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Real-Time Location Algorithm of Node Based on Anchor Node

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Abstract

For traditional RSS location method has higher requirements of environmental factors, the workload in the design and calibration and operation phase is great and efficiency is lower, so it put forward a kind of wireless sensor network localization algorithm based on online calibration modeling of RSS anchor node. First of all, to filter the anchor nodes with weak signal and large uncertainty by using the standard deviation threshold method, and make on-line modeling on the relationship between the distance of anchor node and the unknown node and received signal strength. Secondly, using the cycle calibration way for real-time correction of the on-line model, then locate the unknown node by using the weighted average method, thus establish adaptive mechanism of the environmental factors to realize the real-time accurate positioning of the node. Finally, through simulation to indicate this method can effectively locate the unknown nodes in wireless sensor network and its precision meets the requirements, algorithm is simple and easy to implement with practical application value.

Keywords*: Anchor Node, Received Signal Strength, On-Line Modeling, Wireless Sensor Network, Location*

1. Introduction

Wireless sensor network (WSN) has widely used in civil, military and other key areas and important role in [1]. In recent years, wireless sensor network location technology maturity, there are two main directions in this field: the range type localization algorithm and ranging localization algorithm [2]. Ranging localization algorithm of type on the positioning precision of the important indicators are better than the ranging localization algorithm, and there are three main distance access: one is based on the access point distance, use of the unknown node and anchor node connection and the Angle between the reference direction to obtain, such as the AOA [3] algorithm, etc. second, it is based on the time of the distance access, that is, through the wireless signal transmission time calculated each other distance between nodes, such as TOA [4], TDOA [5], *etc*. third is based on the Received Signal Strength (Received Signal Strength, or RSS, the distance of the access method. Although the method based on time and Angle to get a high level of accuracy, but time and Angle calculation module need higher energy consumption limits the both

The main advantages of the algorithm based on RSS is [6-7] : one is without increasing the distance measuring module; Second, no additional algorithms agreement or reading device; 3 it is to need time synchronization. So it has lower computational complexity and easy implementation, but the traditional algorithm of RSS to environment dependence degree is higher, need more onerous prophase work deployment, obviously not suitable

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for the reality of large construction of wireless sensor network. To solve this problem, this paper puts forward a kind of online RSS mapping modeling algorithm, to replace the traditional offline map calibration, in order to meet the scalability, power consumption and robustness requirements.

2. RSS Online Modeling Location Algorithm

2.1. RSS On-Line Distance Model

Literature [8] through the experiment to study the environmental impact factors of RSS distance model, and get three conclusions: one is the spread process of random multipath effect and interference exists, RSS variation is very large; Second, because of the influence of environment and the transmission power, in the practical application of the RSS model noise is difficult to ideally gaussian distribution; Three is the signal propagation of different behavior is spatial variability of wireless sensor network model. In fact, because of the existence of this random multipath effect in the process of signal transmission objects will be blocked or even distorted signals, which directly lead to RSS algorithm positioning is not allowed. Therefore RSS online adaptive wireless sensor network model is established to improve precision of the algorithm has very important significance.

Based on RSS localization algorithm is the core of constructing the mapping relationship between distance and received signal strength of RSS, the mapping relationship is based on wireless sensor network (WSN) RSS values with the increase of distance attenuation based on assumptions. For RSS localization algorithm based on wireless sensor network research mainly divided into two categories: based on the mapping, and based on the model. Because based on mapping algorithm needs to the early stage of the training of network mapping relationship, the inconvenience for the realization of large-scale sensor networks. So in this paper, the localization algorithm based on the model, the theoretical model of a typical formula [9] as follows:

$$R_d = R_{d_0} - 10\xi \log\left(d/d_0\right) + W_{noise} \quad (1)$$

where, R_{d_0} is the given reference signal strength and the distance from reference point is d_0, used to calibration of the calculation distance; R_d is the signal strength of the signal with the distance from signal sensor of d ; ξ is the path attenuation coefficient, mainly used to assess the decay rate of RSS strength as the distance, the selection of this value has close relation with environmental factor; W_{noise} is the white Gaussian noise of zero mean value of σ^2 variance, the selection of this value also has close relation with environmental factor.

