A New Type of Weighted DV-Hop Algorithm Based on Correction Factor in WSNs

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Abstract—In wireless sensor networks, the node localization algorithm is very important. In this paper, we have further studied the traditional DV-Hop algorithm and proposed a new type of weighted DV-Hop algorithm. Based on the selecting of referenced anchor nodes and the calculation method of the average hop distance, we propose a new type of localization algorithm called wDV-cf (weighted DV-Hop algorithm based on correction factor). Firstly, the unknown nodes record the average hop distance from all anchor nodes in one hop distance. Secondly, the percentage error is introduced as the correction factor to calculate the average hop distance for the unknown node. The simulation results show that, compared with the original DV-Hop, the wDV-cf algorithm has a remarkable improvement in the localization accuracy for the sensor nodes in WSNs.

Index Terms —DV-Hop, weighted, correction factor, WSNs

I. Introduction

Node localization algorithm in WSNs is one of the research hotspots in recent years. According to the changes in the network topology, node self-organized selects localization algorithm to locate. Technicians required obtaining critical data information by detecting the target node, and then they can analyze the environment condition of current node, which requires the target node feedback the position information to the technician [1]. Such as forest fires, sensor nodes can not only send out fire alarm signals, but also need to transmit the approximate position of the fire to monitors. So for the localization algorithm, the previous researchers and scholars have made a great contribution, given a variety of localization algorithms. When using or improving the algorithm, people also need to pay attention to the limitations of sensor nodes, such as the limitation of node energy[2], the random distribution of node and the fickle node environment. However, each localization algorithm has its own advantages and disadvantages, not only try to improve the localization accuracy, to reduce the time complexity and space complexity, at the same time to extend the service life of the sensor nodes and solve the energy saving problem and so on [3]. Therefore, how to maximize use of advantages and reduce disadvantages is the ultimate goal for studying the localization algorithms.

In wireless sensor networks, the localization algorithms of the sensor nodes are commonly divided into two categories range-based algorithm and range-free algorithm [4]. This classification is based on the hardware of sensor node whether need to estimate and measure the distance of neighbor nodes. Range-based algorithm has higher localization accuracy compared with the range-free algorithm, and it usually includes RSSI algorithm (based on the intensity of the arriving signal), AOA algorithm (Angle of Arrival), TDOA algorithm (Time Difference of Arrival), TOA algorithm (Time of Arrival) and so on. Although the range-based algorithm can get more accurate positioning results, and can use the hardware equipment to remove nodes which have a larger error, it has increased the capital requirements, and not suitable for application in low-cost projects. In this paper, we will focus on the DV-Hop algorithm, which belongs to the range-free algorithm [5].

In recent years, the researchers in the field of Node localization algorithm in wireless sensor networks have made a lot of improvements for DV-Hop localization algorithm. In [6], Wang *et al*. divided the measurement area to improve the accuracy and took advantage of the partial Hope-Size to estimate the distance instead of the global average hop distance which is employed by in standard DV-Hop algorithm and its variants. In [7], Yu *et al*. introduced threshold M and used the weighted average hop distances of anchor nodes within M hops to calculate the average hop distance of unknown nodes, by changing the method to calculate the average hop distance. In [8], Tomic introduced the weights to weight the average hop distance by changing the selection of criteria beacon nodes. Although the literature mentioned above considers the average hop distance in studying nodes' localization [9], they just focus on making a little change in computing the accuracy of average hop distance.

In this paper, we focus on the DV-Hop algorithm, and put forward a new type of weighted DV-Hop algorithm based on correction factor. First, we described the DV-Hop algorithm in detail; secondly, we propose an improved algorithm and describe the principles of the improved algorithm; finally, we design a multiple simulations to verify the effectiveness of the new algorithm in WSNs.

