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The Research on WSNs Localization Algorithm for Danger Area Warning

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Abstract

Wireless sensor networks (WSNs) are a new kind of data acquisition technology for danger area warning to ensure the safety of personnel production operation. In order to apply the suitable wireless node localization algorithm for danger area warning,an improved CT-IPIT+ algorithm is proposed in this paper.Considered the "edge effect", the algorithm improved the interior point judgment rules which reduces the error rate of Out-To-In effectively.Through the selection of reasonable restriction threshold, the In-To-Out error is eliminated.By counting number of inside and outside judgement results, the purpose of reducing the total error rate of misjudgment is further realized.Simulation results show that the proposed algorithm can reduce the rate of two types of errors and the total error rate can be controlled under 6.3%.

***Keywords**: Danger Area Warning, WSNs, Node Localization, CT-IPIT+ Algorithm*

1. Introduction

At present, there are lots of localization technologies can locate the objects. However, there is a few technologies which is suitable for pervasive computing requirements and positioning moving objects [1]. Among them, Tian He [2] from the University of Virginia proposed the APIT algorithm which is a kind of no-ranging localization technology, and suitable for pervasive computing requirements in WSNs. The theoretical basis is the perfect Point-In-Triangulation test (PIT) algorithm [3]. Due to the PIT algorithm can be more reasonable positioning accuracy, relatively stable of performance, low costs of network and easy to implement in the fixed structure of the network. And it is applicable to determine the location of the mobile nodes [4]. However, the PIT algorithm is also prone to generate two types of common errors that are the In-To-Out Error and the Out-To-In Error. So how to reduce the two types of errors is the current main focus on the research in mobile nodes location [5]. In addition, it requires eliminating the In-To-Out Error in the danger area warning, which is also the main focus on the PIT algorithm improvement research.

Currently, there are two kinds of improvement methods: One is to optimize the node selection process, reduce the node location area. Another one is to improve the determination methods, reduce the error rate of determination results. The people who use the first kind of method as Yang Ji who proposed the PB-APIT algorithm in literature [6]. It used the perpendicular bisector of the three sides to divide the triangle of the APIT algorithm into four or six small and available regions to reduce location area of the original APIT algorithm by detecting the strength of the signal to determine the position

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of the unknown node.Zhou Yong proposed the improved APIT algorithm in literature [7]. Through increasing the legitimacy inspection of neighbor nodes, it improves the fault tolerance rate and adaptability of the algorithm. But the effect that reduces the rate of two types of errors is still not significant. For reducing the errors [8] from the approximate Point-In-Triangulation test in the APIT algorithm, Cao Meili proposed the RAPIT algorithm by using the RSSI ranging technology in traditional APIT algorithm. Through introducing the concept of limit distance, it can limit the position of the nodes that cause the errors into the overlapping areas that take the anchor nodes as the center of the circle, and take limited distance as the radius. Eventually it can reduce the errors and improve the positioning coverage. With using the second method, improved APIT algorithm by combining with cosine theorem by optimizing the judgment rules of the interior point, and reduce the incidence of the two types of errors [9].In general, their improvements have a role in optimizing the final results. But these algorithms cannot meet the requirements of danger area warning application, because when it ensures the low Out-To-In Error, it cannot eliminate the In-To-Out Error.

Through the analysis of the characteristics of the mobile node location judgment, the reasonable partition way of target area is proposed in this paper.The PIT algorithm and the causes for the two types of errors is introduced. Finally,through the analysis of test results and combined with the actual application requirements for CT-IPIT algorithm,an improved CT-IPIT+ algorithm for danger area warning application is proposed.

2. Location Tracking of Mobile Nodes in Sensor Network

In engineering practice, a danger area can be represented by a polygon area. Then the judgment of the mobile nodes in danger area can be transformed into the judgment of the mobile node in polygon area. And the polygon area can be divided into a number of triangle areas eventually. The nodes which are need to be located in the WSNs are called target nodes. The nodes that its position is known and it can help locating the target nodes are called anchor nodes. Within a communication radius of the target nodes, the nodes that can directly communicate with target nodes are called neighbor nodes. In this paper the sensor network is composed of these three kinds of sensor nodes. This is necessary to make the following assumptions: the sensing range of each node is a circular area that it takes its own coordinates as the center of the circle and the communication distance R as the radius. In the target area, the communication radius of anchor nodes is RS1 and the communication radius of target nodes and neighbor nodes is RS2 (RS1>RS2). The position of anchor nodes is fixed and knowable, and the target node has the ability to move.

