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Localization Algorithm Research Based on the Least Square Method and Modifying the RSSI Weighted Centroid Algorithm

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Abstract. In the paper, through analyzing the inaccuracy for distance measuring and positioning during the target node positioning led to by the error of received signal strength indicator and studying the RSSI and centroid algorithm in-depth，a union positioning algorithm is proposed based on the least-square method for RSSI and modified weighted centroid algorithm: first to estimate the node position roughly by the least square method，then to calculate the node position coordinates precisely by the modified weighted centroid algorithm. In the algorithm, the sum of the reciprocal of the distance is used as the weight instead of the reciprocal of total distance to make the result more accurate. The simulation result demonstrates that the positioning accuracy can be increased greatly by this algorithm.

Keywords: least square method, positioning, received signal strength indicator, weighted centroid algorithm, Wireless Sensor Network (WSN)

1 Introduction

In recent years, large airports, underground shopping malls, office buildings and other public facilities are developing rapidly as China's urbanization process. With the expansion of the building area, it is becoming more and more important to provide location and navigation services for the indoor personnel. In the application of sensor networks, accurate target orientation is extremely necessary. So far, there are several methods commonly used for measured signals to achieve localization such as: TOA, TDOA, RSSI, AOA and so on. TOA and TDOA depends on accurate clock to achieve positioning effect, AOA requires the use of a particular antenna array to detect the source and location of the signal. While RSSI ranging has the advantages of low cost, high positioning accuracy, and no need to add additional hardware support. Although RSSI positioning accuracy is relatively better, it is often vulnerable to such as reflection, multipath propagation, antenna gain, barrier, and the impact of environmental factors.

We use RSSI to achieve user's localization, at present, the research on RSSI mainly has two aspects: the first is the combination of different error measurement algorithm to reduce the transmission loss caused by the model; second is set to improve the parameters of transmission loss model, and build a mathematical model of the actual environment. This paper focuses on the first case, and a joint positioning algorithm is presented based on least square method and modifying the RSSI weighted centroid algorithm. In this algorithm, the least square method is used to locate roughly for node to be positioned first, and then modifying the RSSI weighted centroid algorithm is used to avoid the accumulation of error in the case of anchor node disjoint, and prevents the phenomenon of data flooding. Finally, compared with the traditional weighted centroid algorithm, this algorithm has higher accuracy and meets the actual industrial needs.

2 Algorithm model

2.1 Analysis of Radio Propagation Path Loss Model

When the radio signals propagate in the air, there exist the different degrees of loss. These losses have a great impact on the accuracy of the algorithm based on RSSI. Choosing the appropriate loss model has contributed to the positioning results. There are so many typical loss models such as: Hatha model, logarithmic - normal distribution model, the free space propagation model, logarithmic distance path loss model, etc. In this paper, the logarithmic - normal distribution model is used. Logarithmic - normal distribution model is as follows:

$$P(L) = P(O_0) - 10 \times k \cdot \lg(L) - \sigma \quad \textbf{(1)}$$

Here $P(L)$ is the received signal power when the transmission distance is L, $P(L_0)$ is the received signal power known before when the distance is L_0. Usually L_0= 1 m. k is the path loss index of the radio signal, and its value is related to the environment of communication. σ is Gaussian random distribution function with the 0 mean and ε variance. It can be seen that the $P(L_0)$ and k is equivalent to constant in the same environment. Analysis shows that: σ determines the relationship between the received signal strength and signal transmission distance. When the distance between the target location node and the beacon node is close, the error caused by RSSI is less affected by the distance. When the distance between the target node and the beacon node becomes larger, the error caused by the RSSI makes the result of the calculation node distance fluctuate greatly. Therefore, the key point of the positioning is to select more accurate RSSI value. From the relationship between RSSI and distance it can be known that the farther the distance of the transmission signal, the smaller the value of RSSI, the weaker the signal, the stronger the impact on the environment, the more inaccurate results. So the common method of work is arranging the value of RSSI according to the order from large down to small. The front of larger values severs as numerical to get relatively accurate distance information.

