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Improving Positioning Algorithm Based on RSSI

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Abstract
Nowadays, a large number of positioning studies based on RSSI technology mainly focused on the coordinate position by measuring the distance using the certain algorithm. The difference between calculated distance and real distance became rather lager due to the poor solution to improve the impact of environment to RSSI, and the bad repeatability. Resulting in the inaccuracy of positioning. According to the RSSI distance measurement technology and Zigbee communication technology, this paper investigated the distance between the unknown node and anchor node based on the "RSSI-Distance". As the distance was less than 10 m or not, the position can be calculated by the "Mini-Max Positioning Method" or "Maximum Likelihood Estimation Method", respectively. The results showed that this accuracy of this positioning system can be limited within 3 m.

Keywords ZigBee · CC2530 · RSSI · Wireless sensor network · Positioning technology

1 Introduction

Today, the wireless positioning technology (WPT) is paying an increasingly important role in people's lives because of the rapid advancement of communication technology. GPS, Radio Frequency Identification (RFID) [1–3], Ultra Wideband (UWB) [4, 5] and ZigBee [6] have been regarded as common wireless positioning technology. However, the GPS with the most mature -WPT, does not be applied to the large-scale wireless sensor networks (WSN) because of its absence of the indoor positioning and high cost. Similarly, the RFID possesses the short, positioning distance, and the UWB does not develop its technology, though it had strong penetrating power, high positioning accuracy and low power consumption, resulting in hindering their applications. Conversely, Zigbee has become an important technology in area of WSN because of low cost and power consumption, large capacity, as well as flexible network topology characteristics [7].

As a new technology of obtaining and processing information, the application of WSN extensively involves military, monitoring environmental and forecast, health care, intelligent household, monitoring building, monitoring complex machinery, urban transportation,

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space exploration, a large workshop and warehouse management, Chen et al. [8], as well as those areas such as airports, monitoring safety of large industrial park. As one of the most important application in the WSN, it is very significant to study the wireless positioning technology.

The wireless ad-hoc network technology of ZigBee and the TI CC2530 chip as node chip were used in this paper, and the positioning technology was based on RSSI (Received Signal Strength Indicator). In Sect. 3.1, we discussed the RSSI ranging technology and the improvement of the present study. First, we got 5 RSSI values at each node by the method of weighted mean, and then calculated the mean without the maximum value and the minimum value, finally set up the corresponding relation of "RSSI-Distance", which can improve the ranging accuracy and stability. In Sect. 3.2, this paper introduced the positioning algorithm and the improved solution were described. First to analyze and determine the position of the locating node through testing the distance between node and certain anchor node when the distance was less than 10 meters or over, "Mini-Max Positioning Method" or "the Maximum Likelihood Estimation Method" was used to position, respectively. In the fourth chapter of the paper introduced the structure of positioning system, and the methods and results of verification.

2 Related Works

At present, according to the positioning mechanism of wireless positioning technology, the positioning algorithm can be divided into two kinds of distance-based and distance-free [8–10]. There are two steps for distance-based, calculating the range between the nodes and calculating the coordinates of nodes. The distance between nodes can be measured through the angle, time and intensity of nodes, and this algorithm includes: RSSI [9–11], TOA (Time of Arrival) [12, 13], TDOA (Time Difference of Arrival) [14, 15] and AOA (Angle of Arrival) [16, 17], etc. The distance is the basis of positioning calculation, so the precision of distance measurement and precise of positioning calculation is very important conditions for precise of positioning. The stage of node coordinates calculation is to get the coordinates of some unknown node depending on the distance between the known anchor node and unknown node, and the related algorithm includes Trilateration, Triangulation and "Maximum likelihood estimation method" [18–20]. These algorithms exhibit respectively advantages and disadvantages, as shown in Table 1.

Though the positioning technology based on RSSI is simple, the large errors of distance measurement makes the precise of positioning away from the requirement based on above research results, leading to hinder the application of this technology. In the paper, an improved positioning algorithm based on RSSI is proposed.

