International Journal of Future Generation Communication and Networking
Vol. 9, No. 11 (2016), pp. 125-136
http://dx.doi.org/10.14257/ijfgcn.2016.9.11.12

DV-Hop Node Localization Algorithm Research and Optimization

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Abstract

The purpose of sensor network node localization is to obtain the information about the absolute or relative locations of various kinds of sensor nodes on the plane or in space. In many sensor network application fields, one important issue that users are concerned about is: in what location or area an inappropriate use or detection situation occurs. Sensor network node technology provides vital node location information for a whole network system's obtaining a large amount of detailed and reliable monitoring information. The obtaining of node location information will directly influence the effectiveness of the whole network system, so study on the node localization mechanism and algorithm involved in a wireless sensor network is the key to realizing node localization technology. In this paper, based on wireless sensor network research, a range-free localization mechanism based on DV-Hop localization algorithm is analyzed, with the optimized processing of this algorithm preliminarily realized, with an intuitive understanding of the relationship between nodes and localization errors realized through MATLAB simulation experiment.

***Keywords**: sensor network node technology; range-free; DV-Hop localization algorithm*

1. Introduction

A range-free localization mechanism is a localization mechanism that can realize certain accuracy localization simply based on the network connectivity situation and beacon node location information. Despite its relatively low localization accuracy compared with a range-based localization mechanism, with its measurement permitting, no need for additional equipment makes it able to use low-cost and low-power consumption wireless network sensors. At the current stage, low cost and energy consumption is a trend in technical development and research. The experiment shows that when the required location error is 40% less than the wireless communication radius of sensor nodes, the localization error won't have a great effect on routing performance and target tracking [1]. Therefore, for some wireless network applications, its localization accuracy can meet the application requirements. The DV-Hop (Distance Vector-Hop) localization algorithm studied in this paper is a localization algorithm that utilizes multi-hop beacon nodes in the range-free localization mechanism. The whole algorithm involves three stages, with a typical distance vector exchange method used to enable all unknown nodes to obtain the hop count of beacon nodes in Stage 1; with the network's average hop distance of bacon nodes calculated based on relevant formula after the locations and interval hop count of the other beacon nodes are obtained, with the calculated distance used as a correction value to be broadcast to the network to ensure that most nodes can receive the average single-hop distance value from the nearest beacon node and then calculate the distance to each bacon distance based on the recorded hop

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ISSN: 2233-7857 IJFGCN

count in Stage 2; with a multilateral measurement and localization process [2] implemented in Stage 3.

2. Wireless Sensor Network Node Localization and Algorithm Analysis

2.1. Basic Principle and Method of Node Localization

The basic principle of node localization is consistent with the principle of the commonly used global positioning system (GPS), which means in a three-dimensional (two-dimensional) space, if a certain nodes to be determined obtains the distance to another four or more (more than three, including three) reference nodes, it is possible to obtain the location information of this node [3]. At the currently stage, the commonly used calculation methods for node coordinates mainly include trilateration [4], triangulation method and multilateral algorithm (maximum likelihood estimate).

Figure 2-1 shows the trilateration, in which the coordinates of three known Nodes A, B and C are set to be (x_a,y_a),(x_b,y_b) and (x_c,y_c), and their distances to the unknown Node D are set to be da,db and dc. This equation can be obtained:

$$\begin{cases} \sqrt{(x-x_a)^2+(y-y_a)^2}=d_a \\ \sqrt{(x-x_b)^2+(y-y_b)^2}=d_b \\ \sqrt{(x-x_c)^2+(y-y_c)^2}=d_c \end{cases}$$

If there exist errors in the measurement process, it will be impossible for the three circles above to meet at a point, and there will be errors in the obtained d_a, d_b and d_c, which makes it impossible to get a correct understanding of the equation above.

Figure 2-2 shows a triangulation method diagram, in which the coordinates of three known Nodes A, B and C are set to be (x_a,y_a),(x_b,y_b) and (x_c,y_c), with the angle of Node D in relation to Nodes A, B and C set. Actually, the triangulation method is still the transformation of trilateration, which means the node coordinates of Node D can be obtained based on the trilateration calculation principle.