As shown in Figure. 1, using the hexagonal for dividing the target area is a more rational division manner [9]. Assume that a target node moves along the trajectory P→P'→P", then the distance from each vertex of the nearest adjacent triangle will change. The change in the distance is often accompanied by the change in signal strength between the nodes. So this property can be used as an important reference basis of the position determination of mobile nodes.

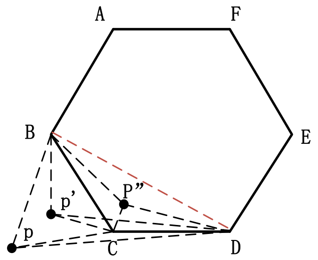
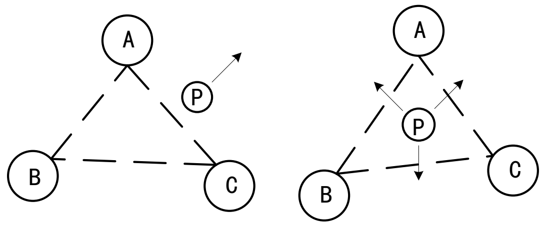


Figure 1. Schematic Diagram of Mobile Nodes

3. Pit Localization Algorithm

3.1. Pit Algorithm Principle

Assuming that there is a direction which P moves along, the target node P will stay away from or be close to vertex A, B, C at the same time, then P is out of △ABC.Otherwise, P is located in the triangle, as shown in figure 2. In practical applications, we usually select 3 anchor nodes from all nodes that can be monitored by mobile nodes to test whether its composition in the triangle of three nodes. The algorithm is the original PIT test algorithm [10].



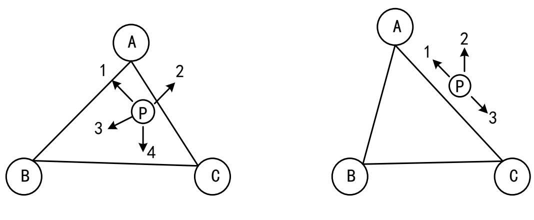
(A)Node P Outside △Abc (B) Node P Inside △Abc

Figure 2. Schematic Diagram of Pit Principle

3.2. Shortcomings of PIT Algorithm

In the actual PIT test, the node located in the interior of a triangle is often judged in its external which is called In-To-Out Error, and the node in the external is misjudged in the interior which is called Out-To-In Error, figure 3 shows the two kinds of wrong decision the scene.

As shown in Figure 3(a), the target node P is inside the triangle and close to an edge, but compared with the neighbor node 2, we found node 2 received signal strength from A, B, C three anchor nodes is less than the strength of the signal they receive value. According to the PIT algorithm, the node P is located outside △ABC, then In-To-Out error occurred. As shown in Figure 3(b), the target node P is close to the external triangle edge. When node P compared with the neighbor node 1 , neighbor nodes 1 received signal strength value from B and C is less than P, but receive signal strength value from A is greater than node P, then judge the P is located in the internal of △ABC, and generates Out-To-In error. What causes these two types of errors is due to the target node near the edge of the region, to determine the location of rules on the target node is not sufficient, and an error judgment which is called the "edge effect" of algorithm.



(A) In-To-Out Error (B) Out-To-In Error

Figure 3. Two Types of Errors

In the simulation test, due to the sensor nodes remain stationary generally, it cannot move like above to perform a PIT test, but it can exchange information with neighbor nodes to judge the distance to an anchor node, which follow the example of nodes move in PIT. As shown in Figure 3(a), assuming that the target node P is surrounded by 4 neighbor nodes 1,2,3 and 4, by exchanging information with its neighbor node 1, simulation node P moves toward to the neighbor nodes 1 using radio propagation characteristics of the received signal strength to realize the PIT test. So similarly, simulation node P moves toward other neighboring nodes, then you can determine whether P is in △ABC according to PIT algorithm. As mentioned above, PIT algorithm has two types of inherent errors. If the errors cannot reduce effectively, it will reduce the correct rate of the final test results.

