Research on Indoor Localization Based on Joint Coefficient APIT

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Abstract. The APIT algorithm has become a popular technology for indoor localization due to its simplicity and low power consumption. However, the APIT algorithm often has misjudgments of In-to-Out in practical applications. And a large number of nodes cannot be located, when the density of anchor nodes (AN) is low. For this, this paper proposes a joint coefficient triangle APIT localization algorithm (JCTA). First, an effective triangle decision method is proposed. Then, the RSSI localization, the maximum likelihood method, and the weighted triangular coordinate calculation method are introduced and combined. Finally, an iterative co-location idea is used to locate the pending node (NP). The simulation results show that the JCTA algorithm can show good performance in terms of localization coverage rate and localization error about nodes.

Keywords: Indoor localization · Misjudgments of In-to-Out · APIT · Iterative co-location

1 Introduction

As the importance of location information in the WSN increases, various nodes localization algorithms emerge continuously. Among them, the location method based on ranging includes: the bias reduction method using the source locating explicit solution of TDOA [1], Received Signal Strength Indicator (RSSI) [2], RSSI-based automatic positioning method [3], etc. Although they can achieve high localization accuracy, they are costly. In contrast, location algorithms based non-ranging are low cost and can meet the requirements of localization accuracy for most applications. Among them, the typical non-ranging algorithms includes: an adaptive location algorithm based on APIT proposed for nodes randomly distributed in WSN [4], three-dimensional localization algorithm of APIT based on tetrahedral centroid iteration [5], and the traditional APIT algorithm [6]. Although the above algorithms can complete the localization of the nodes under certain conditions, the localization accuracy of the

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APIT algorithm depends on the locations of adjacent ANs and is susceptible to the density and distribution of sensor nodes. To this end, a JCTA algorithm is proposed to reduce the localization error and increase the localization coverage rate of nodes.

2 APIT Algorithm

The principle of APIT [7] is to use the ANs around the Pending Node (PN) to determine whether the PN is within a triangle consisting of ANs. And the APIT algorithm is invalid when the number of ANs around the PN is less than 3 or the ANs cannot form a valid triangle. We assume that there are C_N^3 triangles composed of N ANs around the PN, and it is determined by the APIT that there are M effective triangles. And different effective triangles have different roles in the evaluation.

A tricky issue with APIT is the misjudgments of In-to-Out [8]. As shown in Fig. 1, when the node D is in the inner boundary of the ΔABC, if the node D moves toward the node 4, the node D may be judged to be outside the ΔABC.

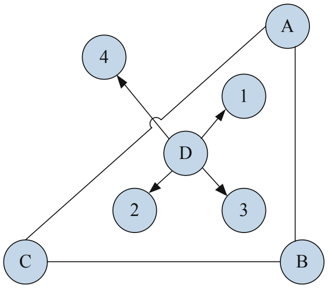


Fig. 1. Misjudgments of In-to-Out in APIT algorithm

The limitation of the APIT algorithm is that it requires a high density of ANs and a large communication radius. If the above requirements are not met, a large number of nodes cannot be located and the localization error will be large.

3 Proposed JCTA Algorithm

Aiming at the problems in APIT application, a JCTA algorithm is proposed. The algorithm includes determining effective triangles, RSSI assisted locating, maximum likelihood coordinate estimations and weighted triangle coordinate calculations, and interactive communication between nodes. Figure 2 depicts the overall flow chart of the JCTA algorithm. The detailed steps are as follows:

Step 1. Define the identification information of the node by $u\_f = 0$ represents a PN that is not located, $u\_f = 1$ represents a known AN, $u\_f = 2$ represents a PN that has been located.
Step 2. The PN collects the transmitted signal power from the neighbor ANs.

