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Study on DV-Hop Algorithm Based on Modifying Hop Count for Wireless Sensor Networks

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***Abstract*—Localization is an indispensable part in wireless sensor networks. In consideration of its importance, extensive research has been carried out resent years. On account of the process that DV-Hop algorithm is implemented in anisotropic density sensor networks, there can be a big localization error in local area， where the information transfer has excess hop counts between two nodes. We proposed a measure that can eliminate the distorted hops by setting threshold value; To solve the problem that there can also be distance accumulated error, we proposed an RSSI based hop count calculation method, that can accurately reflect the distance between adjacent nodes, and thereby the location error can be reduced for the original DV-Hop algorithm. The simulation shows that the localization accuracy of the improved algorithm is better than the original algorithm.**

Keywords- localization；wireless sensor network；DV-Hop；hop count；RSSI

I. Introduction

A Wireless Sensor Network, which can real-time acquire and process information in the distribution area of network, is a large ad hoc network consisting of dense mini sensor nodes [1].Various applications of wireless sensor networks(WSNs) have practical significance while their position information of the sensor nodes are known. Such as battlefield reconnaissance, the prevention of forest fire and the safety monitoring of large industrial estate. The observers can make emergency measure only if they know well accurate location information of the source. Therefore, nodes localization is very important for WSNs.

In WSNs, according to whether measuring the distances between nodes, localization algorithms can be divided into two kinds: range-based algorithms and range-free algorithms. Range-based algorithm need to measure the absolute distance between two nodes: time of arrival(TOA)[2],time difference on arrival(TDOA)[3],angle of arrival[4],receive signal strength indicator(RSSI)[5][6][7]. Range-free algorithm realizes nodes localization on the basis of the information of hop count or connectivity between anchor node and unknown node. Such as Centroid algorithm, DV-Hop algorithm, APIT algorithm [9],and Sequence-Based algorithm [10].

DV-Hop algorithm is a kind of APS localization algorithm, which relies mainly on distance vector routing protocol to achieve localization. Aiming to enhance positioning accuracy of DV-Hop algorithm, many improved localization schemes have been put forward. The paper[11]has reduced the error of the minimum hop count values by setting threshold value N.A new scheme of calculating unknown node coordinates displaces least-square theory in[12].The researches[13-14]are carried out to modify the distance calculation methods, in order to reduce the distance error between unknown nodes and anchor nodes. An iterative numerical method with the initial values of estimated node locations was presented by setting proper threshold in [15].

The key points of all these improved algorithms above mainly lie in two aspects: Modifying the calculation of distances between unknown nodes and anchor nodes, and improving the calculation method of solving unknown nodes coordinates. Although location accuracy has been improved, the degree is very small. the main reasons show as follows: these improved algorithms only process obtained data by modified calculation formulas or improved solving methods, but they ignore the errors generated by no match of nodes distribution scenarios and the obtained data depending on algorithm theoretical model. Furthermore, a few part of the obtained data themselves are distorted. Aiming at the two defects, we present an improved DV-Hop algorithm. Compared with traditional DV-Hop algorithm, this paper makes two major improvements. First, we eliminate those distorted data by setting threshold value. Second, we establish a new hop count calculation method, which is more objective to reflect the nodes distribution scenarios.

II. DV-Hop Algorithm

DV-Hop algorithm has been proposed by Niculescu and Nash, which is one kind of APS distributed localization algorithm. The algorithm can be divided into three steps described as follows.

In the first step, all nodes get the minimum hop count values to all anchor nodes. Each anchor node broadcasts a beacon containing self position information and hops to its neighbor nodes to be flooded throughout the network. The initial value of hop field is 0.Receiving nodes record the minimum hops to each anchor node and ignore the message with larger hops from the same anchor node. Then, the beacons are flooded outward to their neighbor nodes with one hop increased. Through this mechanism, all nodes in the network get the minimal hop counts to every anchor node.

In the second step, when an anchor node obtains hop counts to other anchors, it estimates an average distance for one hop, which is subsequently flooded to the entire network. Anchor i estimates the average hop-size using the following formula:

$$\text{HopSize}_i = \frac{\sum_{i \neq j} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{i \neq j} h_{ij}} \quad (1)$$

Where (x_i , y_i), (x_j , y_j)are the coordinates of anchor i and anchor j, h_{ij} is the hops between anchor i and anchor j. Then, each anchor node broadcasts its hop-size to network by using controlled flooding. Unknown nodes receive the information of hop-size and preserve the first one. Simultaneously, they transmit the hop-size to their neighbor nodes. After all unknown nodes have received the hop-size from anchor nodes which have the least hops between them, they compute the distance to the anchor nodes based on two factors of hop-size and minimum hop count (labeled as h_{id}).The formula is as follows:

$$d_i = h_{id} \times \text{HopSize}_i \quad (2)$$

In the third step, unknown nodes calculate their position according to the distance to each anchor node which is obtained in the second step. The coordinates representation of anchor i are (x_i , y_i), and (x , y) are coordinates of unknown node, there is the following formula:

$$\begin{cases} (x-x_1)^2 + (y-y_1)^2 = d_1^2 \\ (x-x_2)^2 + (y-y_2)^2 = d_2^2 \\ \quad\cdot \\ \quad\cdot \\ \quad\cdot \\ (x-x_n)^2 + (y-y_n)^2 = d_n^2 \end{cases} \quad (3)$$

