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A Cooperative Location Algorithm in Wireless Sensor Network Based on DV-Hop

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Abstract: DV-hop is a typical node location algorithm in wireless network, but the location accuracy is not high and the rate of remaining nodes is too large, under the circumstances that the distribution of sensor network is uneven and the node density is relatively small. We proposed a cooperative location algorithm to improve the performance by calculating the collinear degree of candidate anchor nodes, correcting the average hop distance as well as estimating the error of node location. Simulation results show that the improved algorithm can get high location accuracy and small rate of remaining nodes than DV-Hop algorithm when the node density and the number of anchor node are equal.

Key words: wireless sensor networks, DV-Hop, collinear degree, cooperative localization

INTRODUCTION

Wireless sensor network node location technology is the key supporting technologies of the network application. For the applications of wireless sensor networks, the node location information is very important. Location of sensor nodes can be marked to monitor the location of the data source, to provide topology structure for network management and generates a routing protocol used for data transmission.

So far, researchers have considered the WSN node localization problems from different angles, such as network topology, device capabilities, location accuracy and energy demand and came up with a lot of effective localization algorithms. Niculescu proposed a series of distributed location algorithm APS (Ad hoc location system) and DV-Hop (Distance Vector-Hop) currently is the most widely used one. This algorithm base on distance vector routing and GPS location principle and rely solely on the connectivity of the network nodes to realize the location of the unknown nodes and the sensor nodes do not need any extra hardware. For sensor network with regular node distribution and high anchor nodes density, DV-Hop has advantages on a fast location speed, low computational complexity and a better scalability.

Cooperative localization is a new concept proposed in recent years. It is an extension to traditional localization methods. In conventional method, location parameter mainly refers to distance and angle information between anchor nodes and unknown nodes, but the information bet unknown nodes are ignored. In the cooperative mode, any two unknown nodes could obtain measurement data each other and used to locating unknown nodes beyond the communication range of anchor nodes. By the use of cooperative idea, nodes after location can conditionally transformed into anchor node and obtain redundant information to further improve the location accuracy and robustness of the algorithm. Some literatures apply cooperative idea into node localization algorithms to get high location accuracy through the process of circulating refinement (Savvides *et al*., 2002).

DV-HOP LOCATION ALGORITHM

DV-Hop localization algorithm process is divided into three steps. The first step is the distance vector exchange phase. Anchor nodes send broadcasting message to its neighbors in flood way. The messages contain anchor node ID, location coordinates and hop count. Take advantage of distance vector routing exchange protocol, each node in the network could obtain minimum number of hops between all the anchor nodes.

$$HS_i = \frac{\sum_{j \neq i} \sqrt{(x_i - x_i)^2 + (y_i - y_j)^2}}{\sum_{j \neq i} h_j}$$

While, (x_i, y_i) and (x_j, y_j) is the coordinate of anchor node i and j, h_j is the hop number between i and j.

The third stage is the coordinate calculation stage, when the unknown node obtains three or more anchor nodes estimated distance information, using the maximum likelihood estimation method to calculate the unknown node coordinate information.

If you select three anchor nodes to carry out triangulation, then the coordinates of the unknown node U1 can be obtained by solving the following equations:

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 = d_1^2 \\ (x_2 - x)^2 + (y_2 - y)^2 = d_2^2 \\ (x_3 - x)^2 + (y_3 - y)^2 = d_3^2 \end{cases}$$

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While, $(x_i, y_i) = (i = 1, 2, 3)$ is the coordinates of anchor node M_i, d_i $(i = 1, 2, 3)$ is the distance between M_i and U_1. DV-Hop algorithm use average one-hop distance of the most recent anchor node to calculate the unknown node location. But in fact, because of the uneven distribution of nodes, using a single anchor node estimates the average one-hop distance values can not accurately reflect the actual network-wide average hop distance, resulting in a larger distance estimation error; Secondly, when we use the maximum likelihood estimation method to calculate the unknown location of the node, if the selected anchor nodes are almost in a line, the position estimation error is large; Further, since the sensor nodes are random geographic distribution, there can be plenty isolated nodes and lead to many isolated nodes may not find enough anchor nodes within its communication range to complete location calculation (Niculescu and Nath, 2004) and (Jin and Yoo, 2009).

