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An Improvement of DV-Hop algorithm Based on Collinearity

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Abstract—In order to fully consider the topology relationship among the anchor nodes and the topology relationship between the anchor nodes and unknown nodes, an Improvement of DV-Hop Algorithm Based on Collinearity is proposed. The main principle of the proposed scheme is to introduce the concept of normalized colinearity (NC) into the selection phase of beacon nodes. Based on DV-Hop, best available anchor terns are elected to accomplish more accurate localization by using NC. The experimental results show that the location accuracy of the proposed algorithm outweighs significantly the DV-Hop algorithm, especially in the cases where the connectivity is lower than 10.

I. Introduction

A wireless sensor networks is a large ad-hoc network consisting of densely distributed light, small, cheap sensor nodes which are equipped with low power transceivers and have limited data processing capabilities. Many applications of WSN are based on sensor self-positioning, such as battlefield surveillance, environments monitoring, indoor user tracking and others, which depend on knowing the location of sensor nodes. Because of the constraint in size, power, and cost of sensor nodes, the investigation of efficient location algorithms which satisfy the basic accuracy requirement for WSN meets new challenges [1].

Today, GPS is the most widely used and mature currently. It has high positioning accuracy and good real-time. Although GPS is better applied in the outdoor environment, it cannot work indoors or in the presence of many obstacles that may block the line of sight from the GPS satellites. Therefore, WSN provides a good alternate to sense the information of the environment such as the location in the indoor situation and the outdoor situation that blocks the use of GPS satellites.

Recently, many localization algorithms for sensor networks have been proposed. Most of them suppose that the networks are consisted of a small number of anchor nodes, which know their position by using GPS or other methods, and a large number of the unknown nodes which positions need to be commutated with the help of the anchor nodes. People use trilateration, triangulation, and maximum likelihood estimation to get the position [2]. The trilateration and maximum likelihood estimation are mainly used to figure out its position when an unknown node knows three or more than three anchor nodes' position information.

At present, based on whether it is required to measure the actual distance between nodes or not, the localization algorithm can be divided into two categories: Range-based and Range-free. The range-based algorithms need to measure the exact distance or orientation between neighbor nodes, and then use the information to localize nodes. Range-free algorithms use estimated distance instead of metrical distance to localize nodes. Several ranging techniques are often used for range measurement, such as angle-of-arrival (AOA) [3], received signal strength indicator (RSSI) [4], time-of-arrival (TOA) [5], and time difference of arrival (TDOA) [6]. Due to conquer the drawbacks of the high cost and energy consumption in the range-based algorithm, solutions in range-free localization are being pursued without using any additional hardware. There are many range-free algorithms: Centroid algorithm [7], DV-Hop algorithm [8], Amorphous [9] and APIT [10].

Some previous works [10]–[12] study the effect of the localization accuracy with the different node deployment, especially the effect of beacon placement. Savvides [13] investigates how the deployment geometry affects localization accuracy and concludes the localization error in the perimeter of the network is usually large because the angles to each beacon are very small. C. Poggi [14] studies when anchors are much aligned (but not totally) a little distance estimation error could cause great position error due to the intersection point between circumferences could be very far from the real sensor position.

In this paper, we present an Improvement of DV-Hop Algorithm Based on Collinearity. The proposed method considers sufficiently the topology relationship of beacons and the topology relationship between beacon nodes and unknown nodes. And our algorithm can improve location accuracy without increasing additional hardware cost of sensor node. Simulation results show that the performance of this algorithm preponderates over the DV-Hop algorithm. Compared with DV-Hop, it is more available for WSN.

This paper makes three major contributions to the localization problem in WSN. First, we propose a practical, effective and easy to actualize localization scheme with relatively high accuracy and need no any extra-hardware to

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assist. Second, the proposed algorithm improves significantly positioning accuracy than the DV-Hop algorithm. Third, we investigate the influence of the topology relationship among beacons and the topology relationship between beacon nodes and unknown nodes on localization performance of the DV-Hop algorithm, together with the effect of the radio of anchor nodes and nodes density.

The rest of this paper is organized as follows: Section II introduces the basic DV-Hop algorithm and analyzes the error resources of the DV-Hop algorithm. Our algorithm is described in Section III. Section IV evaluates the algorithm performance by simulations. And Section V draws the conclusion.