II. Related Work

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A. DV-Hop Algorithm

DV-Hop algorithm is one of the widely used localization algorithms in wireless sensor networks, which belongs to the range-free algorithm. The algorithm is one of the APS distributed localization, proposed by Dragos Niculescu in Rutgers University, based on the distance vector routing algorithm and GPS positioning ideas [10]. The main advantages of the DV-Hop algorithm are the low demand for hardware devices, convenient operation, high efficiency and low energy consumption. Therefore, it can be widely applied to practical applications. In DV-Hop algorithm, the sensor nodes do not need to configure additional hardware devices, and it improves the reliability of node localization by receiving a great deal of redundant information during transmission.

The main idea of DV-Hop algorithm is that unknown nodes record average hop distance form the first received anchor node as their average hop distance, and then calculate the length of path between unknown nodes and the anchor nodes by using the average hop distance and the minimum hop counts between the unknown nodes and anchor nodes. Finally, after getting three or more anchor nodes' location information, use trilateration method or maximum likelihood estimation method to calculate their coordinates.

Process of node localization in DV-hop algorithm is divided into the following three steps:

Step 1: Calculate the minimum hop count between the unknown node and each anchor node.

Anchor nodes in wireless sensor networks broadcast the group of its own location information to the neighbor nodes by flooding algorithm, and the group includes jump digital section which is initialized to 0. The receiving nodes record the minimum hop count to each anchor node, and add 1 to the hop count. The new hop information will be forwarded to the neighbor nodes.

Step 2: Calculate the estimated distance between the unknown nodes and the anchor nodes.

According to the position information and hop count recorded in the first stage, each anchor node computes the average hop distance by using the equation (1):

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

where $\mathrm{HopSize}_i$ is the average hop distance of anchor node i; (x_i, y_i) and (x_j, y_j) are the coordinates of the anchor nodes i and j; h_{ij} is the hop count between i and j.

Anchor nodes broadcast calculated average hop distance group with a lifetime field to the network. The unknown node only records the first received average hop distance, and forwards it to the neighbor nodes. After obtaining average hop distance, unknown nodes compute the distance to each anchor node according to the hop count obtained in the first stage.

Step 3: Calculate their own coordinates by using the trilateration method or maximum likelihood estimation method.

The unknown nodes use the trilateration method or maximum likelihood estimation method to calculate their own coordinates, according the distance to each anchor node recorded in Step 2.

The flow chart of the DV-Hop algorithm is shown in Fig. 1.

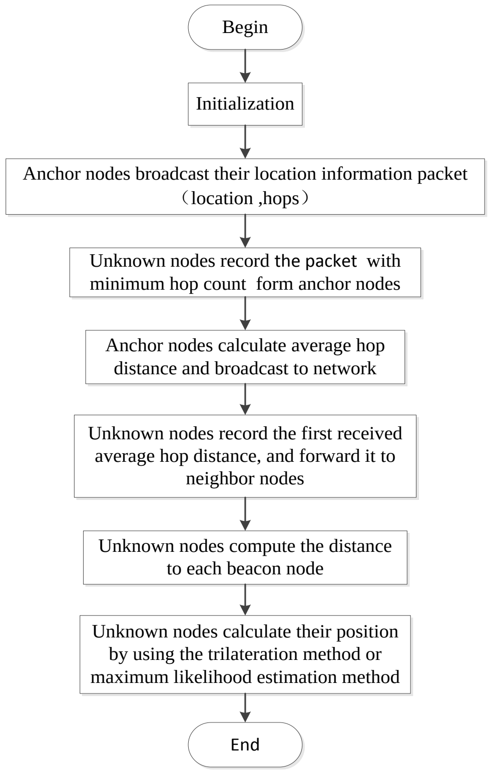

Fig.1. The flow chart of DV-Hop algorithm.

B. The Error Analysis of DV-Hop Algorithm

DV-Hop algorithm is very simple, and it has convenient operation, high efficiency and low energy consumption. It uses the average hop distance to calculate the actual distance, which has a low demand for hardware devices. The disadvantage is that using hop distance instead of straight line distance causes some errors. What's more, considering the factors such as network latency, the average hop distance in DV-Hop algorithm is difficult to guarantee that it is obtained from the nearest anchor node. Therefore, the localization accuracy in DV-Hop algorithm needs further improved.

