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Research on Dynamic Node Location Optimization Method for Wireless Sensor Networks

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Abstract

Static wireless network sensor does not consider the mobility problem of nodes in the design process, which leads to the current node location method cannot meet the needs of dynamic wireless sensor network positioning. Aiming at the shortcomings such as low positioning accuracy and long response time of traditional node location strategy, a dynamic node location optimization method is proposed. The method uses the optimized inter-node distance model to optimize the path, and minimizes the estimated area of the unknown node through the rotatable directional antenna mounted on the anchor node so that the estimation of the path is closer to the actual distance. The experimental results showed that the proposed method has better accuracy and stability than the current positioning method.

Key Words: Wireless Sensor, Network Dynamic Node, Node Location Optimization, Inter-node Distance Model

1. Introduction

Wireless sensor network is the current hotspot research in the world, involving highly interdisciplinary approach and highly integrated knowledge [1,2]. As one of the key technologies of wireless sensor networks, positioning technology is one of the key technologies of wireless sensor networks. As the dynamic node size and quality of the sensor should be relatively small, and the node's power supply module can only use a battery with limited energy to achieve, therefore, the ability of the battery to carry energy, become one of the bottlenecks in recent years, [3,4]. Restricted by node energy conditions, the main problem to be solved at node positioning technology is how to achieve node location with minimal communication overhead and hardware cost [5].

At present, the simplest wireless sensor network dynamic node location method is to set the dynamic nodes of the network with the installation of global satellite positioning system receiver (GPS), thus determining the dynamic node of the random change position. However, due to the conditions, it is not possible for all nodes to load the GPS receiver. Therefore, under normal circumstances, many unknown node location information must be obtained through a certain positioning algorithm. To improve the positioning accuracy of the dynamic node of the wireless sensor network, Yingyan Wang et al. [6] proposed a method of wireless sensor network node location based on improved single anchor node. Firstly, single mobile anchor node is moved in the wireless sensor network to construct the learning sample of the wireless sensor location model. Then, the dynamic node location model is constructed by SVM, and the fisherman fishing algorithm is used to simulate the fisherman fishing behavior to find the optimal SVM parameter. The simulation experiment tests the positioning performance of dynamic nodes. This method can effectively improve the positioning accuracy of wireless sensor nodes, but the positioning efficiency is low. Xiaomin Zhao et al. [7] aimed at the wireless sensor node location problem

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under the situation of beacon node drift. Aiming at the problem of the decrease of the positioning coverage after the large number of beacon nodes in the wireless sensor network, the positioning reliability model of the common dynamic nodes is established, and use some of the more reliable general dynamic nodes in the locating blind spot as the temporary beacon node. The performance of the method is better in terms of false detection and positioning error, but the communication cost is too large. Jinghui Wang et al. [8] proposed a distributed collaborative DV-Hop improved algorithm for wireless sensor network dynamic node self-localization problem. Based on the weighted average, the average jump distance of each unknown node is calculated based on the reliability criterion, and the positioning error of the unknown dynamic node is calculated. The unknown dynamic node with the positioning error lower than the preset threshold is transformed into the anchor node, expand the positioning range. The method has a low positioning error, but the corresponding positioning efficiency is also low. In view of this, this paper proposed a fan-based wireless sensor network dynamic node location optimization method. The performance of the method is analyzed, and the experimental results showed that the proposed method has great advantages in calculating the cost and positioning accuracy. Compared with the traditional node localization method, the proposed method has the advantages of high positioning accuracy and better stability.

2. Description of Wireless Sensor Network Dynamic Node Location

Assuming that $M_i = \{d_{ij} \le r\}$ represents the neighbor node of a node i of the wireless sensor network, $M_j = \{d_{ij} > r\}$ represents the neighbor node of a node j of the wireless sensor network, d_{ij} represents the Euclidean distance between nodes i and j, r represents the communication radius, and the distance between the neighboring nodes of the wireless sensor network is expressed by the following formula:

$$RND(i, j) = RND(j, i) = 1 - \frac{M_i + M_j}{2M_i M_j} m_{ij} \tag{1}$$

where m_{ij} represents the number of identical neighbor nodes of node i and node j. According to the RND distance model, the unknown nodes in the wireless sensor network can be located [9], and the positioning process is summarized as follows:

Step 1. The minimum value of the distance between the node s_i and the node s_n is calculated by Floyd-Warshall according to the RND distance information between the obtained nodes, and is expressed by the following equation:

$$RND_{\min}(Path(s_i, s_n)) = \min\{\sum_{i=1}^{n-1} END(s_i, s_{i+1})\} \tag{2}$$

where $Path(s_i, s_n)$ represents the path of node s_i and node s_n. In equation (3), where A represents all the anchor nodes in the network.

$$\varphi_{end} = \frac{\sum_{i \ne j, i, j \in A} d_{ij}}{\sum_{i \ne j, i, j \in A} RND_{\min}(Path(i, j))} \tag{3}$$

Step 2. According to equation (3) to estimate the distance from any unknown node to the known anchor node, as shown in equation (4):

$$\hat{d}_{rnd}(s, i) = \varphi_{rnd} \times RND_{\min}(Path(s, i)) \tag{4}$$

Step 3. When obtain a sufficient number of estimated distance of the unknown nodes in wireless sensor network, trilateral measurement method or the maximum likelihood estimation method can be used to obtain the node coordinates. But this algorithm is still inadequate:

First, the method of the formula (1) can only use the nodes in the range of one hop. When calculating the whole path, it is necessary to calculate the cumulative value of the adjacent node RND on the path, as in the equation (2), the information between nodes separated by paths is independent of each other and does not make full use of the information of the same neighbor nodes between nodes. In the network, the distance d_{ij} of any two nodes is in the range of $\{d_{ij} \mid 0 \le d_{ij} \le rhop_{ij}\}$, where hop_{ij} is the hop count between nodes i and j. From the range of values, when the number of hops of two nodes is 2, the two nodes have at least one common neighbor node, so the RND distance estimation of adjacent nodes should be extended to the interval distance estimation.

Second, it still cannot solve the path when there is a large turning point brought by the estimated error. When calculating the RND distance information between node i and node k', then $RND_{\min}$ $(Path(i, k')) = RND(i, j) + RND(j, k')$, a large calculation error occurs.

3. Dynamic Node Location Optimization Method Based on Fan-shaped Wireless Sensor Networks

3.1 Wireless Sensor Network Model and Basic Assumptions

If the randomly deployed sensor network nodes are divided into two categories: one is the sensor node to load the omnidirectional antenna, the network density is ρ_s, the location information is unknown to be positioned sensor dynamic node, which is called the unknown node; the other is the sensor node load the rotatable directional antenna, which has the network density of ρ_L, and the location information is known, is called the anchor node. At the same time, it is assumed that all unknown nodes in the wireless sensor network deployment area can move quickly, the anchor nodes and the unknown nodes have different heterogeneous networks. The anchor nodes is thought to have sufficient energy, without regard to the energy consumption problem. In general, the number of anchor nodes in a wireless sensor network is less than the number of nodes, so $\rho_s > \rho_L$. Assuming that the communication radius of the nodes in the wireless sensor network is r, and LH is a set of anchor nodes that the dynamic node S can communicate directly, then the probability that the number of elements in LH is K is:

$$p(|LH_s| = K) = \frac{(\rho_L \pi r^2)^k}{k} e \cdot D \tag{5}$$

where e represents the channel attenuation factor, and at time t, the estimated position of a dynamic node is expressed as l_t, then the motion model of the mobile node can be expressed as:

$$p(l_t | l_{t-1}) = \begin{cases} \dfrac{1}{\pi(\Delta t \times v_{\max})^2} & if \quad d(l_t, l_{t-1}) \le \Delta t \times v_{\max} \\ 0 & otherwise \end{cases} \tag{6}$$

where Δt represents the time interval of each step and $v_{\max}$ represents the maximum motion speed of all nodes in the wireless sensor network.

3.2 The Strength of the Wireless Sensor Node Signal (RSSI) Value Calculation

The intensity of the wireless sensor node signal is related to the transmission distance. The greater the sensor node distance is, the greater the RSSI value is. Conversely, the RSSI is smaller. Each time a wireless communication transceiver module receives a data frame, it obtains an RSSI value that reflects the change in signal strength, so that the wireless signal propagation loss can be converted to an RSSI value by a path loss model. In this paper, Shadowing model is adopted as the wireless signal attenuation model.