Figure 2-2 shows a multilateral algorithm diagram, in which it is assumed that the distances of n beacon nodes (n≥3) are obtained from the measurement of a certain unknown Node u, with the location coordinates of the i^{th} beacon node being(x_i,y_i) and its distance to Node u being d_i. This equation can be obtained:

$$\begin{cases} (x_1-x)^2+(y_1-y)^2=d_1^2 \\ (x_2-x)^2+(y_2-y)^2=d_2^2 \\ \vdots \\ \vdots \\ (x_n-x)^2+(y_n-y)^2=d_n^2 \end{cases}$$

Where (x,y) is the coordinate of Node u. To linearize this issue, the above binary quadratic equation group can be converted into the form of AX=b by means of the former (n-1) equations minus the last equation respectively, where:

$$A=\begin{pmatrix} 2(x_1-x_n) & 2(y_1-y_n) \\ \vdots & \vdots \\ 2(x_{n-1}-x_n) & 2(y_{n-1}-y_n) \end{pmatrix}, \quad b=\begin{pmatrix} x_1^2-x_n^2+y_1^2-y_n^2+d_n^2-d_1^2 \\ \vdots \\ x_{n-1}^2-x_n^2+y_{n-1}^2-y_n^2+d_n^2-d_{n-1}^2 \end{pmatrix}$$

$\hat{X}=(A^TA)^{-1}A^Tb$ can be obtained by using a least square solution equation, based on which the estimated value of Location X can be obtained.

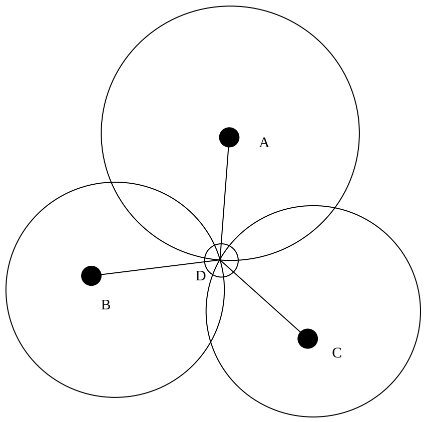

Figure 2-1. Trilateration Diagram

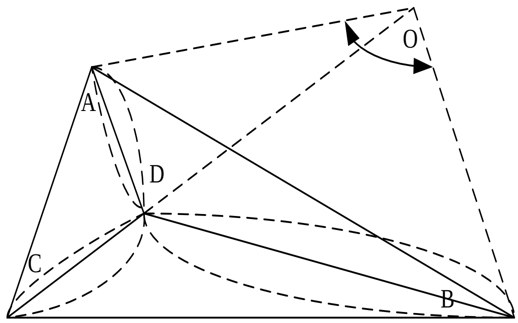

Figure 2-2. Triangulation Diagram

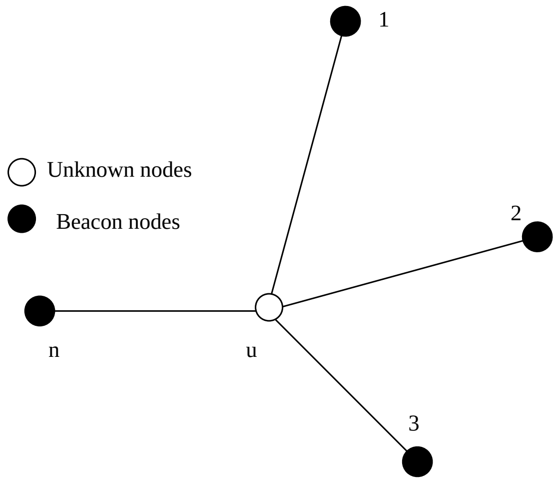

Figure 2-3. Multilateral Algorithm Diagram

2.2. Three stages of DV-Hop Algorithm

DV-Hop localization algorithm features simplicity and high localization accuracy, and it is one of a series of distributed localization methods[5] put forward through the utilization of distance vector routing and positioning ideas of GPS. A so-called distributed localization algorithm is a localization method based on the own calculation of nodes by depending on the information exchange and coordination between nodes.

The basic idea DV-Hop range-free localization algorithm is to express the distance from the unknown node to the beacon node with the product of the network's average hop distance and the hop count of the shortest path between the two, followed by the use of trilateration or its transformation form to obtain node location information, with the algorithm realization mainly including three stages [2].

