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ADAPTIVE MOBILE ANCHOR LOCALIZATION ALGORITHM BASED ON ANT COLONY OPTIMIZATION IN WIRELESS SENSOR NETWORKS

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Abstract- In wireless sensor networks (WSNs), node's locations play a critical role in many applications. Having a GPS receiver on every sensor node is costly. In this paper, we propose an adaptive mobile anchor localization algorithm based on ant colony optimization , firstly, some virtual anchor nodes are distributed in the area, second, ant colony was used which has the maximum of transition probabilities to obtain the optimal path, last, the centroid-weighted localization algorithm was proposed to locate the position of unknown nodes. Simulation results show that the localization accuracy of the proposed algorithm is better than the traditional centroid algorithm, the more number of anchor nodes, namely, the density is bigger, the position errors is smaller. Under the same anchor nodes, the more number of unknown nodes, the position errors is smaller and the overall trend is downward.

Index terms*:* Wireless sensor networks, mobile anchor, ant colony optimization, localization algorithm, centroid-weighted

I. INTRODUCTION

Recent, wireless sensor networks (WSN) have been used in many applications with advances of the micro-electro-mechanical system (MEMS) technology. Interesting applications of WSN include target tracking, disaster management, environmental monitoring, smart home applications, intelligent transportation and reconnaissance, etc. [1]. In all of these WSN applications, a wireless sensor network is composed of a large number of sensor nodes that are densely deployed in a field, the sensor nodes should have the ability to sense, process and communicate. There are several issues in wireless sensor networks. Location is one of the most important subjects, this is because that sensed data are meaningful to most applications only when they are labeled with geographical position information; position information is essential to many location-aware sensor network communication protocols, such as packet routing and sensing coverage. It has been a challenging task to design a practical algorithm for node localization given the constraints that are imposed on sensors, including limited power and low cost [2]. The simplest possible localization solution would be to attach a global positioning system (GPS) (Global Positioning System) [3] to all the sensor nodes. However, in many applications, hundreds or thousands of sensor nodes might be involved and it is not practical to use a GPS for all the sensor nodes because of cost concerns and some technical problems related to line-of-sight. Therefore, it is often the case with a general assumption that the positions of some nodes (called anchors), are known, so that it is possible to find the absolute positions of the remaining nodes (called unknown nodes) in the WSNs.

The localization system's architecture influences the outcome of a localization system. It plays a more important role especially when we have mobile nodes or/and mobile anchors in the network. The architecture of a localization system has a significant impact on its scalability, its ability to preserve user location privacy, its ease of deployment, and its accuracy. The indoor localization architectures in the presence of mobile nodes or/and mobile anchors can be classified into two different indoor localization architectures, namely the mobile active architecture and the passive mobile architecture [4]. The active mobile architecture has an active transmitter on each mobile node, which periodically broadcasts a message on a wireless channel. Receivers deployed in the infrastructure (anchors) listen for such broadcasts and estimate the distance to the mobile node on each broadcast they hear. Typically, each receiver propagates this distance information to a central database (sink) that then updates the location of each mobile node [5].

II. RELATED WORK

In the past several years, a number of localization protocols have been proposed. We classify the existing localization algorithms into two categories: the stationary anchor localization algorithms and the mobile anchor localization algorithms. The deployment and number of anchor nodes could greatly influence localization accuracy [6]. However, the more anchor nodes are, the larger the cost of deployment network is. Once all the nodes are located, anchor nodes will be not so important. So we could use a mobile anchor node (AN) dynamic moving in the network to assist location, which can reduce cost of computation and communication. Furthermore, since the AN can move to blind areas where static anchor nodes do not cover, it may communicate with all the nodes directly, which could enhance localization accuracy.

Stationary anchor location algorithm use stationary anchor information for localization, which can be classified as range-based and range-free. The range-based algorithm uses absolute point-to-point distance or angle estimates for calculating the location, which are relatively precise but require additional hardware and their cost is relatively high [6], Common approaches for distance or angle estimation include received signal strength indicator(RSSI)[7]; time of arrival (TOA)[8]; time difference of arrival (TDOA) [9] and angle of arrival (AOA) [10], Maximum likelihood estimation (MLE) is an alternative used in AHLOS system (Ad-Hoc Localization System) [11], whose aim is to minimize the differences between the measured distances and estimated distances to determine the position of nodes. While producing fine grained locations, range-based protocols remain cost-ineffective due to the cost of hardware for radio, sound, or video signals, as well as the strict requirements on time synchronization and energy consumption. Range-based approaches can obtain more accurate measurements, but they require complex and expensive hardware.

