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An Improved DV-Hop Localization Algorithm Based on Bat Algorithm

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Abstract: *In the DV-Hop algorithm, the average distance per hop is one of the factors that affect the accuracy of the positioning. In this paper, an improved DV-Hop localization algorithm based on bat algorithm (BAD-Hop) is proposed to solve the error which is brought by the average distance per hop. In BAD-Hop algorithm, bat algorithm which is a kind of intelligent optimization algorithm with good performance is introduced into DV-Hop localization algorithm to calculate average distance per hop of anchor nodes. Firstly, the average distance per hop of anchor node is calculated by using bat algorithm, which makes it closer to the actual value. Then the average distance per hop of the unknown node is weighted by using the average distance per hop of anchor nodes which hop-count is less than or equal to 3 to reduce errors caused by average distance per hop. Simulation results show that the improved algorithm can effectively reduce the positioning error without additional hardware.*

Keywords: *Wireless sensor networks, DV-Hop algorithm, node localization, bat algorithm, average distance per hop.*

1. Introduction

Node localization is the precondition and foundation of the application of Wireless Sensor Networks (WSNs) [1]. At present, there are two types of WSNs location algorithm: range-based localization algorithm and range-free localization algorithm [2]. The former algorithms have the characteristics of high cost and power consumption. The latter algorithms have the characteristics of no additional hardware, low cost and low power consumption, so they have been widely used in WSNs [3-5]. DV-Hop algorithm is one of range-free localization algorithm which is widely used in node localization in WSNs, but it has low accuracy, so many scholars have improved the DV-Hop algorithm based on intelligence algorithm, such as particle swarm optimization algorithm [6], genetic algorithm [7], artificial bee colony algorithm [8] and shuffled frog leaping algorithm [9] and so on, in order to improve the localization accuracy.

The Bat Algorithm (BA) is a new swarm intelligence algorithm, which is based on the simulation of bat echo location. Compared with other algorithms, it has a great advantage in the iterative optimization and the parameters in need of adjustment are few [10]. Therefore, combining the main principles of the bat algorithm with an improved DV-Hop localization algorithm (BAD-Hop) is proposed to solve the error which is brought about by the average distance per hop in DV-Hop. Firstly, this algorithm optimizes and improves the average distance per hop of the anchor nodes by using the bat algorithm. Then, the average distance per hop of the unknown node is weighted by the average distance per hop of the anchor nodes within 3 hops. The accuracy of the algorithm is improved by improving the accuracy of the average distance per hop of the unknown node. The simulation results show that the algorithm has good performance.

2. DV-Hop algorithm and BA

2.1. DV-Hop algorithm

DV-Hop algorithm, proposed by N i c u l e s c u et al. [11] (see also [12]), estimates the distance between beacon nodes and unknown nodes by multiplying the hop count by average distance per hop, and then uses the three edge measurement method to estimate the coordinates of unknown nodes. The positioning process is as follows:

Step 1. The anchor node broadcasts a packet {id_i, x_i, y_i, hop} containing node ID, node location and hop-count to neighbor nodes. The neighbor nodes record the identification number of each node, the coordinate values and the smaller hop values. The packet is forwarded after hop values plus 1. In this way, all nodes obtain the minimum number of hops to other nodes.

Step 2. The average distance per hop of each anchor node is calculated by

$$\text{hopsize}_i = \sum_{j\neq i}\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \Big/ \sum_{j\neq i}\text{hops}_j, \tag{1}$$

where (x_i, y_i), (x_j, y_j), hops_j, are position of beacon node (i, j) and the minimum number of hops between the two nodes, respectively. The unknown node estimates distances to anchor nodes by using the minimum hops (hops) times the average distance per hop (hopsize) of the nearest anchor node.

Step 3. Unknown nodes use distances of three or more anchor nodes to estimate their coordinates.

2.2. BA

BA is a kind of swarm intelligence optimization algorithm, proposed by Xin She Yang, which is inspired by the echo location behavior of micro bats correlation with objective function optimization. According to the effect of the optimization, the feature of the bat algorithm is more powerful than that of the genetic algorithm and particle swarm algorithm [13, 14].

