Research on Node Location Algorithms in Wireless Sensor Networks

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Keywords: WSN, DV-hop, deploy nodes model

Abstract: Wireless sensor network node positioning technology has a very important application in maritime positioning. According to the characteristics of static node location algorithm in wireless sensor networks, we simulated the DV-hop algorithm. Firstly, this paper introduces three node location methods, and then simulates and analyzes four node distribution modes. The special C-type distribution in military applications is analyzed emphatically.

1. Introduction

In modern military applications, the accuracy of location information plays an increasingly important role. WSN are mainly used to monitor various environmental characteristics in the network deployment area, such as temperature, humidity, illumination, magnetic field strength, etc. In wireless sensor networks (WSN) [1], location information is critical to the monitoring activity of the sensor network.

WSN are not only the focus of the development of Internet of Things, but also have broad application prospects in information warfare [2]. This paper first introduces the basic concept and structure of wireless sensor networks, and then briefly introduces the potential advantages of wireless sensor networks in the battlefield environment and the application status in the military, finally, simulates and analyzes four node distribution modes. The performance of each nodes deployed type are analyzed.

2. Basic concepts of WSN

Some important basic concepts in WSN can be summarized into the following:

Anchor node: nodes with known location information in wireless sensor networks [3].

Ordinary node: these nodes need to use the location information of the anchor node and then use the node location algorithms to estimate their position.

Neighbor node: other nodes included in the communication radius of the node in the WSN.

Hop count: the total number of hops that need to pass between two nodes for communication [4].

Connectivity: the number of nodes that the node includes within the communication radius [5].

3. Basic method of wireless positioning

3.1 The trilateration method

The trilateration method is based on the principle of geometric calculation to locate the unknown node [6]. First, the distance between the unknown node and the anchor node needs to be calculated, and then the coordinates of the unknown node are solved by solving the unknowns in the equations. As shown in Figure 1, the coordinates of the three anchor nodes A, B, and C are known as $(x_a, y_a), (x_b, y_b), (x_c, y_c)$. Suppose the coordinates of the unknown node D are set to (x, y), and the distance from the anchor nodes are d_a, d_b, d_c. The distance relationship between the four points A, B, C, and D is as shown in Equation 1.

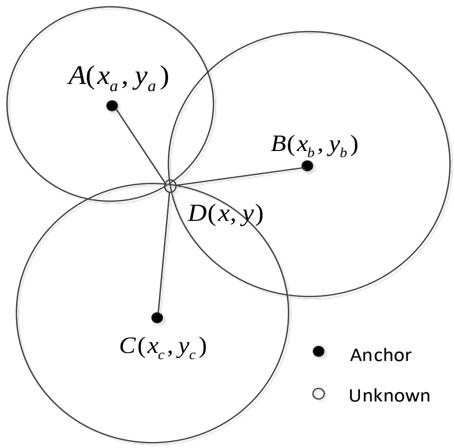


Fig 1 The Schematic diagram of trilateration method

$$\begin{cases} \sqrt{(x_a - x)^2 + (y_a - y)^2} = d_a \\ \sqrt{(x_b - x)^2 + (y_b - y)^2} = d_b \\ \sqrt{(x_c - x)^2 + (y_c - y)^2} = d_c \end{cases} \tag{1}$$

The coordinates of the node D obtained by the formula (1) is as shown in the formula (2).

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 2(x_a - x_c) 2(y_a - y_c) \\ 2(x_b - x_c) 2(y_b - y_c) \end{bmatrix}^{-1} \begin{bmatrix} x_a^2 - x_c^2 + y_a^2 - y_c^2 + d_c^2 - d_a^2 \\ x_b^2 - x_c^2 + y_b^2 - y_c^2 + d_c^2 - d_b^2 \end{bmatrix} \tag{2}$$

