An Improved Three-dimensional DV-Hop Localization Algorithm Optimized by Adaptive Cuckoo Search Algorithm

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Abstract—Aiming at the low accuracy of DV-Hop localization algorithm in three-dimensional localization of wireless sensor network, a DV-Hop localization algorithm optimized by adaptive cuckoo search algorithm was proposed in this paper. Firstly, an improved DV-Hop algorithm was proposed, which can reduce the localization error of DV-Hop algorithm by controlling the network topology and improving the method for calculating average hop distance. Meanwhile, aiming at the slow convergence in traditional cuckoo search algorithm, the adaptive strategy was improved for the step search strategy and the bird's nest recycling strategy. And the adaptive cuckoo search algorithm was introduced to the process of node localization to optimize the unknown node position estimation. The experiment results show that compared with the improved DV-Hop algorithm and the traditional DV-Hop algorithm, the DV-Hop algorithm optimized by adaptive cuckoo search algorithm improved the localization accuracy and reduced the localization errors.

Key Words—WSN, three-dimensional localization, DV-Hop algorithm, adaptive cuckoo search algorithm

1 Introduction

Wireless sensor network as a monitoring network composed by a large number of sensor nodes which are randomly deployed in task area through self-composition. With the advantages of the real-time monitor, self-organization and easy deployment, WSN is widely used in many fields[1]. In the field of target tracking, smart transportation, environmental monitoring and precision agriculture, node position information is particularly important. Without the position information, the data acquired by sensor nodes will be pointless[2]. Nowadays, the research on WSN localization is mostly based on two-dimensional space. However, with the improvement of the practical application requirements, nodes are often distributed in complex three-dimensional(3D) space. Traditional two-dimensional localization algorithm is difficult to meet the application requirements. Hence, 3D localization with high accuracy and high fault tolerance has more applied value.

The WSN localization algorithm is usually divided into range-based localization algorithm and range-free localization algorithm. The range-based localization algorithm calculates node distance or angles through the use of external device during the localization process. Then the unknown node is located through the information of distances or angles. The range-based localization algorithm includes RSSI, TOA, AOA, TDOA algorithm, etc[3]. The range-free localization algorithm locates the position of unknown nodes according to the network topology and the position of anchor nodes, totally without the use of external device in the localization process, including centroid, DV-Hop, APIT algorithm, etc[4]. Due to the characteristics of low energy consumption and low cost, the range-free localization algorithm has become the focus of the WSN localization algorithm.

DV-hop algorithm is a range-free localization algorithm, which is widely used in two-dimensional environment[5-6]. Xinsheng Wang proposed an improved DV-Hop algorithm, different from the traditional DV-hop algorithm, the average distance of each node is calculated by using differential calculation algorithm[7]. Fully consider the effect of dynamic topology and anchor nodes difference, an intelligent algorithm for nodes localization based on processing strategy of optimal hopping distances was proposed by Mudong Li [8]. Recently, scholars have extended the DV-Hop localization algorithm to the 3D environment. Lin Li proposed a weighted 3D DV-Hop localization algorithm[9]. In the process of calculating the average hop distance between beacon nodes, a weighted average hop distance is constructed to reduce localization errors according to contribution degree of beacon nodes with different distances. Rui-Jin Wang [10] presented a new 3D localization algorithm, which can significantly improve the performance on localization errors and coverage by using self-tune selection of projection plane and exploiting partial average hop size instead of global average hop size.

Generally, DV-Hop algorithm using least squares method to estimate the unknown node coordinate. Although this method can reduce the localization errors to a certain extent, solving speed of the least square method is slow, and the method is easy to be affected by the distance measurement errors, which will affect the accuracy of localization. Hence, scholars considered introducing swarm intelligence optimization algorithm into improving this. Bo Peng proposed an improved DV-Hop algorithm based on genetic algorithm[11]. After establishing a mathematical optimization model by using the distance between the unknown node and anchor nodes, genetic algorithm was used to solve the optimization model. Xiao Chen proposed a 3D DV-hop algorithm based on particle swarm optimization(PSO) algorithm[12]. After performing the

3D DV-hop algorithm, the PSO algorithm with the inertia weight was used to emend unknown nodes' position. Chakchai So-In proposed a novel hybrid scheme called hybrid fuzzy centroid, which fuzzy logic system was selected to derive the extra weight. Obviously, with the introduction of swarm intelligence optimization algorithm, the accuracy of node localization improved to a certain extent [13].