2.2 Traditional Weighted Centroid Algorithm Model

As shown in Fig. 1, weighted centroid algorithm is joining the RSSI data based on the traditional centroid algorithm. In this way, the factors of distance are also considered to achieve the purpose of improving the accuracy. The steps of weighted centroid algorithm are as followed. Firstly, the RSSI data obtained are transformed to the distance. Secondly, three circles are determined in which the anchor node is as the center and the distance is as the radius of circle. These circles will intersect in one region where the target node can be seen. After that, the intersection point A, B, C coordinates are to be calculated. At last the weight of the coordinates is determined in order to show the contribution of each coordinate point. It is easy to be seen that the farther the distance of anchor node, the smaller the contribution of the intersection point coordinate, and the vertices of these intersecting regions are determined by two distances. So when the weight is set to $\frac{1}{r_1+r_2}$ 、 $\frac{1}{r_2+r_3}$ 、 $\frac{1}{r_3+r_1}$, the coordinates of the target node D are:

$$\begin{cases} x_0 = \dfrac{\frac{x_1}{r_1+r_2} + \frac{x_2}{r_2+r_3} + \frac{x_3}{r_3+r_1}}{\frac{1}{r_1+r_2} + \frac{1}{r_2+r_3} + \frac{1}{r_3+r_1}} \\ y_0 = \dfrac{\frac{y_1}{r_1+r_2} + \frac{y_2}{r_2+r_3} + \frac{y_3}{r_3+r_1}}{\frac{1}{r_1+r_2} + \frac{1}{r_2+r_3} + \frac{1}{r_3+r_1}} \end{cases} \quad \textbf{(2)}$$

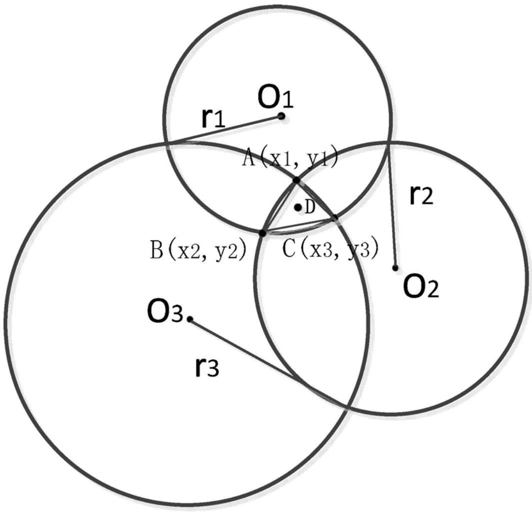

Fig. 1. Schematic diagram of weighted centroid algorithm

It can be seen that the weighted centroid algorithm can improve the accuracy of the positioning algorithm by introducing the distance factor compared to the traditional centroid algorithm, but some problems still exist in the weight selection.

3 Joint Positioning Algorithm Based On Least Square Method and Modified Weighted Centroid Algorithm

3.1 Using the Least Square Method to Locate the Target Node

As shown in Fig. 2, in the range of communication, setting the coordinates of the target node is $B_0(x_0, y_0)$. It can receive the signals of M beacon nodes, and the received beacon node are $A_i(x_i, y_i)$ (i=1, 2, 3⋯m). The RSSI values of the received beacon nodes are arrayed from large down to small. The front values of the larger RSSI beacon node $A_i(x_i, y_i)$ (i=1, 2, 3⋯n) are taken, and according to every value of the RSSI, the distance between each signal point to the target point can be calculated (r_1 、 r_2 、 r_3 、⋯ r_n). To obtain multiple sets of target coordinates, any (n-1) r is taken for grouping: {(r_2 、 r_3 ⋯ r_n) 、(r_1 、 r_3 、⋯ r_n)⋯(r_1 、 r_2 、⋯ r_{n-1})}, and (r_1 、 r_2 、⋯ r_{n-1}) are taken as an example here. By using the distance formula between two points, the following equations can be obtained:

$$\begin{cases} (x_1 - x_0)^2 + (y_1 - y_0)^2 = r_1^2 \\ (x_2 - x_0)^2 + (y_2 - y_0)^2 = r_2^2 \\ (x_3 - x_0)^2 + (y_3 - y_0)^2 = r_3^2 \\ \quad\vdots \\ (x_{n-1} - x_0)^2 + (y_{n-1} - y_0)^2 = r_{n-1}^2 \end{cases} \tag{3}$$