2.2.1 The minimum hop count for a node in the network to obtain itself and each beacon node: Each reference node broadcasts its own location information grouping to neighboring nodes via a typical distance vector exchange protocol to enable all nodes in the network to obtain the information about the minimum hop count to the reference nodes.

At the first stage of DV-Hop algorithm, as long as the whole network is connected, each node, including each beacon node, can obtain the minimum hop count from the node to each beacon node and the location information of each beacon node. In Figure 2-4, taking a single node for example, the dissemination process of hop count in the network is shown, with the circles representing the communication radiuses of the node.

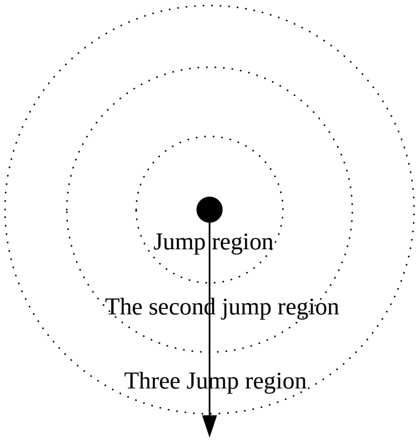

Figure 2-4. Hop Count Dissemination Process Diagram

2.2.2 Calculation of correction value of average hop distance by each beacon node : Each beacon node estimates the correction value of the average hop distance using next formula based on the location information about the other beacon nodes that is recorded at the first stage and the hop count apart.

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

Figure 2-5 shows a small sensor network consisting of nine nodes, with L_1,L_2 and L_3 being three reference nodes and the rest being unknown nodes to locate Node A.

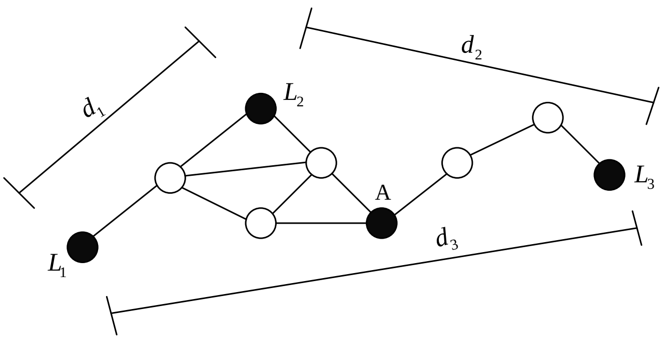

Figure 2-5. DV-Hop Localization Algorithm Diagram

(x_i,y_i),(x_i,y_j): Coordinates of Anchor Node I and Anchor Node j;
d_{ij}: Actual distance between Anchor Node i and Anchor Node j;
h_j: Hop counts between Anchor Node i and Anchor Node j;
Hs^D_i Hs^N_i:Average hop distance calculated, with Anchor Node i as datum;
M: Total number of anchor nodes;
λ_i: Weight of the average hop distance of Anchor Node i.

Each reference node calculates the average hop distance based on the location information about the other reference nodes and the minimum hop count apart and broadcasts it as a correction value to the network. After the correction value is received, a node calculates the distance to the reference node based on the hop count. The weight of the average hop distance can be obtained through normalized processing using Formula

$$\begin{cases} \lambda_i = \dfrac{h_i}{\sum_{k=1}^{M} h_k} \\ Hs^D = \sum_{i=1}^{M} \lambda_i Hs_i^D \end{cases}$$

The weighting process enables the average hop distance for node localization to be reflected in the average hop distance of a number of beacon nodes and makes the average hop distance for node localization closer to the actual average hop distance of the network.

2.2.3 Use of trilateration or maximum likelihood estimate to calculate its own position: Each unknown node calculate its own coordinate with trilateration or maximum likelihood estimate based on the distances of three or more beacon nodes recorded at the second stage. Analysis shows that DV-Hop localization algorithm uses some basic information about wireless sensor networks, such as network topology and location relationship between nodes, to realize the localization of the unknown node, which is a relatively simple process. Figure2-6 shows the general flow chart of DV-Hop localization algorithm.