The coordinate based on distance-free is measured by estimating the distance between the nodes without measuring the distance or direction, or in the possible area with the determinate unknown nodes. Thereby, the complexity of hardware and the cost of sensor networks are reduced. The technology is hardly affected by environment, like other some algorithms, such as Distance Vector-hop (DV-Hop) [8], Approximate Point-in-Triangulation Test (APIT) [20], Centroid Localization Algorithm (CLA) [21–27], etc. The comparison of algorithms based on distance-free are shown in Table 2.

Besides the positioning error of the positioning technology with distance-free are big, and their accuracy is dependent of the estimated accuracy of every hop, and the

Table 1 Comparison of positioning algorithm range-based

Algorithm	Principle	Precise	Advantage	Disadvantage
RSSI	The transmitting loss was calculated based on the signal strength of transmitter and receiver, then converting the loss into distance depending on the transmitting model. The node coordinates were calculated by the algorithm range-base	Medium	Low hardware complexity, low power dissipation and low cost	The measuring precision was affected by environment, multipath reflection, and non-line of sight
TOA	The distance was calculated by multiplying the time of signal from sensor node to target node by the signal velocity, then calculating the coordinates of node by the algorithm	Higher	Simple method, high positioning accuracy	High cost of hardware, high power dissipation
TDOA	The coordinates of node was calculated by algorithm based on the time signal achieving node	High	Higher positioning precision	High cost of hardware, single application
AOA	The relative angle between transmitting node and receiving node was calculated by the direction of signal received by array antenna signal of multiple receiving node	Low		Complicated hardware, high power dissipation and high cost

Table 2 Comparison of algorithms based on distance-free

Algorithm	Principle	Precise	Advantage	Disadvantage
DV-Hop	The minimum hop count is calculated between mobile node and reference node, then the distance between nodes is calculated by average distance estimated. The coordinate of node is calculated by the existing positioning algorithm	Low	Low hardware complexity, simple method, easy to realize, low power dissipation and low cost	Large error, low accuracy
APIT	First a polygon area is formed at the overlap of the triangle area containing mobile node, which can determine a smaller polygon area containing mobile node. The coordinate of mobile node is calculated by CLA	High	High precision, low cost, low dissipation	High requirement for connectivity of network
CLA	Beacon signal including the ID and positioning information is sent by beacon node to near node every once in a while. When the signal quantity from different beacon nodes excess target threshold, or after a while, the position of the unknown node is the centroid of polygon made up by these beacon bodes	Low	Simple method, easy to realize, low cost	Low precision

requirements for communication is high, so it is not available for the application of positioning with high accuracy.

Compared with the above study, the positioning algorithm in this paper was based on distance-based. Firstly, the mapping table "RSSI-distanced" was established, and the distance between nodes was measured by comparing the linear relationship of RSSI and distance with mapping table, which can ensure the high accuracy and high stability. At last, the positioning algorithm "Mini-Max Positioning Method" and "Maximum Likelihood Estimation Method" were adopted, and which one can be chosen depending on the distance between the unknown node and anchor node, thus the positioning accuracy was improved within 3 meters.

3 Research for the Positioning Technology Based on RSSI

3.1 Improvement of Distance Measurement Based on RSSI

During measuring distance based on RSSI, the transmitting loss of RSSI was at first calculated based on the RSSI value from lunching node and the RSSI value measured by receiving node, then the distance was converted from transmitting loss model of wireless signal.