Cuckoo search (CS) algorithm is a swarm intelligence optimization proposed by Yang and Deb in 2009. As a kind of new bionic swarm intelligence algorithm, it has the advantages of simple, few parameters, easy to realize and so on. With efficient balance of local search and global search ability, CS algorithm provides a new research idea for optimizing the localization performance of WSN[14]. An improved DV-Hop localization algorithm optimized by cuckoo algorithm was proposed in this paper. The algorithm transforms the traditional localization problem into a common mathematical multidimensional constrained optimization problem. And the CS algorithm was introduced into establishing specific fitness function and optimizing the localization of the DV-Hop algorithm, in which the estimation coordinates of unknown nodes are much closer to real coordinates.

The paper is organized as follows: section 1 focuses on the insufficient of traditional DV-Hop algorithm localization accuracy, and proposed an improved 3D DV-Hop localization algorithm. Aiming at the shortcomings of the traditional CS algorithm with slow convergence, we proposed an adaptive cuckoo search (ACS) algorithm in section 2. Section 3 uses the ACS algorithm to optimize the improved 3D DV-Hop localization algorithm. From different aspects to simulate the proposed algorithm in this article and carry on the contrast analysis in section 4. Finally, section 5 gives the conclusion and future work.

2 Improved 3D DV-Hop Localization Algorithm

2.1 Introduction of traditional 3D DV-Hop localization algorithm

In the localization process of WSN nodes, the anchor node can obtain accurate position information with its own localization equipment. The unknown node needs to obtain the information of anchor nodes through a certain communication method. And the information of anchor nodes is used as a reference to estimate the position information of unknown node, according to some algorithms or localization mechanisms. When the unknown node obtains 3 or more than 3 anchor nodes position information, the distance to anchor nodes can be used to estimate their position. In order to further improve the localization accuracy, the influence of individual ranging errors on the localization results is generally reduced by introducing additional anchor node information when estimating the position of the unknown node. 3D DV-Hop localization algorithm can be divided into the following 3 steps:

1. Obtain the minimum hops between the anchor nodes. Through the distance vector exchange protocol, each anchor node sends a data package to its adjacent nodes in flood broadcast way. The data package includes the identification of the anchor node, the anchor node position coordinates and the hop counts. The initial value of the hop

counts is 0. Hop counts will increase by 1 if the node received the data package information, and the broadcast packets will broadcast to its neighbor nodes with other data remaining unchanged, until every node has each anchor node coordinates and the minimum number of hops to each anchor node. The minimum hops between each anchor node can be measured by this simple broadcast calculation.

2. Calculate the average hop distance of unknown nodes. The broadcast packet includes the anchor node coordinate and the node ID number. Anchor nodes can obtain the coordinates of the other anchor nodes and the minimum hop count, using formula (1) to calculate the average per hop distance in the network.

$$c_i = \frac{\sum_{j \neq i} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2}}{\sum_{j \neq i} h_{ij}} \tag{1}$$

Where $(x_i, y_i, z_i), (x_j, y_j, z_j)$ are the anchor node coordinates, h_{ij} is the minimum hops between the anchor node i and j.

3. Calculate the coordinates of unknown nodes through the least square method. Assuming the unknown node coordinate is (x, y, z) and it connects with n neighbor anchor nodes. Also assuming the coordinates of ith anchor node is (x_i, y_i, z_i), and d_i is the distance between the ith anchor node and target unknown nodes. Then the equation set as formula (2) can be got according to the coordinates of four anchor nodes and their distance to unknown nodes.