For the analysis of DV-Hop algorithm above, this paper proposed an improved cooperative location algorithm named DC DV-Hop. Firstly, to select the candidate anchor nodes for maximum likelihood estimation, DC DV-Hop considering the distance between each anchor node and the unknown node and select three anchor node with small collinear degree; Secondly, the average one-hop distance of unknown node is rely on the average hop distance of each anchor node's credibility obtained by weighting calculation, instead of using the value of its nearest anchor node; Finally, according to the unknown node location error calculation, DC DV-Hop transform some unknown node after location to anchor node if the location error is lower enough, thereby increased the anchor node density, expanded the location range.

MAIN IDEA

Candidate anchor node selecting based on collinear degree: Figure 1 shows parts of the topology of the sensor network, M_1, M_2, M_3, M_4 are four anchor nodes closer to the unknown node U_1. Basing on DV-Hop algorithm's maximum likelihood estimation theory, U_1 at least need to select three anchor nodes to estimate the position information of their own in two-dimensional plane. Taking the selecting of anchor node M_1, M_2, M_3 as an example, one interior angle can meet as follow :

$$\cos\alpha = [\frac{(M_1M_2)^2 + (M_1M_3)^2 - (M_2M_3)^2}{2(M_1M_2)\bullet(M_1M_3)}]$$

While, M_1M_2, M_2M_3, M_1M_3 are distance between two anchor nodes, respectively.

Defining the collinear degree of three anchor node is:

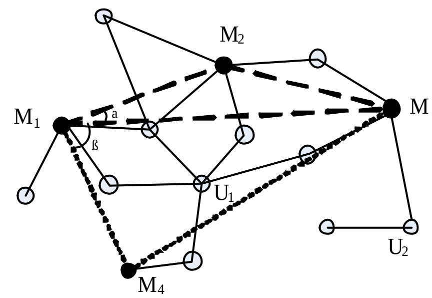

Fig. 1: Selection of candidate anchor nodes

$$DC = \max_{i=1,2,3} \alpha_i$$

wherein a_i is one of the interior angle of triangle. We can know that α_i and if $\pi/3 \le DC \le \pi$ it is said that three nodes will be completely collinear.

When the collinear degrees of three candidates anchor nodes are $DC = \pi$, the location algorithm have lowest average error. Therefore, DC DV-Hop preset a threshold value C (0<C<0.5). When the unknown node receives N routing information from anchor nodes, we calculate the collinear degree of three nearest anchor nodes firstly. If the collinear degree meets $DC = \pi/3$, then we can use these three nodes to perform location algorithm. Otherwise, shown in Figure 1, DC DV-Hop automatically selects the next anchor node M_4 instead of M_3 as the candidate nodes.

Confidence level of anchor nodes: Shown in Fig. 1, the unknown node U1 is connected with anchor node M_1, M_2, M_3 and M_4 and the distance between any two anchor node is similar. The connecting of U_1 to M3 or M4 is closer to a straight line, but the connecting to M_2 is much more tortuous. According to the method of calculating average one-hop distance as formula (1), M2 involved in the calculation may cause the average one-hop distance are smaller than actual, also the distance calculation between U_1 and M_2 is affected (Lee and Kim, 2008) and (Lee *et al*., 2010).

For the above problem, we proposed a method to calculate the confidence level of anchor nodes (Tomic and Mezei, 2012). Assuming sensor network has N anchor nodes, the average one-hop distance on single route between it and the other anchor nodes is $HS_{ij}(j \ne i)$ and the error between single route average one-hop distance and total average one-hop distance of anchor node i, can be normalized to represent the confidence level. Specifically calculation is as follows:

$$w_{ij} = \begin{cases} \arctan(\frac{HS_i}{|HS_i - HS_{ij}|}) \bullet \frac{2}{\pi}, & HS_i \neq HS_{ij} \\ 1, & HS_i = HS_{ij} \end{cases}$$

By the formula (2), when the deviation is large between HS_{ij} and H_i, the confidence value w_{ij} is small, indicating that the anchor node i and j are on a relatively tortuous path, resulting in large error for average one-hop distance calculation.

