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IMPROVED WEIGHTED CENTROID LOCALIZATION ALGORITHM BASED ON RSSI DIFFERENTIAL CORRECTION

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Abstract- Node localization is one of the key technologies of wireless sensor networks (WSN). Due to the indoor environment requires a high positioning accuracy, an improved algorithm based on RSSI is put forward. In terms of RSSI ranging, the error correction coefficient received from self-correcting locator beacon nodes, and then had been applied to distance solving from unknown nodes to the beacon nodes. In the choice of weights, the algorithm uses inverse distance and replaces the method of determining the distance and the reciprocal of the weights, and also fixes the weight factor. On the complexity of the algorithm, select one of the most recent four from unknown node to beacon nodes, reducing the amount of data calculation. Simulation results show that the proposed algorithm positioning accuracy has been greatly improved.

Index terms: Node localization, RSSI, differential correction, wireless sensor networks, indoor environment

I. INTRODUCTION

Node localization is the key technology of WSN, positioning accuracy has a crucial impact on the monitoring of the region. With the development of wireless communication technology, because indoor precise position information demand that more and more position information should be high, simple, rapid, accurate, and positioning of the interior has also become a hot issue in WSN.

At present, more mature GPS positioning system can achieve WSN node localization, but taking into account the node price, volume, energy consumption and environmental factors, sensor nodes with GPS positioning module can not be large-scale arrangement. Many researchers have proposed various positioning algorithm for no GPS module, the proposed localization algorithm for WSN can be divided into two categories: which can be divided into range-based localization algorithms (Range-Based) and range-free localization algorithm (Range-Free) [1-8]. The former needs to be measured the absolute distance or angle information between adjacent nodes. Ranging positioning using more technology RSSI (Received Signal Strength Indication) positioning algorithm [1], TOA (Time of Arrival) positioning algorithm [2], TDOA (Time Difference of Arrival) positioning algorithm [3], AOA(Angle of Arrival) positioning algorithm [4]; The latter only needs to know which network connectivity information to achieve positioning, such as centroid algorithm [5], convex programming algorithm [6], DV-Hop algorithm [7], approximate-point in-triangulation test [8]. Among which localization algorithm is based on high precision positioning ranging, but needs higher hardware requirements[11]; Location algorithm with distance has less demanding on the hardware-independent, but has lower precision positioning. Among them, RSSI location algorithm with simple, low cost, low power consumption and requires no additional hardware and other advantages are widely used. But in the actual environment, location technology of RSSI are strongly influenced by the environment based on the technology, complexity in interior building structure of different circumstances, the positioning error is large.

In recent years, the node localization algorithm and localization scheme have been proposed by domestic and foreign scholars[12-18], Literature [9] presented an improved weighted centroid localization algorithm. The algorithm uses inverse distance instead of the distance and the sum of the weights as the reciprocal. A better solution to the effects of large errors brought on positioning accuracy. However, this algorithm only improve the positioning stage, without considering the effect of RSSI ranging technology brought the location results. Literature [10] proposed a distance measurement algorithm based on RSSI hybrid filter and least square estimation. The value RSSI is corrected by the preferred method. Reduction due to environmental factors on RSSI ranging, But in terms of positioning calculations, which still can not meet the positioning accuracy requirements. Literature [14] proposed an indoor positioning algorithm based on RFID experiment, the paper uses RFID technology to achieve the indoor positioning algorithm by getting high positioning accuracy. The literature [15] presents a weighted hybrid localization scheme for improved node positioning in wireless sensor networks, the algorithm adopt RSSI and DV-Hop technology to solve the hop dependency problem. Literature [19] presented the improved measure algorithm based on cosamp for image recovery. The algorithm superimposed deterministic ring measurement matrix to optimize measurement process on the basis of Fourier measurement matrix. And solve the iterative inverse operation by using FFT fast Fourier calculation method. Literature [20] presented detecting wormhole attacks in wireless sensor networks using hop count analysis. The algorithm set up maximum necessary hop count between the sensor nodes in the same neighbor. The algorithm have been improved by all above these literatures, But it still can not meet the requirements of accuracy.

Based on this, we put forward an improved localization algorithm with high accuracy. The algorithm is mainly positioning error using the beacon nodes, the unknown nodes and beacon nodes distance correction using inverse distance; and replace the traditional distance and reciprocal to determine weights, fixed weight coefficient, and the beacon node is optimized, which reduce the influence of errors on the positioning results, improve the28% positioning precision.