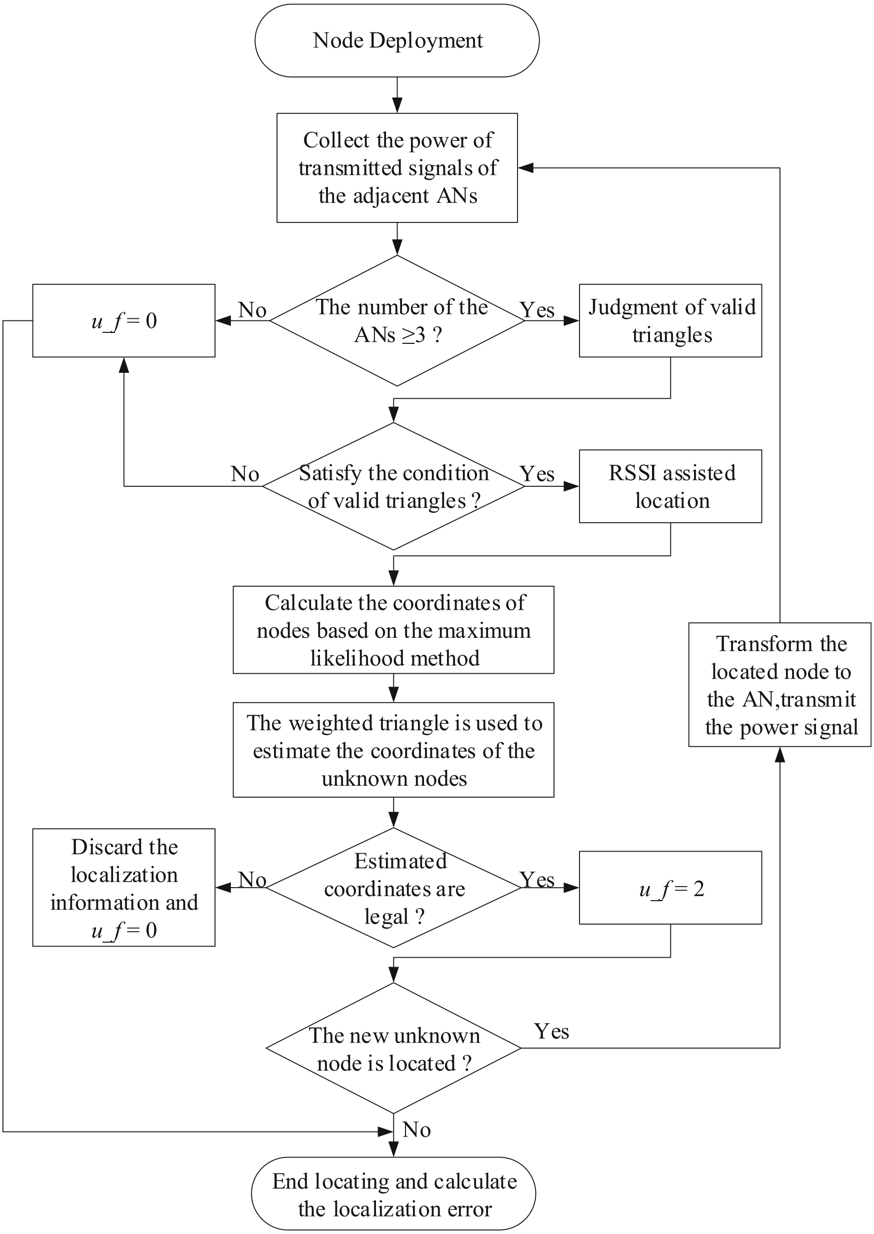


Fig. 2. Flow chart of the JCTA

Step 3. Determine whether the number of ANs is no less than 3. If yes, go to step 4; If no, terminate the locating and set the node ID to $u\_f = 0$.
Step 4. Determine whether the PN is within the triangle by APIT algorithm, and if so, the triangle is a valid triangle. However, the PN is considered to be outside the triangle

only when the number of neighbor ANs outside the triangle exceeds the threshold N. And the calculation of threshold is in (1):

$$N = \mu \times n \tag{1}$$

where μ is the scale factor, n is the number of neighbor ANs involved in the decision, N is the threshold for the number of qualified neighbor ANs.

