

Localization of Wireless Sensor Network Based on Genetic Algorithm

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Abstract: This paper proposes a novel localization approach based on genetic algorithm for Wireless Sensor Networks. In this method, we use a new way to approximate the distance between anchor node and unknown node which is out of the anchor nodes' communication radius. In addition, we use self-adapting genetic algorithm into localization, which will ensure it can produce the result as similar as its real position in any environment. The experiments on various network topologies show the better results. In comparison, we find that previous anchor node free localization approach cannot work well in the unidealization environment. The demonstration explains that the approach can help unknown nodes obtain high accuracy position whether in open space, the environment with obstruction, or even the unconnected well environment.

Keywords: Wireless Sensor Networks(WSNs), Genetic Algorithm(GA), Localization

1 Introduction

Localization is one of key supporting technologies to Wireless Sensor Networks (WSNs). It could provide accurate position information for kinds of expanding application. In this paper, we study the localization problem for a 2D large-scale WSNs with obstruction. If we equip GPS for every sensor node, it will raise the cost much more, and it also brings a new problem of nodes' power support. Can we only use less GPS for large-scale WSNs to obtain the position of nodes, in obstruction or unconnected well environment?

The major challenge is reducing the influence of obstruction between pairs of nodes. How to achieve high accuracy and reliability localization scheme for WSNs that is always the research subject to researcher around the world, in the environment with obstruction or unconnected well. At the beginning of the localization study on WSNs, Received Signal Strength Indicator(RSSI) [1], Time of Arrival(TOA) [2], Time Difference of Arrival(TDOA) [2] [3], Angle of Arrival(AOA) [4] and other range-based localization have been proposed. In addition, centroid algorithm [5], Ad-Hoc positioning system(APS) [6], Amorphous [7], APIT [8] and other range-free localization also have been proposed. Through literature [1] [2] [3] [4] [5] [6] [7] [8], we found that these algorithms only could provide low accuracy position of nodes for us, and couldn't meet the needs of expanding application on WSNs.

There are many approaches with only network connectivity to calculate the position of nodes such as multidimensional scaling (MDS) [9]. It gives us an O.K. localization results on a well-connected dense network (show in Figure 7). But it does not have any well results in the environment with obstruction (show in Figure 9).

More recently, there are many researchers put graph rigidity theory into localization of WSNs [10] [11] [12], they have made a lot of contribution on it. The methods proposed by S. Lederer

et al. just use the network connectivity information to get the position of unknown nodes. In order to obtain the nodes' position, they partition the network into Voronoi cells with using Delaunay triangles closest to the shape of region of concern. These kinds of methods are good choice of localization plan for underwater, underground or indoor environment, but in these way we can't localization in the environment with obstruction or unconnected well. Apart from this, the locations of landmarks should know before localization. How to obtain the nodes' position in obstruction or unconnected well environment also is the research hotspot for us.

Our contribution. We propose a novel localization algorithm, it uses Genetic Algorithm(GA) [13] [14] into localization of WSNs, the approach causes nodes in the environment with obstruction or unconnected well could get high accuracy position by themselves.

We assume WSNs has been deployed in a region with obstruction, in the network only fewer nodes equipped GPS which could localization by themselves, but others are not. All nodes only could communicate with others in its communication radius, unknown nodes could get the position of anchor node and distance between with anchor node. When there are obstruction stop communicating pairs of nodes, unknown nodes could make use of other nodes in its communication radius to get the position of anchor nodes, and they could obtain distance with anchor nodes through the method provide in Section 4. At last, every unknown node could estimate the position by the global search feature of GA.

Through the simulation result in this paper, we prove that the method provided in this paper has a well property in the environment with obstruction than any other methods, especially it's could localization well in the environment where is separated into several parts like Figure 1.



Figure 1: Localization environment with obstruction, these pictures come from Google Maps.

The outline of the paper is as follows: Section 2 presents the theoretical foundations of genetic algorithm. The localization approach based on self-adapting genetic algorithm is proposed in Section 3. Section 4 presents the evaluation of system and compare simulate results use a different approach. Section 5 concludes this paper.