Due to the hardware limitations of sensor devices, range-free localization algorithms are a cost-effective alternative to the more expensive range-based approaches [12]. There are two main types of range-free localization algorithms that were proposed for sensor networks: (1) local techniques that rely on a high density of land marks so that every sensor node can hear several land marks, In [13], each node estimates its location by calculating the center of the locations of all anchors that it hears. If anchors are deployed regularly, the location error can be reduced, although this is almost impossible in WSN deployments. In [14], they proposed a distributed on line algorithm in which sensor nodes use geometric constraints induced by both radio connectivity and sensing to decrease the uncertainty of their position. The sensing constraints, which are caused by a commonly sensed moving target, are usually tighter than connectivity-based constraints and lead to a decrease in the average localization error overtime. Different sensing models, such as radial binary detection and distance-bound estimation, are considered. In [15], they proposed a localization scheme using a mobile anchor. Each anchor, equipped with the GPS, moves in the sensing field and broadcasts its current position periodically. The sensor nodes that obtain the information are able to compute for heir locations. (2) hop-based techniques that rely on flooding a network. To provide localization in networks where land mark density is low, hop-based techniques propagate location announcements through out the network. The DV-Hop [16] uses a technique based on distance vector routing. Each node maintains a counter denoting the minimum number of hops to each land mark, and updates that counter based on beacon packet received. Landmark location announcements propagate throughout the network. When a node receives a new land mark announcement, and its hop counter is lower than the stored hop count for the land mark, the recipient updates its hop count to the new value and retransmits the announcement with an incremented hop count value. The known positions of the land marks as well as the computed ranges are used to perform a triangulation to obtain the estimated node positions. Many multi-hop WSN localization algorithms, both connectivity based (range-free) and distance-based, have been formulated as non-linear optimization problems [17].

Mobile networks play an important role in the field of wireless networks. Most concerns on mobility were focused on the influence of mobility upon wireless sensor networks. GPS-less low-cost outdoor localization for very small devices (the centroid method) [18] assumes that the ranges of coverage of reference points overlap with each other and each node uses the connectivity metric to get a subset of reference nodes and localizes it to the centroid of the selected reference nodes. This method is simple and requires no coordination among sensor nodes, its applications are limited due to the assumption of overlapping coverage of the reference points. Localization for mobile sensor networks (MCL) [19] used a sequential Monte Carlo method to estimate the posterior distribution of discrete time dynamic models. It includes two stages of prediction and filtering. In the prediction step, a node computes its possible location by applying the mobility model to each sample. In the filtering step, a node filters possible locations based on new observations. The disadvantages of MCL are high anchor density to improve location accuracy during. MSL [20] which not only seeds but all other nodes have to exchange their information for localization and RMCL [21] which nodes need to equip distance measurement hardware are the improved algorithms based on MCL method. Mobility-enhanced positioning in ad hoc networks (MAP) [22] used the mobile nodes by bridging gaps within neighbor hoods to improve the location accuracy. RSSI based localization algorithm for wireless sensor networks [23] uses a mobile anchor node to move and broadcasts its current position periodically, a stationary sensor node computes its location using two positions of the mobile anchor node. The unknown nodes compute their locations with the help of localized stationary sensor nodes. The disadvantage of this approach is requires more strength signal measurement capability. Efficient color-theory-based dynamic localization for mobile wireless sensor networks was proposed in [24], it makes use of the broadcast information to help the server to create a location data base and assist each sensor node to compute its RGB value. It is only suitable for applications that need a centralized server to collect sensor data and monitor sensor activities.

Zhang et al [25] proposed very low energy consumption wireless sensor localization for dangerous environments with single mobile anchor node. But this algorithm cannot ensure each node receives three non-collinear anchor coordinates. Koutsonikolas et al [26] studied the problem of path planning for mobile anchor to reduce localization error. Zhang et al.[18] proposed a range-free localization scheme using mobile anchor nodes. When running once, this algorithm only located a part of nodes. In order to increase localization efficiency, the movement mode of the MN needs to be improved. Kuang et al [27] proposed beacons-energy ratios localization (VB-ERL) scheme using the Gauss-Markov mobility model, which was fully distributed and did not need inter-sensor communication. Mobility introduces a real-time component to the localization algorithms. Wireless sensor networks are usually considered delay-tolerant [28]. To the contrary, mobility makes a sensor network delay intolerant: information gathering and location calculation should happen in a timely manner, dependent on the speed of both the nodes and the anchors. This means that in a mobile wireless sensor network, methods relying on global knowledge such as calculating the number of hops or distances to all the anchors in the network are to be avoided. Similarly, a mobile node cannot really benefit from iterative localization techniques where the location estimation is refined whenever a node receives more information from the network. Besides possible information decay, a localization algorithm deployed in a mobile wireless sensor network should be able to cope with the temporary lack of anchors. In other words, the algorithms should be able to produce a location estimate in such conditions if the application layer has a need for it. In such cases, the location estimation could easily be tagged as uncertain, providing a mean for the application to assess how much the results of the localization algorithm should be trusted [29].

