An Improved Localization Algorithm Based on RSSI of Wireless Sensor Networks

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Abstract—**Existing localization approaches are divided into two groups: range-based and range-free. The range-free schemes often suffer from poor accuracy and low scalability, while the range-based localization approaches heavily depend on extra hardware capabilities or rely on the absolute RSSI values, far from practical. In this paper, an improved localization algorithm based on RSSI of wireless sensor networks is proposed, which uses the geometric relationship to find the most accurate point of RSSI for calculating the distance and utilizes the variation law of RSSI for localization. The simulation shows that the proposed algorithm has the smaller average positioning error and more accuracy compared with the trilateral localization algorithm based on RSSI ranging.**

Keywords—distance measurement; localization; RSSI; the geometric relationship

I. INTRODUCTION

Wireless sensor networks(WSNs) are such popular research fields and have emerged as one of the key enablers for a variety of applications such as military, environment monitoring, emergency response, target detection and tracking, and some business fields[1]. Therefore, the localization of sensor nodes plays an important role in the applications of WANs.

In a typical WSN, there are a few number of nodes with a priori known position, or the so-called anchors, whose coordinates may be obtained using the global positioning system. The objective of node positioning is to locate the remaining sensors with the use of the pairwise measurements between the nodes, including the anchors[2]. According to the use of distance between nodes, the localization approaches have been proposed can be divided into two types: Range-free approaches and Range-based approaches. Range-free approaches do not assume the availability or validity of distance information, and only rely on the connectivity measurements (e.g. hop-count) between the reference nodes and unknown nodes. For example, in the Centroid[13] algorithms, it uses the connectivity of networks to ensure the beacon nodes around the unknown node. Then we calculate the centriod of the polygon consisted of beacons nodes as the coordinate of the unknown node. In Approximate Point-in-Triangulation Test(APIT)[12], the intersection of triangle areas is determined to be a polygon contained unknown node . Then the centriod of the polygon is the coordinate. Having lower requirements on hardware, the accuracy and precision of range-free approaches are easily affected by the node densities and network conditions, which are often unacceptable for many WSN applications that demand precise localization[9].Range-based approaches assume that sensor nodes are able to measure the distances or the relative directions of neighbor nodes, for example, AOA,TOA and TDOA[14,15,16], which are the popular measurement modules of sensor nodes positioning[3]. However, in order to acquire the measurements, it always needs the support of hardware, which will lead to much hardware cost and energy consumption.

To solve the above problem, methods based on RSSI have been proposed. Range based on RSSI utilizes the transmission signal intensity of transmitting nodes and the received signal strength of receiving nodes to calculate the transmission loss, and then the theoretical or empirical model of the RF signal propagation is used to transform the loss into distance. Because the range based on RSSI is simple and low requirement of hardware support, ordinary sensor can be common to provide RSSI data[4].In reference[5],according to the signal strength variance for judging the matching degree of the actual received signal power and stored in advance, position of the minimum signal strength variance was regarded as the coordinate of unknown node. In reference[6], the problem of locating multiple nodes was addressed through reducing the RSSI path loss and other environment factors with the use of maximum likelihood algorithm and the two-step weighted least squares method. In reference[7], an anchor-less relative localization algorithm aimed to be used in multi-robot teams was developed, which used the Kalman filter and the Floyd-Warshall algorithm to generate smooth RSSI pairwise signal distance for all nodes.

The measurement of RSSI is relatively easy, but it also faces some problems, for example, irregular in different areas and directions by the effects of channel noise, interference, attenuation and reflection, the rate of decay[10] changing with the environment factors. Therefore the theoretical or empirical model of propagation transformed the RSSI into distance becomes inaccurate. In this paper, we proposed an improved localization algorithm of wireless sensor networks based on RSSI, which uses the geometric relationship to find the most accurate point of RSSI for calculating the distance which makes the distance more accuracy and utilizes the variation law of RSSI for limiting the area of unknown nodes. The simulation shows that the proposed algorithm has smaller average positioning error and more accuracy.