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2 = d_1^2 \\ (x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2 = d_2^2 \\ (x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2 = d_3^2 \\ (x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2 = d_4^2 \end{cases} \tag{2}$$

Then the coordinates of the unknown node can be calculated by the least square method, which is the solution of the formula (3).

$$X = (A^T A)^{-1} A^T b \tag{3}$$

Where,

$$b = \begin{bmatrix} x_1^2 - x_4^2 + y_1^2 - y_4^2 + z_1^2 - z_4^2 + d_4^2 - d_1^2 \\ x_2^2 - x_4^2 + y_2^2 - y_4^2 + z_2^2 - z_4^2 + d_4^2 - d_2^2 \\ x_3^2 - x_4^2 + y_3^2 - y_4^2 + z_3^2 - z_4^2 + d_4^2 - d_3^2 \end{bmatrix} \tag{4}$$

$$A = \begin{bmatrix} 2(x_1 - x_4) & 2(x_2 - x_4) & 2(x_3 - x_4) \\ 2(y_1 - y_4) & 2(y_2 - y_4) & 2(y_3 - y_4) \\ 2(z_1 - z_4) & 2(z_2 - z_4) & 2(z_3 - z_4) \end{bmatrix} \tag{5}$$

$$X = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \tag{6}$$

2.2 Shortcomings of traditional 3D DV-Hop localization algorithm

Traditional 3D DV-Hop localization algorithm has some shortcomings in the actual localization process, including: 1) Network hole caused by the obstacle. In the actual localization process, the emergence of obstacles is inevitable. If there is a barrier between the two nodes, the signal will be weaken or even blocked in the process of transmission. 2) The existence of badness nodes. Because of the node position over deviation, existing less than or only three anchor nodes within the communication radius, more than four anchor nodes in a plane or near to form a plane and many other reasons, large localization errors will be caused in the localization process. 3) The estimated value of the average hop distance. No matter which algorithm used to calculate the average distance of each hop in the network, there will be localization errors. But the appropriate average hop distance can improve the localization accuracy of the algorithm.

2.3 Improved strategy for 3D DV-Hop localization algorithm

This paper mainly discusses how to reduce the localization errors and improve the localization accuracy. Therefore, in view of the shortcomings of the traditional 3D DV-Hop localization algorithm, it is improved from the following two aspects:

1. Network topology control. When the anchor nodes are deployed, the space was divided into four blocks with the center of block. Then, the anchor nodes are uniformly arranged in the partition space to reduce the badness node. In the localization process, the localization errors can be reduced through using a parameter controls the selection of anchor nodes, and selecting the matched conditions anchor nodes to locate the unknown node. When the four anchor nodes are in a plane or near to form a plane, the localization accuracy will be affected and leaded to a large localization error, which is one of the causes of bad nodes[15]. Especially, if there is completely multicollinearity when the nodes are deployed, the quadrilateral measurement method will completely ineffective. In order to avoid this, it is very important to choose the proper anchor nodes. In the 3D environment, the multicollinearity degree of the four anchor nodes can be evaluated by the quality of the tetrahedron mesh. The Q coeffi-

cient is selected to judge the quality of the tetrahedron in this paper, and the calculation method of the Q coefficient is shown in formula (7).

$$Q = C_d \frac{V}{\left[\sum_{1\le i<j\le 4} l_{ij}\right]} \tag{7}$$

Where, V is the tetrahedron volume composed by four anchor nodes, and l_{ij} is one of the six edges of the tetrahedron. In order to make the Q value equal 1 when four anchor nodes form a regular tetrahedron, the proportional coefficient Cd is selected as a constant 1832.8208. When the Q value approaches 0, four anchor nodes are close to a plane.

2. Correction of average hop distance. In the DV-Hop localization algorithm, the calculation of the average hop distance has a great influence on the localization errors. Hence, the calculation of the average hop distance should consider how to correct average hop distance to reduce the localization error and improve the localization accuracy. It can effectively reduce the DV-Hop localization algorithm average errors through correcting the average hop distance of average hop of the four anchor nodes[16]. In this paper, the calculation method of the average hop correction value is shown in the formula (8).

$$s_i = \frac{\sum_{i\ne j}\left|c_i \cdot h_{ij} - \sqrt{(x_i-x_j)^2+(y_i-y_j)^2+(z_i-z_j)^2}\right|}{h_{ij}} \tag{8}$$

Where, s_i is the average hop correction value, c_i is the average hop distance of anchor node i, h_{ij} is the hop count between anchor node i and anchor node j. Anchor node i is the first anchor node and anchor node j is the last anchor according to the sequence of four anchor nodes .