The idea of bat algorithm is that bat individual is taken as the smart search body in the solution space of optimization problem. Objective function of the optimization problem is used to measure position pros and cons of the bat individual. The search target and flight of the bat are analogy to the good feasible solution replaces the poor feasible solution in the iterative process. At time t, the velocity v and position x of the i-th bat can be expressed as

(2) $$v_i^t = v_i^{t-1} + (x_i^{t-1} - x^{\text{best}}) f_i,$$

(3) $$x_i^t = x_i^{t-1} + v_i^t,$$

v_i^t, v_i^{t-1} are the flying speed of bat i at the time t and $t-1$, respectively; x_i^t is space position of bat i at the t time; x^{best} is the location of the best bat in the current group; f_i is pulse frequency when searching for prey of bat i; $f_i \in [f_{\min}, f_{\max}]$ is range of search pulse frequency.

According to the biological mechanism of the bat, in the process of searching for prey, the ultrasonic pulse emitted by bats at the initial stage is strong and the frequency is low, which is helpful in a search in a wider space. When they discover the prey, the pulse intensity decreases gradually while the number of pulse emission increases, in order to grasp the precise spatial location of prey. The intensity and frequency of the pulse emitted by bats can be expressed as

(4) $$A_i^{t+1} = \mu A_i^t,$$

(5) $$R_i^{t+1} = R_i^0 \times [1 - \exp(\gamma t)],$$

where, A_i^t is the pulse emission intensity of bat i at the time t; R_i^{t+1} is the pulse occurrence rate of bat i at the time $t+1$; R_i^0 is maximum pulse frequency of bat; μ is pulse amplitude attenuation coefficient, which is a constant of [0, 1]; γ is pulse frequency increasing coefficient, which is constant and is greater than zero, used as a pulse frequency increasing coefficient.

3. BADV-Hop algorithm

3.1. Improvement of average distance per hop

The location accuracy of the DV-Hop algorithm depends mainly on the accuracy of the average distance per hop in the location process. According to the node position information recorded by nodes, the anchor node uses the next equation to calculate the actual distance between the anchor node i and the anchor node j:

(6) $$d_{\text{t}ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}..$$

The estimated distance between the anchor node i and the anchor node j is equal to the minimum number of hops obtained by Step 1 times the average distance per hop obtained by using (1). That is $d_{\text{e}ij} = \text{hops}_{ij} \times \text{hopsize}_i$; $\varepsilon = |d_{\text{t}ij} - d_{\text{e}ij}|$ is the error caused by $d_{\text{e}ij}$. The reasonable hopsize_i should make ε minimum, therefore, calculating hopsize_i becomes solving minimum value problem. In order to improve the accuracy of the average distance per hop, the bat algorithm is introduced to calculate it in this paper.

The mathematical model is

$$(7)\qquad \begin{cases} \min \varepsilon = \sum_{i \neq j} (d_{ij} - \text{hopsize}_i \times \text{hop}_{ij})^2, \\ \text{s.t.} \quad 0 \leq \text{hopsize}_i \leq \max(d_{ij}). \end{cases}$$

In BADV-Hop, the optimization objective is to find the minimum value of the function, it takes non negative and the fitness of the individual is taken as the objective function value. The fitness function of bat algorithm is shown in the next equation, which is used to solve the average distance per hop (hopsize_i) of the anchor nodes:

$$(8)\qquad f(\text{hopsize}_i) = \sum_{i \neq j} (d_{ij} - \text{hopsize} \times \text{hop}_{ij})^2;$$

$$\text{hopsize}_i \in [0, \max(d_{ij})].$$

Based on the above analysis, steps of using bat algorithm for solving the average distance per hop are eight.

Step 1. Randomly initial population in solution space[0, $\max(d_{ij})$]. Set the following parameters: population size$Q$, the maximum pulse amplitude A^0, the maximum pulse frequency R^0, pulse frequency range[$f_{\min}$, $f_{\max}$], amplitude attenuation coefficient μ, the increasing frequency of intensity coefficient γ, the maximum number of iterations MaxIte.

Step 2. Randomly generates each bat's position x_i, $i = 1, 2, \ldots, Q$. The bat with the best position is calculated by (8).

Step 3. Initial search pulse frequency f_i.

Step 4. The velocity of the bat is calculated by (2) and the position of the bat is updated by the (3).

Step 5. If the updated position of the bat is better than that of the best bat in population, the intensity and frequency of the pulse is updated by using (4) and (5).

Step 6. Find out the value of fitness function and position of the best bat.

