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Research on node localization algorithm based on CNRD in wireless sensor network

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ABSTRACT

This paper puts forward the node localization Algorithm based on cellular network regional division, i.e. below the range-free circumstance, network topological Structure is built up, targeting unit cellular network and cluster cellular network; the deployment strategies of placing anchor nodes at the vertex and the center of each unit cellular are adopted, in order to divide the region according to the geometrical characteristic of the whole network; then match the estimated positions of the unknown nodes with the areas which meet the conditions, in accordance with the hop number relationship between nodes; thus localize the unknown nodes. The MATLAB 10.0 b adopted to conduct the algorithm simulation test and analyze the results. As is shown, with regard to unit cellular network and cluster cellular network, if under the condition of the same density of anchor nodes, the positioning error reaches 20% in average. Also the positioning accuracy is stable. It is concluded that the algorithm is more suitable for large-scale wireless sensor network localization.

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1. INTRODUCTION

Wireless sensor network (WSN) is a multi-hop ad hoc network, which is composed of mass microsensor nodes placed in the monitored region, co-working to collect, process, and report to the observers the real-time environmental information, such as temperature, humidity, pressure, and the movement speed of the target, etc. WSN possesses the characteristic of great quantity and extensive dispersion of sensor nodes, strong network dynamics, large sensor data stream, and low cost of each node. Reputed as one of 21st century's most influential technologies and the ten techniques which change the world, WSN provides a new way to monitor the real-time environment constantly and ubiquitously.

Determined by whether the distance or angle between nodes needs to be measured or not, localization algorithms can be divided into two categories, range-based and range-free. The former localizes the positions by calculating the measured distance or angle, while the latter usually estimates the distance or angle between nodes through the convexity information and multi-hop routing information exchange, to localize positions. In general, range-based localization algorithm can achieve better positioning accuracy. However, it is restricted in hardware cost and power dissipation.

This paper focuses on range-free localization algorithms, and puts forward the node localization algorithm based on cellular network regional division. Due to the special geometrical characteristic of regular hexagon, the structure of cellular network is adopted in this localization algorithm. So each unit can be either divided internally, with each divided region structured as regular triangle, of can be expanded externally to each direction. In either condition unknown nodes are distributed randomly within the networks. This paper tests this localization algorithm mainly by applying it to the networks with 1 unit and 7 units. Meanwhile, correlative simulation experiments are conducted in MATLABT 10.0. The results show that with regard to unit cellular network and cluster cellular network, if under the condition of the same density of anchor node, the positioning error reaches 20% in average. Also the positioning accuracy is Stable. As a result of the above, this algorithm is more suitable for large-scale wireless sensor network localization.

2. CELLULAR NETWORK REGION DIVISION NODE LOCALIZATION ALGORITHM

The nodes localization information of WSN can be divided into 3 categories: information from the communication among anchor nodes, information from the communication between anchor nodes and unknown nodes, and information from the communication among the unknown nodes. The former two kinds of information are usually considered by some traditional localization algorithms, such as DV-Hop, DV-Distance, and APIT, etc. while information from the communication among the unknown nodes is often neglected. Thus this paper makes the corresponding improvement. First all the unknown nodes in each unit are partitioned, according to the hop number relationship. Then the positioning locations of the unknown nodes are mapped as the center of the corresponding area, during which the hop number relationship between unknown nodes is taken for consideration.

As for the unique features of the algorithm discussed in this paper, because based on the premise of ranging-free algorithm, the only information acquired is the hop number between nodes, the arrangement of network is particularly important. Instead of the common square networks, the cellular networks are adopted as the positioning area of nodes. Also, anchor nodes are placed at every vertex and the center of each unit, rather than at some uncertain positions' as in other algorithms tike DV-Hop. The nods will be scanned in a circular manner. But without relatively larger-scale matrix manipulations like least square method, the computation is not much. However, the anchor nodes involved are less. Moreover, the node positioning accuracy is not affected by the changing numbers of unknown nodes much, thus this algorithm can be applied to relatively larger-scale WSN localization.

3. ALGORITHM PROCESS

3.1. Node Localization Algorithm within unit cellular Network

In general, the node localization algorithm based on cellular network regional division can be divided in two phases: the initialization phase and the localization phase.

