Research Article

Localization with Single Stationary Anchor for Mobile Node in Wireless Sensor Networks

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We proposed a localization algorithm named LSARSSI for mobile node based on RSSI (received signal strength indicator) between locating sensor node with inertia module built-in and the single anchor. Instead of directly mapping RSSI values into physical distance, contrasting RSSI values received from anchor in different visited locations, LSARSSI utilizes the geometric relationship of perpendicular intersection to compute node positions. Given that the values of RSSI among two visited locations are equal, we regard that their distances to anchor node are equal. After obtaining several sets of such visited locations, the relative location of mobile node and anchor node can be calculated. Because of the limitations of LSARSSI, we put forward an improved algorithm named ILSARSSI. Our scheme uses only one location-known anchor which is useful in low density environment without using additional hardware. The simulations show that LSARSSI achieves high accuracy and ILSARSSI performs high stability and feasibility.

1. Introduction

Wireless sensor networks (WSNs) are such popular research fields that are highly interdisciplinary and state-of-the-art [1]. It has 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. In recent years, a number of research achievements about WSNs localization have arisen. According to the deployment of beacon nodes (which is also called anchor), the localization approaches that have been proposed can be divided into two types: one of which is based on multiple stationary beacon nodes [2–5], and another is based on mobile beacon node(s) [6–10].

But these methods are not suitable for all the applications of WSNs. In some scenarios, however, there is only a stationary beacon node [11] or a seed (reference node which position is known). For example, when we observe WSN on the sea, data can be transmitted to the shore or on board through an aggregation node, and only the position of aggregation node is known. Another example is regarding mountain inspection; the inspector would carry sensor module to move, transmitting data collected through the aggregation base station on the peak, and only the position of base station is known. In this situation, neither methods based on mobile beacon nor methods based on multiple beacon nodes could be used directly.

To address the previous issues, in this paper we proposed a localization algorithm named LSARSSI, an RSSI-based localization scheme using single stationary anchor. To increase the feasibility of our scheme, we further put forward an improved method called ILSARSSI. Major contributions of this paper are as follows.

(i) Our schemes can be used to locate mobile node in low density environment, which only need single anchor.

(ii) In order to avoid errors from directly mapping absolute RSSI values to distances, we obtain the geometrical relationship of sensors by contrasting the measured RSSI values. We then design a novel localization scheme, LSARSSI, which has a better accuracy and low overhead.

(iii) The simulation results show that our schemes perform high accuracy and feasibility, even in large-scale environment.
The rest of this paper is organized as follows. Section 2 introduces the related works about the localization of WSNs. Sections 3 and 4, respectively, present our algorithm of LSARSSI and ILSARSSI. Section 5 presents our implementation and the simulation results. We conclude this paper in Section 6.

2. Related Works

According to the deployment of beacon nodes, localization technology can be classified into two categories: multiple stationary beacon nodes based approaches and mobile beacon node(s) based approaches.

2.1. Multiple Stationary Beacon Nodes Based Approaches

Measurement techniques in WSNs based on multiple stationary beacon nodes can be broadly classified into two categories: range-based approaches and range-free approaches.

2.1.1. Range-Based Approaches

Range-based approaches assume that sensor nodes can measure the distance and/or the relative directions of neighbor nodes. Several mechanisms have been proposed to measure the node’s physical distance. For example, time of arrival (TOA) obtains range information through signal propagation times [12], and time difference of arrival (TDOA) estimates the node location by utilizing the time differences among signals that are received from multiple senders [13]. As an extension of TOA and TDOA, angle of arrival (AOA) allows nodes to estimate the relative directions between neighbors by setting an antenna array for each node [14].

All the previous approaches require additional hardware equipment so as to increase the cost of the sensor nodes greatly. Such, TDOA needs at least two signal generators [13]. AOA needs antenna arrays and multiple ultrasonic receivers [14].