II. DESCRIPTION OF THE PROPOSED ALGORITHM

This section is divided into three parts. At the first, we represent the positioning frame of the algorithm. Then, describe the process of information gathering. Finally, localize the unknown nodes based on the gathering information.

A. Description of Positioning Frame

Unknown nodes are fixed and can receive the signal strength and information of the beacon node. Beacon node moves along a straight line with constant speed and wears a directional antenna which can emit signal for a certain direction. It broadcasts its location information periodically(move fixed distance L in every period).

The positioning frame is shown in Fig.1.

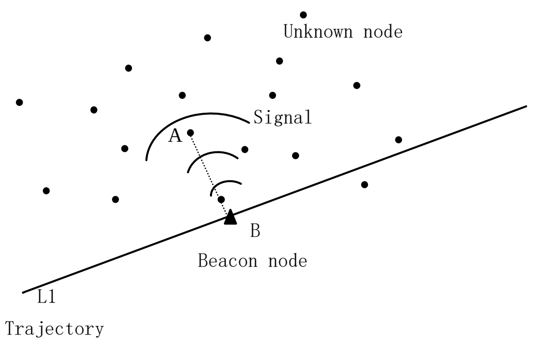

Figure1. Localization Frame

B. Process of Information Gathering

When beacon node B moves along the trajectory L1 with a constant speed, it broadcasts its location information to the unknown nodes periodically. At the same time, the unknown nodes receive the message which is come from the beacon node and the received signal strength. We take one of the unknown nodes called A as an example.

$B_i(a_i, b_i)$, $RSSI(d_i)$ and d_i are used to represent the position of beacon node B , the received signal strength of the unknown node A and the distance between A and B at the i^{th} period respectively, the value of i is 1~n.The initializing information recorded by the node A is showed in the Table 1.

TABLE1. INITIALIZING INFORMATION OF UNKNOWN NODE

NO.	Position of beacon node B	RSSI of node A
1	B_1 (a_1,b_1)	$RSSI(d_1)$
2	B_2 (a_2,b_2)	$RSSI(d_2)$
3	B_3 (a_3,b_3)	$RSSI(d_3)$
…..	…..	…..
i	B_i (a_i,b_i)	$RSSI(d_i)$
…..	…..	…..
n	B_n (a_n,b_n)	$RSSI(d_n)$

Usually, with the RSSI values from node A to a node, in ideal sense the distance between other nodes and node A should be calculated according to the log-normal shadowing model in Eq. (1), which is widely used in range-based localization approaches.

$$RSSI(d)=P_T - PL(d_0) -10n\log(d/d_0)+X \quad (1)$$

Where P_T is the transmission power, $PL(d_0)$ is the path loss for a reference distance of d_0, n is the path loss exponent and X is the Gaussian random variable.