II. POSITIONING ALGORITHM MODEL

a. Indoor Radio Propagation Loss Model

In wireless sensor network localization algorithm, there is RSSI ranging technique commonly used positioning technology [16-18]. On the one hand, Communication function of sensor itself and its RSSI function make the simple measurement range. On the other hand, when positioning under the complexity of the different building structure, there may be more serious multipath effect, reflection, refraction and other interference, resulting in RSSI measurement error will be large and positioning error increasing. The relationship between received signal strength RSSI and signal transmission distance d can be given by Eq. (1):

$$RSSI = P_{send} - (P(d_0) + 10k\log10(\frac{d}{d_0})) + \xi \qquad (1)$$

where, P_{send} is the transmitted signal power, k is the path loss factor, ξ is a mean zero and variance σ of the Gaussian random distribution function, $P(d_0)$ is radio signal propagation distance d_0 ($d_0 = 1\mathrm{m}$) of loss, it can be written as transmitting power and the receiving power difference and calculated by Eq. (2):

$$P(d_0) = -10\lg\left(\frac{P_r}{P_t}\right) = -10\lg\left[\frac{G_t G_r \lambda^k}{(4\pi)^k d_0^k L}\right] \qquad (2)$$

where P_r and P_t are respectively the receiving and transmitting antenna power, P_t =1W, G_r and G_t are respectively the transmitting and receiving antenna gain, $G_r = G_t$ =1, $\lambda = c/f$, λ is the wavelength, c is the speed of electromagnetic wave propagation, c= 3×10^8 m/s .

By the formula (1) and (2) can be seen, relation between the size of the received signal strength RSSI and the path loss factor k as well as that between RSSI and the distance between the receiving and transmitting antenna d are very close. In the different environment that the path loss factor k values are not the same, with the increase of distance, the relationship between the received signal strength RSSI and k is shown in Figure 1. In the theoretical and practical situations, the relationship between the received signal strength RSSI and signal transmission distance d is shown in Figure 2:

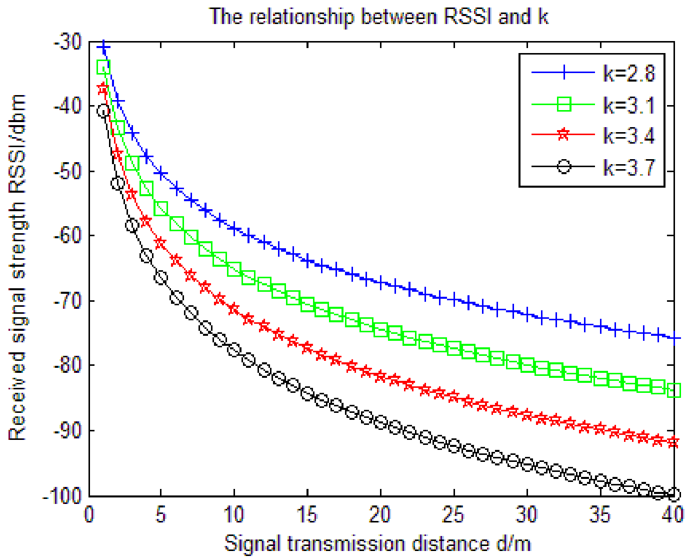

Figure 1. The relationship between RSSI and path loss factor

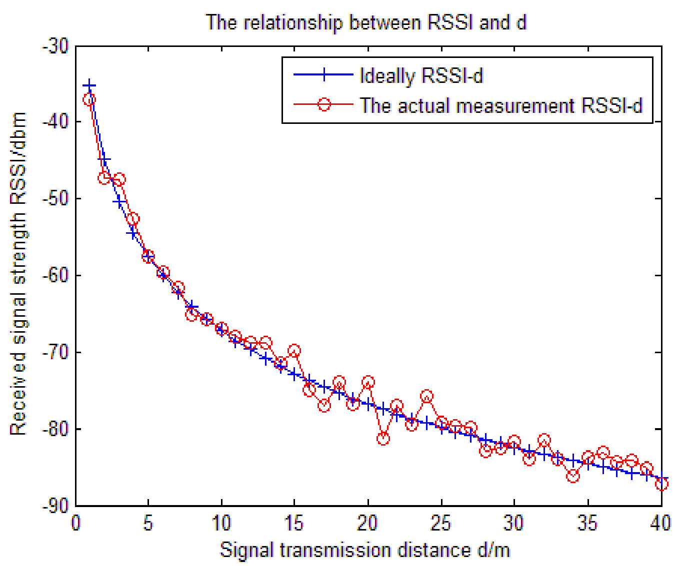

Figure 2. The relationship between RSSI and signal transmission distance

After a large number of experiments show that, when the complexity of the indoor environment of building structure is higher, the path loss factor is 3.2 and the Gauss random distribution function variance is 11.8dBm, $P(d_0)$ = 35.2dBm.