The formula (3) can be schemed with the following linear equation: $AX=B$, where

$$X = \begin{pmatrix} x \\ y \end{pmatrix}, \quad A = 2\begin{bmatrix} x_n - x_1 & y_n - y_1 \\ x_n - x_2 & y_n - y_2 \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ x_n - x_{n-1} & y_n - y_{n-1} \end{bmatrix}$$

$$B = \begin{bmatrix} d_1^2 - d_n^2 + x_n^2 - x_1^2 + y_n^2 - y_1^2 \\ d_2^2 - d_n^2 + x_n^2 - x_2^2 + y_n^2 - y_2^2 \\ \cdot \\ \cdot \\ \cdot \\ d_{n-1}^2 - d_n^2 + x_n^2 - x_{n-1}^2 + y_n^2 - y_{n-1}^2 \end{bmatrix}$$

The position of the unknown node is obtained by using least square method , which can be expressed as:

$$X = (A^{\mathrm{T}}A)^{-1}A^{\mathrm{T}}B \quad (4)$$

III. MODIFIED DV-HOP ALGORITHM

In this section, we take improvements over in its first and second steps, and have pointed out what cause location errors through analysis on traditional algorithm. The corresponding modified methods have also been given in detail.

A. Analysis and elimination of the distorted minimum hop counts

Unknown nodes collect the minimum hop counts to each anchor node in original algorithm. Then, the distances to all anchor nodes are obtained by using formula (2). For example,

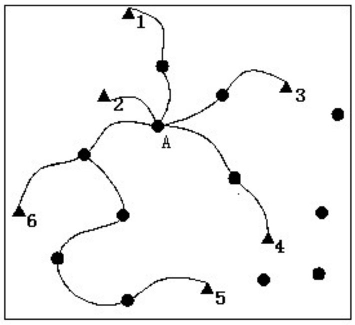

Figure.1 The minimum hop counts of unknown nodes to anchor node

as shown in Fig.1 which is a small part of random distribution networks, black triangle represents anchor node and black circular represents unknown node. The minimum hop counts of A to 1,2,3,4,5,6 are 2,1,2,2,5,2 respectively. According to the original algorithm, the distance between A and 5 is 2.5 times as long as that between A and 4, but in fact, the two distance values are very near. Thus, excessive hop counts lead to a big distance error between A and 5.If this minimum hop count between A and 5 is used for calculating hop-size and unknown node coordinate, the location error can be caused to some extent.

Due to anisotropic density nodes in random distribution networks, some minimum hop counts are distorted. An accumulated distance deviation can be caused because of themselves excessive hops. In order to eliminate the distorted hop counts, we put forward a measure of setting maximum hop count threshold value *F*. *F* can be obtained by using the following formula.

$$F = \lambda \sqrt{\frac{S}{Br^2}} \quad (5)$$

Where *S* is the area of the nodes distribution region, and *B* is the number of the anchor nodes. *r* is communication radius and λ is the connectivity factor.

If the minimum hop count of a node to another node is larger than F, it can be discarded. In the first step of DV-Hop algorithm, all nodes in the network get the minimal hop count to every anchor node. We can eliminate some distorted minimum hop counts by taking this measure, and it has not any influence on the location process of the original algorithm.

B. Modified hop count calculation method based on RSSI

In the first step of the original algorithm, every node collects minimum hop count to each anchor node. If two nodes can communicate directly, the hop count between them is regarded as one hop. However, the distances between every couple of nodes are different in general case.

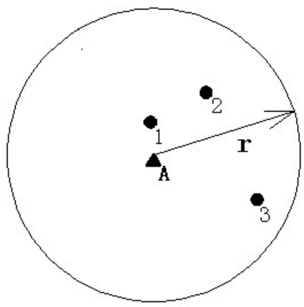

Figure.2 The neighbor nodes of the anchor node

In figure 2, the hop counts of anchor node A to unknown nodes 1, 2, 3 are all one hop. According to the original algorithm, the distances of A to 1, 2, 3 are all 1×hop-size. But in fact, they are quite different. So the distance of every one hop has deviation from actual value. An accumulated error is caused after completing multi-hops. Finally, the location error increases evidently for using inaccurate distances values to get unknown nodes coordinates.