2 Theoretical Foundations

Genetic Algorithm (GA) is a bionics optimize algorithm. It has been put forward by John Holland on 1975 [13] [14]. It is based on Darwin's biological evolutionism which is "survival of the fittest" and Mendel's genetic variation principle which is "biological genetic evolution mainly take place in the chromosome". GA through selection, crossover and mutation to die out the low-fitness individuals and maintain high-fitness individuals like in the real nature, it can make the population towards to optimize and converge to a global optimum individual. TABLE 1 shows the pseudocode of the genetic algorithm.

In this paper, we use the self-adapting GA which has been proposed in literature [15], the algorithm could change the operate points by the different multiformity of group. We should set up some parameters like code length L , group size N , cross probability P_c , mutation probability

Table 1: Pseudocode of genetic algorithm

Step 1: Initialization
The number of individuals, NIND;
The maximum number of generation, MAXGEN;
The precision of variables, PRECI;
The generation gap, GGAP;
Initialized the times of generation gen= 0;
<hr/>
Step 2: Coding
Initialize the group by Gray, P(t);
<hr/>
Step 3: Evaluate
Evaluate the fitness of each individual in the group P(t);
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Step 4: Genetic Iteration
While t < MAXGEN
Selecting the individuals for Crossover;
Crossing the selected individuals by certain probability;
Mutating the individuals of group by certain probability;
Evaluating the fitness of the new group;
Producing a new group after the evolution, P(t);
Partial Best = min(Evaluate P(t));
Update the times of generation, t = t + 1;
End
<hr/>
Step 5: Obtain the result
Global Best = Partial Best;
<hr/>

P_m and so on. Using GA into the node localization approach of WSNs, we make use of the partial search ability and the global search ability of GA. The partial search ability will help nodes in class I (shown in Section 3.1) to obtain its position; the global search ability will help nodes in class II (shown in Section 3.1) to obtain its position, these two kinds of abilities are supplied by cross probability and mutation probability.

3 Algorithm Description

The localization approach based on genetic algorithm (GAL) proposed in this section is divided into two phases: firstly unknown nodes obtain the distance to adjacent anchor nodes; secondly unknown nodes use genetic algorithm to estimate unknown node's position.

3.1 Obtain the Distance

After all sensor nodes been deployed, all anchor nodes begin broadcasting their position information. Then unknown nodes could obtain messages with anchor nodes' position directly which is in its radius, and they also could obtain other anchor nodes' position through other nodes by routing forwarding. At last, unknown nodes metric distance with adjacent anchor nodes through RSSI. After these steps, unknown nodes are classified into two categories:

Definition 1. Consider an unknown node has obtained the distance to three or more anchor nodes called Class I nodes. We say that this kind of nodes can use genetic algorithm to calculate its own position directly.

The calculate method will proved in section 3.2.

Definition 2. Consider an unknown node hasn't obtained the distance of which to three or more anchor nodes called Class II nodes. We say that this kind of nodes cannot use genetic algorithm to calculate its own position directly.

Now we are ready to explain how to estimate the distance for Class II nodes. Shown in Figure 2.

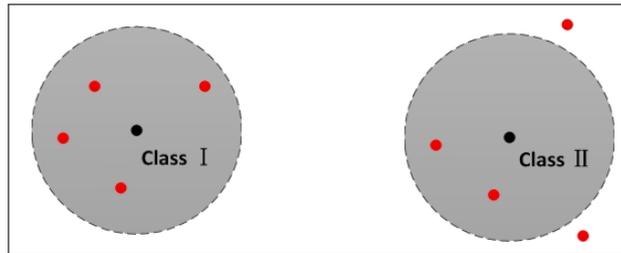


Figure 2: Two types of unknown nodes in the WSNs. The red points mean anchor nodes and the black means unknown nodes.

Definition 3. There are two kinds of nodes, one is anchor node such as node A, the other is unknown node such as node C. Node K is either kind of nodes in the network. Node K can communicate with node A and C. Let node K to node A farther than to node C. Node B also is an assume node on the circle K, the radius of this circle is the distance of between node K and node C. Shown in Figure 3.