The first part of the Shadowing model is the path loss model, which can calculate the average energy received when the distance is d_i, showed as $p_r(d)$. Let the existence of two anchor nodes A' and B', which has the distance of d_0, then:

$$\left(\frac{p_r(d_i)}{p_r(d_0)}\right)^{1/\beta} = \frac{d_i}{d_0} \tag{7}$$

where $p_r(d_0)$ represents the average signal strength of the anchor node A' received from B', and $p_r(d_i)$ represents the average signal strength of the under-tested node C' received from A'; d_i represents the distance between C' and A', and β represents the path loss index. In general, the path loss model is measured in dB as a unit of measure. Therefore, equation (7) is transformed into:

$$\overline{[p_r(d_i) / p_r(d_0)]}^{1/\beta} = d_i / d_0 \tag{8}$$

The second part of the Shadowing model showed that when the distance is constant, the received energy change is a lognormal random variable and satisfies the Gaussian distribution. If the unit is in dB, then a complete Shadowing model can be expressed as:

$$\overline{[p_r(d_i) / p_r(d_0)]} = -10\beta \log(d_i / d_0) + X_{dB} \tag{9}$$

where X_{dB} represents a Gaussian random variable. At the same time, this paper simplifies the Shadowing model, ignores the second part, and finally converts the wireless signal propagation loss into RSSI value through the path loss model.

3.3 Location Initialization, Location Prediction and Predictive Location Filtering of Wireless Sensor Network Dynamic Node

In the shadowing wireless signal attenuation model, the time is divided into discrete time slots, because the dynamic network nodes are always moving, the historical location information may be independent of the location of a node at any time. To make the positioning method more widely used, it is assumed that the nodes in the wireless sensor network are stationary and the nodes with unknown location can move. The anchor node is pre-configured in a fixed position, or its position can be determined. Other nodes with unknown location are randomly distributed. After the wireless sensor network is deployed according to formula (2) and formula (3), the unknown dynamic node estimates its position and predicts the next position. After obtaining the next prediction position of the moving node by $p(l_t \mid l_{t-1})$, the unknown dynamic node uses the received anchor node information to determine the current position estimation value of the anchor node through the overlap of the fan area of the anchor node. Assuming o_t represents the position observation information at time t, the prediction point which is not in the overlapping region can be filtered with $p(l_t \mid o_t)$ in the previous prediction position and the prediction point is randomly generated in this area instead of the deleted prediction point. As a new positioning model to re-positioning, followed by the cycle until the end of the positioning process. Wherein the probability of filtering for each predicted position is 0 or 1. If the deployment area of the wireless sensor network is determined by the origin (0,0) and ($X_{\max}$, $Y_{\max}$) of the Cartier coordinates, the initialization sample of the node is:

$$\begin{cases} x_i = rand \times X_{\max} \\ y_i = rand \times Y_{\max} \end{cases} \tag{10}$$

where (x_i, y_i) represents the initial sampling point position coordinate and rand represents the filter coefficient.

If the maximum velocity of the node motion in the wireless sensor network is $v_{\max}$ and the position of the unknown node i is s_{t-1}^{i} at time $t-1$, then the dynamic node i must be located in the circle with s_{t-1}^{i} as the center and $\Delta t \times v_{\max}$ as the radius. Define $\Delta t = 1s$, then:

$$p(l_t | l_{t-1}) = \begin{cases} \dfrac{1}{\pi v_{\max}^2} & if \quad d(l_t, l_{t-1}) \le \Delta t \times v_{\max} \\ 0 & otherwise \end{cases} \tag{11}$$

At this stage, since the number of samples obtained with the anchor node information in the unknown hop range is small, the use of two-hop anchor node information can effectively increase the number of reference to the sample. However, if more jumping anchor node information is used, it is difficult to limit the constraint conditions with the node communication range and will greatly increase the computational cost and traffic. Thus, false or useless predictive positions can be filtered based on the information of the hop and the two-hop anchor nodes. The above process assumes that the time is discrete and all observations are received immediately. Therefore, each node can receive the position information from the anchor node in the fan-shaped area covered by the anchor node at time t, that is, the anchor node L transmits its current position information, and the unknown node S simultaneously receives the information of the anchor near its neighbor node $L2$, the relationship of node S can be expressed as:

$$c \to S \quad HELLO | ID_c | \{(ID_{L2}, loc_{L2_t})\} \tag{12}$$

where (ID_{L2}, loc_{L2_t}) represents the average distance of each anchor node.