The main purpose of on-line calibration is to let every anchor node through the information exchange with neighboring nodes to establish the mapping relation of individual distance with RSS value. No need the complex environmental analysis required in building the mapping relation of a global distance and the RSS value. The specific process of on-line calibration is as shown in figure 1. According to formula (1), the log Koc $\log\left(d\right)$ of RSS strength and distance d can be expressed as a linear model, let $a = R_{d_0}$, $b = 10\xi$, formula (1) can be translated to one-dimensional linear model as follows:

$$R' = a + b \times \log\left(d\right) \quad (2)$$

It can define the residual error formula between actual data and model predicted value:

$$q=\sum_{i=1}^{n}\left[R_i-\left(a+b\times\log\left(d_i\right)\right)\right]^2 \quad (3)$$

Then, the selection of linear coefficient a,b can be solved by the following formula.

$$\frac{\partial q}{\partial a}=-2\sum_{i=1}^{n}\left[R_i-\left(a+b\times\log\left(d_i\right)\right)\right]=0 \quad (4)$$

$$\frac{\partial q}{\partial b}=-2\sum_{i=1}^{n}\log\left(d_i\right)\left[R_i-\left(a+b\times\log\left(d_i\right)\right)\right]=0 \quad (5)$$

Where, d_i and R_i are the distance of unknown node with ith anchor node, and the signal strength of the received anchor node, respectively.

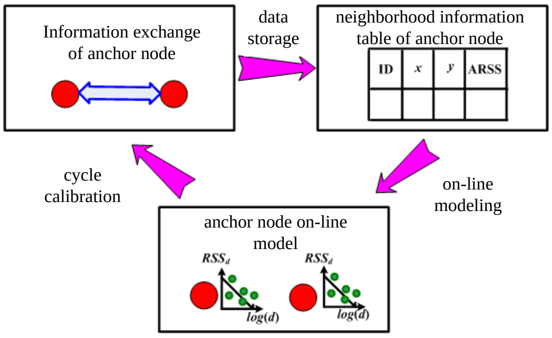


Figure 1. Specific Process of on-Line Modeling Calibration

2.2. Data Filtering and Three Circles Location

There might be many anchor nodes in a WSN network, but for the location of unknown node or anchor node modeling, so many location information is unnecessary, so to select suitable node number under the premise that the positioning accuracy is guaranteed can effectively reduce the computational complexity of the algorithm. To solve above problem, it proposed a method based on standard deviation threshold to select suitable anchor nodes. For the received signal strength of anchor node N from other anchor node can be expressed as:

$$N_i=\left\{lc_i \middle| i=1,\mathrm{n},k\right\} \quad (6)$$

Due to the influence of environment noise factors on RSS value has variability, single received RSS signal value has no representation, the common way is each anchor node N receive signal n times, then formula (2) can be extended as:

$$N_i\left(n\right)=\left\{lc_i^j \middle| i=1,\mathrm{n},k,\ j=1,\mathrm{n},n\right\} \quad (7)$$

Where, k is the anchor node number used for receiving GPS location information, I is the serial number of participated anchor node location, lc is the strength level of anchor node RSS, unit is dB. Standard deviation σ is the value for measuring statistical distribution character, the larger of the σ value indicates the volatility of the anchor node signal is great. the receive data standard deviation σ given by formula (3) can be expressed as:

$$\sigma_{i,j}=\sqrt{\frac{1}{n-1}\sum_{r=1}^{n}\left(lc_{i,j}^{r}-\frac{\sum_{r=1}^{n}lc_{i,j}^{r}}{n}\right)^{2}} \qquad (8)$$

We know that, in the actual modeling, quality and quantity of node data model has influence on node location model accuracy and computational complexity, so it is necessary to limit and select the anchor node, to simplify the calculation, using a simple threshold method to restrict selection for anchor nodes in online modeling. Threshold filtering operation is as follows:

$$\begin{cases} if\ \sigma_{i,j}\geq c, \overline{lc}_{i,j}\ values\ discarded \\ otherwise, \overline{lc}_{i,j}\ used\ for\ calibration \end{cases} \qquad (9)$$

After establish the relation function of distance and RSS value through formula (1) to (5), can take advantage of the location of the anchor nodes and RSS value to estimate the position of the unknown node. First to define the position of the unknown node metrics as (signal strength)

$$P=\left\{lp_{i}\left|i=1,\text{n},y\right.\right\} \qquad (10)$$

where, y is the number of received anchor node signal of node P, lp_i is the signal strength of ith received anchor node of node P .the same process mode of formula(7), for unknown node P receive signal for n times, then it can be extended as：

$$P(n)=\left\{lp_{i}^{j}\left|i=1,\text{n},y,j=1,\text{n},n\right.\right\} \qquad (11)$$