b. Centroid Localization Algorithm

The core idea of the centroid algorithm [5, 13]: Beacon nodes periodically broadcast information to unknown nodes, and the information including its own ID and position coordinates. Lots of different beacon nodes of packets information are recorded by unknown nodes. After a certain time t, the threshold of communication success rate P is set to the δ, is calculated between the unknown node and beacon nodes. Once the communication success rate of unknown nodes and beacon nodes exceeds the threshold, the node can be considered to be in the range of the communication and communicates with beacon nodes, then the unknown nodes is the centriod of polygon region composed of these beacons. Figure 3:

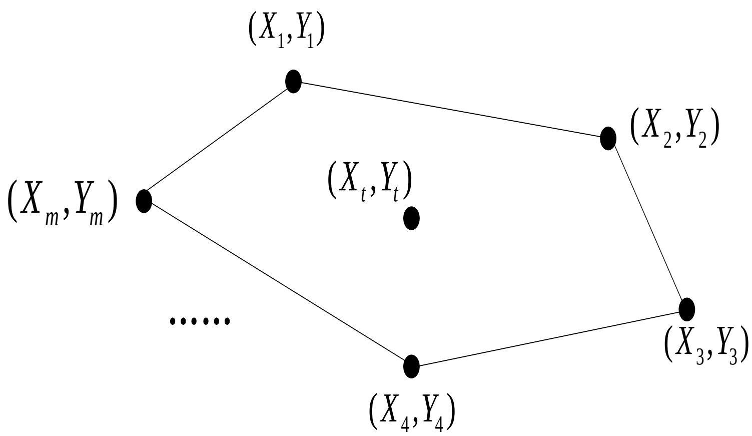

Figure 3. Polygon region

The coordinates of the unknown node can be estimated by using Eq. (3):

$$(X_t,Y_t)=(\frac{X_1+X_2+\cdots \mathrm{X}_m}{M},\frac{Y_1+Y_2+\cdots Y_m}{M}),0<m\leq M \qquad (3)$$

where $(X_1,Y_1)\cdots(X_m,Y_m)$ are the coordinates of these beacon nodes that can communicate with the unknown nodes, M is the number of beacon nodes.

c. Weighted Centroid Localization Algorithm

The core idea of weighted centroid localization algorithm [5,13]: According to the unknown node receives the signal strength RSSI size of these beacon nodes, calculate weights between the unknown node and every beacon nodes. These weights can indicate beacon nodes have influence on centroid position and reflect the intrinsic relationship between them. The coordinates of the unknown node can be estimated by using Eq. (4):

$$(X_{est},Y_{est})=(\frac{\sum_{i=1}^{i=\mathrm{M}}W_i\cdot X_i}{\sum_{i=1}^{i=\mathrm{M}}W_i},\frac{\sum_{i=1}^{i=\mathrm{M}}W_i\cdot Y_i}{\sum_{i=1}^{i=\mathrm{M}}W_i}) \qquad (4)$$

where (X_{est},Y_{est}) is the coordinates of the unknown node, (X_i,Y_i) is the first i coordinates of beacon node, M is the number of beacon nodes, W_i is the first i weight of beacon node influencing on the unknown node, is a function of the distance between unknown nodes and beacon nodes. Typically, the farther the distance, the smaller the weight, if the beacon node is not within the scope of communication nodes, then W_i is 0.

The traditional location algorithm, the location technology of RSSI are strongly influenced by the environment based on the same node, the measured RSSI values are very different, although the centroid localization algorithm is simple, but the positioning accuracy is low, the weighted centroid algorithm certain extent high positioning accuracy, but there are still some disadvantages. For these reasons, this paper proposes an improved positioning method, which greatly improves the positioning accuracy.

III. IMPROVED LOCALIZATION ALGORITHM IMPLEMENTATION

a. RSSI-based ranging technology of differential correction

Effect of obstacles and other environmental factors in the actual environment, ranging out of the RSSI value does not directly meet the radio to propagation loss model. If you are still use the model without RSSI values can be corrected will cause low positioning accuracy[21]. In this paper, using the beacon node from the nearest unknown node in the process of locating the correction coefficient feedback to unknown nodes, the unknown node through the error correction coefficient obtained to correct range beacon node. The method of error ranging from existence makes the improvement to the algorithm, fundamentally reduces the influence on positioning result, so it is possible to improve the positioning accuracy.