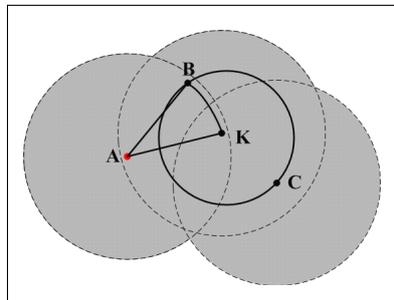


Figure 3: How to estimate the distance to anchor nodes for Class II nodes. Every node has the same communication radius, and it is marked by gray area.

Definition 4. Node D an assumed node which is the intersecting point of the extended line of line AK and circle K. θ is the included angle of line AK and KB, then $\varphi = \pi - \theta$. Shown in Figure 4.

Lemma 5. For isocetes triangle ABK , it has

$$\sin \frac{\theta}{2} = \sqrt{\frac{AK^2 + (CK - AK)^2}{4AK^2}} \tag{1}$$

Lemma 6. For the small circle of concentric circles K, it has

$$\widehat{BD} = \varphi \cdot BK \tag{2}$$

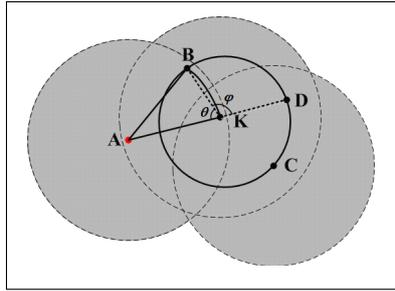


Figure 4: How to estimate the distance to anchor nodes for Class II nodes.

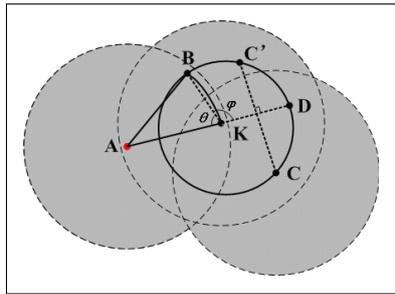


Figure 5: Class II unknown nodes get the distance to anchor nodes.

Based on Lemma 5. and Lemma 6. we can conclude that:

Theorem 7. For Class II nodes like the node C in the Figure 5, the distance between node A and C is equal to the distance between node A and C'. In this paper, we use the sum of AB and the length of \widehat{BC} to similar the distance between node A and C'. As point C is an uncertain node, point C' is also, it could appear on any position of \widehat{BD} . Because of this, we use the half length of \widehat{BD} to measure \widehat{BC}' . According this, we estimate the distance between anchor node and Class II unknown node as following

$$AC = AC' \approx AB + \widehat{BC}' \approx AB + \frac{1}{2}(\widehat{BD}) \tag{3}$$

Proof: Node C' is the mirror image of node C, it subjects to uniform distribution on \widehat{BD} . So if $C \sim U [B, D]$, then the probability distribution of node C subinterval $[b, d]$,

$$P(b \leq C \leq d) = \int_b^d \frac{1}{B - D} dx = \frac{d - b}{B - D} \tag{4}$$

In order to estimate the distance between node A and C', we use the expectation of the length \widehat{BC}' similar as the longer part of AC' than AB. The expectation of the length \widehat{BC}' is

$$E(\widehat{BC}') = \frac{0 + \widehat{BD}'}{2} \tag{5}$$

□

3.2 Compute Unknown Node's Position by Genetic Algorithm

This paper measure the multiformity of group by $F(t) \times \rho(t)$, to guarantee GA group's multiformity and it could expand search range during the previous period of iterate, moreover, optimize well during the later period of iterate. In this way, the self-adapting GA makes this localization approach can deal with the unconnected environment well.

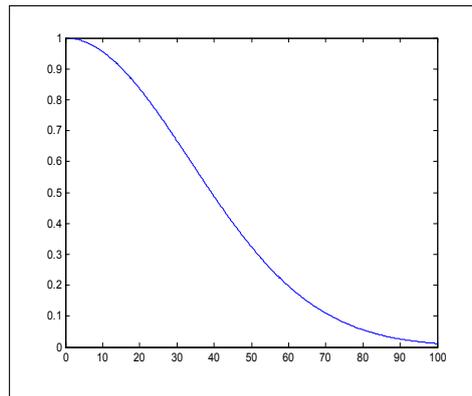


Figure 6: The function of $\rho(t)$, $T=100$.