Setting $S_{ij}(\theta_{i,j}(t), j)$ as the sector of the anchor node i at t, and the angular information of the anchor node $\theta_{i,j}(t) = \{\theta_{i,j,\min(t)}, \theta_{i,j,\max(t)}\}$ indicates the direction of the rotatable directional antenna, where $\theta_{i,j,\min(t)}$, and $\theta_{i,j,\max(t)}$ represent the lower and higher range in the sector, Contains the fan-shaped area information currently covered by the directional antenna. The multiple information that the sensor collects from the multiple propagation of each anchor node is:

$$S_i(t) = S_{i,j}(\theta_{i,j}(t), j)(ID_{L2}, loc_{L2_t}) \tag{13}$$

The intersection region $ROI(t)$ of the plurality of sectors of the wireless sensor network can be expressed as:

$$ROI(t) = (\bigcap_{i=1}^{|LH_t|} S_{i,j}(t)) \tag{14}$$

Assuming *LH* represents the unknown node *S* can communicate directly with the set of all anchor nodes, *WN* represents the set of nodes that can communicate directly with the neighbor node of node *S*, but cannot communicate directly with node *S*. At the same time, assume that all angles refer to the x'-axis. The filter condition for any predicted position *b* of the unknown node *S* can be expressed as:

$$fi(b) = \forall LH_i \in LH, d(b, LH_i) \le r \wedge \theta_{i,\min(t)} < \eta < \theta_{i,\max(t)} \tag{15}$$

$$\begin{aligned} fi(b) = \forall WN_i \in WH, d(WN, LH_i) \le r \wedge \theta_{i,\min} \\ < \eta_2 < \theta_{i,\max} \wedge d(WN_i, b) \le r \end{aligned} \tag{16}$$

where η represents the straight angle of the connection b and LH_i, η_2 represents the straight angle of the connection LH_i and WN_i, $\theta_{i,\min}$ and $\theta_{i,\max}$ represent the minimum angle and the maximum angle of the fan node of the wireless sensor network respectively.

Since the anchor node coordinates and the beam direction are known, the range of η can be determined. If the filter conditions of formulas (16) and (17) are false, then the probability is $p(l_t \mid o_t) = 0$, and the predicted position is false. Otherwise, the probability $p(l_t \mid o_t) = 1$, that is, the forecast position is reasonable, acceptable. Since the erroneous prediction position is deleted by the above filter condition, the predicted position of the filtered node may be less than *N*, so it is necessary to randomly generate some prediction positions in the prediction area satisfying the filter condition so that the total number is kept at *N*. Subsequently, the above position prediction and position filtering stages are repeated until the estimated position of all *N* nodes is obtained in the wireless sensor network.

4. Experimental Results and Analysis

The wireless sensor nodes are randomly distributed in the 200 × 200 square meters, the number of nodes is 200 (60 anchor nodes, 140 nodes to be measured). The communication radius is 2 meters. The simulation experiment is carried out on the Matlab platform. The distance between nodes is 2 m. Unknown nodes use a free random motion model that does not know their own motion direction and only knows the speed of random value from 0 to the maximum *v*. Define the maximum velocity between the anchor node and the unknown node is $v^* = 25$ m/s, the positioning time interval is 2s.

The error of the wireless sensor network node location is:

$$error = \sqrt{(x_e - x_r)^2 - (y_e - y_r)^2} \tag{17}$$

The accuracy of the wireless sensor network node positioning is:

$$PA = \sqrt{(x_e - x_r)^2 - (y_e - y_r)^2} / D_2 \tag{18}$$

where x_e and y_e represent the estimated point of the wireless sensor network node, x_r and y_r represent the true position of the node, and D_2 represents the current communication radius.