So, the distance between the two nodes is estimated by $d = (c_i + s_i)\cdot h$. Where, h is the hop counts between the unknown nodes to the involved anchor node in the localization process.

3 Adaptive Cuckoo Search Algorithm

3.1 Traditional cuckoo search algorithm

CS algorithm was proposed according to the inspired of cuckoo reproductive behavior. In order to simulate the cuckoo randomly search nest to breed, and the following three ideal states are assumed: 1) Each time the cuckoo only lay one egg and find a suitable nest to hatch the egg, and the behavior of finding nest is randomly. 2) A group of nests will be selected randomly, and the best nest will be retained to the next generation. 3)The number of available nest is fixed, and the egg will be found and discarded by the bird's nest owner, which probability is p_α.

According to above three ideal states, the renewal strategy that cuckoo search nest path and position can be described as formula(9) .

$$X_i^{t+1} = X_i^t + \alpha \cdot s_L \otimes (X_i^t - X_b) \otimes r_n \tag{9}$$

where, α is the search step adjustment factor, X_i^t is the i nest coordinate of t evolution generation, X_b is the historical optimal solution, $\otimes$ is the point to point multiplication, r_n is a random number obeying standard normal distribution, S_L is a random step based on the Levy flight.

CS algorithm search strategy is the Levy flight, which is a kind of random movement, and meets the stable distribution of heavy-tailed. With the increase of iterations, the relationship between the variance and the number of iterations is as formula (10).

$$\sigma^2(t) \sim t^{3-\lambda}, \lambda \in (0,1) \tag{10}$$

Because Brownian movement has a linear relationship between the variance and the number of iterations, Levy flight is more efficient in a wide search environment. As the core of the CS algorithm, the flight step of Levy flight can be described as formula (11).

$$s = \frac{\mu}{|\upsilon|^{\frac{1}{\beta}}} \tag{11}$$

Where, the general value of β is 1.5, μ and υ are normal distribution random numbers as formula (12).

$$\begin{cases} \mu \sim N(0, \sigma_\mu^2) \\ \upsilon \sim N(0,1) \end{cases} \tag{12}$$

Where, σ_μ is calculated by the formula (13).

$$\sigma_\mu = \left[\frac{\Gamma(1+\beta)\sin(\frac{\pi\beta}{2})}{2^{\left(\frac{\beta-1}{2}\right)}\Gamma\left(\frac{1+\beta}{2}\right)\beta} \right]^{1/\beta} \tag{13}$$

Where, Γ is the gamma distribution function.

3.2 Improvement strategy for traditional cuckoo search algorithm

The CS algorithm has strong global search ability, but its convergence rate is slow. Aiming at this problem, the traditional CS algorithm is improved from the following two aspects, which in order to make it adaptive to find the optimal solution and improve the convergence rate.

1. Improvement strategy of search step. In traditional CS algorithm, step adjustment coefficient is usually a fixed value. When the position of the nest is far from the optimal position, small step will lead to slow convergence. Therefore, the search step automatic adjustment strategy is used in this paper. Increase step if optimal position is far from the rest of the nest, or decrease the step [17]. Step upgrade strategy can be described as formula (14).

$$step_i = step_{\min} + \left(step_{\max} - step_{\min}\right)\frac{\left\| n_i - n_{best} \right\|}{d_{\max}} \tag{14}$$

Where, $step_{\min}$ is the minimum step, $step_{\max}$ is the maximum step, n_i is the position of the i nest, n_{best} is the optimal nest position, $d_{\max}$ is the length between the optimal nest to the rest nests. In the iterative process, step will adjust with the distance between optimal solution and the position of the nest automatically, which can accelerate the convergence speed of the CS algorithm greatly.