Research showed [8–12], there was determinate relationship between RSSI and the distance the wireless signal transmitting, and the RSSI with distance changing from lunching node to receiving node was defined by formula (1). In this formula, P_R was the RSSI value received by anchor node, P_T denoted the RSSI value transmitted by lunching node. The d represented the distance between the lunching nodes and receiving nodes, and n was loss coefficient, which depended on the environment of wireless signal transmission.

$$P_R = P_T/d^n \tag{1}$$

Formula (2) was formula (1) taken the logarithm,

$$10 * n * \lg d = 10 * \lg P_T - 10 * \lg P_R \tag{2}$$

Formula (2) was transformed to formula (3),

$$10 * \lg P_R = A - 10 * n * \lg d \tag{3}$$

A in the formula (3) was regarded as the received power after transmitting 1 m.

Generally, the RSSI was represents the received power, and $10*\lg P_R$ was the received power in dBm. So, the formula (3) was transformed into formula (4),

$$\mathrm{RSSI} = A - 10 * n * \lg d \tag{4}$$

Although transmitted power of each node was fixed, the transmission of wireless signal was affected by the unstable factors such as multipath, diffraction, obstacles, besides, and the coefficient of transmission loss could change with environment change. All these factors affected the measure-distance. So, in order to improve the accuracy of distance measurement, it was significant to build different models for measurement distance in different environments, which could make the attenuation characteristics of signal match environmental.

RSSI was high sensitive to the environment change, and its high volatility affected the accuracy of distance measurement [13–15]. To reduce the volatility of RSSI, and improve the accuracy of distance based on RSSI, this paper adopted the weighted

Table 3 The mapping table "RSSI-d"

d (m)	RSSI (dBm)
1	− 40
5	− 66
10	− 70
15	− 75
20	− 80
25	− 82
30	− 83
35	− 85
40	− 88
45	− 90
50	− 91

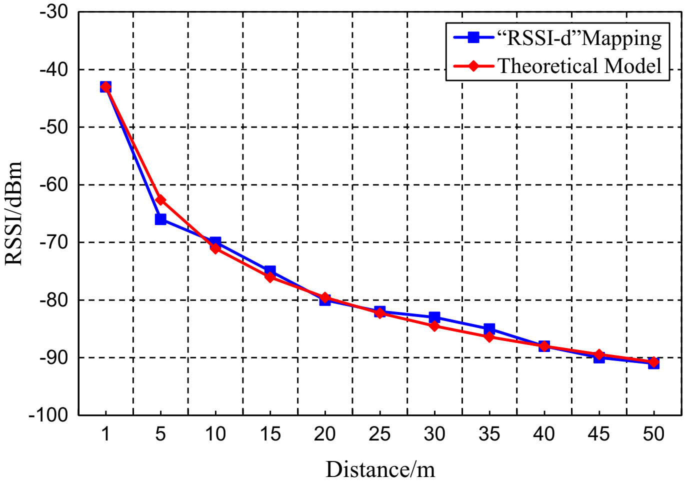

Fig. 1 Ranging model simulation

average to calculate the RSSI value of each node, and then removed the maximum and the minimum from continuous 5 RSSI. Finally, the average of last RSSI was used to calculate distance.

Steps were listed as follow.

1. Test environment. The testing environment was open, and no tall buildings around the testing area. The mapping table "RSSI-Distance (d)" was established by testing the RSSI values between fixed distance (Table 3). The distance from launching node to receiving node was gotten based on the mapping table. The changing of RSSI with distance between adjacent nodes was assumed as linear.

   The mapping table "RSSI-d" was simulated, and the results were consistent with the theoretical model $RSSI = A - 10 * n * lgd$, where $A = -43$ dbm, $n = 2.81$, as shown in Fig. 1. The Fig. 1 shown, the RSSI values reduced with d increasing. When the distance was more than 20 m, the changing of RSSI with distance was gradual. To reduce the effect of the random fluctuations of signal to positioning accuracy and the positioning error, the distance between the nodes should be limited within 20 m.