Almost all the existing dynamic node localization methods use the expression of formula (17) and (18) to evaluate the positioning error. Therefore, to facilitate the comparison with the proposed method, we also use the evaluation indexes of expression of formula (17) and (18) to express the positioning error of different methods. In addition, to eliminate the contingency factors in a single experiment, statistically verify the positioning performance of the positioning method, each set of experimental data were analyzed using the mean of multiple randomized experimental results.

Through the simulation experiment of group 1, the change of network positioning coverage (%) under the condition of different numbers of anchor nodes (s) compared with the methods proposed in reference [7] and [9].

The results in Figure 1 showed that the node coverage of the method proposed in reference [7] increases with the increase of the number of anchor nodes. However, when the number of anchor nodes is small, the node coverage is not high. When the number of anchor nodes is greater than 30, the coverage rate of the node is only 80%. In our method, when the number of anchor nodes is small, the nodes of the wireless sensor network can be located, which reduces the number of nodes in the network and reduces the network cost. It showed the availability of the proposed method when the proportion of anchor nodes is small.

Through the simulation experiment of group 2, compared the positioning accuracy (%) the proposed method and the methods proposed in reference [7] and [9] with different number of anchor nodes. It can be seen from Figure 2 that the positioning accuracy of the three different methods increases with the number of anchor nodes. Under the same conditions, the accuracy of the proposed method is much higher than that of the reference [7] and [9]. This is mainly due to the introduction of RSSI information in the proposed method, which increased the anchor node weight information, and improved the dynamic node positioning accuracy. Figure 2 also showed that when the wireless sensor network anchor node density is small, the node positioning error is large, when the anchor node density increases, the positioning error is relatively small.

The comparison of the performance of the three methods are shown in Table 1. No additional hardware overhead is required in different methods, the methods proposed in reference [7] and [9] requires a higher anchor node density, and the proposed method only required a small number of anchor nodes with variable transmit power and the fault tolerance is not affected by the ranging error. So, the cost of the proposed method is low.

Through the simulation experiment of group 3, the influence in three methods is compared. The nodes are randomly arranged in the 100×100 m^2 area, select any 4 of them as anchor nodes Figure 3 showed that with the increase number of sensor network nodes, the proposed method has maintained a good positioning accuracy. In particular, when the number of nodes is less than 10, the proposed method can maintain high positioning accu-

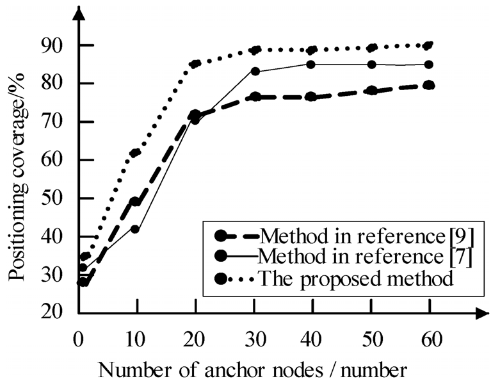

Figure 1. Comparison of wireless sensor network positioning coverage in different methods.

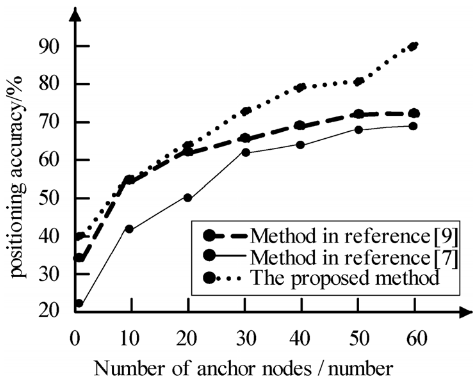

Figure 2. Comparison of positioning accuracy in different methods with different number of anchor nodes.

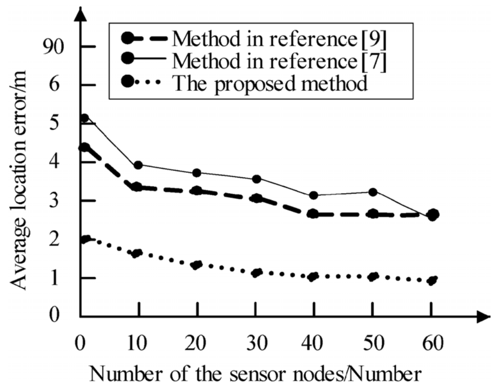

Figure 3. The influence of the total sensor node number in different methods.