Step 7. Repeat Step 3-Step 5 until the specified number of iterations is reached.

Step 8. Output optimal solution to variable hopsize_i.

3.2. Weighted the average distance per hop of unknown nodes

The average distance per hop of a single anchor node cannot reflect the real property of the whole network. Based on this, the BADV-Hop algorithm uses the average distance per hop of multiple anchor nodes instead of a single anchor node when calculating the average distance per hop of the unknown nodes. The positioning error increases with increasing the minimum hop-count and effects of different hops on BADV-Hop algorithm are shown in Fig. 1.

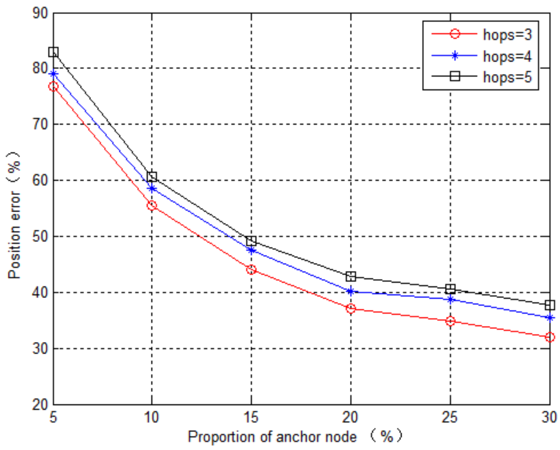

Fig. 1. Effect of hop number on the positioning error

As can be seen from Fig. 1, when the number of hops is 3, the BADV-Hop algorithm has the least error, so the average distance per hop of the anchor nodes within 3 hops is used to weight the average distance per hop of unknown nodes. Specific steps are five as follows.

Step 1. After calculating the optimal hopsize_i, the anchor nodes broadcast packets $\{\text{id}_i, \text{hopsize}_i\}$ in the network;

Step 2. Comparing id and hop recorded in the table, unknown nodes only record hopsize_i of the anchor nodes with less than or equal to 3 hops;

Step 3. After broadcasting, the unknown nodes receive all hopsize_i of the anchor nodes with less than or equal to 3 hops.

Step 4. To calculate the weight of each anchor node unknown nodes use

$$w_i = \frac{\frac{1}{\text{hop}_i}}{\sum_{i=1}^{N} \frac{1}{\text{hop}_i}}, \tag{9}$$

where N is the number of anchor nodes with less than or equal to 3 hops; hop_i is the minimum hops between the anchor node i and the unknown node.

Step 5. The average distance per hop of the unknown node is

$$\text{avg\_hopsize} = \sum_{i=1}^{N} \text{hopsize}_i w_i. \tag{10}$$

4. Simulation experiment

4.1. Simulation environment

In order to test the performance of the improved algorithm proposed in this paper, MATLBA is used to simulate DV-Hop and BADV-Hop. Simulation environment settings are as follows: Anchor nodes and unknown nodes are randomly distributed in the area: [0, 200]×[0, 200] in the network, coordinates of the anchor nodes and unknown nodes are randomly generated, communication radius of nodes are R = 40 m, population size Q = 100, the maximum pulse amplitude A^0 = 0.25, the maximum pulse frequency R^0 = 0.75, pulse frequency range is [–1, 1], amplitude attenuation coefficient μ = 0.95, the increasing frequency of intensity coefficient γ = 0.05 and the maximum number of iterations MaxIte = 50. In the same network environment, experiments are carried out 100 times to take the average values. Algorithm accuracy is an important performance index to measure the positioning algorithm. This paper uses the average positioning error to compare the performance of the two algorithms, which is defined as

(11) $$\mathrm{Aerr} = \frac{\sum(d_i)}{\mathrm{NR}} \times 100\%,$$

where d_i is positioning error of node i, $d_i = \sqrt{(x_t - x_e)^2 + (y_t - y_e)^2}$; (x_t, y_t), (x_e, y_e) are the true position and the estimated position of the node, respectively; R is communication radius of nodes and N is the number of unknown nodes.

4.2. Result analysis

4.2.1. Comparison of position errors of unknown nodes

Positioning errors of the unknown nodes of DV-Hop algorithm and BADV-Hop algorithm are as shown in Fig. 2 and Fig. 3, respectively. Fig. 2 and Fig. 3 show that the positioning error of BADV-Hop algorithm is quite smooth, but the positioning error of DV-Hop algorithm is very sharp and the positioning error is relatively large. The comparison results show that positioning results can be improved as the DV-Hop algorithm is optimized by BA.