4. Ct-IPIT Algorithm

Due to the above two types of errors' objective existence, the overall accuracy of test results is affected. And original PIT algorithm is unable to meet the needs of the actual location. In order to overcome the above shortcomings, the CT-IPIT (improved point in triangulation test based on cosine theorem and Triangle theorem) algorithm was proposed, according to the relationship of nodes position and triangle regions in the actual environment.

4.1. Basic Principle

With the change of mobile node`s location, its distance relative to the three anchor nodes will also change. Meanwhile, the size of angles which is formed by the three anchor nodes will also change. It is an important way of using the characteristic of the mobile node to improve algorithm. The main idea of CT-IPIT algorithm is to tell that through the PIT test, the target node determine whether itself is inside triangle or not, thus get the preliminary screening results. Then further verify the nodes which are judged in triangle primary with the characteristics of inside and outside triangle points, and decide whether to change the primary result according to the results of the validation, and determine the role of the target node combining with combination decision function optimization. The specific contents of the algorithm are as follows:

Rules (1): cosine decision rule. In view of the two types of errors, improve respectively with the characteristics of inside and outside triangle points. If a point is located inside the triangle, then it has the following features: The sum of the length of point to three vertices is less than that of the 3 edges. The obtuse angles consist of the point and the three vertices exits more than 2. As shown in figure 4, assuming the distance between three anchor nodes A, B, C are d_{AB},d_{BC},d_{AC}.The distance of target node P to anchor nodes are d_{AP},d_{BP},d_{CP}.The cosine of target node P between three anchor nodes will be calculated with cosine theorem:

According to the positive and negative of the cosine of a obtuse angle, the number of obtuse angle in the three angles can be determined. In order to reduce the In-To-Out error, we added the decision rules to the algorithm: If there are at least 2 obtuse angles between P and three anchor nodes, we can tell that P is in △ABC. Otherwise, outside △ABC.

$$\begin{cases} \cos\angle APB = \dfrac{d_{AP}^2 + d_{BP}^2 - d_{AB}^2}{2 d_{AP} \times d_{BP}} \\ \cos\angle APC = \dfrac{d_{AP}^2 + d_{CP}^2 - d_{AC}^2}{2 d_{AP} \times d_{CP}} \\ \cos\angle BPC = \dfrac{d_{BP}^2 + d_{CP}^2 - d_{BC}^2}{2 d_{BP} \times d_{CP}} \end{cases} \quad (1)$$

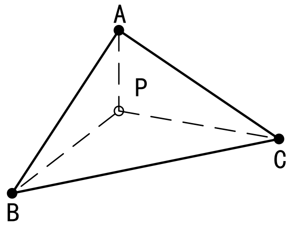


Figure 4. Example of Calculating Distance

Rule (2): edge effect rule. When the target node move from outside to the edges of the triangle, there will appear 2 obtuse angles, as shown In figure 5(a), then based on the cosine value of decision rule Out-To-In, error occurs, this is the previous "edge effect". As shown the shaded part in figure 5(b), 2 obtuse angles will be displayed in the outer area. Therefore, in the event of a 2 obtuse angles, we introduced restriction threshold K, add a layer of decision rule: If PA+PB-AB<K, namely the sum of the distance between the target node and the two anchor nodes and the difference between the two anchor nodes are less than the threshold K, then they determine the P is outside △ABC. Otherwise, it still decide that P is in △ABC.

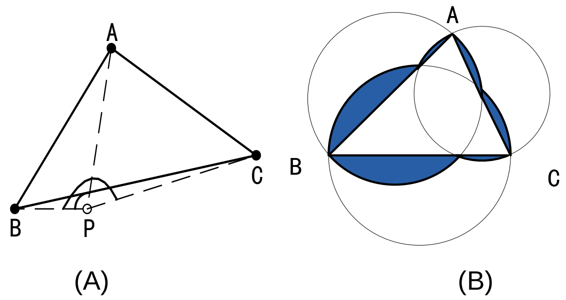


Figure 5. External Point Appears Two Obtuse Angles

Due to the distribution of nodes in different condition is different, the constraint threshold K should also change accordingly. So at the beginning of the algorithm it needs to be simulated the site environment on the simulation platform simulation for many times, in order to find out the appropriate constraints threshold K to substitute algorithm, and to ensure the performance of the algorithm.