Aiming to reduce the distance deviation of every hop, we establish a new hop count calculation method by introducing a model called traditional path loss model. This method can reflect the distance of each hop, thus an accumulated distance error can be reduced. The traditional path loss model [16] can be expressed as:

$$P = P_0 - 10\eta \lg(\frac{d}{d_0}) + X_\sigma \quad (6)$$

Where P is the received power at the distance *d* between two communication nodes, P_0 is the received power at the reference distance d_0, and the path loss exponent can be denoted by η. X_σ is a zero mean Gaussian distributed random variable with standard deviation σ,which is used to approximate the fading of environments.

The model reflects the relationship of the receiving node RSSI and the distance between two communication nodes. According to the relationship, the new hop count calculation method can be established. Here, we describe the computation steps of the method as follows：

Step 1.Assuming that the distance between a couple of adjacent nodes is $\frac{r}{2}$ (r is communication radius),the transmission power is constant, the received power of the receiving node is P_r .Then, the received power P at the distance *d* between two nodes is obtained as follows by using the formula(6):

$$P = P_r - 10\eta \lg(\frac{2d}{r}) + X_\sigma \quad (7)$$

Step 2.We define that there is a linear relationship between the hop count *h* and the distance *d* of two communication nodes. *K* is the proportional factor. So we can have the following formula:

$$\frac{h}{d} = k \quad (8)$$

Step 3.A definition can also be made that the hop count is 1, when the distance of two adjacent nodes is $\frac{r}{2}$. Thus, we can get the proportional factor *K* as follows using formula (8):

$$k = \frac{2}{r} \quad (9)$$

Step 4.According to (7), (8) and (9), the relationship between the hop count *h* and the received power P can be established.

$$h = 10^{\frac{P_r + X_\sigma - P}{10\eta}} \quad (10)$$

We can get the hop count *h* between any couple of adjacent nodes with the formula (10), because P of every receiving node is known. In the original algorithm, the receiving node broadcasts the beacon with 1 hop increased. As the improved algorithm, the receiving node broadcasts the beacon with h hop increased. For every transmission of the beacon, corresponding hop count h is calculated and added into hop field. At last, the minimum hop count is obtained by using this new hop count calculation method .And any other original process of traditional DV-Hop is not changed.

IV. SIMULATION AND PERFORMANCE ANALYSIS

In this section, we used OPNET Modeler 11.5 to model our protocol .We mainly created data packet model，anchor node model, unknown node model and network topology model. The antenna module is isotropic. The attribute "process model" of packet generating model is "simple-source". The transmitting power of all anchor nodes is the same.

The objective of the simulation is to compare our improved algorithm with the original DV-Hop algorithm and IDV in [17]. The experiment region is a square area with the fixed size of $100\times100\ m^2$ and the communication range (r) is 15m.We deploy 35 sensor nodes randomly in a two-dimensional space, and the number of anchor nodes is 10.The nodes distribution is as shown in figure 3.

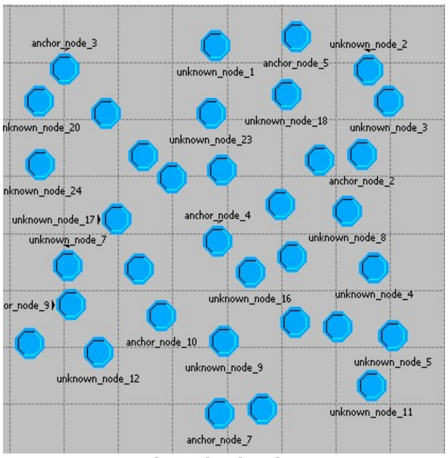

Figure.3 The nodes distribution

The simulation results have been analyzed. Fig.4 compares the performance of the modified algorithm and the original algorithm. It reflects that the location errors of 17 unknown nodes decrease significantly. Table 1 shows statistical data results, from which, we can find that compared to the original algorithm, the modified algorithm can get more positioning accuracy. The precision values enhanced of the improved algorithm are also showed in table 1 compared to DV-Hop algorithm.