1) Beacon Nodes Self-correcting Positioning

As is shown in Figure 1, beacon node $A_0(x_0, y_0)$ is the nearest distance from the unknown node O . From the beacon node within its communication range of the nodes $A_1(x_1, y_1)$, $A_2(x_2, y_2)$, $\cdots$ $A_i(x_i, y_i)$ are the actual distance $d_{01}, d_{02}, d_{03}, \ldots, d_{0i}$, Beacon node $A_0(x_0, y_0)$ through RSSI ranging the distance between the estimated and other beacon nodes are respectively $\hat{d}_{01}, \hat{d}_{02}, \hat{d}_{03}, \ldots, \hat{d}_{0i}$, $\hat{A}_0(\hat{x}_0, \hat{y}_0)$ as the difference of beacon node.

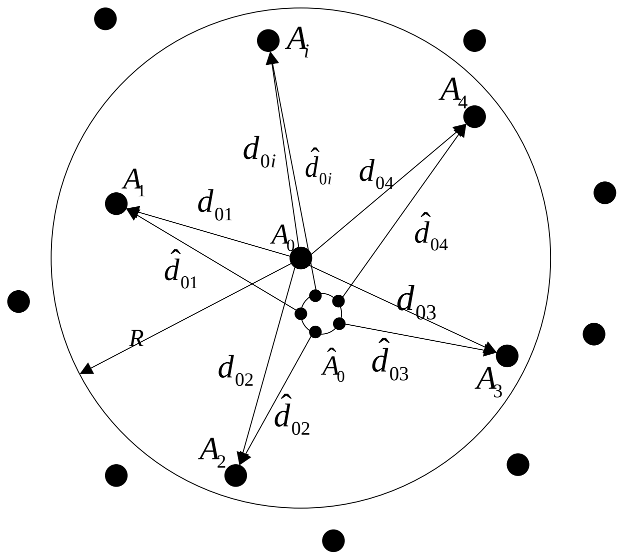

Figure 4. Differential correction positioning of beacon node

(1) The Correction Coefficient of Beacon Nodes:

$$\beta = \frac{1}{M_r}\sum_{i=1}^{n}\frac{d_{0i}-\hat{d}_{0i}}{\hat{d}_{0i}} \qquad (5)$$

where, M_r are the standard letters to all nodes within a radius of unknown node communication. Other beacon nodes in a sensor network can also gain correction factor itself through the above methods, so that the beacon nodes can be corrected from its recent unknown node. β represents the information measurement of RSSI using beacon node value differential correction coefficient.

(2) The correction distance between beacon nodes to unknown nodes:

$$d_i = d_{0'i} + \beta d_{0'i} \qquad (6)$$

where, d_i is the unknown node estimated distance from the differential corrections; $d_{0'i}$ is the measured distance from the unknown node O to beacon nodes; β is correction coefficient of beacon nodes.

b. Weighted centroid algorithm based on modified

Choose the right value weighted centroid algorithm is very important. It plays a key role for precise positioning. For the traditional weight is the reciprocal of distance, there are a lot of methods to improve it. This article references [22]. On the basis of it considers different beacon node contribution to the weight; the weight is modified, so that the positioning accuracy has been greatly improved.

In this paper, the core idea of weighted centroid algorithm weights modified is: Firstly, through the difference of radio propagation loss model calculate the distance between nodes, and these distance values are arranged from small to large, take the first four values of beacon nodes information to calculate the unknown node position. Then select one of three nodes in turn to be combined, there are a total of four combinations, the beacon nodes of each combination as the center of the circle respectively, the unknown node to the corresponding combination of beacon node distance as the radius of circle, calculate the three round of overlapping region centroid coordinates of the triangle. Similarly, you can find the centroid coordinates of other combinations. Finally, the centroid coordinates of these four weights which are revised; we can calculate the coordinates of unknown nodes. The improved coordinate of unknown nodes in the algorithm as follows:

$$
\begin{aligned}
X &= \frac{X_1(\frac{1}{d_1^{\,n}}+\frac{1}{d_2^{\,n}}+\frac{1}{d_3^{\,n}})+\mathrm{X}_2(\frac{1}{d_1^{\,n}}+\frac{1}{d_2^{\,n}}+\frac{1}{d_4^{\,n}})+\mathrm{X}_3(\frac{1}{d_1^{\,n}}+\frac{1}{d_2^{\,n}}+\frac{1}{d_4^{\,n}})+\mathrm{X}_4(\frac{1}{d_2^{\,n}}+\frac{1}{d_3^{\,n}}+\frac{1}{d_4^{\,n}})}{2\times(\frac{1}{d_1^{\,n}}+\frac{1}{d_2^{\,n}}+\frac{1}{d_3^{\,n}}+\frac{1}{d_4^{\,n}})} \\
\mathrm{Y} &= \frac{Y_1(\frac{1}{d_1^{\,n}}+\frac{1}{d_2^{\,n}}+\frac{1}{d_3^{\,n}})+\mathrm{Y}_2(\frac{1}{d_1^{\,n}}+\frac{1}{d_2^{\,n}}+\frac{1}{d_4^{\,n}})+\mathrm{Y}_3(\frac{1}{d_1^{\,n}}+\frac{1}{d_2^{\,n}}+\frac{1}{d_4^{\,n}})+\mathrm{Y}_4(\frac{1}{d_2^{\,n}}+\frac{1}{d_3^{\,n}}+\frac{1}{d_4^{\,n}})}{2\times(\frac{1}{d_1^{\,n}}+\frac{1}{d_2^{\,n}}+\frac{1}{d_3^{\,n}}+\frac{1}{d_4^{\,n}})}
\end{aligned}
\tag{7}
$$

In this paper, $\frac{1}{d_1+d_2+d_3}$ is replaced by $\frac{1}{d_1}+\frac{1}{d_2}+\frac{1}{d_3}$ and n is used to adjust the weighting factor which make positioning accuracy of the proposed algorithm has been greatly improved. By using this approach, the information of the distance of unknown nodes and beacon nodes closer can be fully utilized in the WSN nodes localization. Therefore, we can adjust the correction factor n, and it is better robustness and positioning accuracy for the proposing algorithm to arrange reasonable weights.

IV. ALGORITHM IMPLEMENTATION PROCESS

According to the analysis of the above model of the improved algorithm, the improved algorithm specific process can be implemented as follows:

Step one: beacon nodes broadcasts ID information as well as its own coordinate information to the surrounding node periodically.

Step two: unknown nodes receive more than M nodes coordinate information after a certain of time, which is no longer receive the information, and the differential distance between the nodes is obtained by the radio propagation model correction.

Step three: according to the improved differential correction value of RSSI location algorithm, by (5) (6) can be obtained from two unknown type differential correction beacon node to node distance d_i.

Step four: the unknown node on the differential correction distance d_i is arranged from small to large, and establish the value of RSSI to the mapping relationship between beacon nodes and node distance, relevant set as follows:

Beacon nodes collections: $Beacon = \{A_1, A_2, A_3, \cdots, A_n\}$

Beacon nodes location information collection:

$Position = \{(x_1, y_1), (x_2, y_2), (x_3, y_3) \cdots (x_n, y_n)\}$

The differential correction distance collection from unknown nodes to beacon nodes:

$Dis\tan ce = \{d_1, d_2, d_3, \cdots d_n\}, d_1 < d_2 < d_3 \cdots d_n$

Step Five: select the information of the collection of the first four beacon nodes to calculate the unknown node localization. Then follow the modified weighted centroid localization algorithm proposed in this paper, combined with equation (7), which can be calculated to estimate the coordinates of the unknown node (X, Y).

V. SIMULATION RESULTS AND ANALYSIS

In this paper, we use MATLAB platform for the improved algorithm simulation analysis, and compared with the relevant methods to verify the performance of the proposed algorithm.

a. Simulation Parameters and Definitions

Network emulation environment settings are as follows: WSN area size is 100x100m, randomly arranged 100 sensor nodes in the area (including the unknown nodes and beacon nodes). Assuming the radio signal propagation path loss model attenuation factor k = 3.2, the carrier frequency of the radio signal of 2.4GHz, the distribution of random noise in the channel between 5-8, the node distribution as shown in Figure 5. In order to verify the stability of the algorithm, the algorithm simulation 100 times and take the average, the relevant definitions involved are as follows:

(1) Let us suppose that the actual position of node i is T_i, the estimated position is $\tilde{T}_i$. The average location error of the entire network can be defined as $e = \frac{\sum_{j=1}^{N}\sum_{i=1}^{K}\left|T_i - \tilde{T}_i\right|}{KN}$.

(2) Normalized average location error $\bar{e} = \frac{e}{r}$: r is the communication radius.

(3) To evaluate the performance of algorithms, it usually using the root mean square as a performance measure of the algorithm, the specific formula is

$$\delta_{M,N} = \sqrt{\frac{\sum_{i=M}^{N}(e(i)-r(i))^2}{M-N+1}}, M > N .$$

where, $e(i)$ is an estimate value, $r(i)$ is the true value, M are the number of anchor nodes, $N = 1$.