3.1.1 The Initialization Phase

The main task of initialization phase is to establish the cellular network topological structure, in which anchor nodes are placed at every vertex and the center of the regular hexagon, and unknown nodes are distributed randomly within the network. The anchor nodes will broadcast to unknown nodes their information, including the anchor nodes' positions, and the hop number information from anchor nodes to unknown nodes. Meanwhile, unknown nodes will broadcast the hop number information between each other. Then the minimum hop number can be calculated through shortest path algorithm. With regard to unit cellular network, the communication radius (R) is set to the length of the unit network's side (for better positioning accuracy, some slight adjustments can be taken on the communication radius). As a result, in unit cellular network, the distance between any two anchor nodes is that of the communication radius, i.e. R, as is shown in Figure. 1. After receiving the hop matrix from every anchor node, unknown node will first judge the regular triangle area where it is located, and then further determine its position according to the hop number information received from other unknown nodes. The specific process will be fully described in the localization phase.

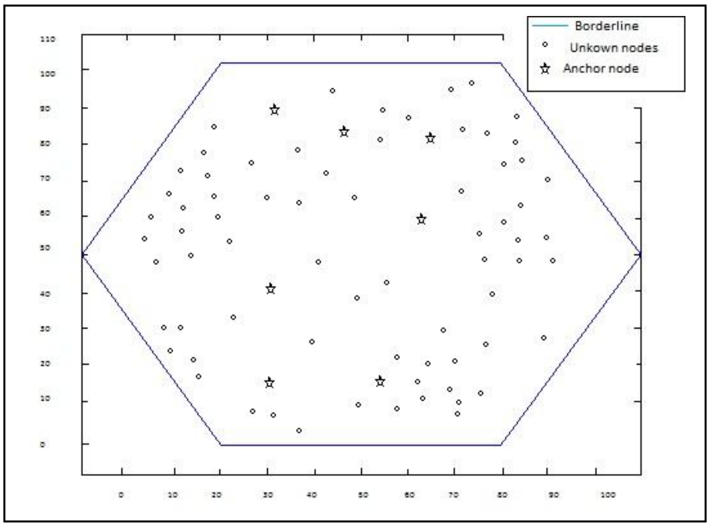

Figure 1. the unit cellular network topological structure

3.1.2 The localization phase

The localization of unknown nodes in unit cellular network falls into two steps.

Step 1: unknown nodes receive the hop number information from anchor nodes. Any unknown node *P*n will receive the hop number information from the 7 anchor nodes in the unit, M1, M2, M3... M7. The former 6 elements in the information will form the hop matrix *H*n of the node *P*n. (the 7th anchor node is not discussed in the hop matrix for its particular position, which is in the center of the network)

$$Hn = [h_{n1}, h_{n2}, h_{n3}, h_{n4}, h_{n5}, h_{n6}] \qquad (1)$$

Step 2: Collect and analyze the hop number information. As is known, before parameter adjustment, the value of the communication radius R equals the distance between any two neighboring anchor nodes, i.e. $R = d_{ij}$ (i and j are the sequence No. of the neighboring anchor nodes).

Also, if the distance between two nodes is within the range of communication radius, the hop number h equals l, i.e. h=l So if we calculate in a circular manner the total number of the elements with 1 as their hop numbers in a hop matrix with n unknown nodes, and we use nsum(i) to mark the total number of the elements with 1 as their hop number in the its hop matrix, we can get the following 4 cases:

a. nsum(i)=0; **b.** nsum(i)=l; **c.** nsum(i)=2; **d.** nsum(i)=3

In order to fulfill the calculation, the communication radius R is reduced slightly, so that R is a little smaller than d, the distance between the neighboring two nodes in the Unit Cellular Network. In the Figure.2, at each vertex of the unit, the circularity formed by the communication range of the anchor nodes cannot cover the anchor node which is at the center of the unit.

a. nsum(i)=0, corresponding to the area 0 in Figure. 2 (the grey area, near the center anchor node). It means the value of all the elements in the *i*-th hop matrix is bigger than 1, which is to say the hop number from the unknown node to all the vertex anchor nodes is beyond 1. In this case, the unknown node is located at the center anchor node.

b. nsum(i)=l, corresponding to the area 1 in Figure. 2 (the green area, near the vertex anchor nodes). It means the value of one element in the *i*-th hop matrix is 1, which is to say the hop number from the unknown node to one of the vertex anchor nodes is 1. Then localize the unknown node by circularly scanning the values of the elements in the hop matrix in (1). If the value of the *k*-th (1 =< k =< 6) element is l, then the unknown node is located at the *k*-th anchor node.

For instance, if H_i = [1, *x*, *x*, *x*, *x*, *x*] (x is any number but 1), the unknown node should be located at the No. l anchor node.