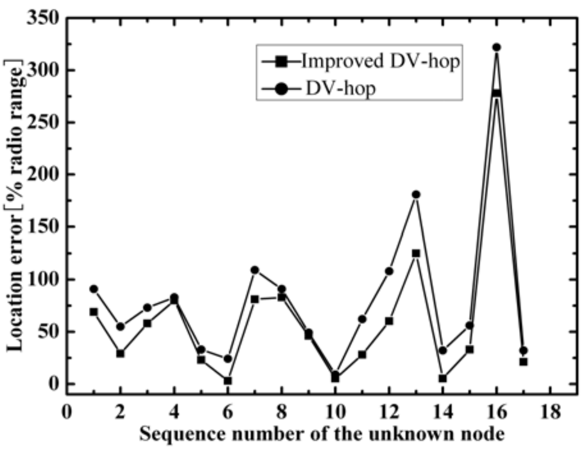

Figure.4 The localization error

TABLE I. THE PRECISION ENHANCED OF THE IMPROVED ALGORITHM

Node ID	DV-Hop algorithm	Improved algorithm	Precision enhanced
1	61.2 , 20.1	56.4 , 23.3	23.5%
2	84.3 , 20.1	80.3 , 22.8	47.1%
4	87.9 , 57.7	85.6 , 57.5	19.4%
5	69.4 , 63	71.7 , 60.3	3.4%
6	57.8 , 64.8	60.6 , 63.1	30.1%
8	75.5 , 47.7	72.3 , 46.8	88.4%
10	44.6 , 92.4	47.2 , 89	25.6%
11	90.4 , 76.6	89.1 , 75.7	9%
16	57.8 , 63.5	60 , 61.4	2.7%
17	40.3 , 46.7	30.6 , 48	18.7%
18	69.6 , 29.6	64.5 , 28.4	54%
19	56 , 25.5	61.1 , 30.6	44.3%
20	−6.3 , 10.7	5 , 11.5	30.9%
22	56 , 42.3	60 , 44.5	85.5%
23	55.6 , 28.6	51.7 , 31.4	40.3%
24	−16 , 1.6	−3.7 , 1.2	13.7%
25	39.7 , 35.7	37.6 , 38.3	33.7%

However, the location error of the rest 8 unknown nodes decrease less obviously. We perform an analysis of nodes distribution condition and information transfer path and get two reasons mainly. One is that these unknown nodes are distributed in edge region, thus the number of nodes for routing is so small that the connectivity (the number of adjacent nodes) of anchor nodes is insufficient.Fig.5 compares the performance of the modified algorithm and the original algorithm while the connectivity of anchor nodes is different. Form the curves in the figure, we find that compared to the original algorithm, the modified algorithm can derive more accurate positions when the connectivity is larger. The other one is that the communication transfer path is not the one which has the minimum hop count, as a result of the collision in MAC layer. It can cause big location errors. In this simulation, the location error of the 15th unknown node is larger than 71.2%r both in original algorithm and modified algorithm, because of the wrong minimum hop count.

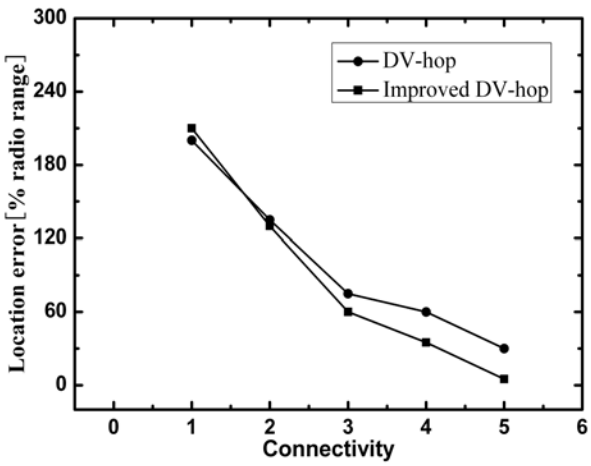

Figure.5 The relationship of connectivity and location error

Fig.6 compares the performance of the improved algorithm and the recent research works. It shows the better location accuracy than IDV in [17].

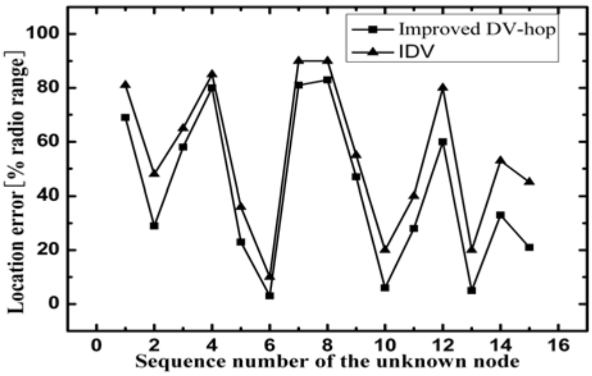

Figure.6 The localization error of IDV and DV-Hop

V. CONCLUSION

Because of the deficiency of the original algorithm, a modified algorithm is put forward. The improved algorithm is more robust to topology variation of the network, which can achieve more positioning accuracy compared with the DV-Hop algorithm. It can be objective and practical in the random deployment network, owing to its comprehensive utilization of the connectivity information and the energy information. But the location error increases in multi-obstacle area, to a certain degree, because RSSI measurements are susceptible to environment variations. For the limitations of the improved algorithm, one is that the number of the nodes can't be small, and the other one is that the location area can't have many obstacles. Based on the two limitations, simulation experiment indicates that the improved algorithm can be an optimum for the nodes localization in the random deployment network.

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