Similar with the definition of formula (8), the standard deviation of unknown node data can be defined as:

$$\sigma_{j}=\sqrt{\frac{1}{n-1}\sum_{r=1}^{n}\left(lp_{j}^{r}-\frac{\sum_{r=1}^{n}lp_{j}^{r}}{n}\right)^{2}} \qquad (12)$$

To locate the unknown node, no need of more anchor node, generally, in order to eliminate the influence of poor anchor node, it needs to filter the anchor nodes, but the process method is different from the above threshold value, here, select the given number m of anchor node by standard deviation σ ranking method. The relation between node P and node N_i (location mapping given by anchor node modeling) can be expressed as:

$$l(P,N_{i})=l_{i}=\sqrt{\sum_{j=1}^{r}\left(\frac{\sum_{r=1}^{n}lc_{i,j}^{r}}{n}-\frac{\sum_{r=1}^{n}lp_{j}^{r}}{n}\right)^{2}} \qquad (13)$$

The coordinate $r_{RSS}=(x,y)$ of location node P can be solved by the following formula:

$$\begin{cases} x_{j}=\sum_{i=1}^{m}(x_{i}/l_{i})\Big/\sum_{i=1}^{m}(1/l_{i}) \\ y_{j}=\sum_{i=1}^{m}(y_{i}/l_{i})\Big/\sum_{i=1}^{m}(1/l_{i}) \end{cases} \qquad (14)$$

where, (x_j, y_j) is the coordinate of unknown node, (x_i, y_i) is the predicted coordinate of unknown node of anchor node N_i model, can be solved and obtained through (14) the anchor node coordinate and received signal strength, as shown in figure 2.

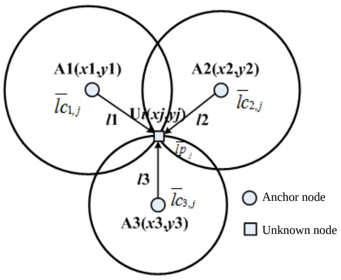


Figure 2. Location Schematic Diagram

Figure 2 take three anchor nodse as the example, provides the basic principle of RSS weighted average localization algorithm, first, the coordinate of three anchor nodes $A=\{A1, A2, A3\}$ can be real-time locate by GPS signal, that is the coordinate of three anchor nodes $(x1, y1)$、$(x2, y2)$及$(x3, y3)$ are measurable. Other measure can be solved by the previous formula.

3. RSS Real-Time Location Algorithm Steps

There are mainly three steps of RSS real-time location algorithm: one is on-line modeling calibration, second is on-line anchor node location algorithm; third is the unknown node location algorithm. The algorithm pseudo-code can be shown as table 1.

Table 1. Program Pseudo-Code

Program 1. On-Line Modeling Calibration

Input: Timer1 *t*1, probe burst size *n*, averaging window *Aw*
Output: Anchor-specific RSS to distance linear mapping

```
thread probeTransmission () {
  if (t1 seconds have elapsed) then
    broadcast a burst of n prbMsg containing
    the ID and the location coordinates X and Y
  end if
}
thread probeReception () {
  if (a prbMsg is received) then
    update neighTB based on received data
    (ID,X,Y, RSS[], AvgRSS, dist, Nb.prbMsg)
  end if
}
thread mappingUpdate () {
  if (Nb. prbMsg ≥ (Aw)) then
    Filter RSS[] vector values, Update AvgRSS and
    Comp the para of the RSS to dist mapping model
    // model: RSS = a + b × log10(distance)
    Clean RSS[] vector and Reset nb.prbMsg
  end if
}
```

Program 2. On-Line Anchor Node Location Algorithm

Input: Timer1 *t*1, Timer2 *t*2, *RSS*-to distance mapping
Output: Distance to the unknown node

1: **if** (a locReq is received) then
2: stop *t*1 and *t*2
3: set *t*2 (*t*2 = 2**IPI* + *e*)
// *e* varies from an anchor to another
4: increment *Nb.locReq*
5: **end if**
6: **if** (*t*2 seconds without receiving a locReq) then
7: comp the ave RSS (*RSSAvg*) of received locReq
8: determ the dist using *RSS*-to distance mapping
9: send the measured distance to unknown node
10: stop *t*2 and relaunch *t*1
11: **end if**

Program 3. Unknown Node Location Algorithm

Input: Locat req burst *w*, Inter-Packet Arrival time *IPI*
Output: Locat of the unknown node
1: send success w locat req (*locReq*) with a period *IPI*
// locReq mess contains Unkn node *ID* and *IPI* information
2: **wait**()
3: **if** (at least 3 dist estim ≤ Distth are received) then
4: estim locat using lateration tech
5: **end if**

The steps of real-time location algorithm as follows:

Step1: the exchange of information of each anchor node with neighboring anchor nodes, collected the original RSS measurements (*prbMsg*).