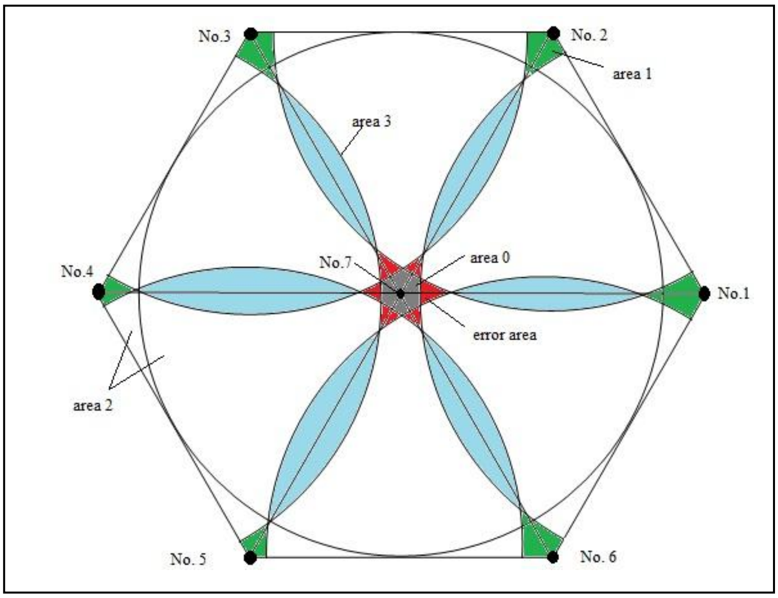

Figure 2. nsum(i) value variety deployment in the unit

c. nsum(i)=2, corresponding to the area 2 in Figure. 2 (the blank area), It means the value of two elements in the *i*-th hop matrix is 1, which is to say the hop number from the unknown node to two of the vertex anchor nodes is 1. Then determine the regular triangle area where the unknown node is located by circularly scanning the values of the elements in the hop matrix in (l). The specific position location algorithm is illustrated in the following example.

If $H_I = [x,1,1,x,x,x]$ (x is any number but 1), the hop number from the unknown node to No. 2 and No. 3 vertex anchor nodes is 1. As is shown in Fig. 3, the unknown node is supposed to be located in the No. 2 regular triangle area.

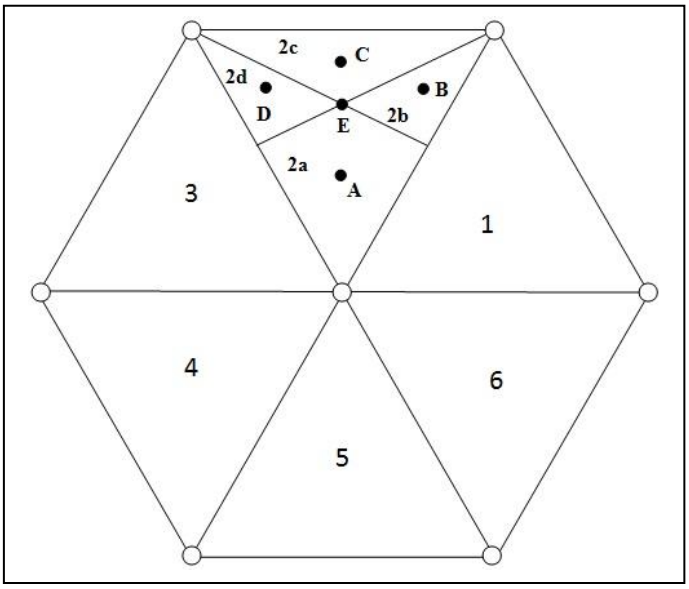

Figure 3. The chart illustrating the node location algorithm when nsum(i)=2

First, calculate the total number of the unknown nodes in No. 4, No. 5, and No. 6 regular triangle areas, which are not neighboring the No. 2 regular triangle area. Mark the number n_k (k = 4, 5, 6).

Second, separately calculate the hop numbers from the

unknown node *i* to all the unknown nodes in No. 4, No. 5 and No. 6 regular triangle areas, and $\boldsymbol{Sumh_{ik}}$.

Third, separately calculate the average hop numbers in No. 4, No. 5 and No. 6 regular triangle areas.

Forth, determine the specific area where the unknown node *i* is located by judging the relationship between the average hop number $AVEh_{ik}$ and the set critical hop number value q, as is shown in Figure. 3.