The main method of selecting the constraint threshold K: According to the communication radius R of the target node, the value of K start from 5%R, then increasing successively in the test. By testing the affection of different constraint threshold K to the total error rate of determination of the algorithm, and ultimately select the appropriate value of K. After testing we find that: When increasing the constraint threshold K, the total error rate of determination is gradually decreased. But the total error rate of determination has a tendency to increase when the value of k is more than 15%R. The reason is that when the constraint threshold value K is too large, it also has an effect on the judgment of internal point which have two obtuse angles, thus it makes additional in-To-Out error that the total error rate increased. So the improved decision rules choose 15%R as the value of K in this paper.

Rule (3): Improved triangular rule. Assuming that the sum of the distance from target node P to each vertex of △ABC is D_P, the sum of the distance between the three vertices of a triangle is D_{ABC}. According the triangles theorem, if $D_P > D_{ABC}$, we can determine that P is located outside △ABC. Otherwise, inside △ABC. To reduce the Out-To-In error probability, add the follow improved judgment rules: 1) If all of the neighboring nodes of the target node are getting close simultaneously to apexs of the triangle formed by the anchor nodes, we determine that the target node is outside the triangle. 2) If all of the neighboring nodes of the target node are getting farther simultaneously to apexs of the triangle formed by the anchor nodes, and $D_P \geqslant D_{ABC}$, we determine that the target node is outside the triangle. Otherwise, use the improved the rules (1) tell whether the triangle is inside or outside the triangle area furtherly. 3) when the relationship between neighbor nodes of the target node and the three vertices of the triangle does not meet the above two rules, and $D_P \geqslant D_{ABC}$, we can conclude that the destination node is outside the triangle. Otherwise, use the improved the rule (1) to determine whether it is in the triangle or not.

Rule (4): Combination judge rule. The CT-IPIT algorithm was proposed here also uses the methods of Combination judge rules so that we can count to achieve the function. When the number of neighbor nodes of the target node is greater than 1, we test each neighbor node, and classify the results of tests by the two counters statistics using CountIn (statistics, including the number of judgment) and CountOut (statistical determination outstanding number). If it is determined in the interior, then the counter CountIn's value will increase 1. If it is determined in the outside, the counter CountOut's value will increase 1. If the total number of CountOut is greater than that of the CountIn, it is determined that the target node is in the region. Otherwise externally.

4.2. The Test Steps of CT-IPIT Algorithm

The main steps of the CT-IPIT algorithm test are as follow:

1) Initializing test environment and choose a target node P (mobile node).
2) Find out all neighbor nodes (record the total number as N) which are satisfied the test condition of the target node P, then do PIT test in turn.
3) After the PIT test, if node P meets the conditions of interior point, then use the rule (1) to test. If it meets the conditions of interior point in the rule (1) and the number of obtuse angle is not 2, then judge P inside triangle. If it meets the conditions of inside triangle in the rule (1) and the number of obtuse angle is 2, then continue to use the rule (2) for test. if the test results meet the conditions of outside, then change the judgment into outer. Otherwise, keep the judgment of inside the triangle. If it doesn't meet the conditions of inside triangle in the rule (1), then using the rule (3) to test whether the node is in triangle or not. If the test results meet outside, then contract outside, or commute inside.
4) After the PIT test, if node P doesn't meet the conditions of outer point, then using the rule (2) to test. If it meets the conditions of outer point in the rule (3), then judge P outside triangle. If it doesn't meet the conditions of outside triangle in the rule (3), then using the rule (1) to distinguish whether the node P is in triangle or not. So according to the test results, it can directly determine inside or outside.
5) According to the Judgment rules in the CT-IPIT algorithm, it can get the results whether the target node locate in triangles or not. Then, to update counting results of CountIn and CountOut based on the result of determination.
6) To determine whether all of the N neighbor nodes test over. Otherwise, turn to step 2).
7) According to the final counting results of CountIn and CountOut after the test, determine the counting size of them and get the comprehensive judgment results.

The Flow Chart Of CT-IPIT Algorithm Is Shown In Figure 6.