III. NETWORK MODEL

There are a set of anchor nodes and a set of sensor nodes in a WSN. A mobile anchor node moves in the area cyclically and broadcasts anchor signals. The unknown sensor nodes are distributed randomly in the sensing field and receive messages from the moving anchor nodes. The main responsibility of the moving anchor nodes is to send out anchor signals to help the unknown sensor nodes to locate themselves. Each sensor node listens for a fixed time period and collects the RISS information of moving anchor signals. In this environment, it is assumed that [30].

(1) The network is a static randomly deployed network. It means a large number of sensor nodes are randomly deployed in a two-dimensional geographic space, forming a network and these nodes do not move any more after deployment.

(2) There exists only one Sink node, which is deployed at a relative static place outside the WSNs.

(3)There are N static anchor nodes, which their positions are known through GPS or by other means such as pre configuration, and M unknown nodes, and there is a mobile anchor node (AN).

(4) The radio propagation is perfectly spherical and the transmission ranges for all radios are identical.

(5) We define the real geographic distance between two anchor nodes ani and anj as

$$d_{ani,\,anj} = \sqrt{(x_{ani} - x_{anj})^2 + (y_{ani} - y_{anj})^2} \qquad (1)$$

We adopt a simple disk model for network connectivity: nodes ani and anj j can communicate with each other and only the distance is less than r, where r is the connectivity range.

IV. ADAPTIVE MOBILE ANCHOR LOCALIZATION ALGOTITHM BASED ON ANT COLONY OPTIMIZATION

The algorithm has three parts: first is distribution of virtual anchor, second is gets the optimal path, centroid- weighted localization algorithm.

a. Distribution of virtual anchor

Mobility model has a significant effect on the position accuracy. The anchor-based position algorithm is very practical. Establishment of mobile model needs to pay attention the following problems: the signal of mobile anchor can coverage all areas by moving, for unknown nodes, the number of signal which received from anchor nodes is larger than 3; mobile anchor node should reduce the transmission signal which ensure traverse all area to save energy. There are three parts: The transmission radius is R, in order to coverage all area, there are at least three round coincide each part which the center is the coordinate of virtual anchor. The figure of triple coverage without loopholes is shown in figure 1.

Assume that the monitoring area is C×D, it can calculate the number of rows and columns.

$$i_{\max} = \left[\frac{D}{R}\right] + 1,\ j_{\max} = \left[\frac{C}{R}\right] + 1 \tag{2}$$

Then the coordinates of virtual anchor can be calculated by formula (3)

$$\begin{cases} x_{ij} = jR \\ y_{ij} = iR \end{cases} \quad i, j \ \text{are odds}; \quad \text{or} \quad \begin{cases} x_{ij} = (j-1)R \\ y_{ij} = (i-1)R \end{cases} \quad i, j \ \text{are evens} \tag{3}$$

If the calculated coordinates are larger than the side length, the boundary of the monitoring area will instead of the original coordinates.

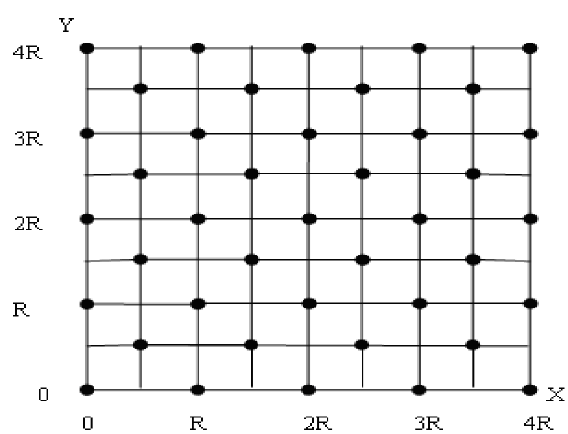

Figure 1. Triple coverage without loopholes

b. Optimal path

After obtained the specific coordinates of virtual anchor, it is critical to get the optimal path. In this paper, we use an improved ant colony optimization algorithm to obtain the optimal path, the specific steps are shown as follows:

(1) Initialization colony

The number of ants m was deployed in n virtual anchor nodes, the next virtual anchor node s can be calculated by formula (4)

$$s=\begin{cases}\arg\left\{\max_{j\in allowed}\left[\left(\tau_{ij}(t)\right)^{\alpha}\left(\eta_{ij}(t)\right)^{\beta}\right]\right\}, & q\le q_0\\ s, others\end{cases} \tag{4}$$

Where q is a random number which between 0 and 1, q0 determines the related degree of search path which is sets in advance, η_{ij} is the inspired factor of ant path which is set by $\eta_{ij}=1/d_{ij}$, d_{ij} is the distance between node i and node j, τ_{ij} is the pheromone on the path which is a variable about path. α reflects the size of pheromone, β is a variable which determine how to select path, allowed k is set which includes the all possible virtual anchor nodes in the next steps.

(2) Transition probabilities of ant moving

In order to obtain the optimal path of ants, a concept of angle was introduced to determine the moving direction in the next.