I. If $AVEh_{i4}$ < q, $AVEh_{i5}$ < q, and $AVEh_{i6}$ < q, then the unknown node *i* is located at the point of *A* in Area 2a;
II. If $AVEh_{i4}$ > q, $AVEh_{i5}$ > q, and $AVEh_{i6}$ < q, then the unknown node *i* is located at the point of *B* in Area 2b;
III. If $AVEh_{i4}$ > q, $AVEh_{i5}$ > q, and $AVEh_{i6}$ > q, then the unknown node *i* is located at the point of *C* in Area 2c;
IV. If $AVEh_{i4}$ < q, $AVEh_{i5}$ > q, and $AVEh_{i6}$ > q, then the unknown node *i* is located at the point of *D* in Area 2d;

In consideration of the less possibility of other cases, the unknown nodes under other situations are mostly located at the point of *E* in No. 2 regular triangle area.

With the method discussed above, the unknown node *i* in No. 2 regular triangle area can be located. This method applies to unknown nodes in other areas.

d. nsum(i)=3, corresponding to the area 3 in Figure. 2 (the blue area on the line between the vertex anchor nodes and the center anchor node), It means the value of three elements in the *i*-th hop matrix is l, which is to say the hop number from the unknown node to three of the vertex anchor nodes is 1. Then circularly scan the values of the elements in the hop matrix in (1). For instance, lf $H_i = [1,1,1, x, x, x]$ (x is any number but 1), then the unknown node *i* should be located at the midpoint of the line between No. 2 anchor node and No .7 anchor node. Under the situation that the communication radius R is a little small than the side of the unit, the unit area discussed above takes up to 95% and above of the total area. However, error area still exists.

e. Error area, around area 0 (the red area in Figure.2).The unknown nodes in this area are supposed to be located at the No. 7 anchor node. But because in this case, nsum(i)=l, the unknown nodes will be miss-located to the vertex anchor node, just as the case b So with regard to this situation, some slight adjustment are taken in the progress, locating the unknown nodes to the No.7 anchor node.

3.2. Node Localization Algorithm within Cluster Cellular Network

As for the cluster cellular network with 7 units, the principle is the similar with that of the unit cellular network. First set the 7 units counterclockwise, from the outside to inside, as is shown in Figure. 4. Apply the method discussed above to each unit of the cluster cellular network, i.e. divide the cluster cellular network according to the unit. When the localization of each unit is completed, the unknown nodes in cluster cellular network are located.

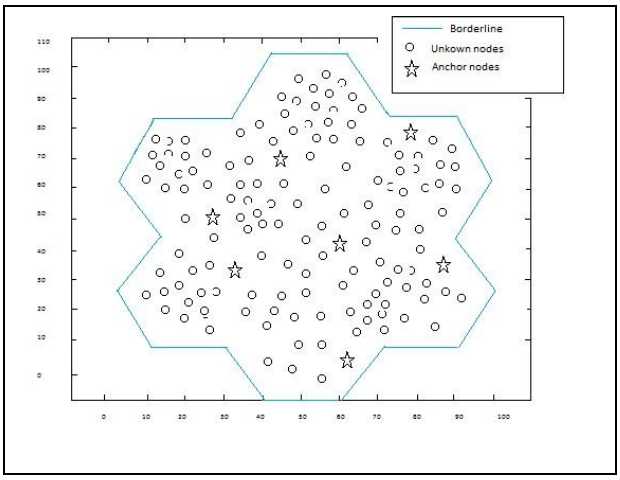

Figure 4. The topological structure of cluster cellular network

3.3. Algorithm Extension

Because the networks can be expanded boundlessly, the algorithm is supposed to apply to the boundlessly expanded networks. It has been proved that with the stable density of anchor nodes, the localization algorithm can achieve a good effect in cluster cellular network. Also the positioning accuracy of the whole networks gets improvement. That's because many units share anchor nodes in cluster cellular network, which leads to low cost of anchor nodes, with the same chance of error. So this algorithm is more suitable to massive network node location. This paper has discussed only one cluster cellular network. While in practice, this algorithm can be applied to the cellular networks of 2 clusters, 3 clusters, and so on, if considering the factors like the acreage of the monitored area and the communication radius. Under the situation of the same density of anchor nodes, the bigger the scale of the networks is, the better the positioning accuracy will be.

4. SIMULATION AND ANALYSIS

The simulation of the node localization algorithm based on cellular networks regional division is mainly conducted by using the MATLAB10.0 in WinXP system. The MATLAB10.0 will generate randomly the location of nodes, and distribute the unknown nodes randomly in the network bordered by anchor nodes. In each simulation experiment, MATLAB10.0 will generate different random numbers.