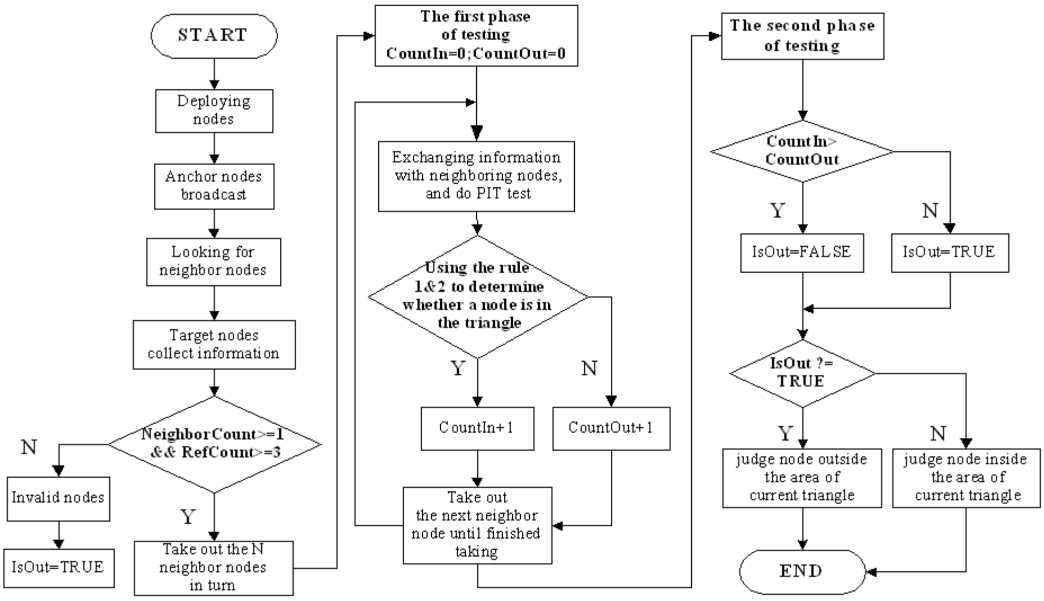


Figure 6. Flow Chart of CT-IPIT Algorithm

4.3. RSSI Ranging Quantitative Model

In the implementation of the algorithm, according to the relationship between signal strength and distance in the actual environment, we use the RSSI ranging quantitative model to convert signal strength into distance in the rule (1).in the rule (3), in order to avoid the substitution errors that is generated by the relative errors of the substitution parameters in the formula. So in the back of the actual test, we use RSSI values directly that it can reduce the computation and increase the accuracy.

In wireless sensor networks, many localization algorithms convert RSSI into the actual distances between the nodes through classic propagation path loss models.

In real environment, the wireless communication signal is affected by multipath, refraction, reflection, and many other environmental factors.

So choose the logarithmic decay model, and consider the environmental factors that cause the signal propagation loss, and increase the path loss exponent:

$$PL(dB) = PL(d_0) + 10n\log_{10}(d/d_0) + X_\sigma \tag{2}$$

In the above formula, the unit of PL(dB) is dBm. PL(d0) is the signal strength value that the general node received at a reference distance d0,d is the distance between receiving nodes and transmitting nodes, n is the path loss exponent in different circumstances,X_σ is a normal random variable whose standard deviation is σ. Thus, when PL(dB) is known, we can calculated with the follow formula:

$$d = d_0 \times 10^{(PL(d_0) - PL(dB) - X_\sigma)/10n} \tag{3}$$

5. Test and Analysis of CT-IPIT Algorithm

In order to verify the performance of CT-IPIT algorithm proposed in this paper, the author has developed a specific algorithm test-simulation platform. The effectiveness of CT-IPIT localization algorithm is verified through the analysis of simulation results, which is helpful to improve the relevant details. This paper test the original PIT algorithm, the improved CT-IPIT algorithm and other several improved algorithms through the test-simulation platform.

5.1. Test Environment

In order to assess the performance of the algorithm, now three circles named A, B, C are made as shown in Figure 7, the anchor nodes A, B, C are set as the center of which, the communication radius of each node is as radius of which and the overlap region MPQ of which is as the test area. One hundred different points in the region MPQ are uniformly selected to test the relevant parameters of the test environment by respectively using the original PIT algorithm and several improved algorithms.

Table 1. Test Parameters

parameter name	set value
Monitoring area size	400×400[m]
Anchor node's communication radius	200[m]
other node's communication radius	100[m]
Reference anchor node's threshold	3

The aim of selecting such a test area is to ensure the target node deployed in this region accompanied by the same settings of reference anchor nodes, which confirms to the prerequisites of PIT test.