We assume that there are n anchor virtual nodes, namely, (x_1,y_1), (x_2,y_2), … (x_n,y_n), the centroid O of all virtual anchor nodes can be calculated by formula (5)

$$(x,y)=\left(\frac{\sum_{i=1}^{n}x_i}{n},\frac{\sum_{i=1}^{n}y_i}{n}\right) \tag{5}$$

Where (xi, yi) is the coordinate of virtual anchor i, n is the number of all virtual anchor nodes.

We assume that ant locates in virtual node A, virtual node B is the next hop, the radius of cycle is OA, θ is the angle between virtual anchor A and B which was shown in figure 2.

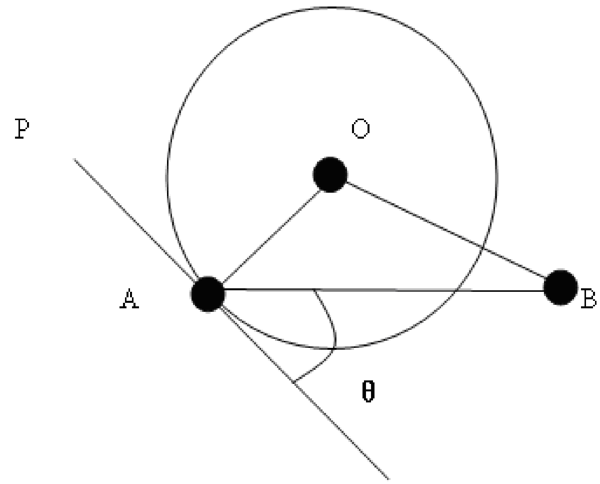

Figure 2. Angle calculation

So the θ can be computed through formula (6)

$$\sin\theta = \cos\left(\frac{\pi}{2}-\theta\right) = \frac{d_{OA}^2 + d_{AB}^2 - d_{OB}^2}{2d_{OA}d_{AB}} \quad (6)$$

Where d_{OA},is the distance between anchor node A and centroid O, d_{AB} is the distance between anchor node A and B.

Angle adjustment factor ε_{ij} can be computed by formula (7)

$$\varepsilon_{ij} = \sqrt{1-(\sin\theta)^2} \quad (7)$$

So the transition probabilities between two nodes at time t can be computed by formula (8)

$$P_{ij}^k(t) = \begin{cases} \dfrac{[\tau_{ij}(t)]^\alpha [\eta_{ij}(t)]^\beta \varepsilon_{ij}(t)}{\sum_{s\in allowedk(t)} [\tau_{is}(t)]^\alpha [\eta_{is}(t)]^\beta \varepsilon_{is}(t)}, & j \in allowed_k \\ 0, & j \notin allowed_k \end{cases} \quad (8)$$

When ant moves to a new virtual anchor node, it should updates the local information table, the value can be computed by formula (9)

$$\tau_{ij} = (1-\rho)*\tau_{ij} + \phi*\tau(0) \quad (9)$$

Where ρ is a coefficient which its value belong 0 to 1, τ(0) is the initial value of information table. When ant passes all virtual anchor nodes, it have completed a traverse, then the global information table would be updated, the value can be computed by formula (10)

$$\tau_{ij} = (1-\rho)*\tau_{ij} + \sum_{k=1}^{k} \Delta\tau_{ij}^{\ k} \quad (10)$$

Where τ_{ij}^{k} is the remaining amount, $\Delta\tau_{ij}^{k}$ is the increment which ant k moves from virtual node i to j.

When all ants have completed a cycle, global information table has been updated, and then repeatedly executed until the research condition has satisfied.

(3) Path planning

Each ant builds a taboo table which includes coordinate of all virtual nodes, when ant traversals a virtual node, it will deletes the information of virtual node until all virtual nodes have been traversal. The specific steps are show in follows

Step 1: Initialization, there are m mobile anchor nodes and n unknown nodes in monitoring area and set parameters, such as $\tau_{ij}(0)=\tau max$, $\triangle\tau_{ij}(0)=0$ and taboo table is empty.

Step 2: at t=0, the coordinate of all anchor nodes are set in taboo table, each anchor node calculates its transition probability and selects the next virtual anchor node according to transition probability size, then updates the taboo table.

Step 3: if there is one virtual anchor node which has not been traversal then go to step 2, else go to step 4.

Step 4: when all virtual anchor nodes have been traversal, the global information table would be updated and N=N+1.

Step 5: if N<max N then taboo table is empty and $\triangle\tau ij(t)=0$, go to step2; else outputs the optimal at the previous time. When the cycle is ends, the optimal path will be obtained.

c. Centroid-weighted localization algorithm

The distance can be calculated according to signal strength and attenuation model through formula (11)

$$P_R = \frac{P_T}{d_{i,u}{}^{n}} \qquad (11)$$

Where PT is the transmitted power, $d_{i,u}$ is the distance between unknown node u and anchor node i, n is an environmental factor.