A popular and widely used ranging technique is the received signal strength indicator (RSSI). RSSI is utilized to estimate the distance between two nodes with ordinary hardware [12, 15]. Various theoretical or empirical models of radio signal propagation have been constructed to map absolute RSSI values into estimated distances [16]. The accuracy and precision of such models, however, are far from perfect because of factors such as multipath fading and background interference [15, 17].

2.1.2. Range-Free Approaches

Given that range-based approaches are limited by hardware limitations and energy constraints, researchers have proposed range-free solutions as cost-effective alternatives.

Range-free approaches rely on the connectivity measurements between the measurement sensor nodes and a number of reference nodes, called seeds. For example, in the centroid algorithm [18], seeds broadcast their position to all neighbor nodes that record all received beacons. Each node estimates its location by calculating the center of the locations of all seeds it hears. In Approximate Point-in-Triangulation Test (APIT) [19], each node estimates whether it resides inside or outside several triangular regions bounded by the seeds that it hears and refines the computed location by overlapping such regions. In ring overlapping based on comparison of received signal strength indicator (ROCRSSI) [20], each sensor node uses a series of overlapping rings to narrow down the possible area in which it resides.

2.2. Mobile Beacons Approaches

Localization algorithms mentioned previously are in static sensor networks, which are not available in some scenarios. Recently, mobile-assisted localization approaches have been proposed to improve the efficiency of range-based approaches [10, 21]. The location of a sensor node can be calculated with the range measurements from the mobile beacon to itself, the localization accuracy can also be improved by multiple measurements that are obtained when the mobile beacons are in different positions.

Several localization schemes are proposed in this field. For example, Bergamo and Mazzini propose a scheme to perform localization, based on the estimation of the power received by only two beacons placed in known positions [22]. By starting from the received powers, eventually averaged on a given window to counteract interference and fading, the actual distance between the sensor and the beacon is derived, and the position is obtained by means of triangulation. In [10], a localization technique based on a single mobile beacon aware of its position (e.g., by being equipped with a GPS receiver) was presented. Sensor nodes receiving beacon packets infer proximity constraints to the mobile beacon and use them to construct and maintain position estimates. In PI algorithm [9], instead of using the absolute RSSI values, by contrasting the measured RSSI values from the mobile beacon to a sensor node, PI utilizes the geometric relationship of perpendicular intersection to compute the position of the node.

In recent years, more researches are focusing on mobile sensor networks, which are mainly based on mobile nodes [23–25]. Unlike other algorithms, the scene of the application
of ours is locating the mobile node with single stationary anchor by comparing the measured RSSI values between the locating sensor node with inertia module built-in and the single anchor. In this sense, LSARSSI and ILSARSSI are actually range-free approaches.

3. LSARSSI Algorithm

In this section, we first describe the application model in Section 3.1. Section 3.2 presents the design of our localization scheme in detail. Section 3.3 further presents the localization algorithm in 3D space.

3.1. Model Assumptions. For better implementing our algorithm, the hypotheses are as follows: (1) an anchor and a mobile node with inertial module whose trajectory is not designated; (2) the environment is an obstacle-free outdoor area; (3) the communication is not continuous, and the locating node receives the RSSI at different time intervals; (4) the RSSI values can be measured, and the offsets can be obtained and stored by the mobile node with inertial module.

We can illustrate it by the following model assumption. The coordinate of anchor A is \((x_0, y_0, z_0)\). Assume that the coordinate of initial location of the locating node N is \(P_0(x, y, z)\). \(P_i (i \in [1, n])\) is a visited location of the mobile node N after time \(T\), the relative offset of node N among \(P_0\) and \(P_i\) in the X, Y, and Z axis is \(\Delta x\), \(\Delta y\), and \(\Delta z\). So the coordinate of \(P_i\) is \((x + \Delta x, y + \Delta y, z + \Delta z)\), as shown in Figure 1.

Table 1 shows the messages obtained by the locating node N in different visited locations; it contains offsets and RSSI values. As the locating node needs to store the relative distances between locations that it visited, as well as the RSSI values between those locations to the anchor. It may require large memory storage for sensors. The issue can be resolved by the following method: assume that sensor can store 1000 messages of \(P_0\) to \(P_{999}\), and if the RSSI value of \(P_i\) is minimum (or maximum), the message of \(P_{1000}\) will replace it as shown in Figure 2.