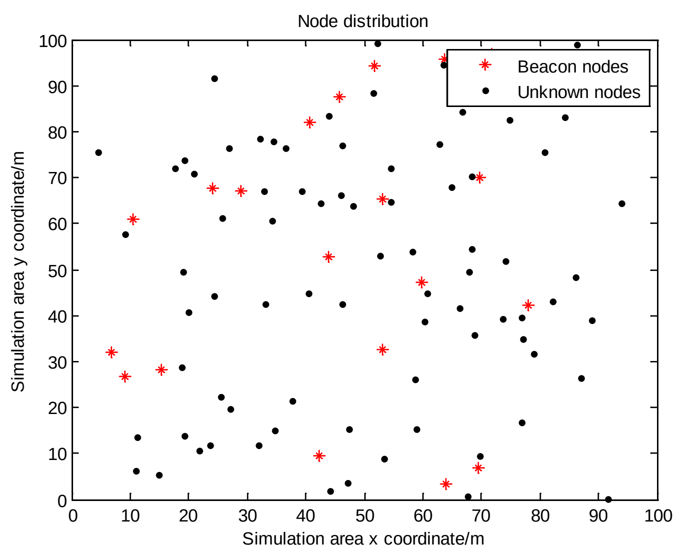

Figure 5. Simulation nodes distributed network environment

b. Analysis of Simulation Results

The simulation comparison of RSSI algorithm, the weighted centroid algorithm and the algorithm proposed in this paper, mainly from the relationship between positioning deviation, network node positioning coverage rate, positioning error and other factors.

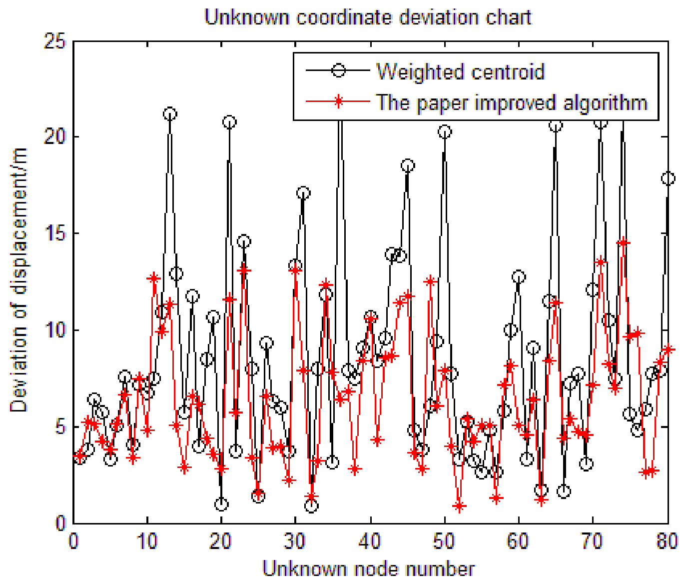

Figure 6. Unknown coordinate deviation chart

Figure 6 Simulation beacon node is 20, deviation map of the estimated coordinates and real coordinates for weighted centroid algorithm and improved algorithm. As it can be seen from the figure 6, the improved algorithm is much higher than the positioning accuracy the weighted centroid algorithm used, and better stability.

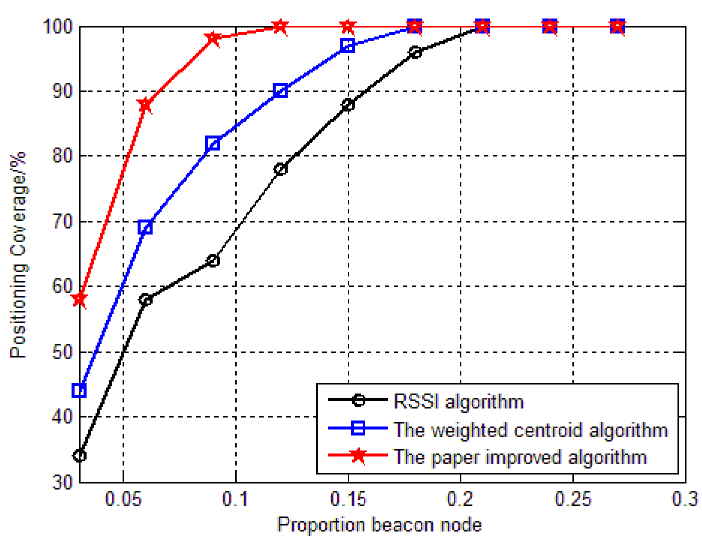

Figure 7. The relationship between the percentage of beacon nodes and the coverage rate of positioning

Communication radius of 20, three different algorithms for network localization coverage changes is shown in figure 7. Contrast from Figure 6 shows that, with the increase of beacon nodes, node location coverage rate of RSSI algorithm and weighted centroid localization algorithm increased; but the ratio of beacon nodes is low, RSSI algorithm and weighted centroid localization algorithm of coverage is low, when the beacon node ratio is about 0.15, two algorithms coverage rate is nearly 90%; and the proposed algorithm the beacon node is small, can be full of WSN localization, effectively reduces the cost of network node localization.