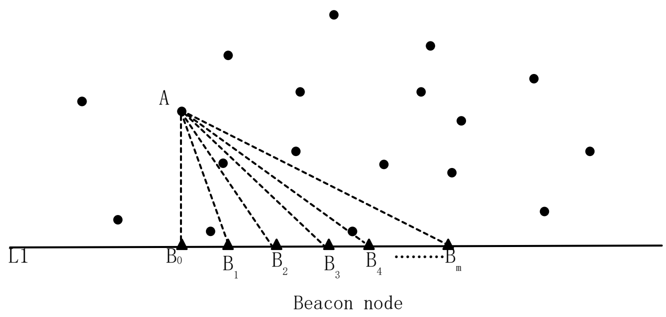

Figure2. The mobile location of beacon node

Through analyzing the Eq. (1), the farther between the sender and the receiver, the weaker the signal strength of the receiver, inversely, the closer between the sender and the receiver, the stronger the signal strength of the receiver. Obviously, the strongest point of signal strength is the shortest distance between the sender and the receiver. Thus, when the sender moves along a straight line, the signal will change from weak to strong then to weak. According to the definition of the vertical segments in the geometry, the line of receiver and the strongest point must be vertical to the sender's trajectory. Then we need to choose a point B_i whose RSSI is the maximum that matches the above analysis from Column 3 of Table 1. However, the RSSI recorded by Table 1 is related to the movement of beacon node. We define the RSSI at the point B_i as $RSSI_{max}$. Since the beacon node moves periodically by the distance of L, the actual strongest signal strength $RSSI_{MAX}$ maybe locate beside the B_i resulting the angle a bit greater or smaller than 90^0. But it locates between B_i and the midpoint of B_i and B_{i-1} or between B_i and the midpoint B_i and B_{i+1}, otherwise, the $RSSI_{max}$ is at the point B_{i+1} or B_{i-1}. The error between the point of the $RSSI_{Max}$ and the point of $RSSI_{max}$ is less than the half of L. In order to reduce the error, the L is set small. At the same time, half of L is much smaller than the distance between the point of the strongest signal strength and node A. Through the analysis above, we still consider B_i is what we need. This point is written as $B_0(a_0,b_0)$. Those points behind B_0 are written as $B_1(a_1 ,b_1)$,$B_2(a_2 ,b_2)$….$B_m(a_m ,b_m)$ in proper order, the value of m is n-i. The mobile location of beacon node is shown in Fig.2. As a result, the line of the strongest point B_0 and the unknown node A is vertical to the trajectory L1 of beacon node, namely, it is the Eq. (2).

$AB_0 \perp L1$ (2)

According to the column 3 of Table 1 and the Eq. (1), the distance $\overline{ABi}$ between A and Bi can be calculated, 0~m is the value of i.

However, in practice, reflection, multipath propagation, non-line of sight (NLOS), the antenna gain and other problems will affect the received signal strength and lead to the use of Eq. (1) introduced error. Thus, this paper considers using accurate mathematical relationship to choose the most accurate distance from those calculated distances by the Eq. (1). The corresponding mathematical relationship is described as follows:

In the triangle AB_0B_i, using the Eq. (2) and the Pythagorean theorem, we can acquire: $AB_i^2=AB_0^2+B_0B_i^2$, values of i is 0 ~ m, AB_i is the actual distance between node A and point B_i obviously,

$AB_1^2–AB_0^2= B_0B_1^2=L^2$; (1)

$AB_2^2–AB_0^2= B_0B_2^2=(2L)^2$; (2)

$AB_3^2–AB_0^2= B_0B_3^2=(3L)^2$; (3)

……

$AB_i^2–AB_0^2= B_0B_i^2=(i*L)^2$; (i)

……

$AB_m^2–AB_0^2= B_0B_m^2=(m*L)^2$; (m)

Then, maintain the formula (1) constant and use the formula (i) minus the formula (i-1), we can obtain the following equations.

$AB_1^2–AB_0^2= B_0B_1^2=L^2$;

$AB_2^2-AB_1^2= B_1B_2^2=3L^2$;

$AB_3^2-AB_2^2= B_2B_3^2=5L^2$;

……

$AB_i^2-AB_{i-1}^2= B_{i-1}B_i^2=2(i-1)L^2$;

……

$AB_m^2–AB_{m-1}^2= B_{m-1}B_m^2=2(m-1)L^2$;

Namely, $AB_i^2-AB_{i-1}^2$ is an arithmetic sequence whose first entry is L^2 and tolerance is $2L^2$, where L is the move fixed distance in every period . The arithmetic sequence is defined as $\{a_i\}$, then $a_i = AB_i^2–AB_{i-1}^2 = 2(i-1)L^2=2L^2*i -2L^2$, the value of i is 1~ m. Then it can be expressed as Eq. (3):

$$y=2L^2*x-2L^2 \qquad (3)$$

Where x is positive integer and represent the i, the actual distance squared difference of neighbors is represented by y. Thus, according to the mathematical relationship, the actual distance squared difference of neighbors matches the Eq. (3) and the distance L between B_i and B_{i-1} makes the mathematical relationship as a linear equation .