Definition 8. In this paper, the element of measuring the group's multiformity is multiformity function $F(t)$, it is considered that

$$F(t) = 1 - \frac{H(t)}{L} \quad (6)$$

Where the average Hamming distance is

$$H(t) = \frac{\sum_{i=1}^{N-1} \sum_{j=i+1}^N H(X_i(t), X_j(t))}{\sum_{i=1}^{N-1} (N-i)} \quad (7)$$

Where the Hamming distance between individual $x_{ik}(t)$ and $x_{jk}(t)$ is

$$H(X_i(t), X_j(t)) = \sum_{k=1}^L |x_{ik}(t) - x_{jk}(t)| \quad (8)$$

In the equation (8), $x_{ik}(t)$ means the t generation's k ($k = 1, 2, \dots, L$) bit of individual i ($i = 1, 2, \dots, N$).

Definition 9. In the multiformity measure, the other element is $\rho(t)$, it is considered that

$$\rho(t) = \exp(-t^2/2\sigma^2), \sigma = T/3 \quad (9)$$

In the equation (9) of Definition 9, T means the last generation of GA iteration, when $T=100$, the figure of $\rho(t)$ like Figure 6.

Moreover, we also can't use the encoding method for simple genetic algorithm. The encoding method of simple genetic algorithm is simply binary code, as this way, it will make great hamming distance between neighbor encode elements, the distance is called Hamming Cliff [16]. The Hamming Cliff is too difficult to crossover or mutation, therefore we initialize encoding by Gray code to avoid this problem.

The most important part of genetic algorithm is fitness function. It is used to evaluate the fitness of every node's estimate position.

Definition 10. In this paper, consider the fitness function

$$F(j) = |dist(i, j) - dist(n, i)| + F(j)_{last-iteration} \quad (10)$$

Table 2: Pseudocode of localization based on genetic algorithm

Step 1: Initialization
The number of individuals, NIND;
The maximum number of generation, MAXGEN;
The precision of variables, PRECI;
The generation gap, GGAP;
Initialized the times of generation gen= 0;
The number of anchor nodes, NodeNum;
The number of aimnodes, AimNum;
The distance between anchor and aimnode, D;

Step 2: Coding
Generate the position of aimpoint by Gray code randomly, AimP(t);

Step 3: Evaluate
for n = 1; n < AimNum; n++
 t = 0;
 for j = 1; j < NIND; j++
 F(j) = 0;%F(j) is the fitness function to the group
 for i = 1; i < NodeNum; i++
 F(j) = dist(NodeP(i) - AimP(j)) - D(n,i) + F(j);
 end
 end
end

Step 4: Select, Crossover, Mutation, Reproduce
while t < MAXGEN
 Evaluating the fitness of the new group;
 Selecting the individuals for Crossover;
 Crossing the selected individuals by certain probability;
 Mutating the individuals of group by certain probability;
 Evaluating the fitness of the new group;
 Producing a new group after the evolution, AimP(t);
 Partial Best = min(F(j));
 Update the times of generation, t = t + 1;
end

Step 5: Obtain the result
AimP = Decode(Partial Best);

$dist(i, j)$ be the distance between anchor node i and unknown node j , calculating it needs the coordinate of node i and j . How to get the coordinate of anchor node i has proposed in section 3.1, and the coordinate of unknown node j could estimate by genetic algorithm. $dist(i, j)$ be defined as:

$$dist(i, j) = \sqrt{(x_{NodeP(i)} - x_{NodeP(j)})^2 + (y_{NodeP(i)} - y_{NodeP(j)})^2} \quad (11)$$

The Pseudocode of the localization method proposed in this paper is showed in TABLE 2.