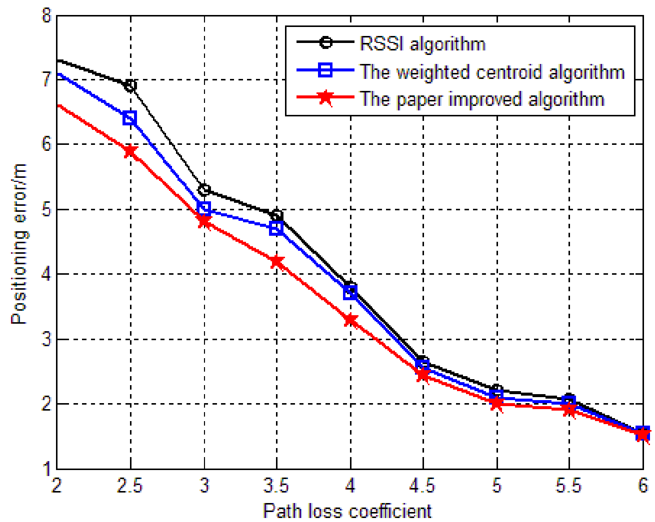

Figure 8. Effect of path loss coefficient of positioning error

Figure 8 Simulation beacon nodes is 30, the path loss factor of the influence of the positioning error, as can be seen from Figure 8, with the increase of path loss coefficient, three algorithms of network node positioning error is reduced, but obviously it can be seen that the proposed algorithm has good performance.

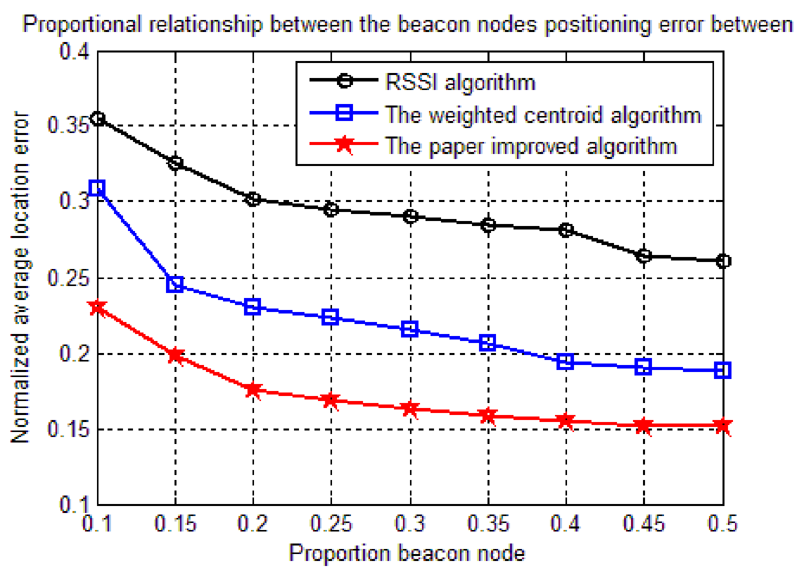

Figure 9. Normalized average position error

Figure 9 simulated three different methods of normalized average location error, can be seen from the diagram, with the increase in the number of beacon nodes, obtaining useful information to the RSSI values are also become more, positioning error first rapidly decline and then slowly decline, and finally tends to be a minimum error, compared with the weighted centroid algorithm improved by about 27.3%.