Step2: According to section 1.2 calculate the standard deviation of the received signal strength for each anchor node, to filter the anchor node on the basis of the standard deviation combined with threshold, and remove the anchor node with overlarge amplitude change, and stored in neighbourhood table of the anchor nodes (*neighTB*).

Step3: Using the storage data of Step 2 to generate on-line the distance and the RSS value model.

Step4: Whether the calibration cycle achieved or not, yes then turn to Step1, cycle calibration of online model. Otherwise turn to Step5.

Step5: According to section 1.2, to calculate the standard deviation of received anchor node signal strength of location node, and filter according to standard deviation combined with rank, to select the given number of m anchor nodes to participate in location.

Step6: Using formula (12) to (14) to calculate node coordinate, and locate unknown node, then output the location coordinate.

Step7: To determine whether satisfy location cycle or not, yes then turn to Step 4, no then turn to Setp7, algorithm into dormant state.

4. Simulation and Result Analysis

4.1. Experiment 1 (Comparative Experiments of Energy Consumption)

Experimental environment：30m2area of experimental environment (5m×6m), there are total 8 anchor nodes and 12 unknown nodes in this area, location anchor node select *nba*=4. Comparison algorithm adopts QPF and QDF algorithm, in order to compare the performance of AMC-RSS-Loc, QDF and QPF algorithm on energy consumption index, according to the proposed energy consumption evaluation model in Literature [10], the energy consumption of data communication mainly include three parts, data transmitting energy consumption, data wireless transmission energy consumption and data receiving energy consumption, then the calculation formula of data wireless transmission of sensor i as :

$$\begin{cases} E_T = \varepsilon_e + L^i \varepsilon_a \beta_i \\ E_R = L^i \varepsilon_r \\ E_S = L^i \varepsilon_s \end{cases} \quad (15)$$

where, ε_a is energy distribution per square meter and bit, unit is J 。 ε_e unit benchmark energy consumption value, unit is J 。 L^i is the data transmission distance. E_R is the received power consumption of receiving data at i th sensor at channel CH, the similar E_S is the wireless transmitted power consumption. In general case, the above parameters are : $\varepsilon_a = 50\,pJ/(bit * m^2)$, $\varepsilon_S = 35nJ/bit$, $\varepsilon_r = 75nJ/bit$, $\varepsilon_e = 80nJ/bit$. Then the comparison curve of the energy consumption value of AMC-RSS-Loc、QDF and QPF algorithm at the same moment as shown is figure 3.