II. THE ERROR ANALYSIS OF DV-HOP

Niculescu and Nath [8] have proposed the DV-Hop which is a distributed, hop by hop positioning algorithm. The algorithm implementation is comprised of three steps. First, it employs a classical distance vector exchange so that all nodes in the network get distances, in hops, to the anchor nodes. And then, it estimates an average size for one hop, which is then deployed as a correction to the entire network. When receiving the correction, an arbitrary node may then have estimate distances to landmarks. Finally, unknown nodes calculate their location by trilateration or maximum likelihood estimation.

A. The Fundamental of DV-Hop

In the first step, each anchor node broadcasts a beacon to be flooded through the network containing the anchors location with a hops value initialized to one. Each receiving node maintains the minimum hops value per anchor of all beacons it receives. Beacons with higher hops values to a particular anchor are defined as stale information and will be ignored. Through this mechanism, all nodes in the network will get the minimal hops to every anchor node.

In the second step, once an anchor gets hops value to other anchors, it estimates an average distance for one hop, which is then flooded to the entire network. When they have the hop-distance and hops to other anchors, they will estimate the distance from themselves to all anchors that they can receive by multiplying the hop-distance by hops. The average hop-distance is estimated by anchor i using the following formula:

$$C_i = \frac{\sum \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum h_i} \tag{1}$$

Where (x_i, y_i) , (x_j, y_j) are coordinates of anchor i and j , h_i is the hops between beacon i and all other beacons.

Each anchor node broadcasts its average hop-distance to the network using controlled flooding. Every unknown node will receive the first correction as its average hop-distance and throw away the other correction from other anchors. This scheme could assure that the most nodes receive the average hop-distance from beacon node that has the least hops between them. In the end of this step, unknown nodes compute the distance to the beacon nodes based hop-distance and hops to the beacon nodes.

In the last step, Let (x, y) be the unknown node M location and (x_i, y_i) is the known location of the i'th anchor node receiver. Let's define the i'th anchor node distance to unknown nodes if d_i , well then, there is the following formula:

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = d_1^2 \\ (x - x_2)^2 + (y - y_2)^2 = d_2^2 \\ \quad\vdots \\ (x - x_i)^2 + (y - y_i)^2 = d_i^2 \end{cases} \tag{2}$$

The coordinates of M is computed by the following formula:

$$A = -2 \times \begin{bmatrix} x_1 - x_n & \mathrm{y}_1 - y_n \\ x_2 - x_n & \mathrm{y}_2 - y_n \\ \vdots & \vdots \\ x_{n-1} - x_n & \mathrm{y}_{n-1} - y_n \end{bmatrix} \tag{3}$$

$$B = \begin{bmatrix} d_1^2 - d_n^2 - x_1^2 + x_n^2 - y_1^2 + y_n^2 \\ d_2^2 - d_n^2 - x_2^2 + x_n^2 - y_2^2 + y_n^2 \\ \vdots \\ d_{n-1}^2 - d_n^2 - x_{n-1}^2 + x_n^2 - y_{n-1}^2 + y_n^2 \end{bmatrix} \tag{4}$$

$$X = \begin{bmatrix} x \\ y \end{bmatrix} \tag{5}$$

Because $AX = B$, so we can obtain the solution:

$$X = \left(A^T A\right)^{-1} A^T B \tag{6}$$

B. The Error Source of DV-Hop

After the second step of DV-Hop, unknown nodes will have the position information and distance estimates of all anchor nodes. Then, they will choose three or more than three anchors to execute trilateration or maximum likelihood estimation to get the position. Generally speaking, the more anchors the unknown nodes choose, the more accuracy estimation is. However, unfortunately, many situations are not that case. In fact, the topology relationship among anchors and the topology relationship between anchor nodes and unknown nodes will affect the localization of unknown nodes to a great extent. In order to simplify the problems, now we will analysis the effect of topology relation of three anchors. In the DV-Hop algorithm, there are three situations which will result in large localization error:

1) When anchors are nearly in a straight line, positioning error could be large because the intersection points between circumferences could be very far from the real

node position, especially when anchors are totally aligned. As shown in Fig.1, anchor A, B, C are almost aligned, and its estimation may have two positions where the real position is D.