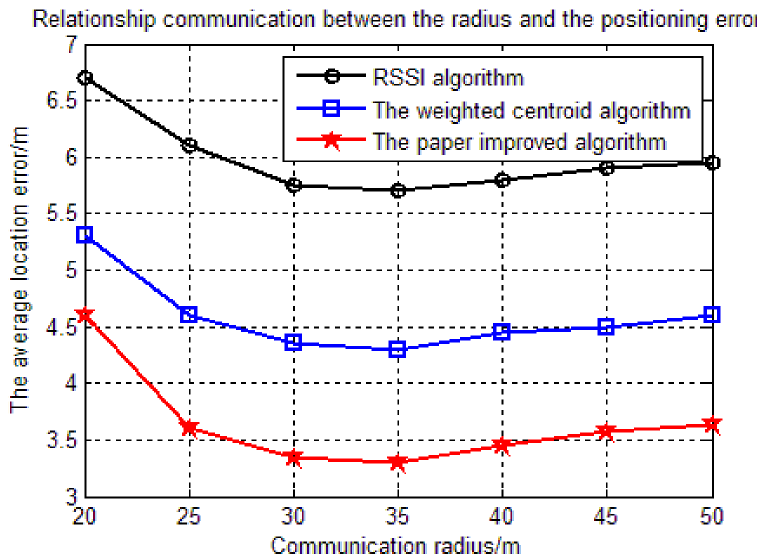

Figure 10. Impact of node communication radius of positioning error

Figure 10 Simulation of beacon nodes is 30, the relationship between the average location error with communication radius changes. Communication radius is too small to make the average error is too large, and even lead to a lot of unknown nodes can not locate. Set up the communication radius from 20m to 50m according step length 5. As it can be seen from Figure 10, the communication radius increases, the average location error of three algorithms are the first decline and then rise slowly, and the proposed algorithm is much better than the weighted centroid localization algorithm. Therefore, the positioning process to select the best communication radius is very important, which is directly related to the error location, optimal communication radius of the improved algorithm is 33m.

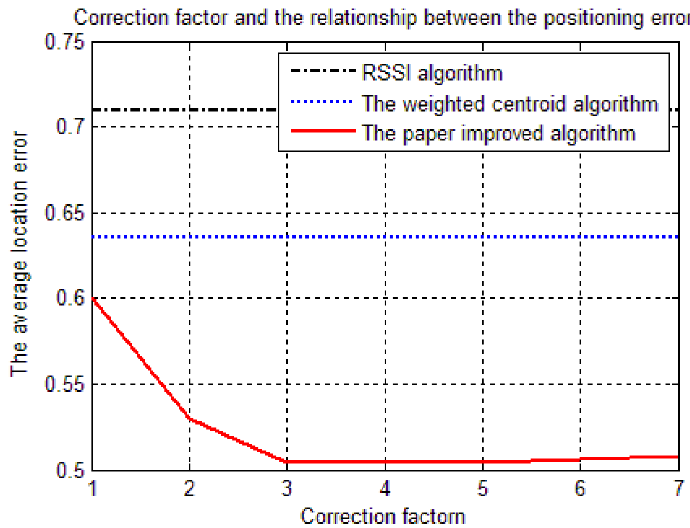

Figure 11. Relationship between the average location error and correction factors

Figure 11 simulated three different methods of the relationship between the average simulated average position error and correction factor n, As can be seen from the simulation diagram, the average positioning error RSSI algorithm is 0.7151, the average positioning error of weighted centroid localization algorithm is 0.6382m, the improved algorithm herein correction coefficient increases as the average positioning error gradually decline. When the correction factor n=5, the positioning accuracy of the improved algorithm basically close to the same.

Table 1 Algorithm performance comparison

Beacon nodes	RSSI		Improved algorithm	
	Error /m	RMS	Error /m	RMS
10	8.3072	0.05231	5.8632	0.00501
20	8.0310	0.04825	4.8476	0.00346
30	7.1267	0.02846	4.2979	0.00226
40	6.7332	0.01253	3.3490	0.00112

In table 1, simulation of the communication radius of 30, performance evaluation and average positioning error of improved algorithm and RSSI algorithm. As can be seen from the table 1, the average positioning error of improved algorithm is much smaller than of RSSI algorithm. The error of improved algorithm root mean square is merely about 1/12 of RSSI algorithm, The improved algorithm has obvious advantage in the positioning performance.

VI. CONCLUSIONS

With the higher complexity of interior structures, we propose an improved weighted centroid localization algorithm based on RSSI differential correction. Through the experimental test of each parameter on the influence of RSSI value, model parameters are given in the wireless signal transmission in indoor environments. Improvements in the algorithm, making full use of RSSI location algorithm and weighted centroid localization algorithm based on improvements to improve the positioning accuracy of the algorithm from RSSI corrected and weighted centroid. Under the same simulation environment, the improved algorithm on the accuracy and robustness which is better than RSSI algorithm and weighted centroid algorithm, while the positioning algorithm has less demand for the hardware to meet the requirements of low cost and low power consumption, the paper has very high application value. In future work, we will carry out further research on different floors of wireless transmission model to identify the wireless transmission model for different floors and do some experience to be verified.

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