Each front equation subtracting the last one, (n-2) binary order linear equation group can be obtained:

$$\begin{cases} 2(x_1 - x_{n-1})x_0 + 2(y_1 - y_{n-1})y_0 = x_1^2 - x_{n-1}^2 + y_1^2 - y_{n-1}^2 + d_{n-1}^2 - d_1^2 \\ 2(x_2 - x_{n-1})x_0 + 2(y_2 - y_{n-1})y_0 = x_2^2 - x_{n-1}^2 + y_2^2 - y_{n-1}^2 + d_{n-1}^2 - d_2^2 \\ 2(x_3 - x_{n-1})x_0 + 2(y_3 - y_{n-1})y_0 = x_3^2 - x_{n-1}^2 + y_3^2 - y_{n-1}^2 + d_{n-1}^2 - d_3^2 \\ \quad\vdots \\ 2(x_{n-2} - x_{n-1})x_0 + 2(y_{n-2} - y_{n-1})y_0 = x_{n-2}^2 - x_{n-1}^2 + y_{n-2}^2 - y_{n-1}^2 + d_{n-1}^2 - d_{n-2}^2 \end{cases} \tag{4}$$

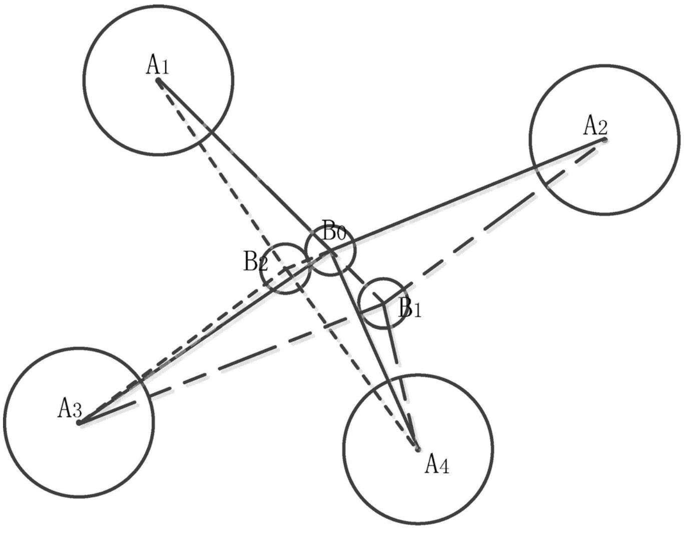

Fig. 2. Using the least square method to locate the target node schematic

Set the followings respectively:

$$x = \begin{pmatrix} x_0 \\ y_0 \end{pmatrix}$$

$$A = \begin{pmatrix} 2(x_1 - x_{n-1}) & 2(y_1 - y_{n-1}) \\ 2(x_2 - x_{n-1}) & 2(y_2 - y_{n-1}) \\ 2(x_3 - x_{n-1}) & 2(y_3 - y_{n-1}) \\ \vdots & \vdots \\ 2(x_{n-2} - x_{n-1}) & 2(y_{n-2} - y_{n-1}) \end{pmatrix} \quad \textbf{(5)}$$

$$b = \begin{pmatrix} x_1^2 - x_{n-1}^2 + y_1^2 - y_{n-1}^2 + d_{n-1}^2 - d_1^2 \\ x_2^2 - x_{n-1}^2 + y_2^2 - y_{n-1}^2 + d_{n-1}^2 - d_2^2 \\ x_3^2 - x_{n-1}^2 + y_3^2 - y_{n-1}^2 + d_{n-1}^2 - d_3^2 \\ \vdots \\ x_{n-2}^2 - x_{n-1}^2 + y_{n-2}^2 - y_{n-1}^2 + d_{n-1}^2 - d_{n-2}^2 \end{pmatrix}$$

It can be seen as a kind of formation Ax=b;

In the ideal case of that the wireless signal is not subject to any interference or loss, there exists a unique solution of Ax=b, the location of B_0, as shown in Fig. 2. In the fact, there are various factors that influence the transmission of radio signals such as reflection, multipath propagation, antenna gain, barrier, and so on. Because the general situation is (n-1) >3, equation group (3) has no solution. This is the problem subject to the least squares. By using the least square method, the solution of equation group (3) can be obtained:

$$B_n : (x_{0n}, y_{0n}) = (A^T A)^{-1} A^T b \quad \textbf{(6)}$$

Although the position coordinates of the solution B_n calculated by this calculation exist some error with the original target location, it has been the best matching of the data to be found out by minimizing the square sum of the error.

The solution of $\{(r_2 、 r_3 \cdots r_n) 、 (r_1 、 r_3 \cdots r_n) \cdots (r_1 、 r_2 、 r_{n-2} \cdots r_n)\}$ $\{B_1 、 B_2 \cdots B_{n-1}\}$are all can be obtained.