As the communication is not continuous, and the visited locations for our schemes needed are countable, the computation and communication costs are acceptable.

### Table 1: Messages stored by sensor.

| Locations | Messages (node N) |
|-----------|-------------------|
| \(P_0\)   | \(\Delta x\) \(\Delta y\) \(\Delta z\) RSSI\((P_0)\) |
| \(P_1\)   | \(x + \Delta x_{01}\) \(y + \Delta y_{01}\) \(z + \Delta z_{01}\) RSSI\((P_1)\) |
| \(\vdots\) | \(\vdots\) \(\vdots\) \(\vdots\) |
| \(P_i\)   | \(x + \Delta x_{ii}\) \(y + \Delta y_{ii}\) \(z + \Delta z_{ii}\) RSSI\((P_i)\) |
| \(\vdots\) | \(\vdots\) \(\vdots\) \(\vdots\) |
| \(P_{n-1}\) | \(x + \Delta x_{0n-1}\) \(y + \Delta y_{0n-1}\) \(z + \Delta z_{0n-1}\) RSSI\((P_{n-1})\) |
| \(P_n\)   | \(x + \Delta x_{0n}\) \(y + \Delta y_{0n}\) \(z + \Delta z_{0n}\) RSSI\((P_n)\) |

3.2. Localization Algorithm Design. Typically, the ensemble mean received power in a real world obstructed channel decays proportional to \(d^{-\eta_p}\), where \(n_p\) is the path-loss exponent [26]. The ensemble mean power at distance \(d\) is typically modeled as

\[
P_r (d)_{dBm} = P_r (d_0)_{dBm} - 10n \log \frac{d}{d_0},
\]

where \(P_r\) is the received power (dBm) at short reference distance \(d_0\).

From (1) we know that, ideally, the longer the distance between sender and receiver, the weaker the signal strength detected by the receiver. The localization scheme was inspired by the **perpendicular bisector of a chord conjecture** [27]. With two chords of the same circle, the intersection point of two perpendicular bisectors of the chords will be the center of the circle. The localization problem can be transformed based on the conjecture. The center of the circle is the position of the anchor; the chord is a segment that is a connection of two positions (the RSSI values of the two positions are equal) of the mobile node at a given moment. The solution is detailed illustrated in Figure 3.

Node A is the anchor, \(N\) is the mobile locating node, \(P_0, P_1, P_2, P_3, P_4\) are the visited locations of locating node \(N\) after the time period of \(t_i\), \(j\), \(k\), \(l\); \(B, C\) are the midpoints of segments \(P_0P_1, P_2P_3, P_4\), and \(\text{RSSI}(P_0) = \text{RSSI}(P_1), \text{RSSI}(P_2) = \text{RSSI}(P_3)\).
The following are the formulas for calculating the location of locating node:

\[ A = (x_0, y_0), \quad P_0 = (x, y), \]

\[ P_1 = (x + \Delta x_{01}, y + \Delta y_{01}), \]

\[ P_2 = (x + \Delta x_{02}, y + \Delta y_{02}), \]

\[ P_3 = (x + \Delta x_{03}, y + \Delta y_{03}), \]

\[ B = (x + \Delta x_{0B}, y + \Delta y_{0B}), \]

\[ C = (x + \Delta x_{0C}, y + \Delta y_{0C}). \]

According to the geometry of vector, we can obtain that

\[ \vec{A} = (\Delta x_{01}, \Delta y_{01}), \quad \vec{P_0} = (\Delta x_{23}, \Delta y_{23}), \]

\[ \vec{AB} = (x + \Delta x_{0B} - x_0, y + \Delta y_{0B} - y_0), \]

\[ \vec{AC} = (x + \Delta x_{0C} - x_0, y + \Delta y_{0C} - y_0), \]

\[ \vec{P_0}P_1 = \Delta x_{01} * (x + \Delta x_{0B} - x_0) + \Delta y_{01} * (y + \Delta y_{0B} - y_0) = 0, \]

\[ \vec{P_0}P_3 = \Delta x_{23} * (x + \Delta x_{0C} - x_0) + \Delta y_{23} * (y + \Delta y_{0C} - y_0) = 0, \]