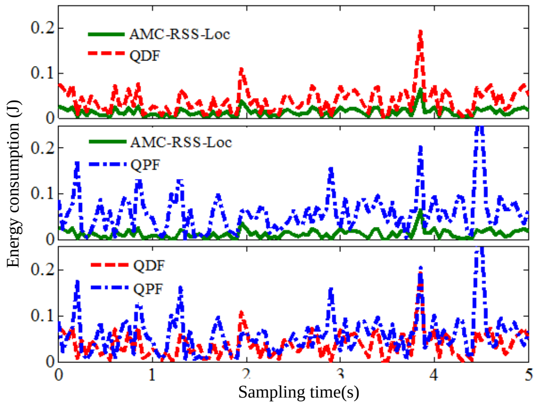


Figure 3. Comparison of Amc-Rss-Loc and Qpf、Qdf Energy Consumption

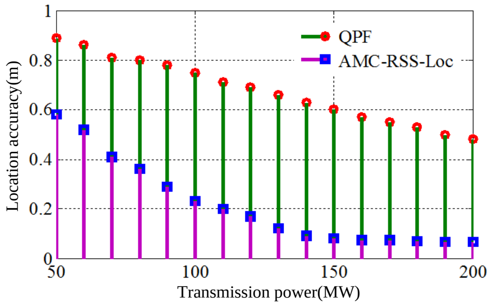
It can be seen from AMC - RSS - Loc and QPF, QDF energy consumption contrast curve in figure 3, although energy consumption of QPF, QDF algorithm in individual time is close to the energy consumption of AMC - RSS - Loc algorithm, but the rest of the time energy consumption of QPF, QDF algorithm are significantly higher than the energy consumption of AMC - RSS - Loc algorithm. From the third picture you can see that the energy consumption of QPF and QDF algorithm is closer, but the overall energy consumption of QPF algorithm is slightly better than the energy consumption of QDF algorithm. From which we can get the following conclusion: AMC - RSS - Loc with control technology of anchor node number, so relative to the QPF, QDF algorithm, it can more effectively save energy consumption to improve tracking accuracy, the overall performance of the algorithm significantly better than QPF, QDF algorithm.

4.2. Experiment 2 (Tracking Accuracy Comparison)

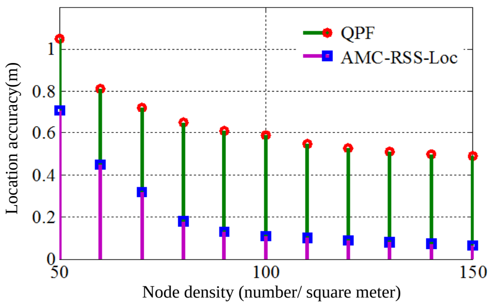
Location accuracy is one of the most direct indicators for algorithm accuracy degree evaluation, especially the tracking and locating of dynamic path, the current location accuracy evaluation method is compared from the Angle of location error. When dynamic tracking index used in evaluation, the common location accuracy can be defined as follows [11]:

$$E = \sqrt{Everage\left(\left(x - \hat{x}\right)^2\right)} \quad (16)$$

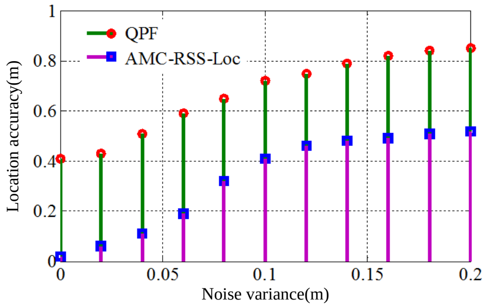
where, x is the actual moving path of the object(sensor), $\hat{x}$ is the object moving path predicted by algorithm, $Everage(\cdot)$ is the mean value solving function. The relevant literature [11] has proposed sensors transmitted power, node density and sensor noise, and many other factors that affect the positioning precision of sensor is very big. Analysis from the perspective of simulation test under the main sensors transmitted power, the density of nodes, sensor noise influence factors to the influence degree of the positioning accuracy, figure 4 (a) ~ (c) are the three factors influencing positioning accuracy of the algorithm under value, contrast algorithm adopts QPF algorithm.



(a) Influence of Transmission Power on RMSE Value



(b) Influence of Node Density on RMSE Value



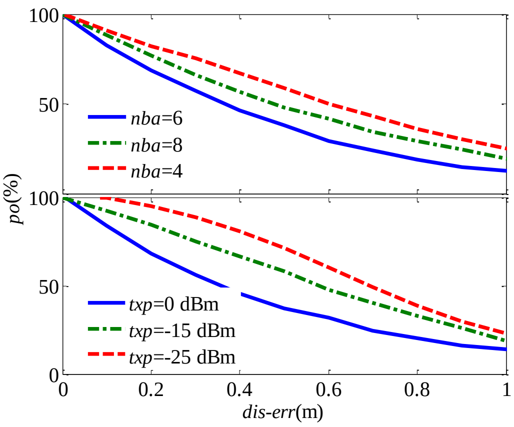
(c) Influence of Noise Variance on RMSE Value