III. THE WDV-CF ALGORITHM AND THE FLOW CHART OF WDV-CF ALGORITHM

A. Onehop-DV algorithm

Onehop-DV algorithm is a weighted sensor node localization algorithm based on DV-Hop algorithm. Onehop-DV algorithm also has three stages in the process of node localization. In the Step 2 of Onehop-DV algorithm, the unknown node records all $\mathrm{HopSize}_i$ from anchor nodes in one hop distance, and forwards it to the neighbor nodes. After obtaining all the average hop distance from the anchor nodes which are in one hop distance, unknown nodes take the average of all recorded average hop distance as their own average hop distance. The Step 1 and Step 2 in Onehop-DV algorithm are same with the corresponding stage in DV-Hop algorithm.

Onehop-DV algorithm just plays a connecting role. In the simulation experiments, we will use the algorithm again, so we do not do too much introduction here.

B. The wDV-cf Algorithm

By analyzing the steps in process of node localization in the DV-Hop algorithm, the main impact factors of error are in Step 2 and Step 3, and localization accuracy of average hop distance form unknown node in Step 2 is one of the main factors. In this paper, we make some improvements in the calculation of average hop distance in Step 2. The unknown node records all average hop distance from anchor nodes in one hop distance, and takes the average of all the recorded average hop distance as its own initial average hop distance. Then we take the reciprocal of percentage error form anchor node plus one as the correction factor for weighting the initial average hop distance, and the weighted result is the final average hop distance.

The main steps of wDV-cf algorithm are as follows:

1) As the Step 1 in DV-Hop algorithm, anchor nodes in wireless sensor networks broadcast the group of its own location information to the neighbor nodes by using the flooding algorithm, and the receiving nodes record the minimum hop count to each anchor node.
2) Calculate the initial average hop distance.

Anchor node compute the Hopsize_i by using the equation (1) in DV-Hop algorithm, and then broadcasts the calculated average hop distance group with a lifetime field to the network. The unknown node records all HopSize_i from anchor nodes in one hop distance, and forwards it to the neighbor nodes. After obtaining all the average hop distance from the anchor nodes which are in one hop distance, unknown nodes compute the distance to each anchor node. Each unknown node computes the initial average hop distance by using the equation (2).

$$\text{OHopSize}_i = \frac{\sum_{j\in \text{AOneHop}_i} \text{HopSize}_j}{\text{AN}_i} \tag{2}$$

Among them, OHopSize_i refers to the initial average hop distance; i refers to the unknown node; j refers to the anchor node; AOneHop_i refers to the collection of adjacent nodes of node i in one hop distance; AN_i refers to the number of elements in the collection AOneHop_i.

3) Calculate the percentage error of anchor nodes.

Multiplying the HopSize_i in Step 2 and minimum hop count between anchor nodes and unknown nodes in Step 1, the result is the estimated distance between anchor nodes. Then using the differences between the actual distance and estimated distance of the anchor nodes divided by the actual distance, the result is the localization error of anchor nodes(as shown in equation (3)).

$$\text{Errpercent}_j = \frac{\sum_{i\neq j} D_{ij} - HopSize_j \times h_{ij}}{N_j} \tag{3}$$

where i and j are the anchor nodes; D_{ij} is the actual distance between i and j; N_j denotes the number of anchor nodes adjacent to node j; Errpercent_j is the localization error of node j.

This step can guarantee the unknown nodes receive the HopSize_i from the nearest anchor node, which reduces the error of average hop distance and improves the localization accuracy.

4) Calculate the final average hop distance.

For each unknown node, uses all average hop distance from anchor nodes in one hop distance recorded in Step 2 and localization error of anchor nodes in Step 3 to calculate the final average hop distance by using the equation (4) and equation (5).

$$\lambda_j = \frac{1}{1+\text{Errpercent}_j} \tag{4}$$

$$\text{reHopSize}_i = \frac{\sum_{j\in \text{AOneHop}_i} \text{HopSize}_j \times \lambda_j}{\sum_{j\in \text{AOneHop}_i} \lambda_j} \tag{5}$$

where i is the unknown node and j is the anchor nodes; λ_j is the weighting factor; AOneHop_i represents the collection of adjacent nodes of node i in one hop distance; reOHopSize_i represents the weighted revised average hop distance of node i.