According to the distance $\overline{AB_i}$ between node A and point B_i calculated by the Eq. (1), the distance squared difference of the neighbors is $\overline{AB_m}^2- \overline{AB_{m-1}}^2$. $\overline{AB_i}$ and $\overline{AB_m}^2- \overline{AB_{m-1}}^2$ are shown in the following Table(2).

TABLE 2. CALCULATED INFORMATION BY UNKNOWN NODE

No.	Position of beacon node B	RSSI of node A	$\overline{AB_i}$	$\overline{AB_i}^2- \overline{AB_{i-1}}^2$
0	B_0 (a_0,b_0)	$RSSI(d_0)$	$\overline{AB_0}$	———
1	B_1 (a_1,b_1)	$RSSI(d_1)$	$\overline{AB_1}$	$\overline{AB_1}^2- \overline{AB_0}^2$
2	B_2 (a_2,b_2)	$RSSI(d_2)$	$\overline{AB_2}$	$\overline{AB_2}^2- \overline{AB_1}^2$
…..	…..	…..	…..	…..
i	B_i (a_i,b_i)	$RSSI(d_i)$	$\overline{AB_i}$	$\overline{AB_i}^2- \overline{AB_{i-1}}^2$
i+1	B_{i+1} (a_{i+1},b_{i+1})	$RSSI(d_{i+1})$	$\overline{AB_{i+1}}$	$\overline{AB_{i+1}}^2- \overline{AB_i}^2$
…..	…..	…..	…..	…..
m	B_m (a_m,b_m)	$RSSI(d_m)$	$\overline{AB_m}$	$\overline{AB_m}^2– \overline{AB_{m-1}}^2$

In the Cartesian coordinate system, we describe the Eq. (3) by the way of scanning points and those points are represented by M_i, the value of i is 1~m. And then scan those points N_i (i, $\overline{AB_i}^2- \overline{AB_{i-1}}^2$). Calculate the distance M_iN_i between M_i and

N_i. Choose the minimum of M_iN_i. Finally, take the distance between B_i (a_i, b_i) and A as the most accurate.

C. Process of Calculation

Assume that the coordinate of A is (x, y), B_0 (a_0, b_0) and B_i (a_i, b_i) are the points of trajectory L1. Combined with Eq. (2) ,we can obtained:

$$\overrightarrow{AB_0} \perp \overrightarrow{B_0B_i}$$

namely,

$$\overrightarrow{AB_0}=(a_0-x, b_0-y),\ \overrightarrow{B_0B_i}=(a_i-a_0, b_i-b_0)$$

$$(a_i-a_0)*(a_0-x)-(b_i-b_0)*(b_0-y)=0 \ldots\ldots\ldots\ldots(4)$$

The distance from the unknown node A to the point B_i can be obtained by Eq. (5):

$$\overline{AB_i} = \sqrt{(x-a_i)^2+(y-b_i)^2} \qquad (5)$$

By Eq. (4) (5) we obtain two sets of solution:

$$\begin{cases} x1 = a_0 - k * \sqrt{\dfrac{\overline{AB_i}^2 + b_0^2 - b_i^2 - (a_0-a_i)^2 - 2*k*b_0*(a_0-a_i)}{k^2+1}} \\ y1 = \sqrt{\dfrac{\overline{AB_i}^2 + b_0^2 - b_i^2 - (a_0-a_i)^2 - 2*k*b_0*(a_0-a_i)}{k^2+1}} + b_0 \end{cases}$$

$$\begin{cases} x2 = a_0 + k * \sqrt{\dfrac{\overline{AB_i}^2 + b_0^2 - b_i^2 - (a_0-a_i)^2 - 2*k*b_0*(a_0-a_i)}{k^2+1}} \\ y2 = -\sqrt{\dfrac{\overline{AB_i}^2 + b_0^2 - b_i^2 - (a_0-a_i)^2 - 2*k*b_0*(a_0-a_i)}{k^2+1}} + b_0 \end{cases}$$

where $k = \dfrac{b_i - b_0}{a_i - a_o}$

Since the movement locus of beacon node L1 is a straight line, and the movement keeps constant speed, then we set its trajectory represented by L1: y = ax + b, (a, b are constants). According to the geometric relationship, L1 divides the plane into two parts, shown in Figure 3:

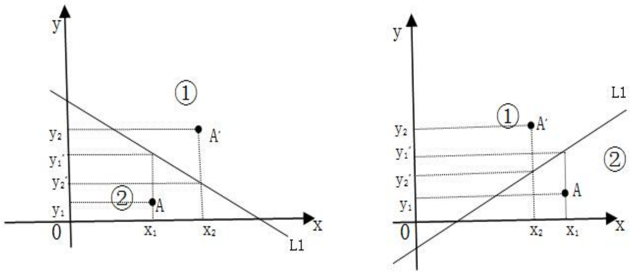

Figure3. Position Analysis

In Fig.3, A(x_1, y_1) and A'(x_2, y_2) are two solutions based on Eq. (4) (5) and the two solutions are symmetric about the locus L1. When x = x_1, the ordinate on the locus is y_1', obviously, y_1'> y_1; when x = x_2, the ordinate on the locus is y_2', y_2' <y_2.

When the abscissa takes a certain value, the ordinate of the portion ① is larger than the ordinate on the locus, the ordinate of the portion ②is smaller than the ordinate on the locus. Additionally, the beacon node wears a directional antenna which can emit signal to the side of the movement trajectory. Assuming that beacon nodes only transmit signals to section ①, the ordinate is larger than it in the locus when the abscissa takes the same value. Then make x_1 and x_2 as the abscissa, calculate the corresponding ordinate y_1' and y_2'of the locus respectively. Next, we need compare y_1, y_1' and y_2, y_2' respectively and chose the value which is larger than the y_1 or y_2. Just like the two solutions shown in Fig.3, y_2 is larger than y_2', there is no doubt that A'(x_2',y_2') is the location information of the unknown node.

III. SIMULATION AND ANALYSIS

To evaluate the performance of our proposed approaches, we use the Matlab to conduct the simulation. In the following, the simulation is compared the proposed algorithm with the trilateral localization algorithm based on RSSI ranging from two aspects: the quantity of the unknown nodes and the moving speed of beacon node. The simulation shows that the proposed algorithm has the smaller average positioning error and more accuracy.

Firstly, the range of the simulation is that twenty sensor nodes are randomly distributed in the area of 50m*50m, the moving speed of the beacon node is 2m/s, the signal coverage radius is 30m, the movement locus of beacon nodes is: y = x + 1, the results of Fig.4.

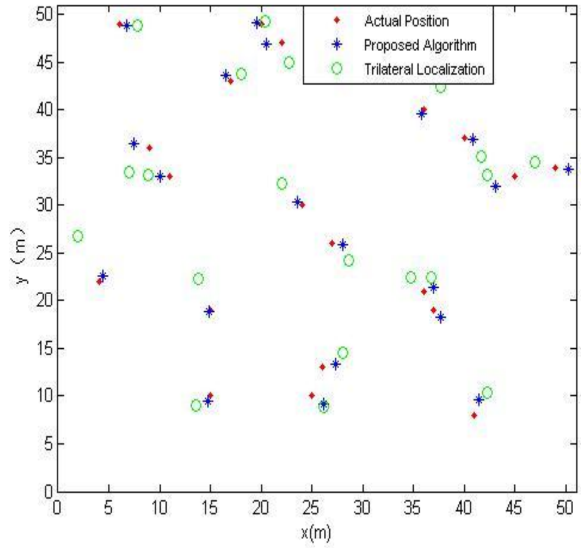

Figure.4 The simulation results of 20 nodes

Next, we use the average location error to analyze the influence of the number of unknown nodes in a certain area on positioning accuracy. To make the analysis intuitive and the positioning error of the mean normal under different conditions [11], the mean of positioning error is defined as Eq.(6):

$$error = \frac{\sum_{i=1}^{M}\sqrt{(xi-\overline{xi})^2+(yi-\overline{yi})^2}}{M*R}*100\% \quad (6)$$

Where (xi, yi) and ($\overline{xi}$, $\overline{yi}$) respectively represent the actual coordinate and the measured coordinate of the i^{th} unknown node. M is the total number of unknown nodes in the positioning process. R is the communication radius of the beacon node.