(1) \[ \Delta x_{01} * x + \Delta y_{01} * y \]

(2) \[ \Delta x_{23} * x + \Delta y_{23} * y \]

\[ = \Delta x_{01} * (x_0 - \Delta x_{0B}) + \Delta y_{01} * (y_0 - \Delta y_{0B}). \]

Assume that

\[ a = \Delta x_{01} * (x_0 - \Delta x_{0B}) + \Delta y_{01} * (y_0 - \Delta y_{0B}), \]

\[ b = \Delta x_{23} * (x_0 - \Delta x_{0C}) + \Delta y_{23} * (y_0 - \Delta y_{0C}). \]

then (1), (2) can be converted into

(3) \[ \Delta x_{01} * x + \Delta y_{01} * y = a, \]

(4) \[ \Delta x_{23} * x + \Delta y_{23} * y = b, \]

\[ x = \frac{D_1}{D}, \quad y = \frac{D_2}{D}, \]

where

\[ D = \left| \begin{array}{c} \Delta x_{01} \\ \Delta x_{23} \\ \Delta y_{01} \\ \Delta y_{23} \end{array} \right|, \quad D_1 = \left[ a \begin{array}{c} \Delta y_{01} \\ \Delta y_{23} \end{array} \right], \]

\[ D_2 = \left[ a \begin{array}{c} \Delta x_{01} \\ \Delta x_{23} \end{array} b \right]. \]

3.3. Algorithm in 3D. Here we extend our algorithm to three-dimensional space. As we know, if there are three noncoincident chords on the sphere, the intersection of three midvertical planes is the center of the sphere provided that these three planes can intersect.

The general idea of this algorithm in 3D utilizes the previous conjecture. This problem can be described as follows: the locations of locating node \( N \) at different times compose a collection \( P = \{P_0, P_1 \ldots P_n\} \). Their RSSI values are \{RSSI(P_0), RSSI(P_1) \ldots RSSI(P_n)\}, locations can be divided into a number of subsets \( |N_1|, |N_2| \ldots |N_m| \) based on RSSI values, and the RSSI values in each subset are equal, respectively.

After that, given that one of the following conditions occurs, our LSARSSI algorithm can be achieved: (1) \( |N_1| = 2 \), and \( |N_2| = 2 \) and \( |N_3| = 2 \) (as shown in Figure 4(a)); (2) \( |N_4| = 3 \) and \( |N_5| = 2 \) (as shown in Figure 4(b)); (3) \( |N_6| = 4 \) (as shown in Figure 4(c)) \( a, b, c \in [1, m] \).

As (2) and (3) are the special cases of (1), here we take \( |N_1| = 2 \), \( |N_2| = 2 \) and \( |N_3| = 2 \) as an example to indicate formulas for calculating the location of locating node. A is the anchor; \( P_0, P_1, P_2, P_3, P_4, P_5 \) are the visited locations of the mobile node; \( B, C, D \) and \( D \) are the midpoint of \( P_0P_1, P_2P_3, \) and \( P_4P_5 \). And

\[ A = (x_0, y_0, z_0), \]

\[ P_0 = (x, y, z), \]

\[ P_1 = (x + \Delta x_{01}, y + \Delta y_{01}, z + \Delta z_{01}), \]

\[ P_2 = (x + \Delta x_{02}, y + \Delta y_{02}, z + \Delta z_{02}), \]

\[ ... \]

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Figure 3: An example of LSARSSI algorithm in 2D.
Figure 4: Examples of LSARSSI algorithm in 3D.