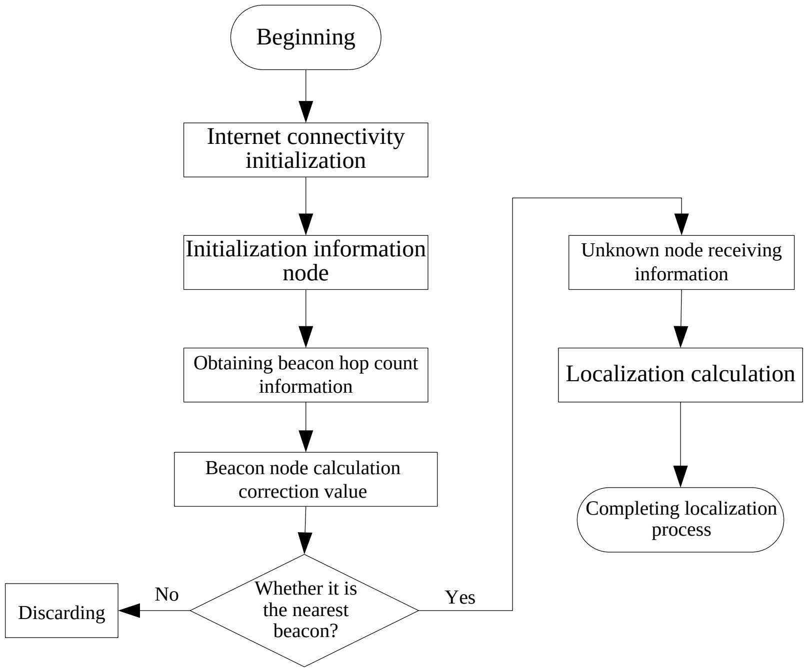

Figure 2-6. General Flow Chart of DV-Hop Localization Algorithm

3. Simulation analysis of DV-Hop Localization Algorithm

Simulation experiment on DV-Hop localization algorithm is conducted using MATLAB to analyze the performance of the localization algorithm, preliminarily realizing the optimization simulation of localization accuracy[6].

3.1. Analysis of Performance of DV-Hop Localization Algorithm

When the localization algorithm is measured in a wireless sensor network, besides node hardware requirements, more attention is probably paid to the localization accuracy of the localization algorithm, the proportion of beacon nodes in the entire network, the effect of network topology on the localization accuracy and the communication traffic and calculated amount involved in the realization of this algorithm. The following is the performance analysis of DV-Hop from the perspective of node localization accuracy.

3.1.1 Effect of the proportion of beacon nodes on the localization accuracy of DV-Hop localization algorithm: On the one hand, the location information of beacon nodes generally relies on manual deployment or GPS implementation. Manual deployment of beacon nodes is not only restricted by the network deployment environment, but also seriously restricts the expandability of the network and application, while the use of GPS as beacon nodes to provide location information costs two orders of magnitude more than the use of ordinary nodes [7], which means that though only 10% nodes are beacon nodes, the price of the entire network will be ten times higher [8]. On the other hand, the localization accuracy of range-free node localization algorithm is more accurate with the increase in the proportion of beacon nodes in the entire network [9].

In this paper, experimental simulation is conducted to analyze effect of the proportion of beacon nodes on localization accuracy. Figure 3-1 shows the random arrangement of 200 network nodes in a 500mx500m plane region, with the communication radium of nodes being R=100m, with the proportion of beacon nodes changed by changing the number of beacon nodes. The experimental result analysis shows that the localization accuracy of DV-Hop localization has improved to various degrees because the larger proportion of beacon nodes can increase the probability of beacon nodes appearing around unknown nodes and reduce the hop count to the nearest beacon node can reduce the localization errors produced during calculation.