2. Signal Acquisition. Assuming that the signal from the anchor node “a” to the receiving node x was R. When R was less than the minimum RSSI value (the minimum value was −91 dBm in this paper), the value was invalid. The R and last RSSI values weighted averagely, then the result was defined as new R value, and was stored. Assuming that the last signal strength was R_0 and the weight was P, the new R’ value was
   $R' = R_0 * P + R*(1 - P)$, the size of P was configurable, and the value in this paper was 50%.
3. Calculation. For any node, the R’ in (2) was not directly used to calculate the distance, and the value used to calculate the distance was set R_0, which was the arithmetic mean of 3 RSSIs from continuous R1, R2, R3, R4, R5 without the maximum and minimum. The ranging algorithm code was as follows.

Algorithm 1 Ranging code

```
int preValue = 0;
for(int dist=0;dist<=100;dist +=5){
 String rssiValueStr = prop.getProperty("rssi."+dist);
 if(rssiValueStr != null && !"".equals(rssiValueStr.trim())){
  int rssiValue = Integer.valueOf(rssiValueStr);
  rssiDistMap.put(rssiValue, (double)dist);
      if(dist == 0){
        this.maxRssiValue = rssiValue;
        preValue = rssiValue;
        }else{
        for(int i=preValue-1;i>rssiValue;i--){
double curDist = ((double)(i-preValue)/(rssiValue-preValue))*5+dist-5;
        rssiDistMap.put(i, curDist);
      }
      preValue = rssiValue;
     }
  }else{
   this.minRssiValue = preValue;
   break;
  }
 }
```

4. Positioning. Based on the RSSI value in (3), the distance d could be gotten from the mapping Table 1, and the d would be used to calculate the positioning. The ranging model simulation was shown in Fig. 1.

3.2 Improvement of Positioning Algorithm Based on RSSI Ranging

At present, for the node positioning technology in the WSN, a small number of nodes in the network with known precise positions were adapted as anchor nodes, and these anchor nodes were as reference points. First, the distance between the unknown node and the anchor node was determined, and then a specific location algorithm was used to calculate the specific position of the unknown node according to the distance data.

In this paper, comparing and analyzing several ranging positioning algorithms, and combing with the characteristics of the application scenarios, "Mini-Max Positioning Method" and "Maximum Likelihood Estimation Method" were used for positioning calculation.

Minimum–maximum positioning method: First to calculate the distance "d" between the unknown node and each anchor node, and then built a square with 2d as the side length and each anchor node as center. The center of mass of the overlapped part of the square was the coordinates of the unknown node, as shown in Fig. 2.

Based on this solution, the advantages of simple algorithm were stable positioning and smooth label position. However, the disadvantages were that the tag could not exceed the largest range made up by the positioning base station, and the positioning base station must be deployed at the boundary of the positioning area.

Maximum likelihood estimation method: As shown in Fig. 3, there were some anchor nodes known as 1, 2, 3…n, and their coordinates were (x_1, y_1), (x_2, y_2), (x_3, y_3)…, (x_n, y_n). Took known node P as an example, its coordinate was (x, y), and the distances from P to each anchor node were d_1, d_2, d_3… d_n. The maximum likelihood estimation method was used to calculate the coordinate.