4 Simulation

In this paper, we develop MATLAB toolbox to verify the effectiveness of our approach, and then contrast the experiment results by using different methods in different environment. During the follow experiment, there are 300 nodes deployed in the area $1000\text{m} \times 1000\text{m}$, the communication radius of anchor nodes and unknown nodes both are 200m. In this paper, the values of main parameters as follow, the GGAP is 0.7, cross probability is 0.85 and the mutation probability is 0.1, it is similar in other application as usual.

4.1 Localization Effect in Different Environment

From the following results, we could easily find that using MDS to get the position of unknown nodes is a good choice for WSNs, which is deployed in the open space environment (show in Figure 7). While we using GAL to localization for this environment, we can find that unknown nodes also could obtain its position accurately, if there are enough anchor nodes around it (show in Figure 7).

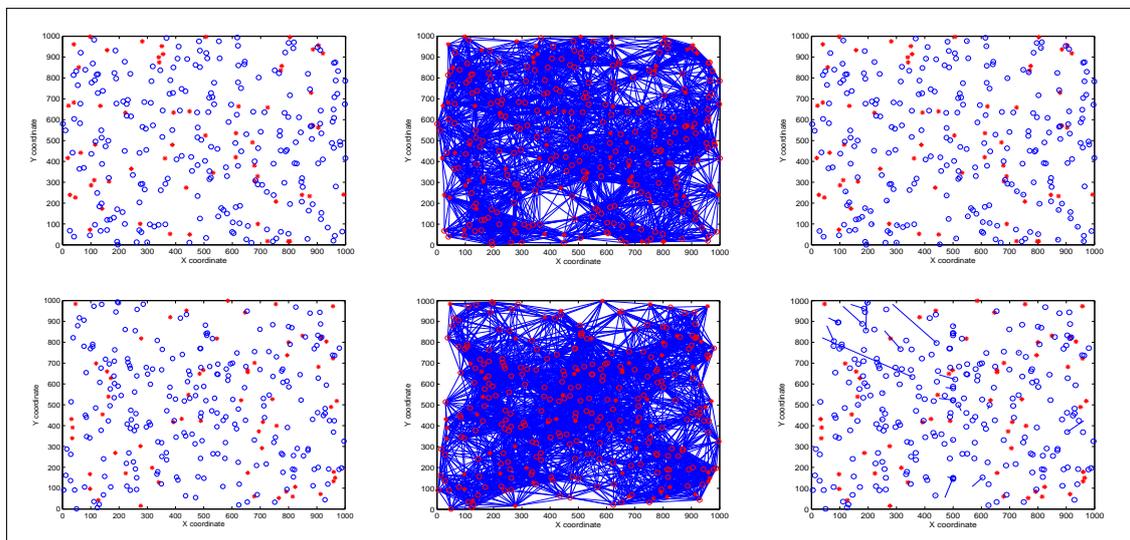


Figure 7: The first row figures are produced by MDS; The second row figures are produced by GAL. The left col figures show the nodes deploy in the open space; The middle col figures show the neighbor relationship have been built; The right col figures show the localization error.

To verify the localization ability of GAL in the environment with obstacles, we put rectangle, Triangle, circle, wall into the region of consideration. When anchor nodes are 20% of all, the localization results are shown in Figure 8.

From the simulate result of Figure 8, it is not difficulty to see that obstacles can't influence localization accuracy much, unknown node also could obtain its position within accepted range.

In the same environment as Figure 8, we use MDS to obtain unknown nodes' position again, the experiment results show in Figure 9.

From Figure 9 it's not hard to find that localization use MDS is much worse than localization using GAL. In the environment like Figure 9 (L) and (O) we can't use MDS to get the position of unknown nodes.