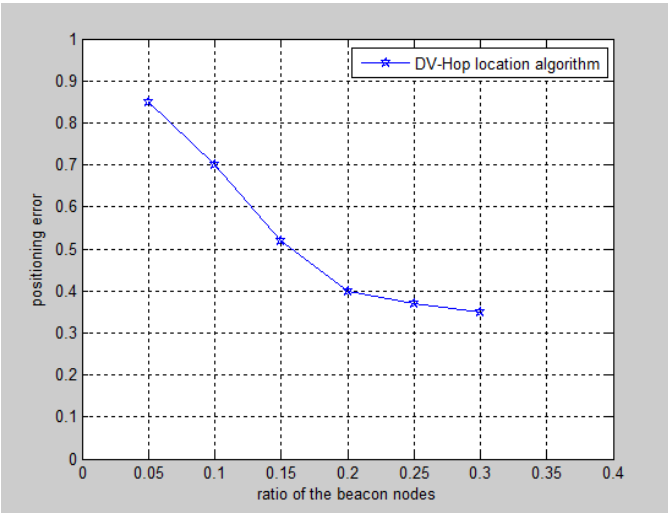

Figure 3-1. Effect of Porportion of Beacon Nodes on Localization Errors

3.1.2 Effect of network topology on the localization accuracy of DV-Hop localization algorithm: In DV-Hop positioning algorithm, the distance between unknown node and a beacon node is expressed with the product of the correction value of the nearest beacon node received by this node and the minimum hop count between the unknown node and the beacon node. If the topology of the network is an isotropic network topology as shown in Figure 3-2, and the network is a high-density network, the correction value of each beacon node in the network can be accurately estimated. However, the network nodes in actual application are usually deployed randomly, resulting in the network topology likely being an anisotropic dense network, in which case the correction value may not be able to be estimated well.

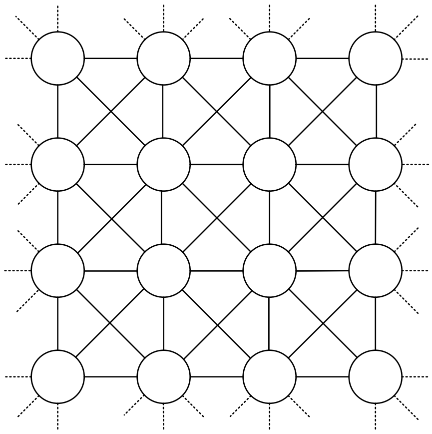

Figure 3-2. Isotropic Network Topology

In an actual network topology, the paths between unknown nodes and beacon nodes are often not linear, which significantly reduces the localization accuracy of DV-Hop localization algorithm in an actual network. As shown in Figure 3-3, Node L is set to be a beacon node, A, B and C are unknown nodes, the average single-hop correction value is set to be 10m, and the distance to Node L should be 3×10m based on the calculation using DV-Hop localization algorithm after Unknown Node C obtains the correction value. However, the path between Node C and Node L is not linear, but involves “holes” [10], making this calculated distance far larger than the actual distance between them.

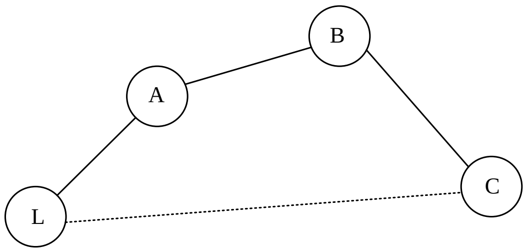

Figure 3-3. Localization Errors of DV-Hop Algorithm

Experimental simulation is conduced to verify effect of network topology on the localization accuracy of DV-Hop localization algorithm. The simulation results of Figure 3-4 and Figure 3-5 are the localization accuracy change trend diagram of isotropic network topology and anisotropic network topology respectively. The number of network nodes involved in the simulation experiment is 200.

The simulation results show that DV-Hop localization algorithm has significantly higher localization accuracy in isotropic network topology than in anisotropic network topology due to the nature of DV-Hop localization algorithm itself, which has no effect on its important reference value in range-free localization algorithm.

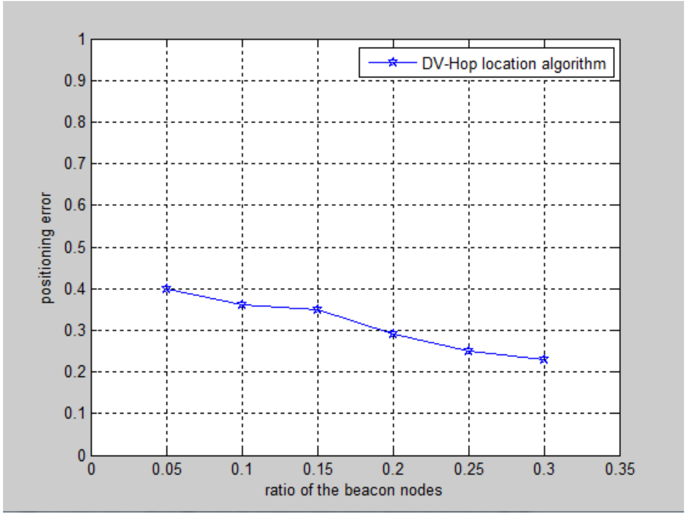

Figure 3-4. **Localization Accuracy of DV-Hop Localization Algorithm in Isotropic Network Topology**