Figure 5: An example of ILSARSSI algorithm in 2D.

\[ P_3 = (x + \Delta x_{03}, y + \Delta y_{03}, z + \Delta z_{03}), \]
\[ P_4 = (x + \Delta x_{04}, y + \Delta y_{04}, z + \Delta z_{04}), \]
\[ P_5 = (x + \Delta x_{05}, y + \Delta y_{05}, z + \Delta z_{05}), \]

\[
\text{RSSI}(P_0) = \text{RSSI}(P_1),
\]
\[
\text{RSSI}(P_2) = \text{RSSI}(P_3),
\]
\[
\text{RSSI}(P_4) = \text{RSSI}(P_5).
\]

(7)

According to the geometry of vector, we can obtain that

\[ \overrightarrow{P_0P_1} = (\Delta x_{01}, \Delta y_{01}, \Delta z_{01}), \]
\[ \overrightarrow{P_0P_3} = (\Delta x_{23}, \Delta y_{23}, \Delta z_{23}), \]
\[ \overrightarrow{P_0P_5} = (\Delta x_{45}, \Delta y_{45}, \Delta z_{45}), \]
\[ \overrightarrow{AB} = (x + \Delta x_{0B} - x_0, y + \Delta y_{0B} - y_0, z + \Delta z_{0B} - z_0), \]
\[ \overrightarrow{AC} = (x + \Delta x_{0C} - x_0, y + \Delta y_{0C} - y_0, z + \Delta z_{0C} - z_0), \]
\[ \overrightarrow{AD} = (x + \Delta x_{0D} - x_0, y + \Delta y_{0D} - y_0, z + \Delta z_{0D} - z_0), \]
Figure 6: A trajectory of the locating mobile node.

\[ \overrightarrow{P_0} \cdot \text{Δ} \overrightarrow{A}\text{B} = \Delta x_{01} \cdot (x + \Delta x_{0B} - x_0) + \Delta y_{01} \cdot (y + \Delta y_{0B} - y_0) \\
+ \Delta z_{01} \cdot (z + \Delta z_{0B} - z_0) = 0, \]

\[ \overrightarrow{P_0} \cdot \text{Δ} \overrightarrow{A}\text{C} = \Delta x_{23} \cdot (x + \Delta x_{0C} - x_0) + \Delta y_{23} \cdot (y + \Delta y_{0C} - y_0) \\
+ \Delta z_{23} \cdot (z + \Delta z_{0C} - z_0) = 0, \]

\[ \overrightarrow{P_0} \cdot \text{Δ} \overrightarrow{A}\text{D} = \Delta x_{45} \cdot (x + \Delta x_{0D} - x_0) + \Delta y_{45} \cdot (y + \Delta y_{0D} - y_0) \\
+ \Delta z_{45} \cdot (z + \Delta z_{0D} - z_0) = 0, \]

(1) \ \Delta x_{01} \cdot x + \Delta y_{01} \cdot y + \Delta z_{01} \cdot z \\
= \Delta x_{01} \cdot (x_0 - \Delta x_{0B}) + \Delta y_{01} \cdot (y_0 - \Delta y_{0B}) \\
+ \Delta z_{01} \cdot (z_0 - \Delta z_{0B}),

(2) \ \Delta x_{23} \cdot x + \Delta y_{23} \cdot y + \Delta z_{23} \cdot z \\
= \Delta x_{23} \cdot (x_0 - \Delta x_{0C}) + \Delta y_{23} \cdot (y_0 - \Delta y_{0C}) \\
+ \Delta z_{23} \cdot (z_0 - \Delta z_{0C}),

(3) \ \Delta x_{45} \cdot x + \Delta y_{45} \cdot y + \Delta z_{45} \cdot z \\
= \Delta x_{45} \cdot (x_0 - \Delta x_{0D}) + \Delta y_{45} \cdot (y_0 - \Delta y_{0D}) \\
+ \Delta z_{45} \cdot (z_0 - \Delta z_{0D}.

Figure 7: RSSI values received by locating node after time T.

