowledgements

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