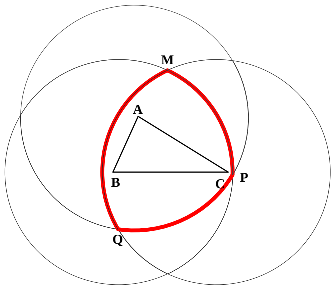


Figure 7. Schematic Diagram of Test Area

5.2. Results Analysis

As shown in Figure 8, when CT-IPIT algorithm is tested on the simulation platform and the nodes are deployed in the test area, the test nodes are required to achieve a uniform distribution and are ensured to have neighbor nodes within its communication radius so that the test can be carried out smoothly.

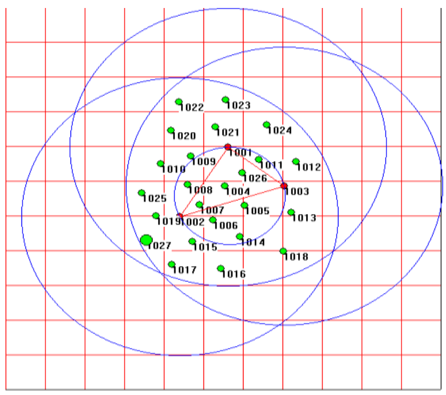


Figure 8. Algorithm Test Simulation

All algorithms are tested 20 times, each of which contains 50 points, and the results are shown in Table 2. As shown in Table 2, the judgment error rate of CT-IPIT algorithm proposed by this paper can be controlled at 5.4%, which is significantly improved compared to the judgment results of the original PIT algorithm and other several algorithms with the lowest In-To-Out Error and the significantly reduced Out-To-In Error.

Table 2. Comparison of Test Results

Test algorithm	Total test times	Out-To-In Error	In-To-Out Error	Error Times	Error rate (%)
Original PIT	1000	143	15	158	15.8
Improved cosine	1000	123	3	126	12.6
Improved triangle	1000	113	2	115	11.5
CT-IPIT	1000	52	2	54	5.4

5.3. CT-IPIT Algorithm Application Discussion

In-To-Out Error of this algorithm is not allowed to occur in the application of the danger areas judgment and a certain degree of Out-To-In Error can be tolerated. While this may result in a slight increase of the total error rate of the algorithm detecting, it is particularly important for the practical danger areas warning application. According to the above reason, the target of CT-IPIT algorithm is to completely restrict In-To-Out Error and appropriately compromise a part of Out-To-In Error. The improved CT-IPIT which is named CT-IPIT+ is achieved by adjusting the threshold value K. Through reducing the K value, the mobile nodes which may be outside the triangular region are determined therein, but the case that the mobile nodes inside the triangular region are determined outside is rejected when the edge effect rules of CT-IPIT algorithm are applied. When the threshold value K of the test environment is 10%R, the simulation results of CT-IPIT+ algorithm are shown in Table 3.

Table 3. CT-IPIT+ Test Results

Test algorithm	Total test times	Out-To-In Error	In-To-Out Error	Error Times	Error rate (%)
CT-IPIT$^+$	1000	63	0	63	6.3

As shown in Table 3, In-To-Out Error of CT-IPIT+ algorithm was completely eradicated, but the Out-To-In Error increased slightly.

6. Conclusions

Compared with other existing algorithms, the CT-IPIT algorithm has these main improvements: (1) the algorithm refer to cosine theorem and triangle theorem, and improve the rules of interior judgment. And in order to solve the problem that the mobile nodes in the edge of area are easy to appear 2 obtuse angles resulting Out-To-In misjudged, the new algorithm proposed the constraint threshold K. By choosing a reasonable value of K, the In-To-Out errors can be eliminated. (2)The algorithm used the method of combination determining. At first, determine all combinations of neighbor nodes and classified counting the number of which is judged to be inside or outside. Then according to the size of the internal and external counting, it can determine the final results and reduce the rate of misjudgment further.

Simulation results show that compared with the existing algorithms, the CT-IPIT+ algorithm could reduce the rate of judgment error greatly in the same experimental environment. Especially after selecting the appropriate threshold, the In-To-Out error can be eliminated. It has great significance for early warning of danger areas. The CT-IPIT+

algorithm increased a certain amount of communication which raised node energy consumption, but it improved the algorithm's correct rate greatly. It is necessary for these applications that need high correct rate.

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