It is well know that MDS has the better localization accuracy than any other classical methods, in order to make this experiment completed we also use DV-hop and centroid algorithm to get the unknown nodes' position in a few environments appeared in Figure 8 and 9. The results

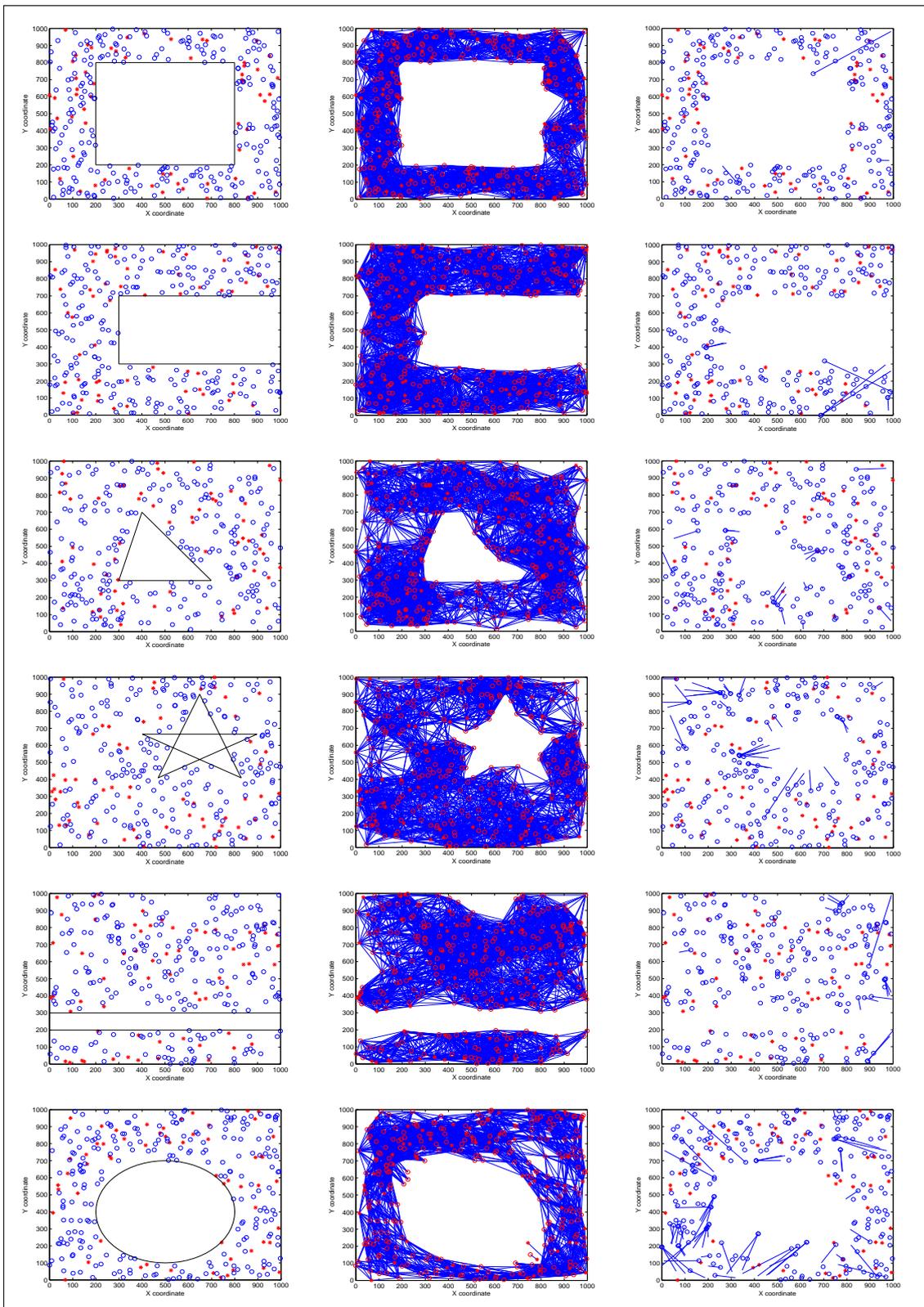


Figure 8: These pictures show the system evaluation by GAL in the environment with obstacles or unconnected. The left col figures show the nodes deploy in different environment; The middle col figures show the neighbor relationship have been built; The right col figures show the localization error of GAL.