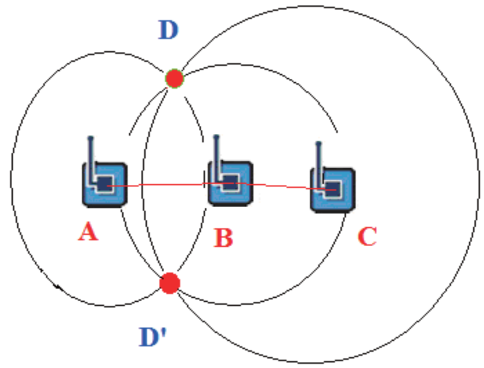


Fig.1 Three Anchor Nodes in a Line

2) The second bad situation is that: when the relative position of any two anchors is too close and they are also far from the unknown nodes, it may be easy to result in large location error. As shown in Fig.2, the position of anchor B, C are near and the distance between them and unknown nodes are too far, so we can nearly ignore the distance between B and C comparing to the distance between them and unknown nodes. And then it will cause real position D to be estimated at the position D'.

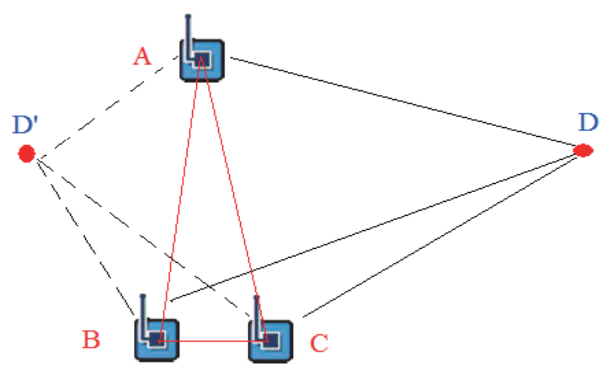


Fig.2 Two Anchor Nodes Too Closed

3) The third bad situation is that: when three anchors are all near by, no matter what triangular shape that they compose is, if unknown nodes have a further distance to them, will lead to a great error. As shown in Fig.3, because DV-Hop estimates their distance by their hops to other nodes, unknown node D may have the same distance estimate to three anchors and then executes trilateration to get no solution or location error is very large.

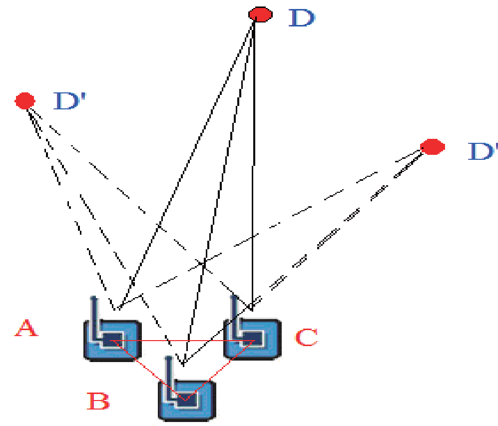


Fig.3 Three Anchor Nodes Too Closed

To solve these problems, we proposed an Improvement of DV-Hop Algorithm Based on Collinearity for wireless sensor networks. In the last step of DV-Hop, we do not use the traditional maximum likelihood method to solve the location of the unknown node, but single out best available anchor terns satisfied with the specified threshold, and then proceed to estimation by performing trilateration. The results may have been a series of position estimates, and we use our weighted estimation mechanism to get the node ultimate location through setting their collinearity degree as their size of the weight.

III. THE PROPOSED ALGORITHM

DV-Hop has good distribution and scalability, but the positioning performances are constrained by the network topology, especially in the sparse network or non-uniform distribution network and the location accuracy is not high. The paper [14] analysed the effect of location with the relationship of the topology of anchors, and put forward to select the combination of good triangular shape by using the parameter of collinearity so as to enhance the positioning accuracy. However, this method has not been applied to multihop node localization. Our proposed algorithm based on the DV-Hop not only redefined the concept of collinearity and introduced the topology relationship of the anchors to multihop sensor networks. Our algorithm achieves the goal of increasing positioning accuracy and does not require any additional hardware.

A. Normalized Collinearity

The paper [14] adopted the minimum of the three heights of the triangle formed by the anchors as collinearity of one tern. However, in fact, the more fundamental parameter about the shape of the triangle is the interior angle of the triangle. As a result, this article will redefine the parameter of collinearity. Fortunately, our normalized collinearity is a constant, so our parameters of collinearity can be used in many other occasions and do not have to make any change.