2. Improvement strategy of abandon nest. In the traditional CS algorithm, the found bird's nest will be eliminated. However, the elimination mechanism directly affects the diversity of the population. In the earlier stage of localization, the diversity of population should be ensured. The eliminated probability should be smaller, as much as possible to preserve the diversity of the population. That is, maximum possible preserves the optimal solution. In the process of iteration, the found nest will be faster abandoned to accelerate the convergence rate through changing the p_α value. p_α upgrade strategy can be described as formula (15) [18].

$$p_\alpha = 1.1 - 2.8^{\left(-\sqrt{\frac{k}{k_{\max}}}\right)} \tag{15}$$

Where k is the current iterations, k_{max} is the given maximum iterations.

In the process of abandoning nest, the optimal solution will be probably abandoned and only get the sub-optimal solution. Therefore, taking a random strategy to recover the nest can recover the abandoned optimal solution effectively[18]. Recover nest strategy can be described as formula (16).

$$\begin{cases} X_{t,new}^{k} = X_{best}^{k} + randn(0,0.001), 0 \le r \le 0.9 \\ X_{t,new}^{k} = X_{t,bd}^{k} \qquad , 0.9 \le r \le 1 \end{cases} \tag{16}$$

Where, $X_{i,new}^{k}$ is the recover nest of i cuckoo in the k generation when $0 \le r \le 0.9$. X_{best}^{k} is the optimal nest in the k generation. $X_{t,bd}^{k}$ is the recover nest of i cuckoo in the k generation when $0.9 \le r \le 1$. $randn(0,0.001)$ is a random number obeying normal distribution, which mean value is 0 and variance is 0.001. According to formula (16), abandoned bird's nests have a probability of 90% to build a nest near the optimal nest in the k generation. Compared with the original bird's nest, the new bird's nest has a better position information, which is conducive to optimize the evolution along a more efficient way, and improves the optimize ability and convergence speed of the algorithm. Another 10% of the abandoned nests choose to build a new nest on the border. It can avoid all the abandoned nests to close to the optimal nest, which can reduce the possibility of being trapped in local optimum.

3. Convergence comparison of improved algorithm. Because there are a large number of local minima in the solution domain, the general algorithm is difficult to obtain the global optimal value, and it is easy to fall into the local optimum. As a result, the convergence speed is slow in the later period, and the optimal precision is reduced. As a typical inseparable multi peak and multi valley test function, the global minimum of Rastrigin function is reached when the variable is 0. Hence, Rastrigin function is chosen as the test function to verify the convergence of improved algorithm. Formula (17) is the Rastrigin function expression.

$$f(x) = 10d + \sum_{i=1}^{d}\left[x_i^2 - 10\cos(2\pi x_i)\right] \tag{17}$$

The basic parameters are chosen as follows: the dimension is 20, the target accuracy is 200, and the search range is [-5.12, 5.12], the iterations are 100.The convergence simulation results of improved algorithm are shown in Figure1. Figure1 represents the traditional CS algorithm and ACS algorithm convergence curve of the Rastrigin function finding the optimal solution. From the graph we can see that with the increase of the number of iterations, ACS algorithm convergence speed is faster than the CS algorithm convergence.

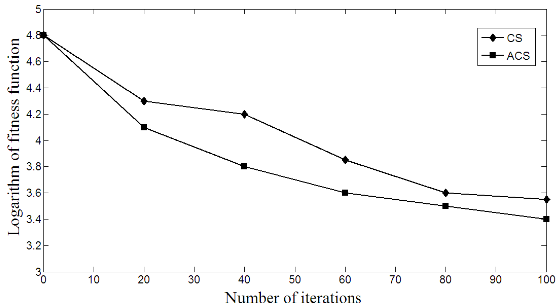

Fig. 1. Convergence comparison of improved CS algorithm and traditional CS algorithm