Step 5. Take RSSI to assist the localization. Assume that there are M valid triangles determined by step 4. Write the i-th valid triangle as $\Delta A_i B_i C_i$ The distance is calculated from A_i, B_i, C_i of ANs to D_i of PN denoted by l_{Ai}, l_{Bi}, l_{Ci}.

First, according to the WiFi locating technology, the transmit power P_{A_i}, P_{B_i}, P_{C_i} and received signal strength RSSI_{A_i}, RSSI_{B_i}, RSSI_{C_i} of the ANs can be obtained. Then, calculate the distance of l_{Ai}, l_{Bi}, l_{Ci}, based on RSSI as in (2).

$$\mathrm{RSSI(l)} = P_T - PL(l_0) - 10\rho lg\left(\frac{l}{l_0}\right) + X_\sigma \tag{2}$$

where RSSI(l) is the signal strength received by the node, P_T is sending energy, $PL(l_0)$ is signal strength received by the node when the reference distance is l_0, ρ is the scale factor between path length and path loss, X_σ is a Gaussian random variable with a mean of 0 and a variance of σ^2.

Step 6. Estimate coordinates by maximum likelihood method. Assume that the coordinates of the ANs are (X_{Ai}, Y_{Ai}), (X_{Bi}, Y_{Bi}), (X_{Ci}, Y_{Ci}), the coordinate of PN is (X_{Di}, Y_{Di}). According to the relationship between distance and coordinates, the coordinates of NPs can be obtained based on the maximum likelihood method. As in (3):

$$\begin{cases} (X_{Ai} - X_{Di})^2 + (Y_{Ai} - Y_{Di})^2 = l_{Ai}^2 \\ (X_{Bi} - X_{Di})^2 + (Y_{Bi} - Y_{Di})^2 = l_{Bi}^2 \\ (X_{Ci} - X_{Di})^2 + (Y_{Ci} - Y_{Di})^2 = l_{Ci}^2 \end{cases} \tag{3}$$

Convert (3) to a linear system of equations as (4):

$$\begin{cases} X_{Ai}^2 - X_{Ci}^2 - 2(X_{Ai} - X_{Ci})X_{Di} + Y_{Ai}^2 - Y_{Ci}^2 - 2(Y_{Ai} - Y_{ci})X_{Di} = l_{Ai}^2 - l_{Ci}^2 \\ X_{Bi}^2 - X_{Ci}^2 - 2(X_{Bi} - X_{Ci})X_{Di} + Y_{Bi}^2 - Y_{Ci}^2 - 2(Y_{Bi} - Y_{ci})X_{Di} = l_{Bi}^2 - l_{Ci}^2 \end{cases} \tag{4}$$

Transform (4) into a matrix form of least squares:

$$BX = c \tag{5}$$

$$B = \begin{bmatrix} 2(X_{Ai} - X_{Ci}) & 2(Y_{Ai} - Y_{Ci}) \\ 2(X_{Bi} - X_{Ci}) & 2(Y_{Bi} - Y_{Ci}) \end{bmatrix} \tag{6}$$

$$c = \begin{bmatrix} X_{Ai}^2 - X_{Ci}^2 + Y_{Ai}^2 - Y_{Ci}^2 + l_{Ci}^2 - l_{Ai}^2 \\ X_{Bi}^2 - X_{Ci}^2 + Y_{Bi}^2 - Y_{Ci}^2 + l_{Ci}^2 - l_{Bi}^2 \end{bmatrix} \tag{7}$$

$$X = \begin{bmatrix} X_{Di} \\ Y_{Di} \end{bmatrix} \tag{8}$$

Thus, the location coordinate of the PN can be obtained by (9):