3.2 The Triangulation method

The triangulation method is also based on geometric principles for node positioning [7]. The basic principle of positioning is shown in Figure 2. The coordinates of the three anchor nodes A, B, and C are respectively as $(x_a, y_a), (x_b, y_b), (x_c, y_c)$. Suppose the coordinates of the unknown node D are set to (x, y), and the angle between unknown node D and anchor nodes A, B, and C to $\angle ADB, \angle ADC, \angle BDC$. For nodes A, C and $\angle ADC$, you can determine a circle with a center of $O_1(x_{o1}, y_{o1})$ and a radius of r_1 can be determined. As can be seen from Figure 3, $\alpha = \angle AO_1C = (2\pi - \angle ADC)$, and the relationship between them is shown in equation (3). In the same way, it can be obtained $O_2(x_{o2}, y_{o2})$ and r_2, $O_3(x_{o3}, y_{o3})$ and r_3 in turn. According to the coordinates of the three points $O_1(x_{o1}, y_{o1}), O_2(x_{o2}, y_{o2}), O_3(x_{o3}, y_{o3})$, and using the three-sided measurement method to get the coordinates of the D.

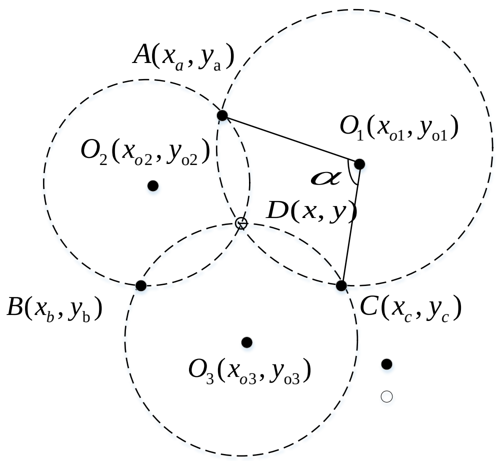


Fig 2 The Schematic diagram of the triangulation method

$$\begin{cases} \sqrt{(x_{o1}-x_a)^2+(y_{o1}-y_a)^2} = r_1 \\ \sqrt{(x_{o1}-x_c)^2+(y_{o1}-y_c)^2} = r_1 \\ (x_a-x_c)^2+(y_a-y_c)^2 = 2r_1^2-2r_1^2\cos\alpha \end{cases} \tag{3}$$

3.3 The maximum likelihood estimation method

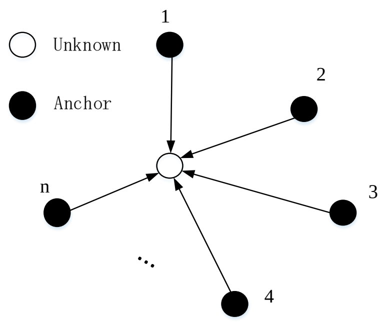


Fig.3 The principle of maximum likelihood estimation

The basic idea of the maximum likelihood estimation algorithm is shown in Figure 3 [8]. The coordinates of nodes $1,2,3,...,n$ are $(x_1,y_1),(x_2,y_2),(x_3,y_3),...,(x_n,y_n)$. The interval between them and node D is $d_1,d_2,d_3,...,d_n$. Suppose the coordinates of the unknown node D are set to (x,y). Using formula (4), we can get the coordinates of D node.

$$\begin{cases} (x_1-x)^2+(y_1-y)^2 = d_1^2 \\ (x_2-x)^2+(y_2-y)^2 = d_2^2 \\ \quad\quad ... \\ (x_n-x)^2+(y_n-y)^2 = d_n^2 \end{cases} \tag{4}$$

We can get formula 5:

$$\begin{cases} x_1^2-x_n^2-2(x_1-x_n)x+y_1^2+y_n^2-2(y_1-y_n)y = d_1^2-d_n^2 \\ \quad\quad ... \\ x_{n-1}^2-x_n^2-2(x_{n-1}-x_n)x+y_{n-1}^2+y_n^2-2(y_{n-1}-y_n)y = d_{n-1}^2-d_n^2 \end{cases} \tag{5}$$

The linear expression of formula (5) is $AX = b$.

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

We can get the coordinates of D node as:

$$\hat{X} = (A^T A)^{-1} A^T b \tag{6}$$

4. Positioning algorithm for WSN

4.1 Rang-free positioning algorithm

Rang-based positioning has high hardware requirements for wireless sensor nodes, resulting in increased hardware costs. Based on these, people have proposed rang-free positioning algorithm. The rang-free positioning algorithm does not require measuring the distance or orientation between the nodes, reducing the hardware requirements for the nodes, but the positioning error is relatively increased. DV-hop algorithm is a typical rang-free algorithm. The positioning process of the

DV-hop algorithm can be divided into the following three stages:

(1) Calculate the minimum hop count of the unknown nodes and each beacon node.