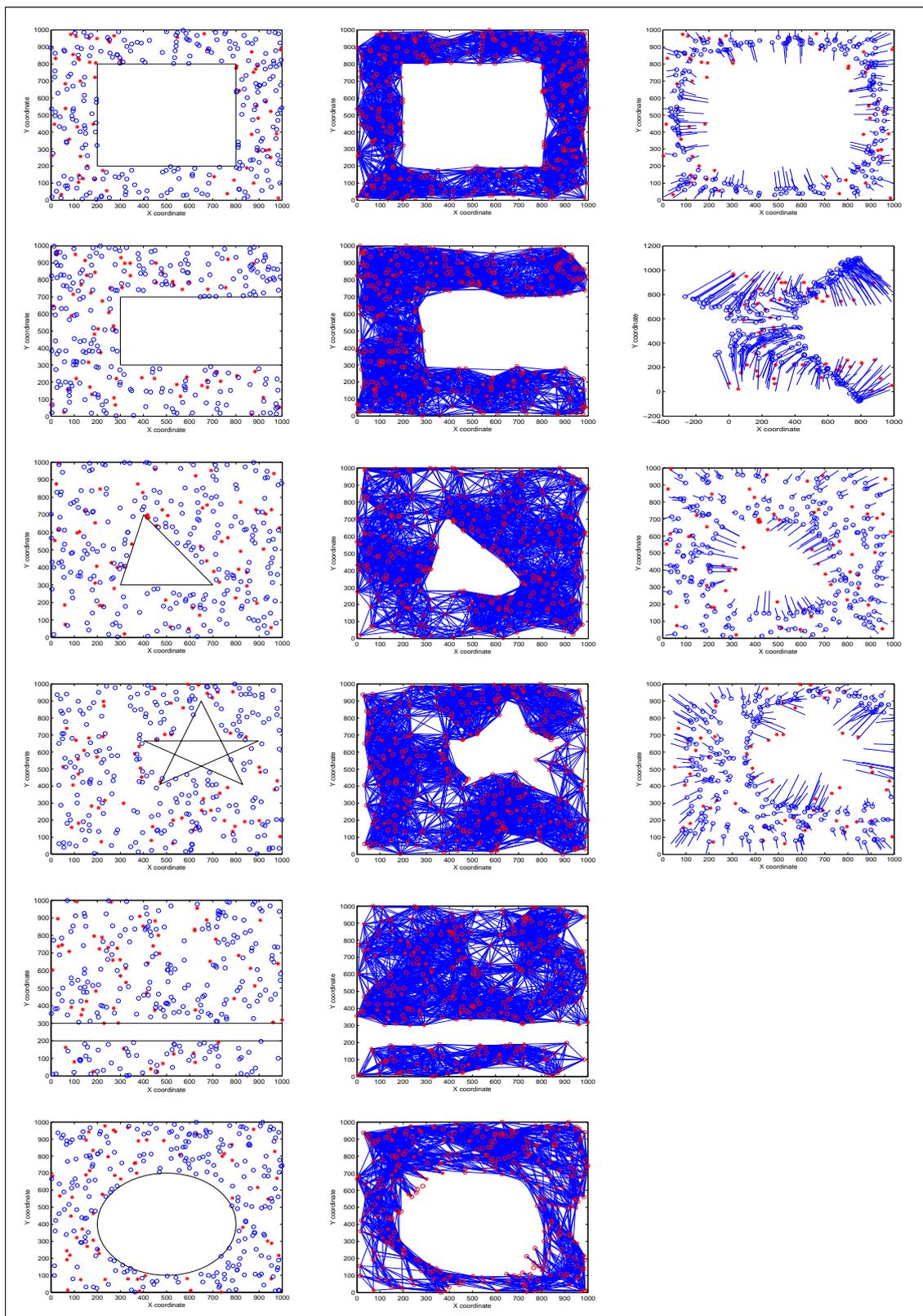


Figure 9: These pictures show the system evaluation by MDS in the environment with obstacles. The left col figures show the nodes deploy in different environment; The middle col figures show the neighbor relationship have been built. The right col figures show the localization error of MDS. But in the last two environment, we can't use MDS to get nodes' position.

of localization error is shown in table 3.