Table 1. Comparison of positioning performance in three positioning methods

Evaluation index	The proposed method	Method proposed in [7]	Method proposed in [9]
Anchor node density	Low	High	High
Positioning accuracy	Associated with the anchor node density	Moderate	Moderate
Fault tolerance	Not affected by distance error	High	Low
Coverage	Associated with the anchor node density	High	Associated with the anchor node density
Network cost	Low	High	High

racy in the sparse node environment, when the positioning error in methods proposed in reference [7] and [9] is very large. The proposed method is proved to be more suitable for large-scale, low-density dynamic sensor localization of wireless sensor networks.

The influence of the communication distance (m) of the dynamic node of the sensor in different positioning methods is evaluated by the simulation experiment of group 4, as shown in Figure 4. The accuracy of the proposed method is better than that proposed in reference [7] and [9]. When the communication distance of the sensor dynamic nodes is 20 m, 40 m, 60 m, 80 m, 100 m, 120 m, respectively, the position error (m) in the proposed method is about 60% lower than that of [7]. When the communication distance of the sensor dynamic node is less than 40 m, the error in the method proposed in reference [9] is obviously larger. It is proved that the proposed method has great anti-interference effect on dynamic node communication distance.

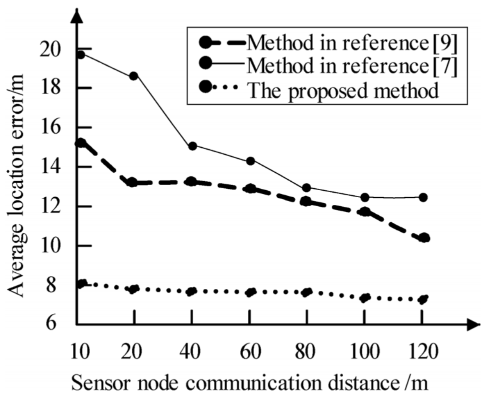

Figure 4. The influence of the communication distance of the sensor nodes in different positioning methods.

According to the simulation experiment of group 4, the positioning error change of the proposed method and the methods proposed in reference [7] and [9] are given in the case of the path loss factor of 2.5, 3.5, 4.5 and 5.5, simulation data as shown in Table 2.

As shown in Table 2, the positioning error of the method proposed in reference [9] is the largest, and the positioning accuracy of the proposed method is the highest, which is mainly due to the optimization of the inter-node distance model for path optimization. The rotatable directional antenna mounted on the anchor node minimizes the estimated area where the unknown node is located so that the estimated distance of the path is closer to the actual distance, thus ensuring the positioning accuracy of the proposed method.

The energy consumption of sensor dynamic nodes in different localization methods is analyzed, as shown in Figure 5. During the experiment, the proposed method of energy consumption has been in a relatively stable state, the energy consumption fluctuation range is relatively large in the methods of literature [7] and [9], which is not steady state. The experimental results show that the dynamic node energy consumption of the method is low

Table 2. Comparison of the number of beacon nodes with 25 different path loss factors

Path loss factor/g	The proposed method	Method in reference [7]	Method in reference [9]
2.5	27.63 m	32.51 m	29.36 m
3.5	35.98 m	45.68 m	59.74 m
4.5	38.59 m	56.49 m	69.58 m
5.5	46.41 m	58.84 m	75.98 m