(2) Calculate the actual hop distance and the beacon node using the formula 7.

$$Hopsize_i = \frac{\sum_{j\neq i}\sqrt{(x_i-x_j)^2+(y_i-y_j)^2}}{\sum_{j\neq i} h_j} \tag{7}$$

In the formula 7, $(x_i, y_i),(x_j, y_j)$ are the coordinates of the beacon node i, j ; h_j is the number of hops between beacon nodes i and j, $(i\neq j)$.

After the unknown node receives the average hop distance, it estimates the distance to the beacon node based on the number of hops recorded. As shown in formula 8.

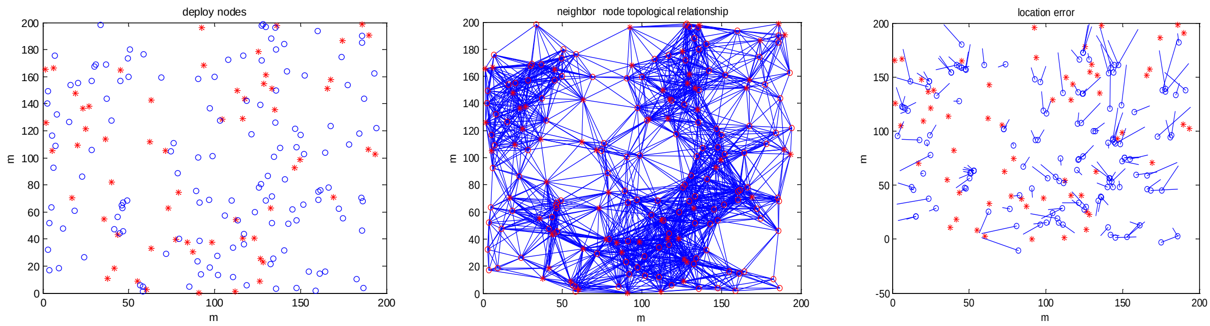
$$D_i = hops \times Hopsize_{ave} \tag{8}$$

(3) Calculate the position of the node itself using trilateration or maximum likelihood estimation.

5. Simulation

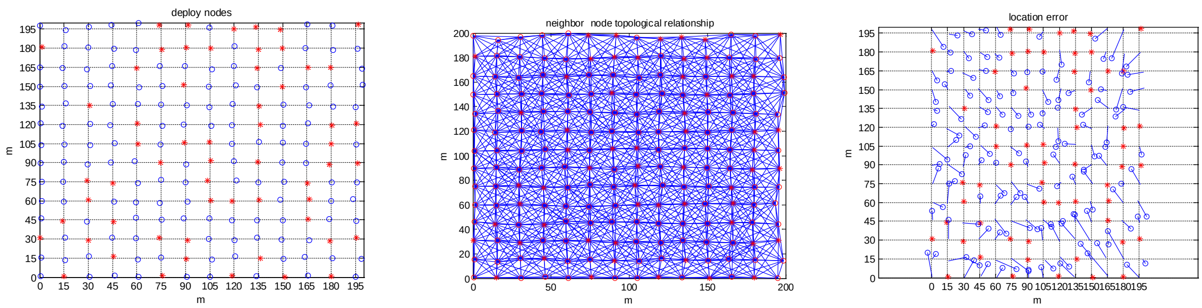
5.1 DV-hop algorithm

As shown in Figure 4 to Figure 8, the DV-hop algorithm is simulated. The specific parameters are as follows: (1) The communication model is based on regular model. (2) Nodes are distributed in the square area of $\mathbf{200} \times \mathbf{200}$m. (3) There 200 nodes, including 60 anchor modes and 140 unknown nodes. (4) The communication radius is 40m. (5) Node distribution adopt random rectangular distribution, regular rectangular distribution, random C-type distribution and regular C-type distribution respectively.