$$\begin{bmatrix} X_{Di} \\ Y_{Di} \end{bmatrix} = (B^T B)^{-1} B^T c \tag{9}$$

Step 7. The weighted triangle location method is used to estimate the coordinates of PNs. The mean value and standard deviation of each effective triangle distance l_{Ai}, l_{Bi}, l_{Ci} are calculated to obtain $E(l_i)$ and $\sqrt{V(l_i)}$, where l_i is the distance from the PN to AN i. Then the mean weighted factor $\beta_{Ei} = \frac{1}{E(l_i)}$ and the standard deviation weighted factor $\beta_{Vi} = \frac{1}{\sqrt{V(l_i)}}$ can be calculated. The mean weighted coordinates and standard deviation weighted coordinates of the M effective triangles are calculated as shown in (10) and (11). Then, the coordinate of the PN are estimated as a linear combination of (X_E, Y_E) and (X_V, Y_V) as shown in (12).

$$(X_E, Y_E) = \left(\frac{\sum_{i=1}^{M} \beta_{Ei} X_{Di}}{\sum_{i=1}^{M} \beta_{Ei}}, \frac{\sum_{i=1}^{M} \beta_{Ei} Y_{Di}}{\sum_{i=1}^{M} \beta_{Ei}} \right) \tag{10}$$

$$(X_V, Y_V) = \left(\frac{\sum_{i=1}^{M} \beta_{Vi} X_{Di}}{\sum_{i=1}^{M} \beta_{Vi}}, \frac{\sum_{i=1}^{M} \beta_{Vi} Y_{Di}}{\sum_{i=1}^{M} \beta_{Vi}} \right) \tag{11}$$

$$(X, Y) = \alpha \times (X_E, Y_E) + \gamma \times (X_V, Y_V) \tag{12}$$

where α and γ are the weighted coefficient of the mean and standard deviation coordinates.

Step 8. In this step, the legality should be checked. Suppose node A is an AN and D is a PN, and the distance from node A to node D is calculated. If the distance is within 120% of the communication radius of node D, the estimated coordinate of PN is legal, the coordinate values are recorded and the node's identity is set to $u\_f = 2$; Otherwise, the locating fails, the location information is discarded, and the identification of node is set to $u\_f = 0$.

Step 9. New anchor node will be added through iterative co-location. After each location is completed, it is judged whether the node that is successfully located this time is a new NP. If so, the node ($u\_f = 2$) is changed to AN, the power signal is sent to the neighboring area, and the localization coordinate of the node is broadcast. Then go to Step 2 and participate in the next round of localization calculation; if not, end the locating and calculate the localization error.

4 Simulation and Results Analysis

This paper verifies the localization performance of JCTA algorithm through MATLAB. The localization error rate E_{mean} and localization coverage rate ε of the node are defined as follows:

$$E_{mean} = \frac{\sum_{i=1}^{n} Q_i}{n} = \frac{\sum_{i=1}^{n} \frac{\sqrt{(X_e - X_t)^2 + (Y_e - Y_t)^2}}{R}}{n} \tag{13}$$

where Q_i is the localization error of a single node, n is the number of PNs in the network, (X_t, Y_t) is the actual coordinates of PNs, (X_e, Y_e) is the estimated coordinates of PNs, R is the communication radius of PNs.

The node localization coverage rate ε indicates the ratio of the number of PNs that can be successfully located to the total number of NPs in the network. Suppose there are a total of n PNs in the network, and the localization algorithm can successfully locate z nodes as (14):