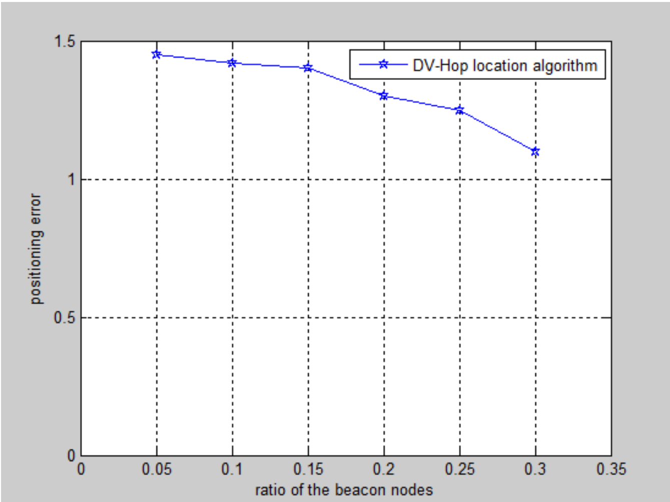

Figure 3-5. Localization Accuracy of DV-Hop Localization Algorithm in Anisotropic Network Topology

3.2. DV-Hop Localization Algorithm based on the Space order Sequence Optimization of Neighboring Nodes

In a wireless sensor network, as shown in Figure3-6, Node L is a beacon node and A, B and C are unknown nodes, of which A and C are both one-hop neighboring nodes of B. If the location information of Node B has been obtained through calculation, which means the |LB| distance value has been obtained, and because Node B is the one-hop neighboring node of Node C, so the distance between B and C *i.e.* |BC| is calculated based on average hop distance. If the value of Angle ∠LBC is obtained at this time, |LC| can be obtained. Although it is impossible to directly calculate or obtain the value of Angle ∠LBC, it is okay to use Angle ∠ABC of Edge BC of Node C and its precursor node B and Edge AB of Node B and its neighboring node A as an approximate substitute for Angle ∠LBC, and Angle ∠ABC can be indirectly calculated based on the number of the neighboring nodes of Node B and the sequence of its neighboring nodes.

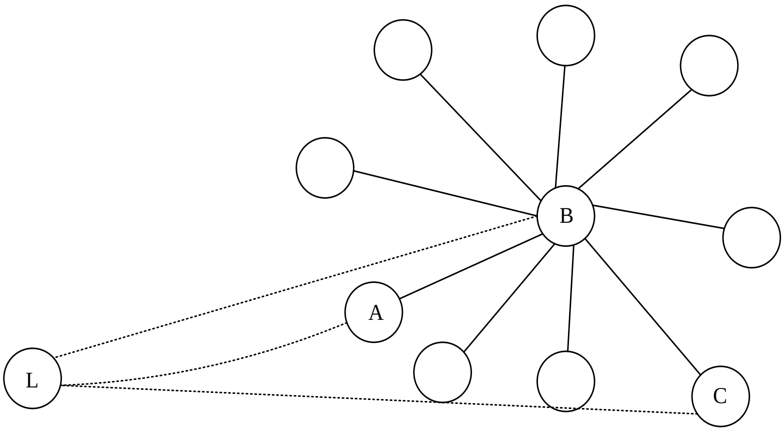

Figure 3-6. Local Network Topology Diagram

Research results show that if the neighboring nodes of two or more nodes in the network are consistent, the algorithm may involve local ordering errors.

In Figure 3-6 above, the number of nodes between Node A and Node C can indirectly reflect the size of Angle ∠ABC. It is assumed that Node B has n neighboring nodes, and among all neighboring nodes of Node B, the space order labels of Node A and Node B are i and j respectively, then:

$$\angle ABC \approx \frac{|j-i|}{n} \times 2\pi$$

In the network where nodes are randomly arranged, the larger the network density of the nodes is, *i.e.* the more neighboring nodes a node has, the larger the probability of even distribution of the nodes around it, *i.e.* the more approximate to the value $\frac{|j-i|}{n} \times 2\pi$ Angle ∠ABC is.