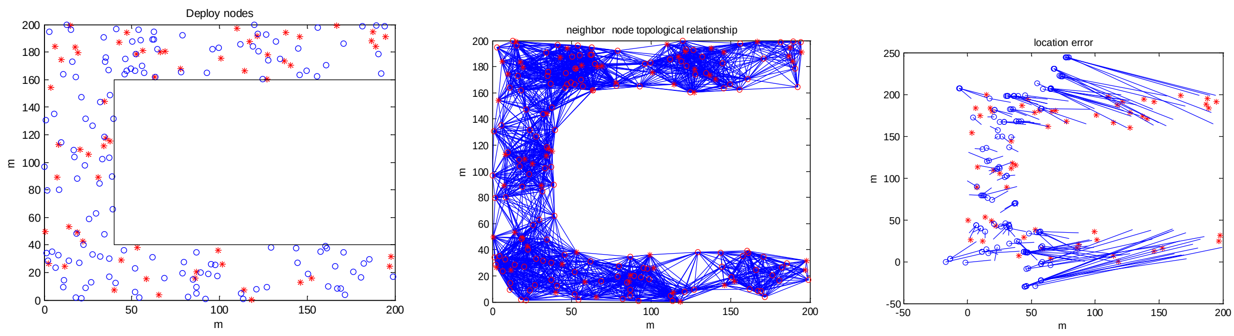
(a) (b) (c)

Fig.4 DV-hop with random rectangular distribution



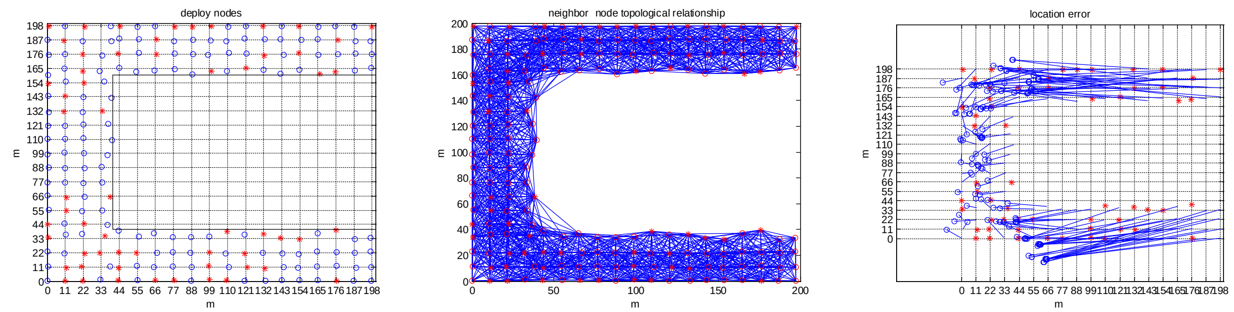
(a) (b) (c)

Fig.5 DV-hop with regular rectangular distribution



(a) (b) (c)

Fig.6 DV-hop with random C-type distribution



(a) (b) (c)

Fig.7 DV-hop with regular C-type distribution

Table 1 performance of four node distribution modes

area	Error(m)	Average connectivity(m)	Number of neighbor anchor nodes
Rectangular random	0.31399	20.65	6.325
Rectangular regular	0.24953	17.0204	5.1276
C-type random	1.4034	27.14	7.96
C-type regular	1.4428	24.0714	7.3469

In Figure 4 to 7, the blue represents the unknown node, the red represents the anchor node, and the trailing behind the blue represents the positioning error. The simulation results of DV-hop algorithm are shown in Table 1. It can be seen that the positioning error of nodes with regular rectangular distribution is lower than that with random rectangular distribution and the positioning error of nodes with regular rectangular distribution is lower than that with random rectangular distribution. Comparing C-type with rectangular type, the location error of DV-hop algorithm with C-type is larger than rectangular type and the greater of the connectivity of nodes, the greater of the positioning error. However, in military applications, the distribution of nodes with C-type is very important.

6. Conclusion

In this paper, the DV-hop algorithm is simulated, and the different situations of node distribution are discussed. The following conclusions are drawn:

(1) The positioning error of nodes with regular rectangular distribution is lower than that with random rectangular distribution.

(2) The positioning error of nodes with regular rectangular distribution is lower than that with random rectangular distribution.

(3) The greater of the connectivity of nodes, the greater of the positioning error.

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