5) The unknown nodes calculate their own coordinates by using the trilateration method or maximum likelihood estimation method.

The unknown nodes use the trilateration method or maximum likelihood estimation method to calculate their own position, according the distance to each anchor node recorded in Step 4.

In DV-Hop algorithm, the unknown nodes record the first received average hop distance from anchor node as their average hop distance. Taking the environmental conditions into account, the first received average hop distance is not necessarily coming from the nearest anchor node. While, in wDV-cf algorithm, the unknown nodes take the average hop distance of anchor node in one hop distance as the reference information, which can ensure that it is from the nearest node. Moreover, introducing the percentage error as the correction factor to calculate the average hop distance for the unknown node, reduces the error of average hop distance and improves the localization accuracy in WSNs.

C. The Flow Chart of wDV-cf Algorithm

The flow chart of the wDV-cf algorithm is shown in Fig. 2.

IV. SIMULATION AND ANALYSIS

A. The Configuration of Experimental Environment Configuration

The algorithm is simulated by the software of MATLAB R2010a. MATLAB R2010a runs on the Windows XP SP3 system with Intel Core 2 Duo CPI and a 2GB of memory. The experimental detection region size is 100 m×100 m. The number of sensor nodes, proportion of anchor modes and the communication radius are determined according to the actual situation of the experiment. In order to verify the accuracy of the simulation, the simulation runs repeatedly 100 rounds. One of nodes distribution is shown in Figure 3. In 100 m ×100 m square area, 150 nodes are randomly scattered. 150 scattered randomly through nodes, of which there are 30 anchor nodes, and the communication radius is 30. With the changes in experimental conditions, the experimental parameters will change accordingly. In Fig. 3, the red stars on behalf of anchor nodes and the black circles represent the unknown nodes.