$$\varepsilon = \frac{z}{n} \times 100\% \tag{14}$$

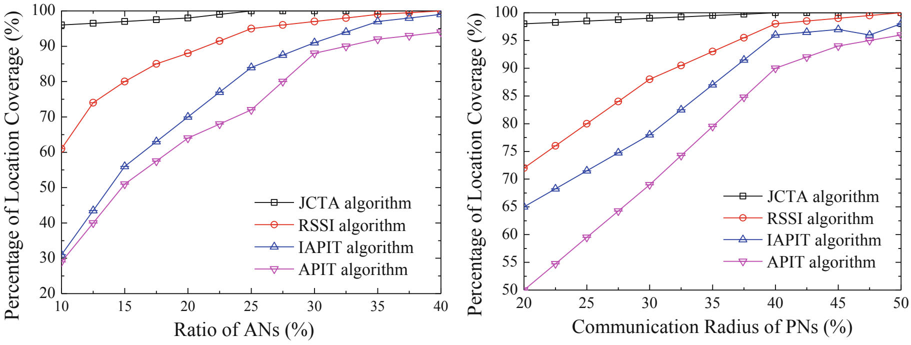
In addition, according to (1), μ is set to be 0.2. According to the (12), a plurality of tests are performed by setting $\alpha = 0.25, 0.5, 0.75$, $\gamma = 0.25, 0.5, 0.75$, and it is found that the minimum localization error can be obtained when $\alpha = 0.5$, $\gamma = 0.5$. Therefore, $\alpha = 0.5$, $\gamma = 0.5$ are used in all of the following experiments.

4.1 Localization Coverage Rate

Figure 3 depicts the localization coverage rate ε of the JCTA, RSSI, IAPIT and APIT algorithms as the density of the ANs in the network and the communication radius of the PNs change. It can be seen from Fig. 3(a) that as the density of the AN increases, the ε of the four localization algorithms increases. However, at the same density of ANs, JCTA has the highest ε of nodes, which is basically maintained at 100%. This is because the JCTA algorithm continuously converts the successfully determined PNs into ANs, and guarantees the legitimacy of the new ANs through the maximum likelihood method and the legality test, thereby greatly improving the problem that the node cannot be located when the density of the ANs is small.

4.2 Error of Localization

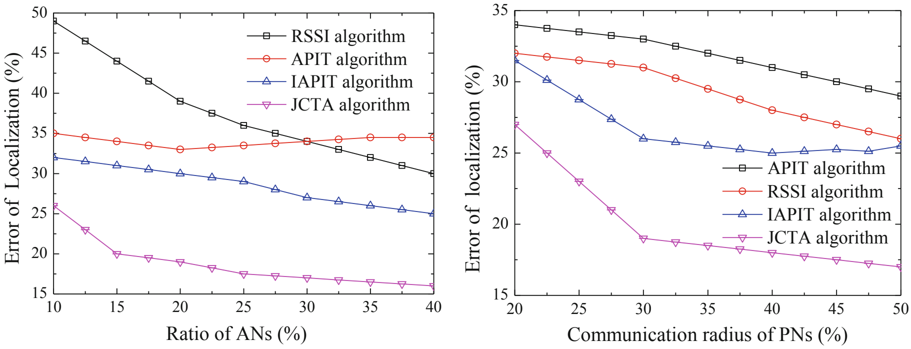
Figure 4 shows the localization error E_{mean} of the four algorithms as the density of the ANs in the network changes and the communication radius of the PNs changes. Figure 4(a) shows the comparison of E_{mean} generated by four simulated algorithms when



(a) **(b)**

Fig. 3. Comparisons of localization coverage with (a) density of ANs and (b) communication radius of PNs

the communication radius of the PNs is 30 m and the density of ANs varies over a large range. It can be seen that the E_{mean} of JCTA is 15% smaller than that of APIT algorithm, 13% smaller than that of RSSI algorithm, and 8% smaller than that of IAPIT algorithm, showing good localization performance. This is because the JCTA algorithm will introduce a legality test to estimate the PNs so as to achieve better localization accuracy.



(a) **(b)**

Fig. 4. Comparisons of localization error with (a) density of ANs and (b) communication radius of PNs

5 Conclusion

This paper proposes the JCTA algorithm for the limitations of the APIT algorithm in practical applications. The algorithm extends the node location coverage by iterative co-location method. The misjudgment of In-to-Out is reduced by the effective triangle decision. The maximum likelihood method and the triangle coordinate calculation method are used to estimate the coordinates, which greatly reduces the localization error rate. The simulation results show that the JCTA algorithm is superior to the traditional APIT and RSSI in terms of localization coverage rate and localization error rate.

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