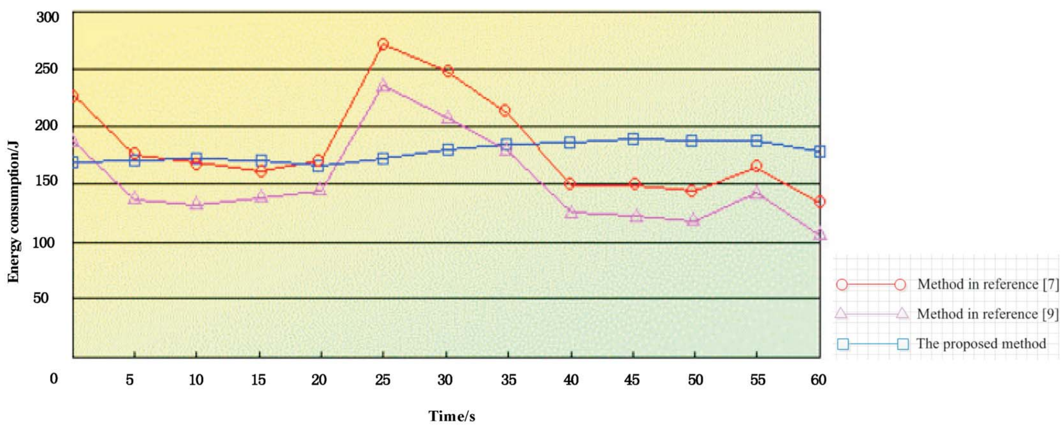

Figure 5. Energy consumption of sensor nodes under different methods.

and the running state is stable.

By analyzing the performance indexes of positioning method, including positioning accuracy, fault tolerance and network cost and coverage rate, three positioning methods comprehensively compared in the theoretical level, and then verified by the simulation. This kind of localization method belongs to the distributed node location method, and the dynamic wireless sensor network does not need any additional hardware support and the energy cost is small, which is an ideal scheme for wireless sensor network node location.

5. Conclusion

In the wireless sensor network, the node location information is the premise of the event location report, tracking and other system functions. To provide effective location information, the sensor node must be able to locate in real time after deployment. Based on the comprehensive analysis of existing positioning algorithms, this paper proposed a dynamic node location optimization method based on fan-shaped wireless sensor networks. Simulation results showed that the RSSI information is introduced in the dynamic node location optimization process, which enriches the information of location, improves the positioning accuracy and reduces the positioning error without increasing the cost and communication power. However, this method is analyzed under the ideal situation, real-world environment often exists non-line of sight, communication blind spots and other issues, future studies need to further consider these issues.

References

[1] Leu, J. S., Chiang, T. H., Yu, M. C., et al., "Energy Efficient Clustering Scheme for Prolonging the Lifetime of Wireless Sensor Network with Isolated Nodes," *IEEE Communications Letters*, Vol. 19, No. 2, pp. 259–262 (2015). doi: 10.1109/LCOMM.2014.2379715

[2] Zhao, L. H. and Liu, W. Y., "Boundary Node Identification for Wireless Sensor Network Based on Connection Information," *Science Technology and Engineering*, Vol. 16, No. 15, pp. 216–222 (2016).

[3] He, L., Kong, L., Gu, Y., et al., "Evaluating the On-demand Mobile Charging in Wireless Sensor Networks," *IEEE Transactions on Mobile Computing*, Vol. 14, No. 9, pp. 1861–1875 (2015). doi: 10.1109/TMC.2014.2368557

[4] Ahmed, A. A., "A Comparative Study of QoS Performance for Location Based and Corona Based Real-time Routing Protocol in Mobile Wireless Sensor Networks," *Wireless Networks*, Vol. 21, No. 3, pp. 1015–1031 (2015). doi: 10.1007/s11276-014-0834-7

[5] Ge, H., "Adaptive Consensus of Wireless Sensor Networks under Local Measurement by a Sink Node," *International Journal of Control*, Vol. 88, No. 2, pp. 256–263 (2015). doi: 10.1080/00207179.2014.948916

[6] Wang, Y. Y. and Zeng, R., "Node Localization Algorithm in Wireless Sensor Network Based on Imrpvoed Single Anchor Node," *Laser Journal*, Vol. 32, No. 11, pp. 128–131 (2015).

[7] Zhao, X. M., Zhang, H. Y., Jin, Y., et al., "Node Localization Scheme in Wireless Sensor Networks under Beacon Drifting Scenes," *Journal on Communications*, Vol. 36, No. 2, pp. 38–47 (2015).

[8] Wang, J. H., "A Node Location Algorithm in Wireless Sensor Network Based on DV-Hop," *Computer Engineering*, Vol. 41, No. 1, pp. 82–86 (2015).

[9] Collotta, M., Bello, L. L. and Pau, G., "A Novel Approach for Dynamic Traffic Lights Management Based on Wireless Sensor Networks and Multiple Fuzzy Logic Controllers," *Expert Systems with Applications*, Vol. 42, No. 13, pp. 5403–5415 (2015). doi: 10.1016/j.eswa.2015.02.011

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