3.2 Modified Weighted Centroid Algorithm

Furthermore, the modified weighted centroid algorithm is used to check all target nodes obtained by using the above method again, so that the positioning accuracy can further be improved. Its idea is to modify the weight on the basis of traditional weighted centroid algorithm. If using the traditional weighted centroid algorithm, the weight should be set to: $\mu = \frac{1}{\sum_{j=1, j\neq i}^{n} r_i} (i = 1, 2, 3 \dots n)$. This leads to that r_i farther away from the target node plays a major role in weights. While if high positioning accuracy want to be ensured, it must be ensured that the nearer distance away from the target node plays the more important role in weights. Based on the above purpose, the weight is modified to: $\mu = \sum_{j=1, j\neq i}^{n} \frac{1}{r_i} (i = 1, 2, 3 \dots n)$.

In this way, it can be prevented that the secondary points play a major role, the nearer distance becomes larger, and the farther distance becomes smaller. The anchor node with the far distance from the target point is weaken to reduce the errors in positioning the situation. The target node coordinates (x_0, y_0) are:

$$\begin{cases} x_0 = \dfrac{\sum_{i=1}^{n} \{x_{0i} \cdot (\sum_{j=1, j\neq 1}^{n} \frac{1}{r_i})\}}{\sum_{i=1}^{n} (\sum_{j=1, j\neq 1}^{n} \frac{1}{r_i})} \\ y_0 = \dfrac{\sum_{i=1}^{n} \{y_{0i} \cdot (\sum_{j=1, j\neq 1}^{n} \frac{1}{r_i})\}}{\sum_{i=1}^{n} (\sum_{j=1, j\neq 1}^{n} \frac{1}{r_i})} \end{cases} \quad (7)$$

4 Algorithm Description

The algorithm is described as follows:

(1) The known nodes are anchor nodes, and the nodes of the anchor nodes send their own ID and the coordinate location periodically.

(2) The target node collects the information transmitted by the anchor nodes, and stores the ID and RSSI values periodically. According to the order from large down to small, the RSSI values are arrayed. Taking the RSSI large number of anchor nodes, and its corresponding coordinate position $A_i(x_i, y_i)$ (i=1, 2, 3⋯n), the corresponding the distance between two points can be calculated by using the RSSI, and put into a collection $R_1 = (r_1 、 r_2 、 r_3 \cdots r_n)$.

(3) In order to get the multi set data, any N-1 nodes are taken from N nodes to calculate, and the calculating results are grouped: $R_2 = \{(r_2 、 r_3 \cdots r_n) 、 (r_1 、 r_3 \cdots 、 r_3) \cdots (r_1 、 r_2 \cdots 、 r_{n-1})\}$. each group of them are used to calculate by the formula (3)-(6), so that n target node coordinate information $\{B_1 、 B_2 \cdots 、 B_n\}$ are obtained.

(4) The position coordinates obtained are modified further by setting fixed weighted centroid algorithm, to get the value which is most close to the actual location coordinates of the target node.

(5) The error is defined as E, and according to the actual target node position coordinate $B_0(x_0, y_0)$ the following can be obtained:

$$E = \sqrt{(x - x_0)^2 + (y - y_0)^2}$$

5 Algorithm Description

By the tools of MATLAB, the effectiveness of the algorithm can be verified, and its performance can be analyzed and compared with the traditional weighted centroid algorithm. First of all, in the area of 10 m x 10 m area, there are nine anchor nodes distributed in four border vertices, the center of the frame and regional center. Another 20 target nodes are randomly generated in this region, and path loss is set to exponent=5. Each anchor node communication radius is 20m. To imitate the actual environment where such interference factors are exist as reflection interference, antenna gain effect, obstacles, multipath propagation of radio interference caused by signal transmission, Gauss noise is added to the RSSI numerical value, where Gauss noise is one of that the mean value is 0 and the standard deviation is 2. The simulation is carried out for 200 times, and the mean value is taken as the final result. The simulation data is shown as Table. 1 and Table. 2 respectively, and the simulation effect diagram is shown in Fig. 3, Fig. 4 respectively.