Assume that 
\[ a = \Delta x_{01} \cdot (x_0 - \Delta x_{0B}) + \Delta y_{01} \cdot (y_0 - \Delta y_{0B}) \\
+ \Delta z_{01} \cdot (z_0 - \Delta z_{0B}), \]
\[
\begin{align*}
    b &= \Delta x_{23} \ast (x_0 - \Delta x_{02}) + \Delta y_{23} \ast (y_0 - \Delta y_{02}) \\
    &+ \Delta z_{23} \ast (z_0 - \Delta z_{02}), \\
    c &= \Delta x_{45} \ast (x_0 - \Delta x_{04}) + \Delta y_{45} \ast (y_0 - \Delta y_{04}) \\
    &+ \Delta z_{45} \ast (z_0 - \Delta z_{04}).
\end{align*}
\]
\((9)\)

Then (1), (2), and (3) can be converted into
\[
\begin{align*}
    (4) \Delta x_01 \ast x + \Delta y_01 \ast y + \Delta z_01 \ast z &= a, \\
    (5) \Delta x_{23} \ast x + \Delta y_{23} \ast y + \Delta z_{23} \ast z &= b, \\
    (6) \Delta x_{45} \ast x + \Delta y_{45} \ast y + \Delta z_{45} \ast z &= c.
\end{align*}
\]
\((10)\)

\[
x = \frac{D_1}{D}, \quad y = \frac{D_2}{D}, \quad z = \frac{D_3}{D},
\]
\((11)\)

where
\[
D = \begin{bmatrix}
\Delta x_{01} & \Delta y_{01} & \Delta z_{01} \\
\Delta x_{23} & \Delta y_{23} & \Delta z_{23} \\
\Delta x_{45} & \Delta y_{45} & \Delta z_{45}
\end{bmatrix},
\]

\[
D_1 = \begin{bmatrix}
a & \Delta y_{01} & \Delta z_{01} \\
b & \Delta y_{23} & \Delta z_{23} \\
c & \Delta y_{45} & \Delta z_{45}
\end{bmatrix},
\]

\[
D_2 = \begin{bmatrix}
a & \Delta z_{01} \\
b & \Delta z_{23} \\
c & \Delta z_{45}
\end{bmatrix},
\]

\[
D_3 = \begin{bmatrix}
a & \Delta y_{01} & \Delta z_{01} \\
a & \Delta y_{23} & \Delta z_{23} \\
a & \Delta y_{45} & \Delta z_{45}
\end{bmatrix}.
\]

4. Improved Algorithm: ILSARSSI

In real scenarios, the measure of the RSS is discontinuous; it may be difficult to obtain several groups of locations with the same RSSI values. So the algorithm proposed previously cannot be successfully used to locate. However, the locating node can be located by comparing the RSSI according to the signal attenuation model \([26]\).

Figure 5 demonstrates an example of the improved algorithm ILSARSSI. The RSSI values of node N measured in \(P_0, P'_0, P_1, P'_1, P_2, P'_2, P_3, P'_3\) are RSSI\((P_0),\) RSSI\((P'_0),\) RSSI\((P_1),\) RSSI\((P'_1),\) RSSI\((P_2),\) RSSI\((P'_2),\) RSSI\((P_3),\) RSSI\((P'_3),\) and RSSI\((P_0) <\) RSSI\((P'_0),\) RSSI\((P_1) >\) RSSI\((P'_1),\) RSSI\((P_2) >\) RSSI\((P'_2),\) RSSI\((P_3) >\) RSSI\((P'_3).\) The anchor is in the enclosed region BCDE of four perpendicular bisectors of the segment \(P_0P'_0, P_1P'_1, P_2P'_2, P_3P'_3.\) After finding a sufficient number of locations that meet such conditions, we can further narrow the area where the anchor node is. We take the centroid of the enclosed area as the position of the anchor, and then the coordinates of visited locations can be obtained.