Our collinearity is very simple definition. Collinearity is the maximum of the three Cosine of interior angle of the triangle composed by a set of anchors. Thus, the process of calculation is also very simple. We can be convenient to use triangular law of cosines to obtain:

$$C_A = \left| \frac{b_{C,A}^2 + c_{A,B}^2 - a_{B,C}^2}{2b_{C,A}c_{A,B}} \right| \quad (7)$$

$$C_B = \left| \frac{a_{B,C}^2 + c_{A,B}^2 - b_{C,A}^2}{2a_{B,C}c_{A,B}} \right| \quad (8)$$

$$C_C = \left| \frac{a_{B,C}^2 + b_{C,A}^2 - c_{A,B}^2}{2a_{B,C}b_{C,A}} \right| \quad (9)$$

And A, B, C represents the angles that are composed by the anchor node A, B, C. $a_{B,C}$, $b_{C,A}$, $c_{A,B}$ represents the sides responding to angle A, B, C. So, we can at once get the normalized collinearity of anchor node terns:

$$NC = \max\{C_A, C_B, C_C\} \quad (10)$$

Due to the normalized collinearity represents the cosine of minimum angle of the triangle its scope is 0.5 to 1.0 (corresponding angle is from 0° to 60°). If NC equals to 0.5, the triangle is equilateral triangle and in this case the localization will be best theoretically. If NC equals to 1, the anchor tern is totally aligned and results in the worst localization. Our goal of defining the parameter of collinearity is to differentiate the good group and the bad group in all anchor node groups that an unknown node can collect. Therefore, we can select the good anchor terns to realize the better position estimate though using the collinearity.

B. *Our algorithm*

After the unknown node collects all anchor nodes information, we extract these anchor nodes at the random way to form a set of combination (take three anchor nodes as a tern). Then we separately calculate the collinearity of these terns. Because we have known position information of all anchor nodes, the collinearity of every tern is very easy to get by using triangular law of cosines. Then, we can establish an especial threshold value to choose good terns. If this threshold value is too large, this leads very few anchor node terns to be selected to complete the localization or even can not complete. If this threshold value is too small, this causes the collinearity to lose capability to select good anchor terns and thus make the collinearity no sense. Therefore, how to choose appropriate threshold of the collinearity parameter will be key research topic in our simulation. After set a good threshold value of the collinearity, it can be able to implement the trilateration to get a corresponding position estimate. And we can obtain a set of positions due to that we may get many anchor nodes tern that satisfies with the special threshold. Therefore, based on the collinearity we put forward a weighted estimate mechanism to get a final estimate of the location. The overall algorithm process is as follows:

4) Implement the first two stages of the DV-Hop, each of the unknown nodes collects all the anchor nodes location and distance information they can.
5) Calculate the NC of each tern, and then select the good terns with NC smaller or equal to special collineartiy threshold.
6) Get a set of locations through using trilateration with selected anchor node terns, and record the NC of each tern.
7) Calculate the reciprocal of each NC and record them, and then compute corresponding weight W_i of each tern.

$$W_i = \frac{\frac{1}{NC_i}}{\sum_i \frac{1}{NC_i}} \quad (11)$$

8) Obtain the final position estimate by multiplying a set of locations by their corresponding weight.

$$Position = \begin{bmatrix} X \\ Y \end{bmatrix} W' \quad (12)$$

As long as the networks are connected, nodes in the DV-Hop can attain anchor nodes information forwarded by other nodes. It seems that it has so good advantage that most of nodes can get enough useful anchor nodes information to achieve their localization. However, we find this also causes large location error in our initial simulation because the more hops, the larger the error of the distance estimate. Therefore, we will set a restriction on the hop values that the unknown nodes can collect. If the hop value between unknown node and anchor node is beyond the given threshold value, then give up the anchor nodes information. Although this mechanism can improve the accuracy of the localization, it also results in the poor coverage. Fortunately, as the improvement of the networks connectivity and the radio of anchor nodes, coverage can quickly increase to good percentage. Thus, how to set an appropriate threshold value of hops is also a key research topic in our simulation. An appropriate threshold value of hops will find a good balance between the location accuracy and the location coverage.