The formula (12) is the result of logarithm calculation

$$10\lg P_R = A - 10\cdot n\lg d_{i,u} \qquad (12)$$

Where A is the power value of 1 meter distance, $10\lg P_R$ is the value of RSSI, so we can get the formula (13)

$$\mathrm{RSSI} = \mathrm{A} - 10 \cdot n \lg d_{i,u} \qquad (13)$$

So the distance between anchor node i and unknown node u is shown in formula (14)

$$d_{i,u} = 10^{\frac{A-RSSI}{10n}} \qquad (14)$$

Assume that the unknown node u have received k virtual anchor node, so the coordinate of unknown node u can be computed by formula (15)

$$x_u = \sum_{i=1}^{k}(x_i \cdot \frac{1}{d_{i,u}}) / (\frac{1}{k}\sum_{i=1}^{k}\frac{1}{d_{i,u}})$$
$$y_u = \sum_{i=1}^{k}(y_i \cdot \frac{1}{d_{i,u}}) / (\frac{1}{k}\sum_{i=1}^{k}\frac{1}{d_{i,u}}) \qquad (15)$$

Where (x_i, y_i) is the coordinate of virtual node i, $d_{i,u}$ is the distance between unknown node u and anchor node i, k is the number of anchor nodes which unknown node u have been received.

V. SIMULATION RESULTS

This section provides a detailed quantitative analysis comparing the performance of our scheme (centroid-weighted algorithm) with traditional centroid algorithm.

In our experiments, the deployment area is a square plane of 100m by 100m, there are 20 nodes randomly deployed in the area, the virtual anchor nodes are 50 and the mobile anchor nodes are 2, the radius is 20m. In order to effectively compare and analyze the performance of centroid-weighted algorithm with traditional centroid algorithm, all data is the average values from 10 tests. Summary of parameters and defined values are shown in table 1.

Table 1 simulation parameters and defined values

Simulation Parameters	**Values**
Field A (network size)	100m*100m
Number of sink	1
Unknown nodes	20
Virtual anchor nodes	50

Mobile anchor nodes	2
Radius	20m
Simulation times	10
Weighted factor	0.005

Figure 3 is the distribution of unknown nodes and virtual anchor nodes, where the red dot is unknown nodes and the blue dot is virtual anchor nodes.

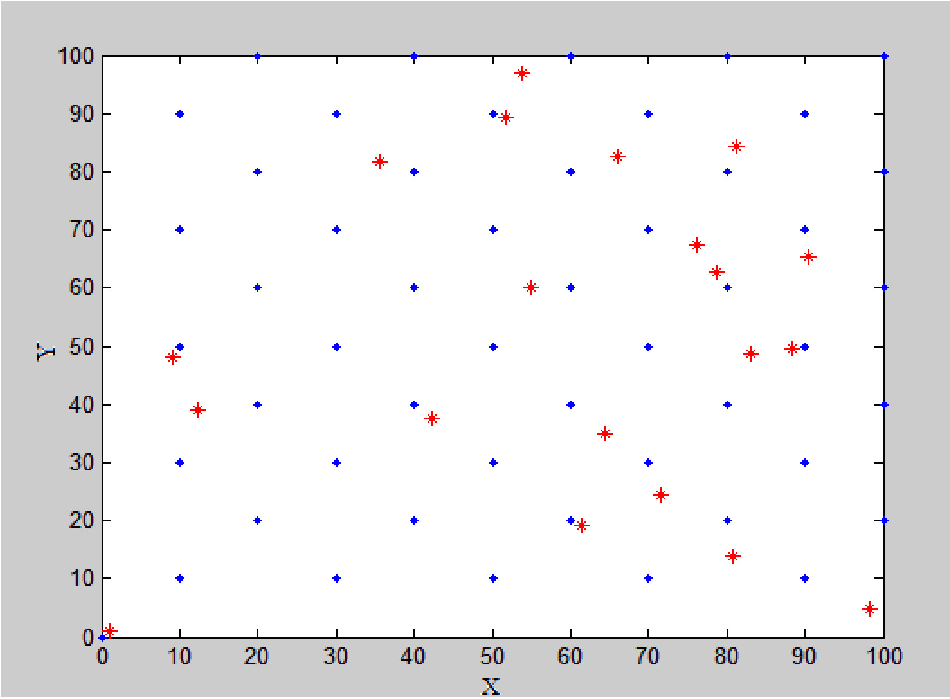

Figure 3. The distribution of nodes

Figure 4 is the distribution of traditional centroid and centroid-weighted, where O is the traditional centroid, △ is the weighted centroid. We can see from figure 5 that centroid-weighted algorithm has a higher accuracy than the traditional centroid algorithm, due to the limited nodes on boundary may cause some errors, but these errors are reasonable.

Figure 5 is the comparison of position error for traditional centroid algorithm and weighted centroid algorithm, we can see from figure 5 that the position error of our algorithm is better than traditional centroid algorithm, especially, under the small bumber of unknown nodes circumstances, this is because of our algorithm uses the weighted factor to reduce position errors.