The following are the formulas for calculating the location of locating node:
\[
A(x_0, y_0), \quad P_0 = (x_1, y_1), \quad P'_0 = (x'_1, y'_1),
\]

\[
P_1 = (x_2, y_2), \quad P'_1 = (x'_2, y'_2),
\]

\[
P_2 = (x_3, y_3), \quad P'_2 = (x'_3, y'_3),
\]

\[
P_3 = (x_4, y_4), \quad P'_3 = (x'_4, y'_4).
\]
\((12)\)

As \(L_1, L_2, L_3,\) and \(L_4\) are the perpendicular bisector of \(P_0P'_0, P_1P'_1, P_2P'_2,\) and \(P_3P'_3,\) according to the geometry of vector, we can obtain that
\[
L_1 : (x_1 - x'_1) \ast x + (y_1 - y'_1) \ast y
\]

\[
= \left(\frac{x_1 + x'_1}{2}\right) \ast (x_1 - x'_1) + \left(\frac{y_1 + y'_1}{2}\right) \ast (y_1 - y'_1),
\]

\((13)\)
\[ L_2 : (x_2 - x_2') \ast x + (y_2 - y_2') \ast y \]
\[ = \left( \frac{x_3 + x_3'}{2} \right) \ast (x_2 - x_2') + \left( \frac{y_2 + y_2'}{2} \right) \ast (y_2 - y_2') \]
\[ L_3 : (x_3 - x_3') \ast x + (y_3 - y_3') \ast y \]
\[ = \left( \frac{x_3 + x_3'}{2} \right) \ast (x_3 - x_3') + \left( \frac{y_3 + y_3'}{2} \right) \ast (y_3 - y_3') \]
\[ L_4 : (x_4 - x_4') \ast x + (y_4 - y_4') \ast y \]
\[ = \left( \frac{x_4 + x_4'}{2} \right) \ast (x_4 - x_4') + \left( \frac{y_4 + y_4'}{2} \right) \ast (y_4 - y_4') \]

As \( L_1 \cap L_4 = B \), \( L_3 \cap L_4 = C \), \( L_2 \cap L_3 = D \), \( L_1 \cap L_2 = E \),
\[ \Downarrow \]
\[ x_C = \left[ \left( \frac{x_2 + x_2'}{2} \right) \ast (x_2 - x_2') + \left( \frac{y_2 + y_2'}{2} \right) \ast (y_2 - y_2') \right] \]
\[ \left[ \begin{array}{c}
\frac{x_2 - x_2'}{2} \\
\frac{y_2 - y_2'}{2}
\end{array} \right] \]
\[ x_D = \left[ \left( \frac{x_3 + x_3'}{2} \right) \ast (x_3 - x_3') + \left( \frac{y_3 + y_3'}{2} \right) \ast (y_3 - y_3') \right] \]
\[ \left[ \begin{array}{c}
\frac{x_3 - x_3'}{2} \\
\frac{y_3 - y_3'}{2}
\end{array} \right] \]
\[ x_E = \left[ \left( \frac{x_4 + x_4'}{2} \right) \ast (x_4 - x_4') + \left( \frac{y_4 + y_4'}{2} \right) \ast (y_4 - y_4') \right] \]
\[ \left[ \begin{array}{c}
\frac{x_4 - x_4'}{2} \\
\frac{y_4 - y_4'}{2}
\end{array} \right] \]
\[ x_B = \left[ \left( \frac{x_1 + x_1'}{2} \right) \ast (x_1 - x_1') + \left( \frac{y_1 + y_1'}{2} \right) \ast (y_1 - y_1') \right] \]
\[ \left[ \begin{array}{c}
\frac{x_1 - x_1'}{2} \\
\frac{y_1 - y_1'}{2}
\end{array} \right] \]

\[ y_B = \left[ \left( \frac{x_4 + x_4'}{2} \right) \ast (x_4 - x_4') + \left( \frac{y_4 + y_4'}{2} \right) \ast (y_4 - y_4') \right] \]
\[ \left[ \begin{array}{c}
\frac{x_4 - x_4'}{2} \\
\frac{y_4 - y_4'}{2}
\end{array} \right] \]
The approach can also be applied to the localization of mobile node in three-dimensional space. The simulation results show that ILSARSSI performs high feasibility and practicality.