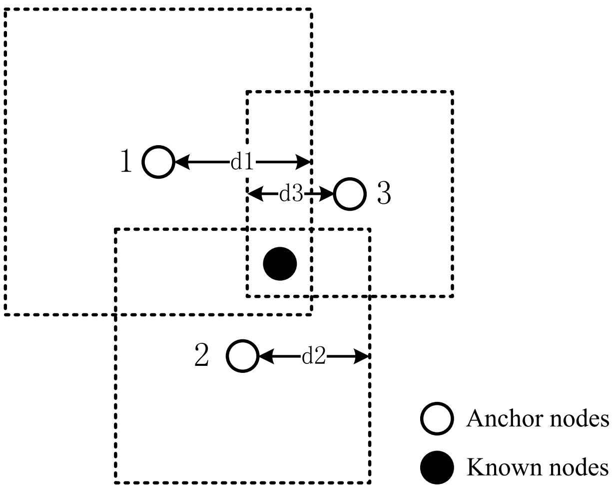

Fig. 2 Diagram of minimal positioning algorithm

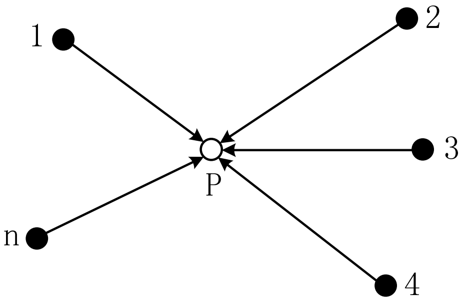

Fig. 3 Diagram of maximum likelihood estimation method

According to the distance formula between two points on the plane, a set of equations were built:

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 = d_1^2 \\ \dots\dots \\ (x_n - x)^2 + (y_n - y)^2 = d_n^2 \end{cases} \tag{5}$$

The last equation was subtracted respectively by the first equation to penultimate, then the results were:

$$\begin{cases} x_1^2 - x_n^2 - 2(x_1 - x_n)x + y_1^2 - y_n^2 - 2(y_1 - y_n) = d_1^2 - d_n^2 \\ \dots\dots \\ x_{n-1}^2 - x_n^2 - 2(x_{n-1} - x_n)x + y_{n-1}^2 - y_n^2 - 2(y_{n-1} - y_n) = d_{n-1}^2 - d_n^2 \end{cases} \tag{6}$$

The Eq. (6) was converted into matrix form: AX = b.

$$\mathrm{A} = \begin{bmatrix} 2(x_1 - x_n) & 2(y_1 - y_n) \\ \dots\dots & \\ 2(x_{n-1} - x_n) & 2(y_{n-1} - y_n) \end{bmatrix}$$

$$\mathrm{b} = \begin{bmatrix} x_1^2 - x_n^2 + y_1^2 - y_n^2 + d_1^2 - d_n^2 \\ \dots\dots \\ x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 + d_{n-1}^2 - d_n^2 \end{bmatrix}$$

Finally, the minimum mean square error method was used to get the coordinates of the node P,

$$\mathrm{X} = (A^T A)^{-1} A^T b$$

The advantages of this method were that the positioning accuracy was high and the location of the nodes was not limited by the layout of the anchor nodes. However, the disadvantages were that the algorithm was complicated and the amount of calculation was large. The position of the node was very sensitive to the fluctuation of the signal strength.

In this paper, a high-precision positioning has been obtained by combined the advantages of “Mini-Max Positioning Method” and “Maximum Likelihood Estimation

Method”. First, location of the positioning node was analyzed and determined, and the positioning method was chosen based on the distance between node and anchor node. As the distance was less than 10 meters or over, “Mini-Max Positioning Method” or “Maximum Likelihood Estimation Method” can be used for positioning, respectively. The part code of positioning algorithm was as follows.

Algorithm 2 part code of positioning algorithm

```
double pixDist = RSSIUtils.getPixDist(calRssiDist(rssi.getRssiValue()));
double lx = curAp.getX() - pixDist;
lx = lx < 0 ? 0 : lx;
if(lx > maxx) maxx = lx;
  double rx = curAp.getX() + pixDist;
  rx = rx > RSSIUtils.PX ? RSSIUtils.PX : rx;
  if(rx < minx) minx = rx;
    double uy = curAp.getY() - pixDist;
    uy = uy < 0 ? 0 : uy;
    if(uy > maxy) maxy = uy;
       double dy = curAp.getY() + pixDist;
       dy = dy > RSSIUtils.PY ? RSSIUtils.PY : dy;
    if(dy < miny) miny = dy;
 }
 location.setX((int)Math.round((minx + maxx)/2));
 location.setY((int)Math.round((miny + maxy)/2));
```

In order to improve the “drift” of unknown nodes due to packet loss, the following methods were used for data collection in the positioning algorithm:

a. The buffer failure time of signal strength was modified to 10 s. If the time of the RSSI tested for positioning 10 s ago, this RSSI was not used for positioning calculation and cleared from cache.
b. When the numbers of buffered data were less than five, the average value of these RSSI was used.