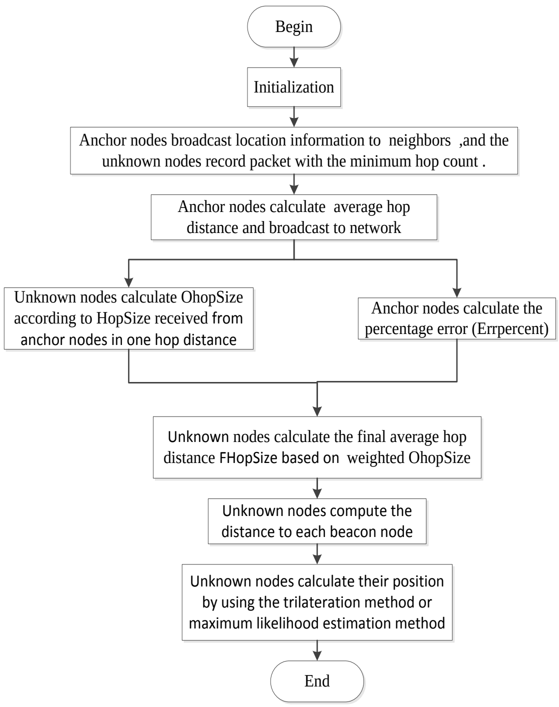

Fig. 2.The flow chart of wDV-cf algorithm

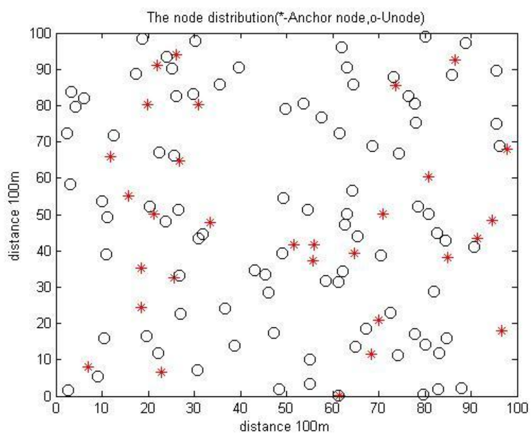

Fig. 3.The distribution of sensor nodes

B. Compared with other Algorithms

In this section, we will compare the localization error of DV-Hop algorithm, Onehop-DV algorithm and twDV-cf algorithm. We conducted the contrast experiment in three different conditions. Firstly, in a fixed area with the same proportion of anchor nodes, the proportion of sensor nodes is a variable; Secondly, in a fixed area with the same number of sensor nodes, the communication radius is a variable; finally, in a fixed area with the same communication radius, the density of anchor nodes is a variable.

1) DV-Hop algorithm and Onehop-DV algorithm

The localization error of both DV-Hop algorithm and Onehop-DV algorithm is compared in conditions of different density of sensor nodes as follows. In the simulation area of 100 m×100 m, the communication radius is 40 and the proportion of anchor nodes is 20%. The scope of network node density is 0.5, 1, 1.5, 2, 2.5, 3, 3.5 and 4. The experimental results are shown in Fig. 4 (a).

The localization error of both DV-Hop algorithm and Onehop-DV algorithm is compared in conditions of different communication radius as follows. In the simulation area of 100 m×100 m, the number of sensor nodes is 100 and the proportion of anchor nodes is 20%. The scope of communication radius is 20, 25, 30, 35, 40, 45 and 50. The experimental results are shown in Fig. 4 (b).

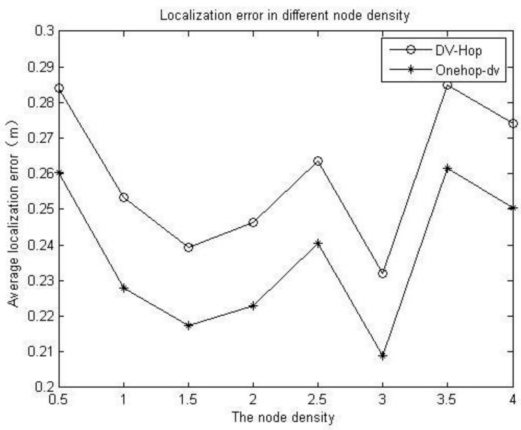

Fig. 4. (a) Localization error with different density of sensor nodes

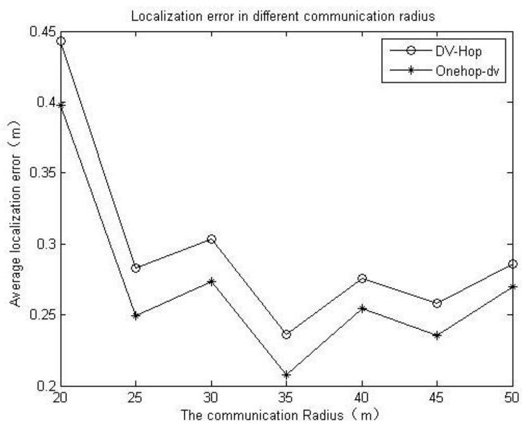

Fig. 4. (b) Localization error with different communication radius.

The localization error of both DV-Hop algorithm and Onehop-DV algorithm is compared in conditions of different proportion of anchor nodes as follows. In the simulation area of 100 m×100 m, the number of sensor nodes is 200 and the communication radius is 30. The scope of proportion of anchor nodes is 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35 and 0.4. The experimental results are shown in Fig. 4 (c).

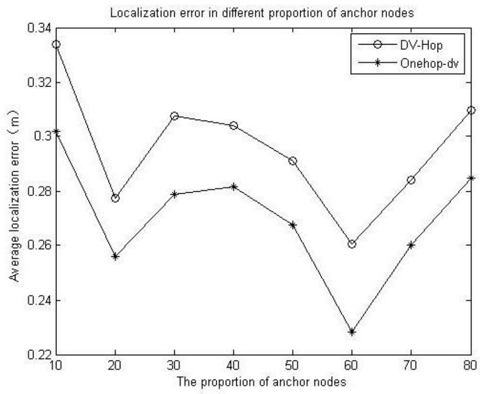

Fig. 4.(c) Localization error with different proportion of anchor nodes

Comparison chart of localization error for DV-Hop algorithm and Onehop-DV algorithm is shown in Fig. 4. Among them, the abscissa represents the vibrational parameters, and the vertical axis indicates the localization error. As can be seen from Fig. 4, Onehop-DV algorithm is superior to the DV-Hop algorithm.