5. Simulation Results

To evaluate the performance of our proposed approaches, we use MATLAB 7.0 to conduct the simulations. In the following, the simulation parameters are listed in Table 2. We assume that the trajectory of the mobile locating node is random (Figure 6 is a trajectory of the locating node), the packet transmission period among anchor and mobile locating node is in a certain time interval (1s, 2s, 3s, 4s, and 5s), the average moving speed of the locating node is 2m/s, and the size of sensor field is in an obstacle-free area of 100 * 100 m², 200 * 200 m², 300 * 300 m², 400 * 400 m², and 500 * 500 m². According to Figure 7 plots the RSSI values received by locating node along the trajectory shown in Figure 6.

In the first section, we mainly validate the feasibility of LSARSSI and LSARSSI algorithm, and in the second section, we discuss the localization error of LSARSSI and ILSARSSI algorithms.

Table 2: Simulation parameters.

| Parameters                  | Value(s)          |
|-----------------------------|-------------------|
| Packet transmission period (s) | 1, 2, 3, 4, 5     |
| Moving speed (m/s)             | 2                 |
| Size of sensor field (m²)     | 100 * 100, 200 * 200, 300 * 300, 400 * 400, 500 * 500 |

5.1. Number of Locations Simulations. Figure 8 compares the number of locations of LSARSSI algorithm and ILSARSSI algorithm. The average number of locations of ILSARSSI is much fewer than LSARSSI algorithm, which demonstrates that the ILSARSSI algorithm performs high feasibility.

(1) Number of Locations versus Packet Transmission Period. The packet transmission period is the time interval of transmitting message among the anchor and locating node. Figure 8(a) indicates that the number of locations of the ILSARSSI algorithm decreases with increasing the packet transmission period. The average numbers of locations of ILSARSSI and ILSARSSI algorithm are approximately 240 and 55 at different transmission period, respectively.

(2) Number of Locations versus Size of Sensor Field. The size of sensor field is the moving range of the locating node. Figure 8(b) shows that the number of locations of ILSARSSI algorithm increases with expanding the size of sensor field.

5.2. Average Localization Error Simulations

(1) Average Localization Error versus Packet Transmission Period. Figure 9 compares average localization error for Ssu’s [28], BT [29], and our algorithm. Figure 9(a) shows that the localization accuracy for both Ssu’s and BT algorithms can be improved by reducing the packet transmission period. However, our LSARSSI algorithm performs higher accuracy with increasing packet transmission period, which can reduce the communication cost and energy consumption. If packet transmission period is 5s, the average localization error of Ssu’s and BT is approximately 15 m, but our algorithm is less than 3 m.

(2) Average Localization Error versus Size of Sensor Field. Figure 9(b) shows the impact of moving range on the localization error, as the size of sensor field expands from 100 * 100 m² to 500 * 500 m². The increased size of sensor field makes the Ssu’s and BT algorithms less accurate, but our localization error remains within 5 m.

(3) Average Localization Error of LSARSSI and ILSARSSI. Figure 10 demonstrates the localization error of ILSARSSI algorithm depends on the locating time. With increasing the locating time, the locating accuracy becomes more and more precise. That is because the possible location falls into a smaller enclosed region. However, the estimated error of LSARSSI algorithm varies slightly with the increase of locating time.
6. Conclusions

In this paper, we propose a localization algorithm named LSARSSI for mobile node with single anchor by aid of inertia module. The simulation results demonstrate that our LSARSSI algorithm outperforms than other range-free localization mechanisms, for example, Ssu’s and BT algorithms. As the number of locations needed is approximately 200, we further proposed an improved algorithm named ILSARSSI. ILSARSSI utilize the signal attenuation model to narrow the region of the anchor, and finally we regard the centroid of the enclosed region as its physical position. The average number of locations of ILSARSSI algorithm is much fewer which performs high feasibility. Our scheme uses only one location-known anchor which is useful in low density environment without using additional hardware. Because our algorithms are adapted to the obstacle-free outdoor scenario, our future work will focus on indoor environment.

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