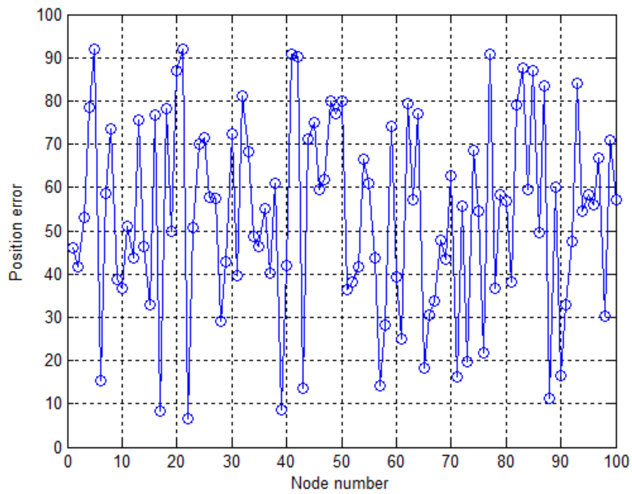

Fig. 2. Positioning errors of DV-Hop

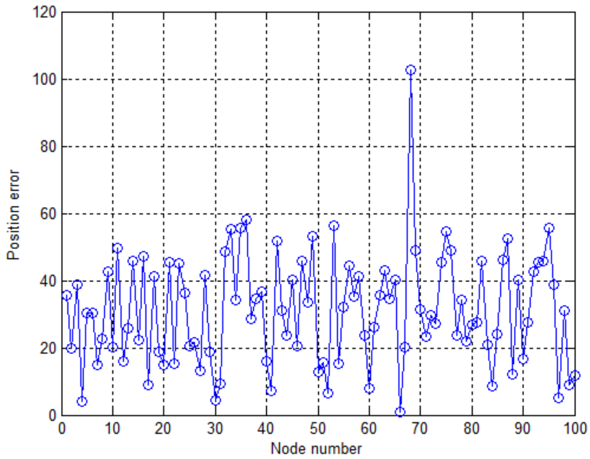

Fig. 3. Positioning errors of BADV-Hop

4.2.2. The relationship between the proportion of anchor nodes and the position accuracy

In the network area, 200 nodes are randomly distributed. The total number of nodes is constant and the proportion of anchor nodes is gradually increased from 40% to 5%. The positioning errors of the two algorithms are compared. The simulation results are shown in Fig. 4. It can be seen from Fig. 4 that the average positioning errors of the two algorithms are gradually reduced and tend to be stable with the increase of the proportion of beacon nodes. When the proportion of beacon nodes is same, the average accuracy of the BACVDV-Hop algorithm is higher than that of the traditional DV-Hop algorithm as the average distance per hop of anchor nodes are optimized and the average distance per hop of unknown nodes is weighted, which make the average distance per hop are more close to the actual value. The positioning accuracy of the BADV-Hop algorithm is improved by 30% compared with that of the DV-Hop algorithm.

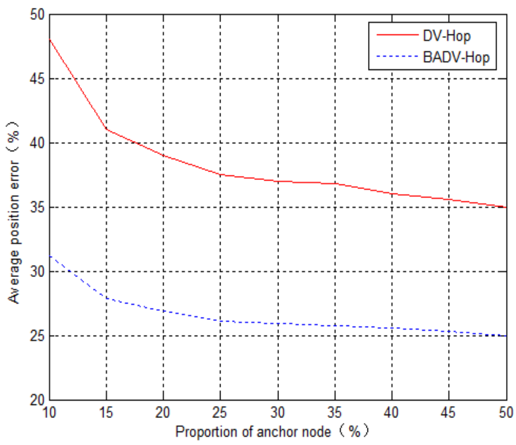

Fig. 4. Comparison of the performance of different proportion of anchor nodes

4.2.3. Relationship between node number and location accuracy

In the network area, 200 nodes are randomly distributed; the proportion of anchor nodes is 10% and remains unchanged. The performance of the two algorithms is compared by changing the number of nodes. The simulation results are shown in Fig. 5. It can be seen from Fig. 5 that the average positioning error of the two algorithms are all decreased with the number of nodes increasing, but average positioning error of the BADV-Hop is much faster than that of the traditional DV-Hop algorithm. When the total number of nodes is 300, the error tends to be stable and the change is not large. Overall, the accuracy of BADV-Hop algorithm is better than that of the traditional DV-Hop algorithm, which is improved by about 20%.