In the research on node localization algorithm, each experimental scene should be implemented a number of times to obtain the average of obtained results. In an experimental plane region with a fixed size, the average network node density is changed by changing the number of nodes, with network nodes randomly arranged in the experiment region, which means network topology is neither completely isotropic nor completely anisotropic.

Figure 3-7 shows the experimental result under different average network node densities in a 500m×500m plane region, with network nodes randomly arranged, with the node communication radius being R=100m, with the proportion of beacon nodes being 10%. Figure 3-8 shows the experimental result in the situation where the proportion of beacon nodes is changed by changing the number of beacon nodes in a 500m×500m plane region, with 200 network nodes randomly arranged, with the node communication radius being R=100m. The experimental data shows that in a situation involving a small proportion of beacon nodes, after the use of neighboring node space order sequence optimization, the localization algorithm has more significant advantages in terms of accuracy. Considering the cost of a wireless sensor network, under the premise of guaranteeing certain localization accuracy, the smaller the proportion of beacon nodes is, the better it is.

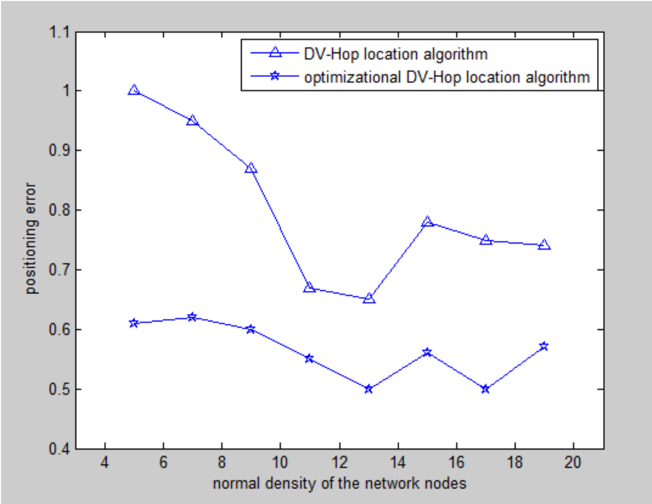

Figure 3-7. Effect of Network Node Density on Errors

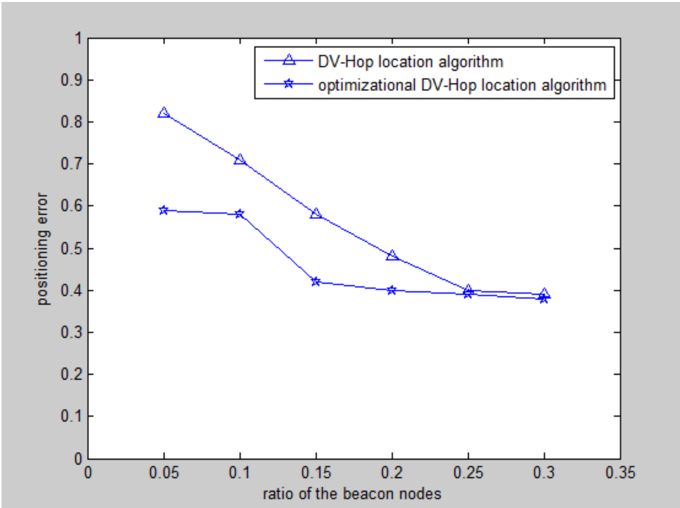

Figure 3-8 Effect of the Proportion of Beacon Nodes on Errors

4. Conclusions

It is stated in this paper that the research the localization issue involved in wireless sensor networks remains a difficult point technically and one of key points in wireless sensor networks from the perspective of a range-free wireless sensor network node localization mechanism, with DV-Hop localization algorithm as the research object. Despite relatively high accuracy of a range-based localization method, its requirements for node hardware are also high, which usually requires a number of measurements and iterative localization refinement, thereby increasing the costs for calculation and communication in industry technology, making it impossible to be widely used. Therefore, in this paper, the analysis of performance of DP-Hop localization algorithm at the current stage is made based on the research on DP-Hop localization algorithm and the DP-Hop localization algorithm based on neighboring node space order sequence optimization is proposed. The optimized localization algorithm can reduce wireless network hardware cost and its localization accuracy can be greatly improved within a certain beacon node proportion scope.

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