4 Structure Design and Verification of ZigBee Positioning System

4.1 The Structure of Zigbee Positioning System

The hardware of positioning system included: terminal server, PC, active RFID tag based on CC2530 (unknown node), anchor node with 3 dB gain antenna, and gateway. The

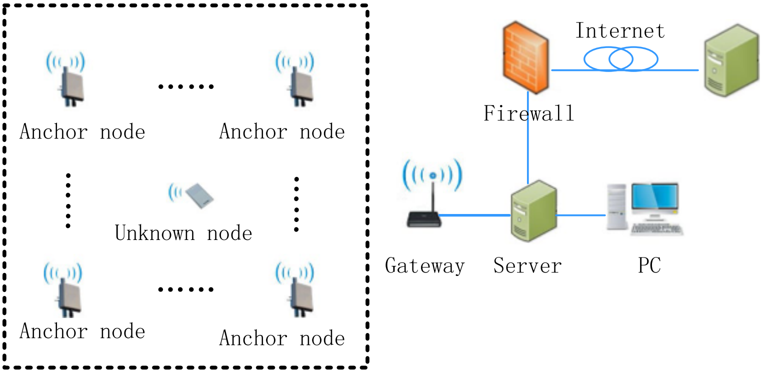

Fig. 4 The structure of positioning system

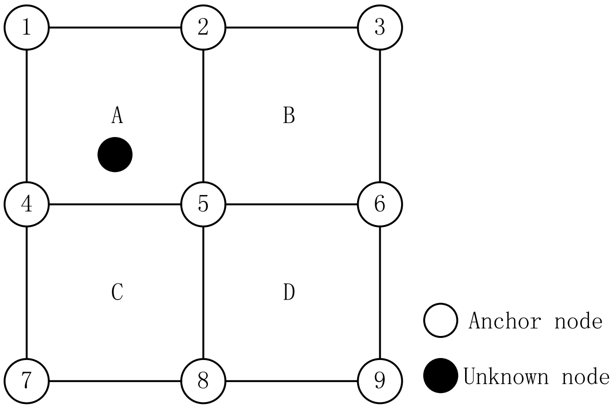

Fig. 5 Diagram of verification scenarios

gateway, as a route translation device at the network layer, was not only used to forward data from the ZigBee network to internet through the Ethernet, but also to automatically assign IPv6 addresses into each anchor node, and establish a mesh network with the wireless signals of each anchor node. In the mesh network, any anchor node could directly or indirectly communicate with the gateway, so that the positioning data was forwarded to the server through the gateway. The structure of positioning system was shown in Fig. 4.

Software: Positioning server software developed by Java, Web program using JSP technology.

The system adopted ZigBee wireless ad-hoc network technology. The active RFID tags, the anchor node and the gateway can communicated wirelessly, rather than the communication line.

4.2 Verification of Positioning System

In an open area, 9 anchor nodes were placed at equal distances of 20 m, 30 m, and 40 m. The height of anchor nodes to ground was 1.8 m, and this area was divided into A, B, C, and D, as shown in Fig. 5.

To verify the stability and repeatability of RSSI and its corresponding position, The No. 1, 5, and 9 were chosen as reference points, and the unknown node moved relative each reference point from near to far or from far to near. The RSSI values at the same distance were measured and the data was shown in Fig. 6.