Table 1. The simulating data obtained by the least square method and modified weighted centroid algorithm

Number	1	2	3	4	5
Actual position	(5.52,6.30)	(0.32,6.14)	(3.62,0.50)	(4.89,1.93)	(1.23,2.05)
Predicted position	(4.42,5.04)	(0.26,4.92)	(2.90,0.40)	(3.92,1.54)	(0.98,1.64)
Error/(M)	1.68	1.23	0.73	1.05	0.48
Number	6	7	8	9	10
Actual position	(1.47,1.89)	(0.42,6.35)	(2.82,5.39)	(6.95,4.99)	(5.35,4.45)
Predicted position	(1.17,1.51)	(0.34,5.08)	(2.25,4.30)	(5.56,3.99)	(4.29,3.56)
Error/(M)	0.48	1.27	1.21	1.71	1.39
Number	11	12	13	14	15
Actual position	(1.23,4.90)	(8.53,8.73)	(2.70,2.08)	(5.65,6.40)	(4.17,2.06)
Predicted position	(0.99,3.92)	(6.82,6.99)	(2.16,1.67)	(4.52,5.12)	(3.34,1.66)
Error/(M)	1.01	2.44	0.68	1.70	0.93
Number	16	17	18	19	20
Actual position	(9.48,0.82)	(1.06,1.42)	(1.66,6.21)	(5.73,0.52)	(9.31,7.28)
Predicted position	(7.58,0.66)	(0.85,1.34)	(1.33,4.97)	(4.59,0.42)	(7.44,5.83)
Error/(M)	1.90	0.35	1.28	1.15	2.36

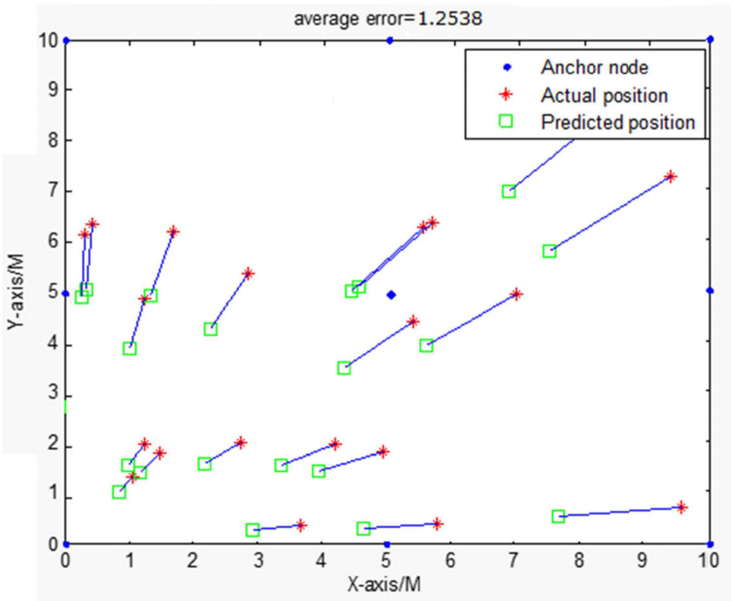

Fig. 3. The fixed joint localization algorithm simulation results of the weighted centroid algorithm

Table 2. The simulating data obtained by the traditional weighted centroid algorithm

Number	1	2	3	4	5
Actual position	(1.12,7.84)	(2.92,6.03)	(9.64,4.32)	(6.95 7.58)	(4.32,6.56)
Predicted position	(1.98,6.01)	(3.41,5.38)	(8.00,2.55)	(6.79,5.70)	(2.98,4.23)
Error/(M)	2.02	0.83	2.42	1.89	2.69
Number	6	7	8	9	10
Actual position	(1.09,9.34)	(1.86,2.67)	(7.98,4.88)	(7.69,3.96)	(2.73,0.37)
Predicted position	(1.80,4.90)	(1.80,2.50)	(8.50,1.29)	(8.47,1.37)	(3.54,2.16)
Error/(M)	4.49	0.18	3.62	2.70	1.95
Number	11	12	13	14	15
Actual position	(6.73,4.30)	(4.52,6.10)	(0.60,3.16)	(7.72,6.97)	(1.25,1.30)
Predicted position	(6.63,1.40)	(2.98,4.31)	(2.07,2.70)	(8.34,5.00)	(1.84,0.97)
Error/(M)	2.90	2.36	1.55	2.08	0.73
Number	16	17	18	19	20
Actual position	(0.92,0.08)	(4.23,6.56)	(7.23,5.31)	(1.09,6.31)	(1.27,1.34)
Predicted position	(1.76,2.09)	(3.00,4.22)	(6.47,5.63)	(1.89,4.23)	(1.84,0.86)
Error/(M)	2.18	2.63	0.83	2.24	0.75