IV. SIMULATION RESULTS

To validate our algorithm, sensor networks consisting of 100 sensor nodes are assumed to be randomly distributed in an 60×60 m2 region. The connectivity of sensor networks is controlled by the radio range of sensor node (R). And we will simulate the DV-Hop algorithm and our algorithm in random deployment and uniform deployment networks.

In our experiment, we define some useful system parameters: Node Density (ND) is that average number of nodes per node radio area, Radio of Anchors (RA) is anchor nodes percentage, Threshold of Hop (TN) is that a node can receive the anchors that must inside the four hops near this node, Threshold of NC (TNC) is that which anchor terns can be chosen if NC of this tern can satisfy the threshold.

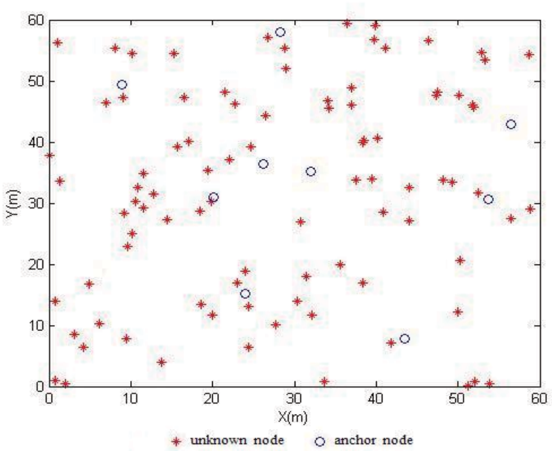
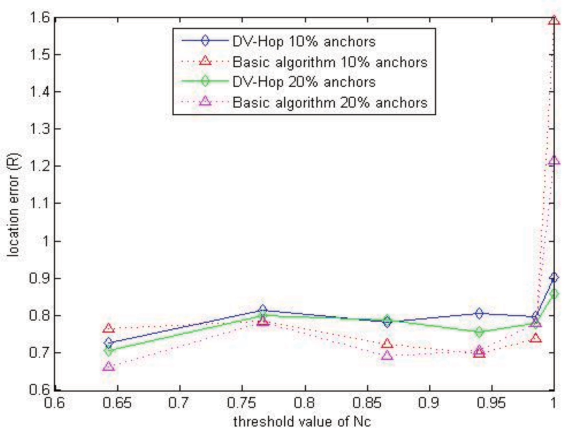