4 The 3D DV-Hop Localization Algorithm Optimized by ACS Algorithm

4.1 Fitness function

When calculate the unknown node coordinates, the optimal value of the coordinates estimated according to the distance between the unknown node and the anchor node. If the CS algorithm is up to localization accuracy or the number of iterations, there is a nest to each anchor node distance is closer than the distance between the unknown node and anchor node. The coordinate of the bird's nest is the estimated optimal coordinate. Root mean square error (RMSE) is often used in calculating the deviation of the position and the position of the nest. When RMSE is the least, the coordinate value is the optimal solution. The RMSE of the distance between the unknown node and the neighbor anchor node is used as the fitness function of the localization problem, as shown in the formula (18).

$$f_{(x,y,z)} = \sqrt{\frac{1}{4}\sum_{i=1}^{4}\left(\sqrt{(x-x_i)^2+(y-y_i)^2+(z-z_i)^2}-d_i'\right)^2} \quad (18)$$

Where, (x,y,z) is the nest coordinate, (x_i,y_i,z_i) is the anchor node coordinate, d_i' is the distance between the unknown node and the neighbor anchor node. When the fitness function $f_{(x,y,z)}$ has the minimum value, the position of the bird's nest is the optimal solution.

4.2 Algorithm realization

Optimize the function solution is the nature of CS algorithm, so the correction of average hop distance in the DV-Hop can be expressed in the function form and transform to a NP problem. The basic steps of DV-Hop optimized by ACS algorithm (ACSDV-Hop) localization algorithm are as follows:

Step 1: initialize parameters and scenario, set the minimum value of Q.

Step 2: get the minimum hop between each node.

Step 3: use formula (1) to calculate average hop distance.

Step 4: select four anchor nodes to locate the unknown nodes within one hop of any beacon nodes, and record the ID of 4 anchor nodes to avoid reuse. Calculate the value Q according to the formula□7□. Check the value Q of these four anchor nodes is bigger than the set value or not. If these four anchor nodes meet the demand, skip to step5; otherwise, re-select anchor node combination until meeting the demand; if all combination don't meet the demand, give up the unknown node localization and end.

Step 5: modify average hop distance. In order to reduce error, use formula 8 to calculate the correction value, then modify the average hop distance by the correction value.

Step 6: calculate the unknown nodes coordinate by the four side measuring method; the product of modified average hop distance and the minimum hop count between two nodes are the estimate distance. Use formula (3), (4), (5), (6) to calculate the unknown node coordinate.

Step 7: use formula (18) as the fitness function of the localization problem, optimize the unknown node coordinate by ACS algorithm. The optimum solution by minimum fitness function value is to estimate coordinate of the unknown node.

Step 8: upgrade the localization node to a new anchor node and return to step 4.

5 Experiment Simulation and Result Analysis

5.1 Experimental parameters and environment settings

This paper uses the MATLAB to simulate a standard simulation environment, in order to carry out simulation and comparison for the localization algorithm. The scene of the WSN is a $100\boldsymbol{m} * 100\boldsymbol{m} * 100\boldsymbol{m}$ 3D space. The obstacle is a cube with the length of 14m, distributed in the $48\boldsymbol{m} \leq \boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z} \leq 62\boldsymbol{m}$ space. The total number of nodes is 200, including 50 beacon nodes and 150 unknown nodes. The communication radius of anchor node is 30m. ACS parameters set as follows: dimension is 3, the search range is [-5, 5], the initial nest number is 20, the iterations are 100, and the target accuracy is 1. In order to reduce the error caused by random distribution and accidental factors, the simulation result is the average value of 100 times simulation. Before the simulation, all nodes are randomly deployed and then the nodes positions are fixed. The node position distribution shown in figure 2, the red dot is anchor node and the green dot is unknown node. Next, from the number of anchor nodes, the communication radius, the total number of nodes and node localization errors to compare with the localization effect between DV-Hop localization algorithm, improved adaptive DV-Hop(ADV-Hop) localization algorithm and ACSDV-Hop localization algorithm.