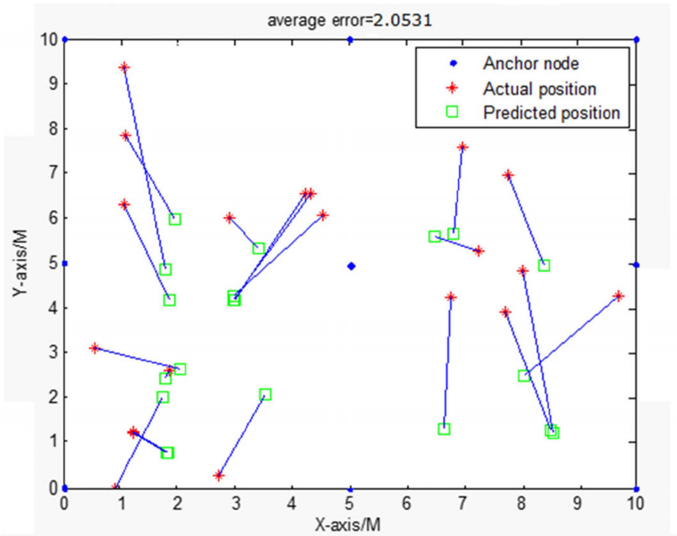

Fig. 4. The traditional weighted centroid algorithm simulation results

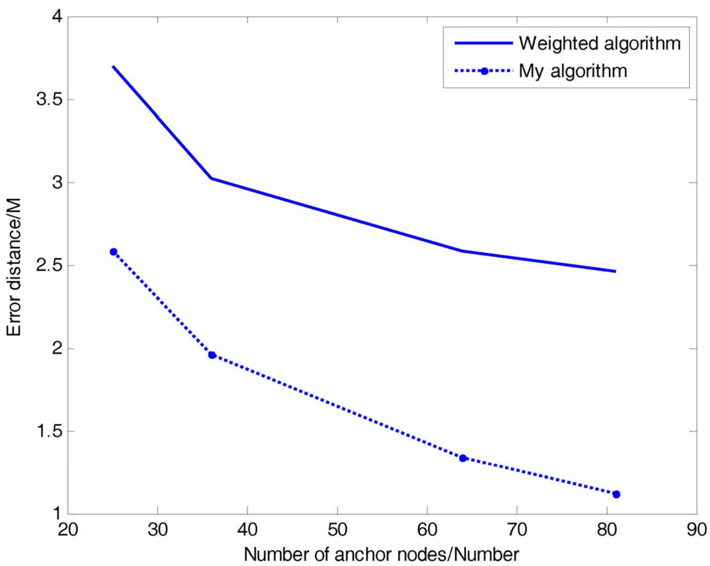

Fig. 5. Error contrast of two algorithms

From Fig. 4 and Fig. 5 can be seen that when the path loss n = 5, weighted centroid algorithm average error is 2.0531m, and the joint location algorithm average error is only 1.2538m, while the average error is better than the weighted centroid algorithm. Compared with the traditional weighted centroid algorithm based on [1], the least squares method and the fixed joint localization algorithm has been improved significantly. The essence of the article is to get the more accurate correction by the joint localization algorithm weighted centroid algorithm, in which the least square method is used to acquire a relative accurate target nodes first,, and then the final target location node is obtained by the modified weighted centroid algorithm.

From Fig. 5 can be seen when the target node number unchanged, increasing the number of anchor nodes can reduces the error of RSSI long distance transmission, and then we can obtain RSSI numerical more accurately, therefore the unknown node is more closer to the actual position.

6 Concluding Remarks

In this paper, through research and analysis logarithm normal distribution model, the optimized RSSI value are selected, which are a group of relative accurate RSSI value. Then RSSI ranging technology is used to calculate the distance between nodes. Here the least square method is used to estimate node in first step. After that the concept of weighted coefficient of correction is introduced to improve traditional weighted factor. Compared with the centroid localization algorithm based on RSSI proposed in literature [2], the positioning accuracy is greatly improved. Furthermore, the anchor node disjoint circle is not considered in the trilateral positioning centroid algorithm adopted in literature [3], while the algorithm proposed in this paper can be applied to the case of circular intersection. By the comparison with based on RSSI correction centroid algorithm proposed in the literature [5], it can be easily found that if the RSSI values do not satisfy the set conditions after the RSSI value be sorted, the back of the RSSI value should be chosen to replace, and this will further expand the error. This drawback is effectively overcome in this article. So the algorithm based on the least square method and modifying the RSSI weighted centroid algorithm of localization algorithm proposed in this article is more scientific and reasonable.

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