The theoretical analysis has proved that, obtaining the average hop distance from anchor nodes in one hop distance in Onehop-DV algorithm have ensured that unknown node can receive the average hop distance from the nearest anchor node. In Onehop-DV algorithm, the unknown nodes have chosen a more appropriate reference node and thus improving the localization accuracy.

2) Onehop-DV algorithm and wDV-cf algorithm

The localization error of both Onehop-DV algorithm and wDV-cf algorithm is compared in conditions of different density of sensor nodes as follows. In the simulation area of 100 m×100 m, the communication radius is 40 and the proportion of anchor nodes is 20%. The scope of network node density is 0.5, 1, 1.5, 2, 2.5, 3, 3.5 and 4. The experimental results are shown in Fig. 5 (a).

The localization error of both Onehop-DV algorithm and wDV-cf algorithm is compared in conditions of different communication radius as follows. In the simulation area of 100 m×100 m, the number of sensor nodes is 100 and the proportion of anchor nodes is 20%. The scope of communication radius is 20, 25, 30, 35, 40, 45 and 50. The experimental results are shown in Fig. 5 (b).

The localization error of both Onehop-DV algorithm and wDV-cf algorithm is compared in conditions of different proportion of anchor nodes as follows. In the simulation area of 100 m×100 m, the number of sensor nodes is 200 and the communication radius is 30. The scope of proportion of anchor nodes is 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35 and 0.4. The experimental results are shown in Fig. 5 (c).

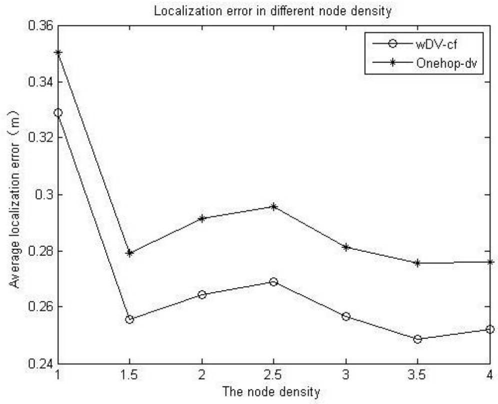

Fig. 5. (a) Localization error with different density of sensor nodes

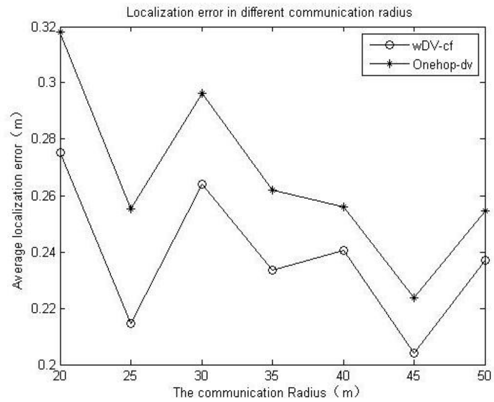

Fig. 5. (b) Localization error with different communication radius.

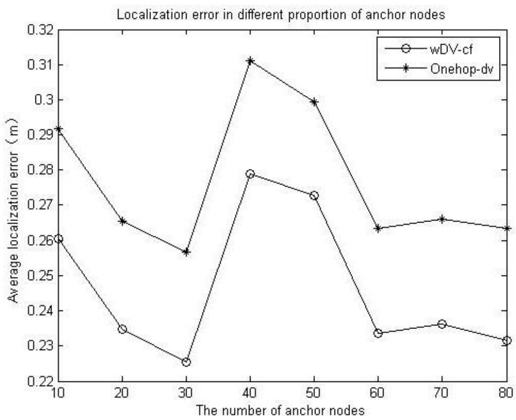

Fig. 5. (c) Localization error with different proportion of anchor nodes

Comparison chart of localization error of Onehop-DV algorithm and wDV-cf algorithm is shown in Fig. 5. Among them, the abscissa represents the vibrational parameters, and the vertical axis indicates the localization error. As can be seen from Fig.5, wDV-cf algorithm has a low localization error than Onehop-DV algorithm, so wDV-cf algorithm is superior to the Onehop-DV algorithm.