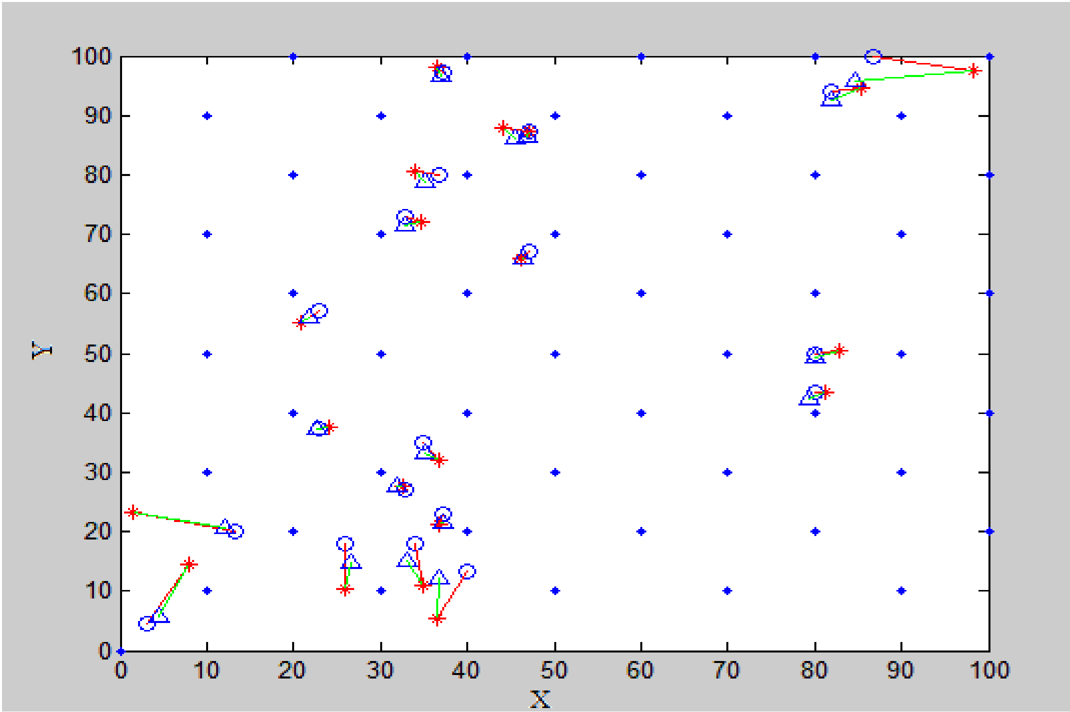

Figure 4. The distribution of centroid for traditional algorithm and our algorithm