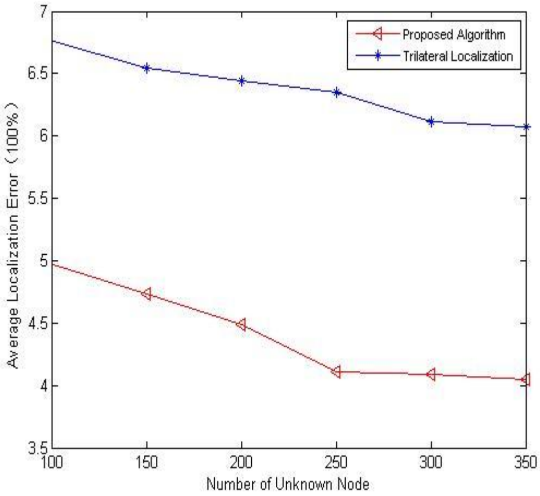

Figure.5 Average localization error vs number of the unknown nodes

As shown in Fig.5, the number of the unknown nodes in the range of 100m*100m is set 100,150,200,250,300,350 respectively and the moving speed of the beacon node is 2m / s. Eq. (6) is used for calculating the average location error. As shown in Fig.5, with the increase of the number of nodes, the average location error algorithm gradually decreased, and error of the improved ranging algorithm based on RSSI is low, when the number of nodes is 100, the average positioning error is 4.97%, while the average position error of trilateral localization algorithm based on RSSI ranging is 6.77%.

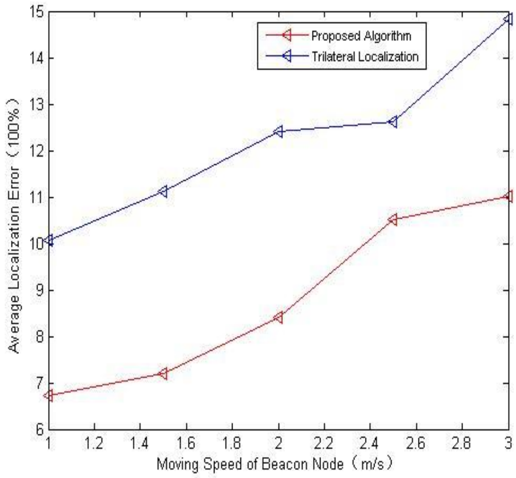

Figure.6 Average localization error vs the moving speed of beacon node

As shown in Fig.6, we distribute 100 nodes in the range of 100m*100m randomly. The moving speed of beacon nodes is respectively 1m/s, 2m/s, 3m/s, 4m/s. We calculate the average positioning error at every speed. We can acquire from the fig.6: With the increasing moving speed of beacon nodes, the average positioning error increases. The increased moving speed of beacon nodes lead to distance which betweens two consecutive signal strength received by the same unknown node increasing ,resulting in an average position error increases.

IV. CONCLUSIONS

In practice, reflection, multipath propagation, non-line of sight (NLOS), antenna gain and other issues will affect the received signal strength. Therefore a big advantage of error of ranging based on RSSI exists. The proposed algorithm uses the geometric relationship to find the point having the most accurate signal strength for ranging, so accuracy of the measured distance is improved, and the use of variation of signal intensity obtains geometric relationships to limit the area contained the unknown node; the algorithm makes use of a mobile beacon node track to achieve positioning. Simulation results show that as the number of unknown nodes is increased, the average location error decreases; with increasing speed of beacon node, the average position error increases, but less than trilateral localization algorithm based on RSSI ranging. Although the proposed algorithms increase the cost of hardware, it improves the accuracy and requires only a movement trajectory can achieve positioning, simplifying the positioning process.

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