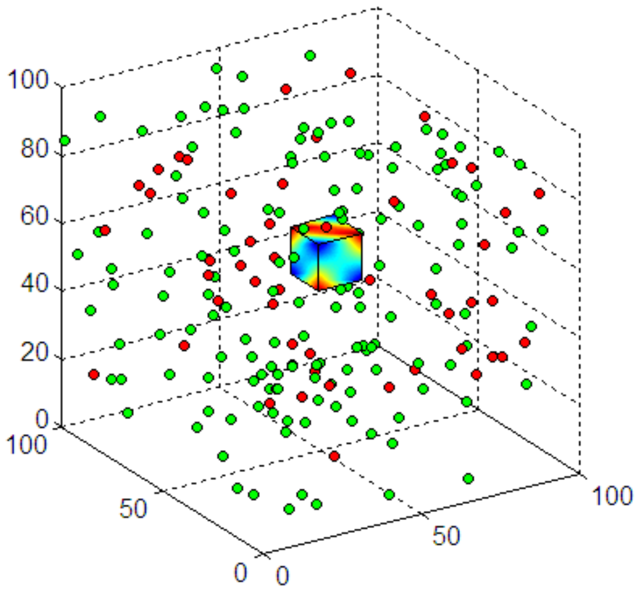

Fig. 2. Initial position distribution of nodes

5.2 Impact of the number of anchor nodes on localization errors

The number of anchor nodes is one of the important factors that affect the localization error. As the number of anchor nodes increases, the localization error will reduce and the localization accuracy will increase. Otherwise, the localization error will be greater and the localization accuracy will reduce. However, with the increase of the number of anchor nodes, the hardware cost will increase, and the power consumption will become larger, which limits the number of anchor nodes. For this pair of contradictions, we need to find a balance point and choose a suitable localization algorithm to reduce the use of anchor nodes as much as possible under the premise of meeting the requirement of localization accuracy. Figure 3 shows the relationship between the number of anchor nodes and the average localization error under the communication radius is 30, the number of the total nodes is 200. From the graph, we can see that with the number of anchor nodes grows from 10 to 50, the accuracy of DV-Hop localization algorithm is improved by 0.6%, the ADV-HOP is improved by 47% and the ACSDV-Hop is improved by 75%. Hence, under the same accuracy requirement, the number of anchor nodes used by ACSDV-Hop algorithm is less than the ADV-Hop algorithm and DV-Hop algorithm, which greatly reduced the cost of localization.

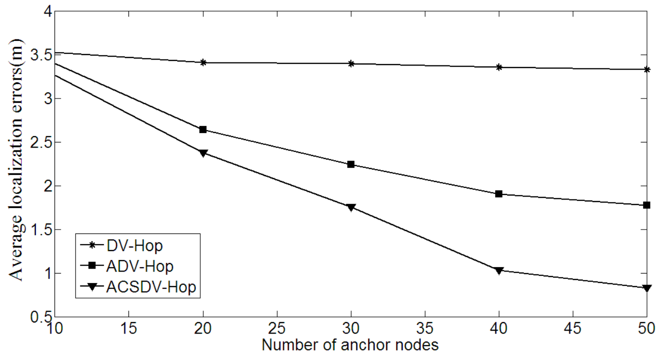

Fig. 3. Average localization errors with the number of anchor nodes

5.3 Impact of the communication radius on localization errors

The radius of the node communication has a great influence on the localization error, particularly in DV-Hop localization algorithm, the DV-Hop localization algorithm depends on the sensor network connectivity. With the increases of communication radius, the connectivity is better, the node coverage area is much larger, more neighbor nodes can be measured and the number of anchor nodes in the neighbor node may also increase. So the localization error will be smaller. Figure4 shows the relationship between the communication radius and the average localization error under the number of anchor nodes is 50, the number of the total nodes is 200. From the graph, with the number of anchor nodes grows from 15m to 50m, the accuracy of DV-Hop algorithm is improved by 26%, the ADV-HOP is improved by 53% and the ACSDV-Hop is improved by 70%. Obviously, with the same communication radius, the average localization error of ACSDV-Hop algorithm is smaller than the ADV-Hop algorithm and DV-Hop algorithm.