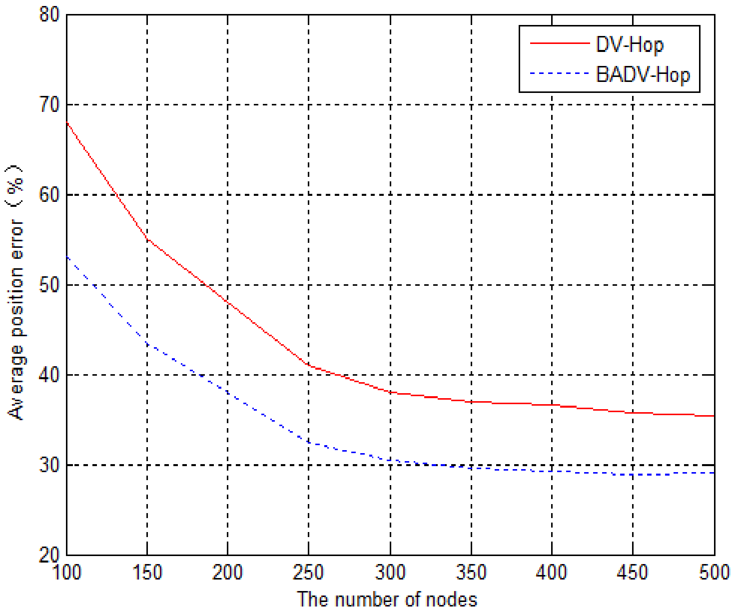

Fig. 5. Comparison of the performance of different nodes

4.2.4. Relationship between communication radius and location accuracy

When other conditions remain the same and communication radius is changed, the performance of the BADV-Hop algorithm and the traditional DV-Hop algorithm are compared. Simulation results are shown in Fig. 6. It can be seen from Fig. 6 that the probability of mutual communication between the nodes increases with the increase in the communication radius, so the average positioning error of the two algorithms reduces. Reduced amplitude of the BADV-Hop algorithm is more than that of the DV-HOP algorithm. On the whole, the positioning accuracy of BADV-Hop algorithm is improved by 25% compared with that of DV-Hop algorithm.

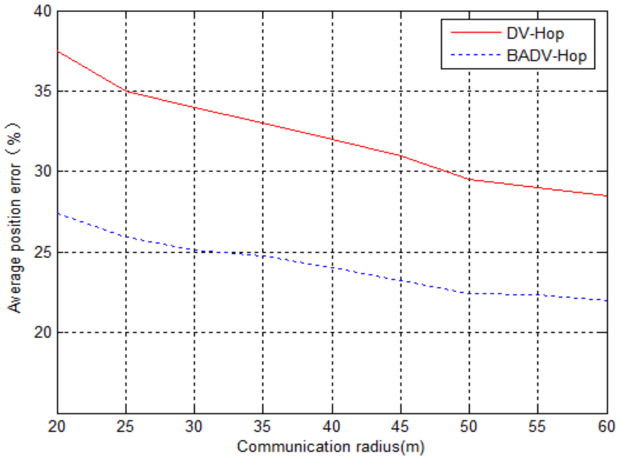

Fig. 6. Comparison of the performance of different communication radius

5. Conclusion

To solve the problem of positioning errors caused by the average distance per hop in DV-Hop algorithm, the bat algorithm with global optimization performance is used to optimize the average distance per hop and an improved DV-Hop localization algorithm based on bat algorithm (BADV-Hop) is proposed. The position of the bat in the two dimensional space is considered as the average distance per hop of nodes. The value of the fitness function is calculated according to the position of the bat and the value is used to update parameters such as position, velocity, pulse intensity, frequency and so on. The optimal average distance per hop of the nodes is obtained by multiple iterations. In the end, the average distance per hop of the unknown node is weighted and the nodes which are unfavorable for positioning are removed. The simulation results show that the accuracy of the average distance per hop of each anchor node is improved without increasing the hardware cost, so the accuracy of the BA DV-Hop algorithm is improved.

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