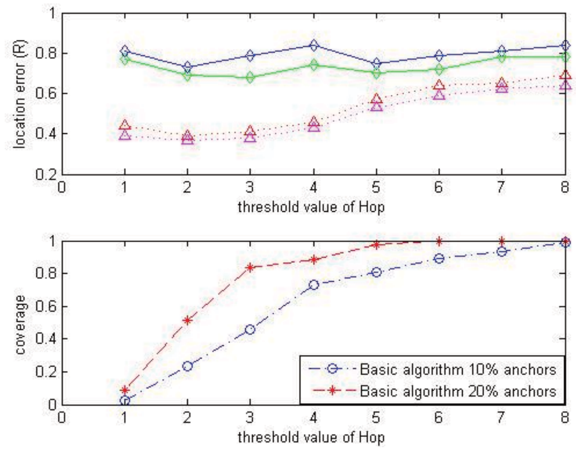
Fig.4 Node Distribution



ND=7.8, TH=INF, Random

Fig.5 Location Error Varying TNC

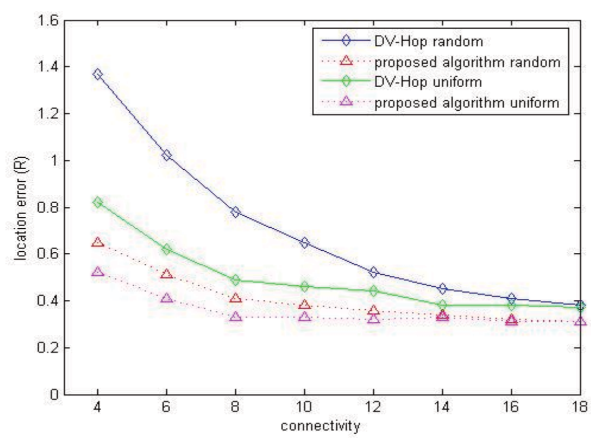
As shown in Fig.5, the performance of our basic algorithm is compared with that of DV-Hop algorithm with varying the threshold value of collinearity. And two conclusions can be drawn: (1) when the collinearity threshold changes from 0.78 to 0.98, positioning accuracy in our basic algorithm almost rises 2% to 13.5% than that in the DV-Hop algorithm, especially raises 10% with TNC from 0.85 to 0.95; (2) when collinearity threshold is too small or too large, the performance of our basic algorithm becomes much worse. This is because when collinearity threshold is too small, equivalent theoretically to use no collinearity to eliminate very bad anchor node terns. Although some anchor terns are good, the final positioning accuracy is obviously not good at all. When the threshold is too large, anchor terns that can be satisfied with given condition are so few, together with coarse distance estimates in the DV-Hop algorithm, that the location error may be very large. But when the radio of anchor nodes increases, the performance of our algorithm significantly improves, especially in the lower and higher threshold. Because at this time nodes can select more and more anchor terns and have high degree of information redundancy.



ND=7.8, TNC=0.9, Random

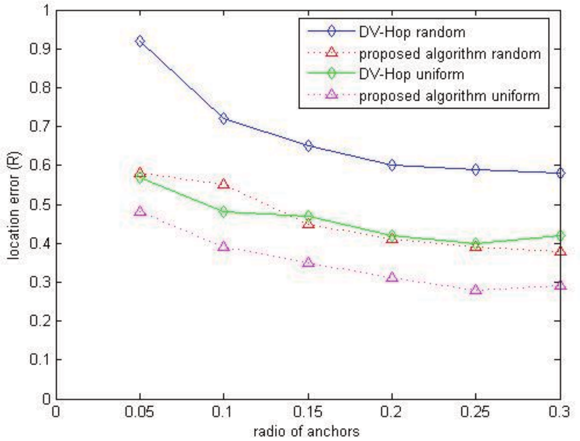
Fig.6 Error and Coverage Varying TH

Fig.6 shows that: (1) as the threshold value of hops increases, the performance of location error in our basic algorithm improves 20% to 40% than that in the DV-Hop algorithm. Location accuracy from one hop to four hops remains high improvement about 40%, but after five hops deteriorates to 20%. At the same time, location coverage changes significantly in the four hops, and after five hops reaches above 80% with 10% anchors and 95% with 20% anchors and increases gradually to slow down; (2) When the radio of anchor nodes increases, the improvement of the location error is not obvious but the location coverage is improved significantly. In the other word, our algorithm does not depend on high initial radio of anchor nodes.



RA=20%, TH=3, TNC=0.9

Fig.7 Location Error Varying ND



ND=7.8, TH=4, TNC=0.9

Fig.8 Location Error Varying RA

As shown in Fig.7 and Fig.8, the proposed algorithm outweighs significantly the DV-Hop algorithm. In terms of random distribution or uniform distribution networks, the average location error in our algorithm decreases 16% to 52% than the DV-Hop algorithm, especially in the cases where connectivity is less than 10. And the performance of both our algorithm and the DV-Hop algorithm in the uniform distribution are better than that in the random distribution, especially in the cases where connectivity or ND is low. In our analysis, there are fewer holes [15] in the networks with low connectivity in the uniform distribution and so better topology effectively reduces location error. As the radio of anchor nodes increases, the location error of the proposed algorithm decreases gradually to 38% in the random distribution and 29% in the uniform distribution. However, we must point out that when the connectivity is low, location coverage has also decreased a lot. Fortunately, as ND and RA increase, the coverage improves rapidly because nodes can select more and more anchor node terns to achieve localization.

V. Conclusions

We present a novel robust and distributed algorithm for solving the problem of localization within wireless sensor networks. We firstly analysis the error resource in the DV-Hop, and explores three bad topology relationship among anchor nodes. Then we introduce the concept of normalized colinearity (NC) and define NC that has more essential meaning and can be applied into many situations without any change. Based on DV-Hop, we add a selection process. By this process, we can choose best available anchor terns to achieve more accurate localization with our weighted estimation mechanism. The experiment results have proven the validity of our method. But the shortcoming of the algorithm is that when the connectivity is too low the location coverage is also very low. Therefore, our future work is planning to design a beacon upgraded mechanism to improve the coverage.

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