Calculation of average one-hop distance of anchor node: When DV-Hop algorithm uses maximum likelihood estimation theory to estimate the unknown node position, the confidence level of the three anchor nodes are considered same. But according to the analysis above, the uneven distribution of anchor nodes would make the confidence level differ from each other. Anchor nodes with the lower confidence level involved in the calculation will reduce the accuracy of location. Because of this, when unknown node receives many anchor node's average one-hop distance information, it will first select the nearest one and take it as its own average one-hop distance, then carry out the weighted average rely on each confidence level of the anchor nodes (Tomic and Mezei, 2012).

Just as what shown in Fig. 2, the unknown node U_1 receives four anchor node average one-hop distance is HS_1, HS_2, HS_3 and HS_4,. M_1 is nearest to the unknown nodes U_1. The confidence value of M_2 M_3 M_4towards M_1 is w_{21}, w_{31}, w_{41} respectively. Then the average one-hop distance of U_1 can be calculated as follow:

$$HS_U = \frac{HS_1 + w_{21}HS_2 + w_{31}HS_3 + w_{41}HS_4}{1 + w_{21} + w_{31} + w_{41}}$$

After get HS_U, we can estimate the distance between U_1 and each anchor node according to minimum number of hops.

Transformation from anchor node to cooperative node: The basic idea of cooperative location algorithm is to conditionally transfer unknown node after location into anchor node and thus participate in the location of other unknown nodes. Only the node whose location accuracy is high enough could it be transformed into the anchor node. Otherwise the error could be accumulated (Li and Kunz, 2007).

Just like what was shown in Fig. 1, the position of the unknown node U_1 was calculated through maximum likelihood estimation by M_1, M_2 and M_4. The location error can be analysis as follows: swap U_1 with any anchor node (M_1), then use another two anchors (M_2 and M_4) to calculate the position of anchor node (M1). Because the position of anchor node is known, if M_1's estimated

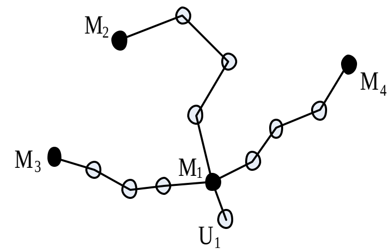

Fig. 2: Confidence level of anchor nodes

position is close to its real position, it could prove that the node's position accuracy is quite excellent. Assuming that the actual coordinate of M_1 is (x, y) and estimated coordinate after swap is (x', y'), node communication radius is R and then the normalized location error could be expressed as:

$$e = \sqrt{(x - x')^2 + (y - y')^2} / R$$

We should determine an error threshold value-M in advance, only when the normalized location error meets $e \leq M$, could it be transformed to the anchor node to participate the position calculation of other unknown node.

IMPLEMENTATION PROCESS

The implementation process of DC DV-Hop is as follow:

- **Step 1:** Through the anchor nodes flood information, each unknown nodes are acknowledged about the number and hops with anchor node which are connected to themselves
- **Step 2:** The unknown node selected three anchor nodes according to their collinear degree
- **Step 3:** Refer to the nearest anchor node of unknown node, we can calculate the other node confidence level and carry out their average one-hop distance according to formula (5)
- **Step 4:** Calculate the distance between the unknown nodes and each anchor node and estimate the position of unknown nodes by maximum likelihood estimation
- **Step 5:** Calculating the location error by the method described in 2.4 and transform nodes into anchor node which meet the error condition
- **Step 6:** cycle steps above by new anchor set, until there is no unknown nodes in the sensor network can be location