The above data shows that the relationship between RSSI and d was an approximate logarithmic when the distance between the unknown node and the anchor node was within 0–20 m. While the distance was within 20–40 m, RSSI and d tended to be linear. So, the error would be large if only one algorithm was used to calculate d in the range of 0–40 m, which would affect the positioning accuracy. Therefore, this study established “RSSI-d”

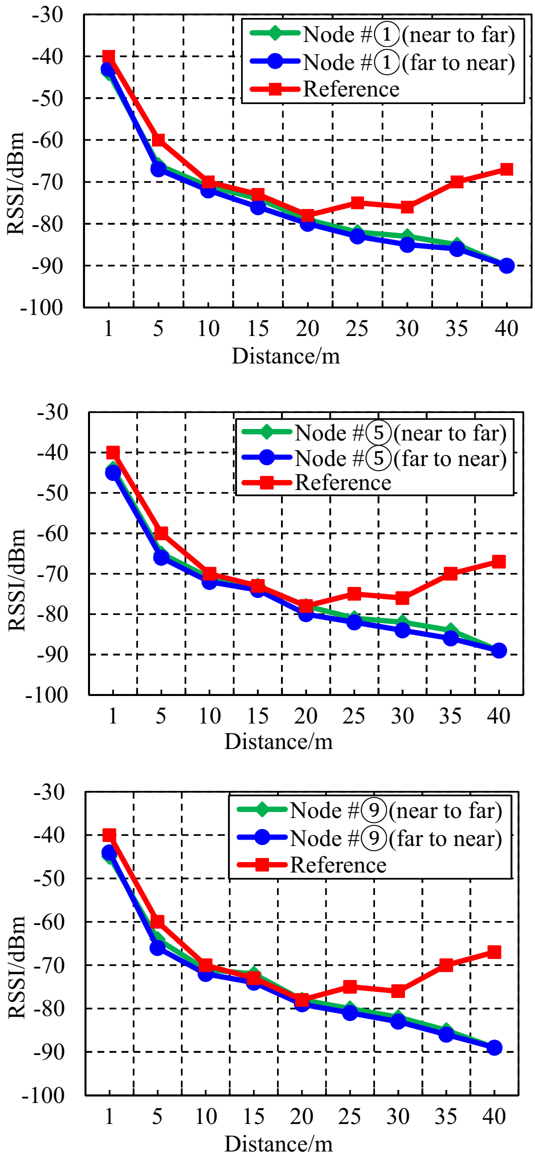

Fig. 6 RSSI & distance of different anchor node

mapping table according to the application scenario at first, which helped to reduce the error and improve the accuracy of distance.

The results show that, the difference of RSSI was within 3 dB as the unknown node was at the same distance from each different anchor node, and the difference was within 2 dB at the same distance when the unknown node moved at different direction. From the mapping table, the error of distance was within 2 m due to 2–3 dB difference. Compared with other research results [28], the accuracy of this study was higher, and the data also shown the stability between the RSSI and the d was higher, which enhanced the final positioning accuracy.

At last, the RFID tag moved freely in the areas A, B, C, and D, and the signal from tag was received by the nearby anchor node and sent back to the positioning gateway then the positioning gateway uploaded the collected signal to the positioning server. The positioning program evaluated distance referring "RSSI-d". If the d was less than 10 m, the "Mini-Max Positioning Method" was used to calculate. If d > 10 m, the "Maximum Likelihood Estimation Method" was used to calculate the distance. Based on the positioning algorithm and the distance, the coordinates were obtained, so the position was gotten.

This study shows that the error 2–3 dB would produce 2 m deviation from distance, so the positioning accuracy of this study was within 3 m, realizing the design goal.

5 Conclusion

TI's CC2530 chip, and the "Mini-Max Positioning Method" and "Maximum Likelihood Estimation Method" were adapted, and a wireless sensor positioning system based on Zigbee technology was designed. In the application, in order to improve packet loss and positioning accuracy, the solution of data collection was optimized to solve the "drift" problem, and the positioning accuracy was within 3 meters. For the RSSI-based positioning method, the positioning was easily affected by the environment, so that the accuracy was low and unstable. Therefore, this positioning method needed to be further researched and optimized.

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