The theoretical analysis has proved that, based on the Onehop-DV algorithm, wDV-cf algorithm introduces the percentage error as the correction factor to calculate the average hop distance from the unknown node, which reduces the error of average hop distance and improves the localization accuracy in WSN.

3) Comparison of three algorithms

The localization error of DV-Hop, Onehop-DV and wDV-cf algorithm is compared in the same conditions as follows. In the simulation area of 100 m×100 m, the number of sensor node is 120, and the communication radius is 30 and the number of anchor nodes is 30. The experimental results are shown in Fig. 6.

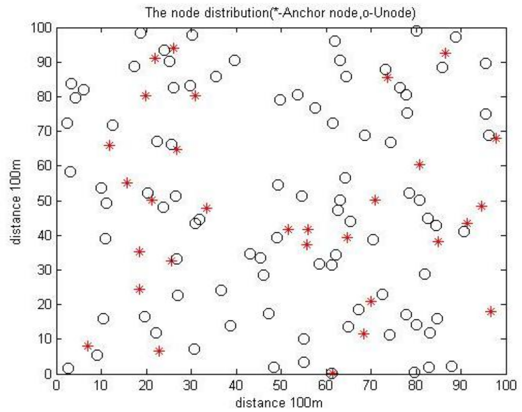

Fig. 6(a) Distribution of nodes

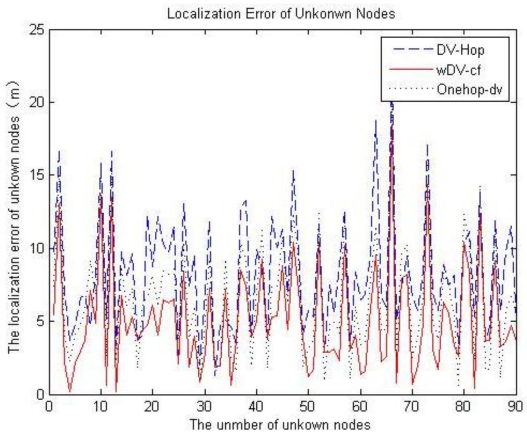

Fig. 6(b) Comparison chart of localization error for three algorithms

As can be seen from Fig. 6, wDV-cf algorithm is superior to the Onehop-DV algorithm, and DV-Hop algorithm has the maximum localization error obviously. In theory, Onehop-DV algorithm guarantees unknown nodes can receive the average hop distance from the nearest anchor node by changing the selecting of referenced anchor nodes; the wDV-cf algorithm takes the percentage error as the correction factor to weighting the average hop distance obtained in Onehop-DV algorithm, which reduces the localization error and improve the positioning accuracy of sensor nodes in WSNs. In summary, the simulation results show that, among the above three algorithms, the wDV-cf algorithm is more superior to the others.

V. Conclusion

In this paper, we have further studied the traditional DV-Hop algorithm. In the step of computing the average hop distance of the unknown nodes, we made some improvements based on the selecting of referenced anchor nodes and the calculation method of the average hop distance from the unknown node; we have proposed a new type of weighted DV-Hop algorithm based on correction factor (wDV-cf) in WSNs. Simulation results show that, compared with the original DV-Hop and the Onehop-DV algorithm, the wDV-cf algorithm has improved the positioning accuracy of the sensor nodes significantly. However, the wDV-cf algorithm still has some deficiencies, such as the positioning problem of isolated nodes, communication overhead, etc. Therefore, about the issue of node localization in WSNs, we will do further research.

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