4.2 Contrast GAL with MDS on Characters

In section 4.1 we have presented the result of localization using GAL and MDS in different environment with obstacles. In order to compare with two localization algorithms quantify and objectively, we make experiment in each environment and use different anchor nodes ratio, then analysis the localization error of these results. Figure 10 shows the localization error use different anchor percentage.

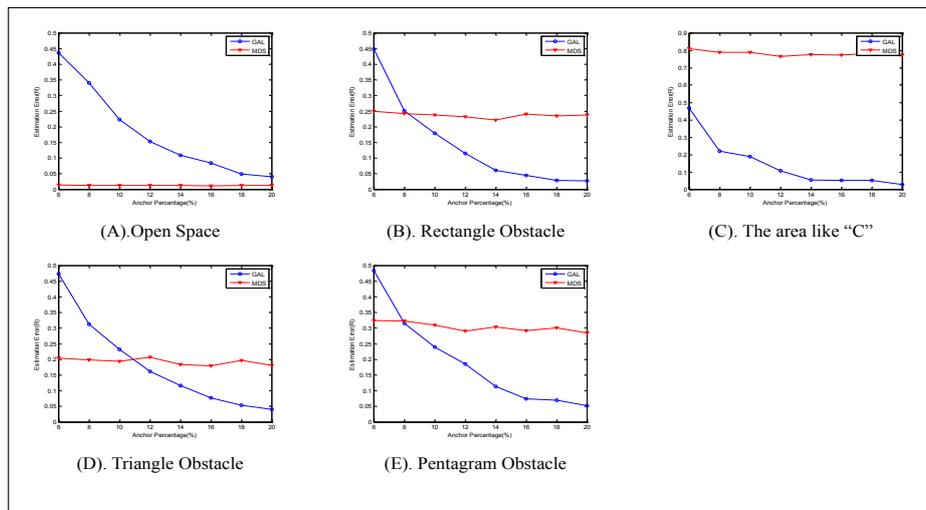


Figure 10: These pictures show the localization error in different anchor percentage by MDS and GAL. In these results, each point is the average result of ten experiments.

Figure 10 (A) shows the localization error in different anchor percentage in the open space. MDS has higher accuracy than GAL, and it just need little number of anchor nodes. The more anchor nodes, the more accuracy of GAL, but the accurate of MDS hardly change. When anchor nodes up to 20%, the localization accuracy of GAL is close to MDS.

Figure 10 (B) to (E) show the localization error comparison of two methods in the environment with obstacles, from these figures we can find that the more anchor nodes percentage, the more localization accuracy of GAL, but the accurate of MDS also hardly to be changed. When percentage of anchor nodes less than 8% in the rectangle or pentagram obstacle environment, or less than 11% in the triangle obstacle environment, MDS could get better localization accuracy than GAL, but the localization error is too high to application. However, GAL could make localization error less than 15%, when percentage of anchor nodes reaches 13%. Therefore, GAL has highly robustness and practicality than any other localization algorithms in the environment not well for communicating.

Table 3: The localization error of DV-hop and Centroid

Method	Without obstruction	Triangle obstruction	Five pointed star obstruction
DV-hop	0.34246	0.375053	0.32259
Centroid	0.318298	NaN	NaN

5 Conclusion

A novel localization approach is proposed in this paper, in this method unknown nodes through their near anchor nodes to obtain their position. In order to reduce error during localization, we use new means to approximate the distance between unknown nodes and anchor nodes when it is larger than node's communication radius. Moreover, we use self-adapting genetic algorithm to calculate the similar position of nodes, it makes the localization error much lower than the common method. Through the contrast experiments in this paper, we find this localization method can work well, whether in the environment with obstruction or not. For the aim of localization in non-planar environment like interior of tall building, we would develop a 3-D localization algorithm in the future study.

Acknowledgment

This work is supported by National Natural Science Foundation of China under Grant No.61063037 and No. 51364001, Key Projects in the Science and Technology Pillar Program of Jiangxi Province of China under Grant No. 20111BBG70031-2 and 20133BBE50033, and Foundation for Young Scientists of Jiangxi Province of China under Grant No. 20133BCB23016.

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