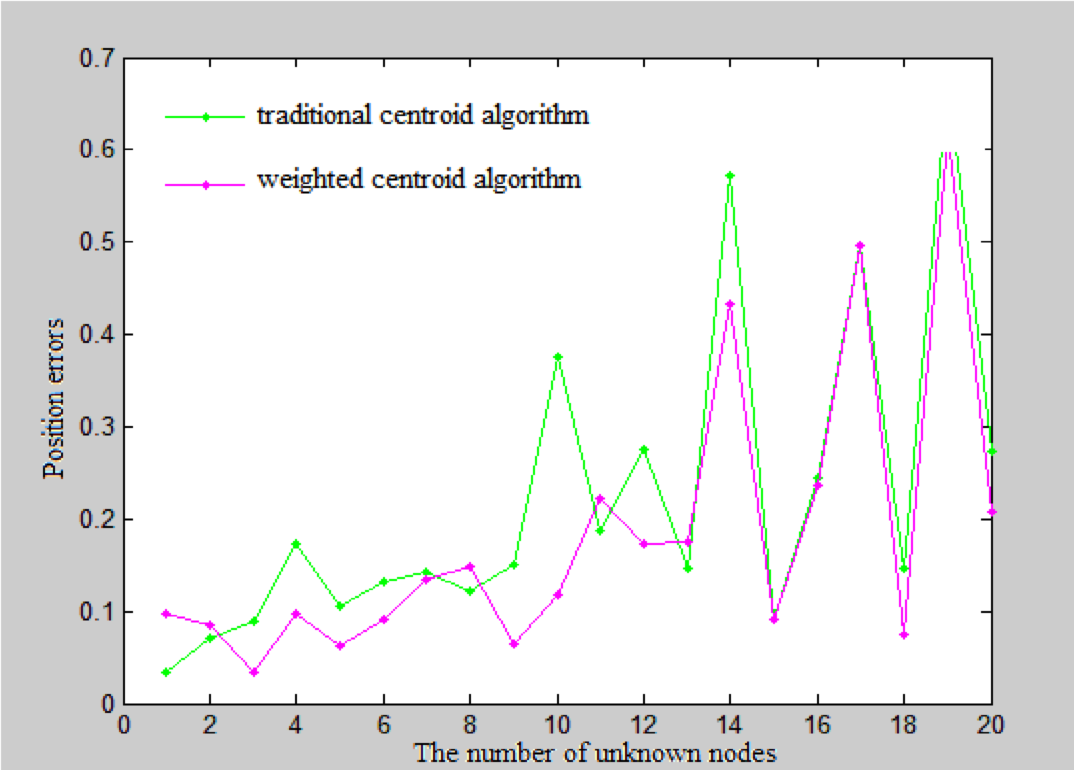

Figure 5. Comparison of position error for two algorithms

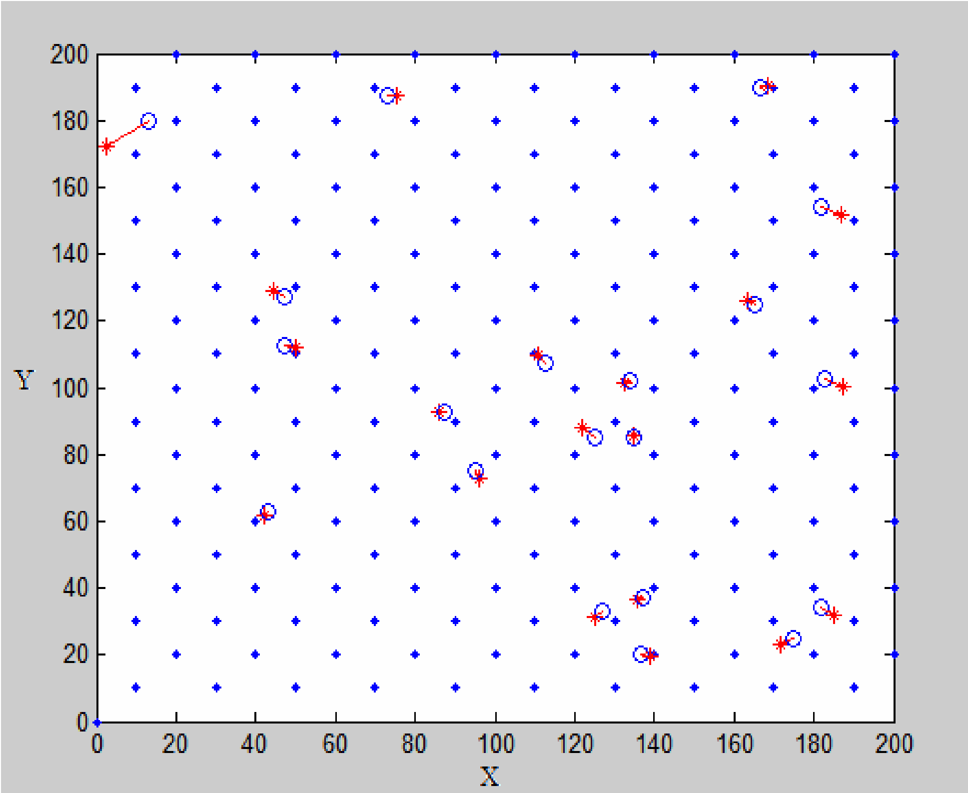

Figure 6. The distribution of 100 virtual anchor nodes

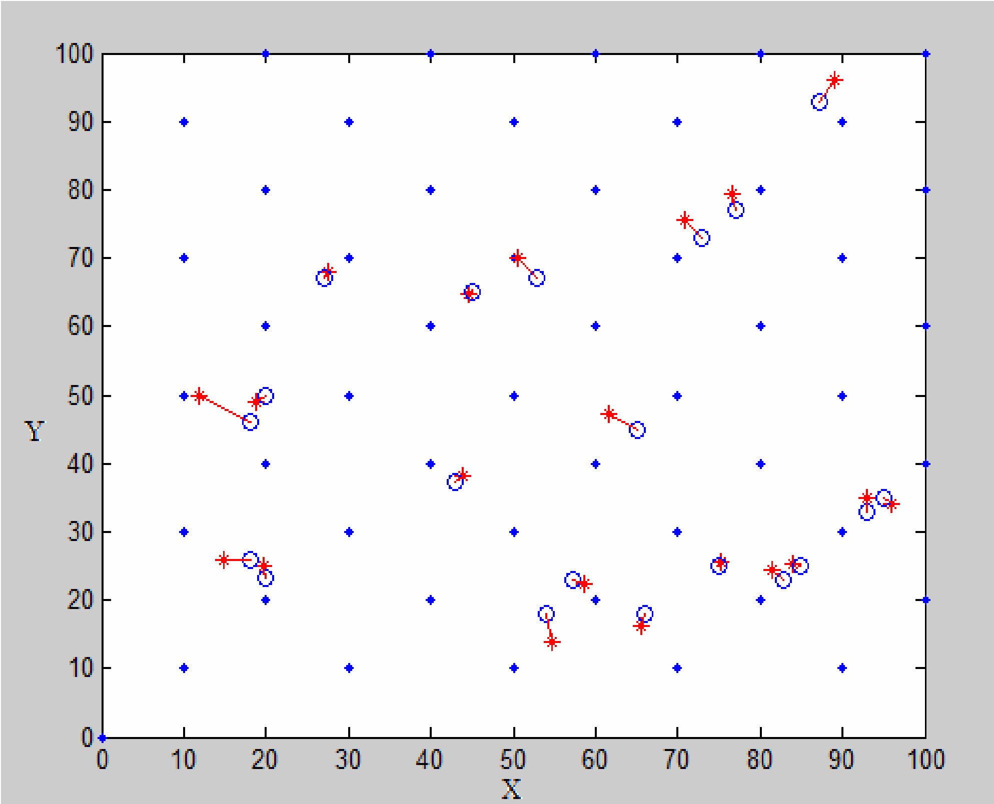

Figure 7. The distribution of 50 virtual anchor nodes

We can see from figures 6 and figure 7 that with the addition of virtual anchor nodes, the position error of centroid is smaller.

In order to better illustrate the performance of position error, we compare the position error of our algorithm under the different number of anchor nodes as shown in figure 8. We can see from figure 8 that the different density of anchor nodes has different errors, the more number of anchor nodes, namely, the density is bigger, the position errors is smaller. Under the same anchor nodes, the more number of unknown nodes, the position errors is smaller and the overall trend is downward.

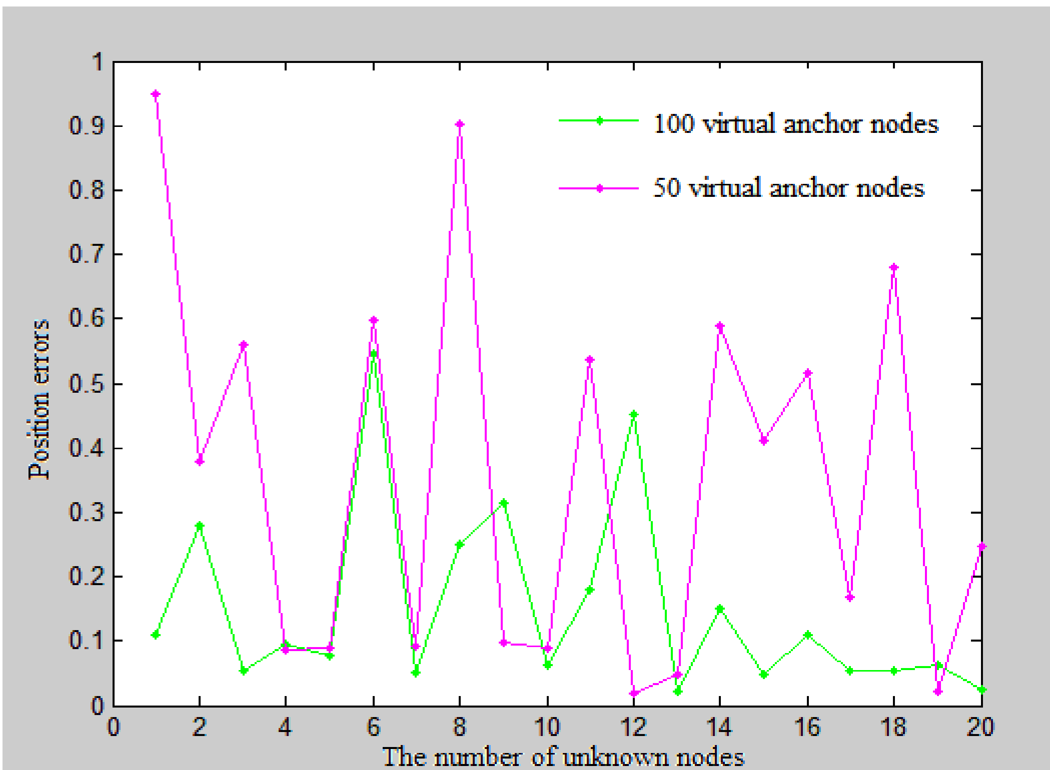

Figure 8. The comparison of position errors for different density of anchor in our algorithm

VI. CONCLUSIONS

Localization is an important topic in wireless sensor networks because sensor nodes are randomly scattered over a region and can get connected into a network on their own. In this paper, we propose an adaptive mobile anchor localization algorithm based on ant colony optimization in wireless sensor networks, firstly, some virtual anchor nodes are distributed in the area, second, ant colony was used which has the maximum of transition probabilities of ant moving to obtain the optimal path, last, the centroid-weighted localization algorithm was proposed to locate the position of unknown nodes. Simulation results show that the localization accuracy of the proposed algorithm is better than the traditional centroid algorithm, the more number of anchor nodes, namely, the density is bigger, the position errors is smaller. Under the same anchor nodes, the more number of unknown nodes, the position errors is smaller and the overall trend is downward.

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