Suppose (X_i, Y_i) is the estimated coordinate value of the unknown node i, (x_i, y_i) is their real coordinate value, and their deviation is:

$$\Delta d_i = \sqrt{(Xi - xi)^2 + (Yi - yi)^2} \quad (2)$$

Then the average distance deviation of the sensor networks with n unknown nodes can be described as:

$$\varepsilon = \frac{1}{N}\sum_i^N \Delta di \times 100\% = \frac{1}{N}\sum_i^N \sqrt{(Xi - xi)^2 + (Yi - yi)^2} \quad (3)$$

According to the average distance deviation of networks, we can calculate the positioning error of the sensor networks made up of n unknown nodes with R as their communication radius.

$$\varphi = \frac{\varepsilon}{R} = = \frac{1}{NR}\sum_i^N \Delta di \times 100\% = \frac{1}{NR}\sum_i^N \sqrt{(Xi - xi)^2 + (Yi - yi)^2} \quad (4)$$

In the simulation experiment of unit cellular network, the anchor nodes are distributed as in Fig. 1. There are altogether 7 anchor nodes, 100 nodes in total, which means the density of anchor nodes is 7%. In an area of 100x100, set a regular hexagon unit network with 50 as the length of its sides; distribute 93 unknown nodes randomly in the unit network bordered by the anchor nodes; assign the communication radius 49.5, a little smaller than the radius of the regular hexagon, and assign the critical hot number parameter q=1.05. Then based on the set value of parameter in the unit network, the distance deviation of every unknown node can be calculated through (3), by MATLAB. (ε =9.74) Then based on the distance deviation, the positioning error of the networks can be calculated through (4). (φ = 22.88%)

In the simulation experiment of cluster cellular network, the anchor nodes are distributed as in Fig. 4. There are altogether 31 anchor nodes, 443 nodes in total, which means the density of anchor nodes is also 7%. In an area of 103.92 × 103 .92, set a regular hexagon unit network with 20 as the length of its sides; distribute 412 unknown nodes randomly in the cluster network bordered by the anchor nodes; assign the communication radius 20.8, and assign the critical hot number parameter q=1.05. Then based on the set value of parameter in the unit network, the distance deviation of every unknown node can be calculated through (3), by MATLAB. (ε = 4.4789) Then based on the distance deviation, the positioning error of the networks can be calculated through (4). (φ=19.61%). Under the situation of the same density of anchor nodes, the positioning error of cluster cellular network is smaller than that of unit cellular network, and the positioning accuracy is higher than latter, as is shown in Fig. 5, which further proves that this algorithm is more suitable to the large-scale WSN localization.

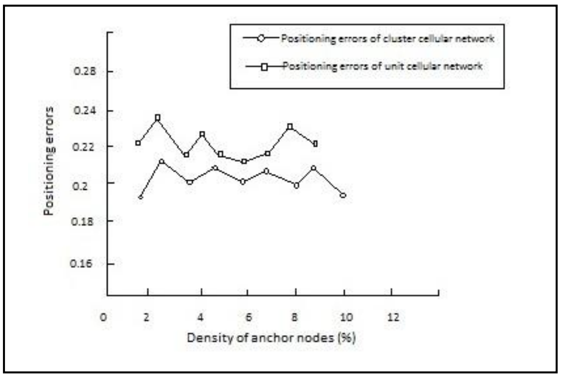

Figure 5. The Comparison of positioning deviation with the same density of anchor nodes

5. CONCLUSION

After the simulation by MATLAB10.0, the result is the same as described above. It has been proved that for unit cellular network and cluster cellular network, the average positioning error can reach to 20% , while the 'density of anchor nodes is lower than 10%. So under the situation of the same density of anchor nodes, the positioning error of cluster cellular network is smaller than that of unit cellular network and the positioning accuracy is higher than latter. Also, the fact that with the low density of anchor nodes, we can still get high positioning accuracy leads to a natural conclusion, which is the positioning accuracy, is less influenced by the changing of the density of anchor nodes.

On the contrary, the positioning accuracy will increase with the increase of the number of the anchor nodes, the same network. So this algorithm is suitable to massive WSN with multi-nodes. What's more, this algorithm possesses the characteristic of extension, as is discussed above. Along with the expansion of the network, this algorithm can achieve better adaptability and positioning accuracy, which makes it better for nodes localization in the massive WSN.

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