Figure 4. Influence Factors Comparison of RMSE Value

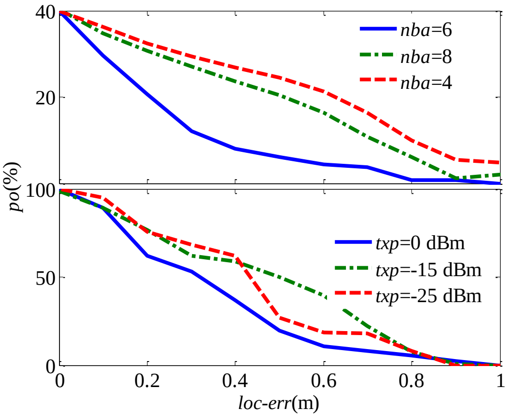
Figure 4 (a - c) provide the change curve of location precision value algorithm under the three influencing factors, it can be seen in figure 4 (a) with the increase of transmission power, locating accuracy of AMC - RSS - Loc, algorithm and QPF algorithm appear gradually decreasing trend, and the larger of transmission power, the higher of the locating accuracy of the algorithm, at the same time it can be seen that the positioning accuracy of AMC - RSS - Loc algorithm under all kinds of transmission power is better than QPF algorithm. It can be seen in figure 4 (b), with the increase of density of sensor nodes, the positioning precision of the algorithm are also growing, intuitively select fixed anchor nodes, and apparent the influence of sensor density on the positioning accuracy is not obvious, but in fact, larger density of experimental environment helps to improve the precision of online RSS modeling, so the tracking accuracy of the algorithm will increases as the density, the same positioning precision of AMC - RSS - Loc algorithm under various sensors density is better than QPF algorithm. It can be seen in figure 4 (c) as the noise increases, the location accuracy evaluation value is increased gradually, and location accuracy of the algorithm is lower, which is easy to understand, the greater of the interference, the poorer of the accuracy.

4.3. Experiment 3 (Location Influence Factor Experiment)

Experimental environment [12]: 30m2 area of experimental environment (5m×6m), there are total 8 anchor nodes and 12 unknown node in this area. The evaluation indicator of the algorithm are mainly two: one is distance error(dis-err), indicates the error between the actual distance and estimated distance of anchor node and unknown node error; second is the location error(loc-err), indicates the error between the actual position and estimated position of the unknown node. Locating error analysis method mainly include the cumulative distribution function(cdf), average value(ave), standard deviation(std)and abnormal value percentage(po), this experiment adopts error abnormal value percentage (po) for comparison, influence factor selects transmission power(txp)and the number of anchor nodes(nba), the experimental parameter setup as shown in table 2, the simulation result as shown in figure 5.



(a) Distance Error Influence



(b) Location Error Influence

Figure 5. Comparison Curve of Error Abnormal Value

Table 2. Experiment Setup

experimental environment	influence factor	repeat times	*nba*	*txp*(dBm)
Small	*txp*	10	8	0,-15,-25
	nba		4,6,8	0
Large	*txp*	20	8	-5,-15
	nba		4,8	0

The so-called error abnormal value percentage (*po*) indicates that, in the processing error experiment, the error is more than a given threshold percentage. Figure 5 (a) ~ (b) provide the percentage of error abnormal value in the selection of different anchor nodes number or under the condition of transmission power, its value changing with the change of anomaly threshold. Here, the selected anomal threshold value is the distance error (dis - err) and location error (loc - err). It can be seen from figure 5 the abnormal value of distance error and location error are decreased with the increase of transmission power, but not decrease monotonously with the increase of the anchor nodes, and from the upper picture of figure 5 (a), (b) you can see that the experimental results of anchor node selects 6 better than the number of anchor nodes of 4 and 8, in theory, the more the number of anchor nodes the location error should be less, the reason of it mainly because the online RSS model and distance model adopted in this paper, if the distance of anchor nodes is larger or the signal is weaker, the undertaken interference is larger, which is not benefit to the establishment of on-line model, and further affect the accuracy of algorithm. From the lower picture of figure 5 (a), (b), it can be seen that with the decrease of the transmission power, the volatility of the location error increases, which represents the interference of the signal from the environment increases. Conclusion: increasing the transmission power can effectively reduce the positioning error, the selection of reasonable number of anchor nodes can also help to reduce the distance and location error.

5. Conclusion

It proposed a kind of wireless sensor network localization algorithm based on the anchor node RSS online modeling calibration (AMC - RSS - Loc), used to solve the higher requirement of traditional RSS location method on environmental factors, the construction of network and the algorithm to calculate the more complex problems. From the perspective of online real-time calibration modeling, the algorithm through the filter and limit of anchor node participating in location, excluded the poor influence of anchor nodes with larger interference larger on location accuracy and algorithm complexity. The simulation experiments show that AMC - RSS - Loc algorithm on energy consumption and dynamic target tracking performance are superior to the compared algorithm. Through the static location influence factors experiment, it gave the influence trend of the signal transmission power and number of anchor nodes selection on location error, and provided the reference data for the network debugging. Simulation shows that the method can effectively locate the unknown nodes in the wireless sensor network and its accuracy meet the requirements, algorithm is simple and easy to implement with practical application value.

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