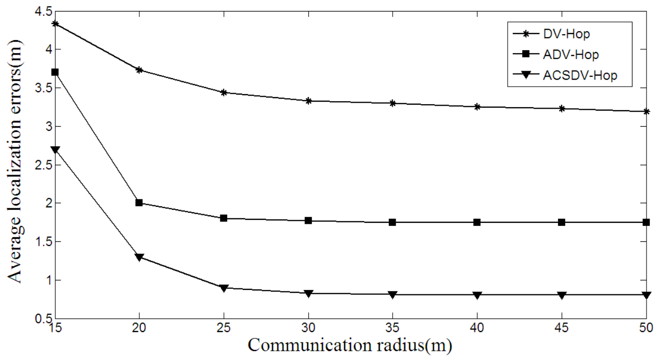

Fig. 4. Average localization errors with the communication radius

5.4 Impact of the total number of nodes on localization errors

In the same simulation space size, the percentage of anchor nodes in all nodes is 25%, the communication radius is 30m, and the total number of nodes at the beginning of 100, with 50 steps increasing to 300, the relationship between average localization error and the total number of nodes as shown in figure 5. From the graph, with the increased of the total number of nodes, the average localization error is reduced. Among them, the accuracy of DV-Hop algorithm is improved by 83%, the ADV-HOP is improved by 90% and the ACSDV-Hop is improved by 96%. It shows that the reasonable layout of the number of nodes can achieve the purpose of node localization in a limited space. Hence, with the same localization accuracy, ACSDV-Hop algorithm can use fewer nodes than the ADV-Hop algorithm and DV-Hop algorithm.

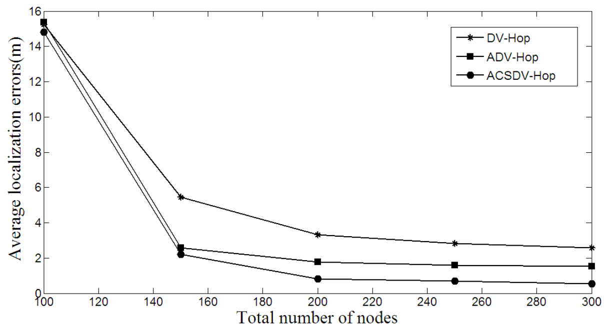

Fig. 5. Average localization errors with the total number of nodes

5.5 Unknown nodes localization errors

Figure 6 is under the condition that the total number of nodes as 200, the communication radius as 30m, the number of anchor nodes as 50, each unknown node localization error of DV-Hop algorithm, ADV-Hop algorithm and ACSDV-Hop algorithm. Obviously, the localization accuracy of ACSDV-Hop localization algorithm is superior to DV-Hop algorithm and ADV-Hop algorithm.

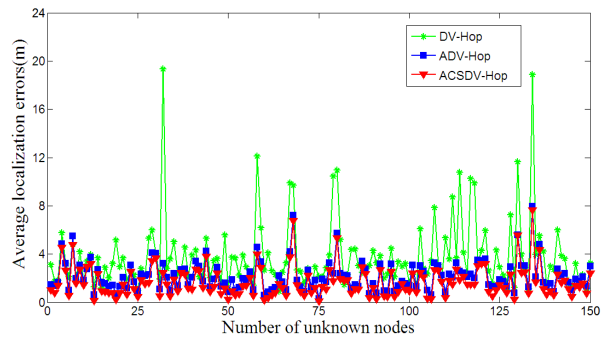

Fig. 6. Average localization errors of each unknown node

6 Conclusions

On the basis of the research of DV-Hop localization algorithm, this paper improved the shortcomings of large algorithm localization error to better reflect the actual average hop distance and effectively reduced the localization error. In order to further improve the localization accuracy of the algorithm, without additional hardware and communication overhead, adaptive cuckoo algorithm is introduced to optimize the improved DV-Hop localization algorithm on position estimation. The simulation results show that the proposed algorithm is significantly superior to the improved DV-Hop localization algorithm and the traditional DV-Hop algorithm. Therefore, the introduction of adaptive CS algorithm, to some extent, improved the tolerance of DV-Hop localization algorithm and made it a better applicability. In the following work, how to improve the localization accuracy in the case of uneven distribution of the anchor nodes and the invalidation of some nodes will need to be further studied.

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