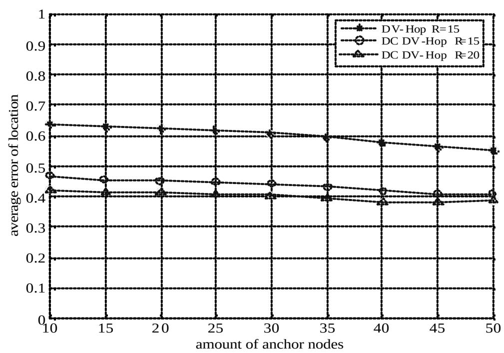

Fig. 3: Location error for anchor nodes number

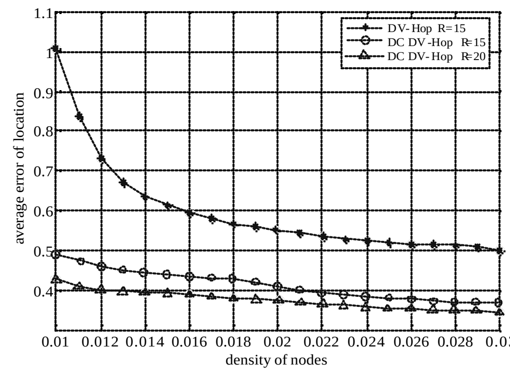

Fig. 5: Average location error for nodes density (anchor nodes number is constant)

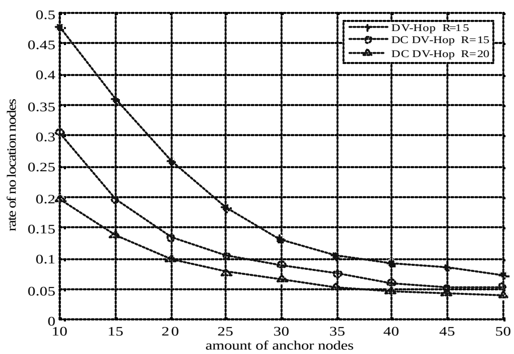

Fig. 4: Remaining node ratio for anchor nodes number

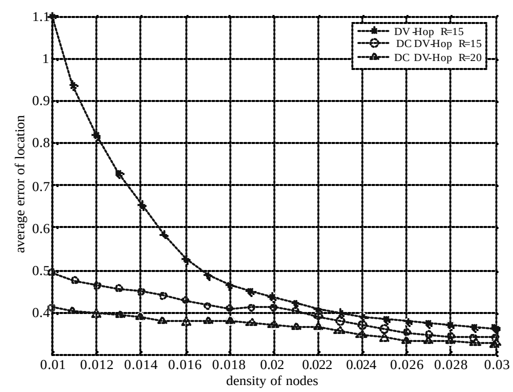

Fig. 6: Average location error for nodes density (anchor nodes ratio is constant)

SIMULATION AND ANALYSIS

We use MATLAB to simulate the calculation process, setting the sensor network in a 100*100m square area,anchor nodes and unknown nodes randomly distributed in. All nodes have the same communication radius.

Figure 3 and 4 show the variation of the normalized location error with the remaining nodes ratio. We simulated the two location algorithm with node communication radius are 15 or 20 meters respectively. Remaining nodes ratio refers to the proportion among the total number of nodes which can not be located after complete the location algorithm. Just as what can be seen from the figure, with the same number of anchor node and communication radius, DC DV-Hop algorithm has lower location error and remaining nodes ratio than DV-Hop algorithm. And we can see that even if the anchors number is smaller, the improved location algorithm can also acquire relatively low error and remaining nodes ratio. When the anchor numbers are at the same, the bigger the communication radius the smaller DC DV-HOP algorithm's location error and remaining nodes will be. When anchor nodes are over 40, the two parameters values tend to stable. This showed that DC DV-HOP algorithm has better robustness.

Figure 5 and 6 respectively show the relationship between average location error and nodes density in the condition that the total number and the ratio of anchor nodes are constant. As what can be seen from the figure, in both cases, improved algorithm's location error would be smaller than the original algorithm, especially when nodes density is quite small, the improved algorithm has a rather low location error ratio, the performance advantage is more obvious. When the node density is at the same, the larger the communication radius is, the smaller location error will be.

CONCLUSION

This study proposed a distributed cooperative location algorithm based on the DV-Hop. To reduce the location error, we first filter the anchor nodes by their collinear degrees; then correct the average one-hop distance by confidence level of each anchor node; finally, in order to reduce the ratio of the position remaining nodes, we transform some node after location as anchor node to continuous perform location algorithm. Through the simulation we could prove that when anchor nodes density and nodes communication radius is small, our algorithm can get small location error and lower remaining node ratio.

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