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Sensor Node Detection in Wireless Sensor Network Algorithm

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Abstract: One important reason for the decline of QoS in wireless sensor network is the failure of sensor nodes. We propose an algorithm to detect failure node based on round trip time. Discrete method is used to generate the round trip path and failure sensor nodes are detected and located by measuring the round trip time of the path. By Physical simulation and software simulation, we justify the applicability of the algorithm. Compared with the methods of linear round-trip path, the discrete method could reduce the number of paths measured and shorten the time of detection.
Keywords: wireless sensor network; quality of service; failure sensor node; round trip path; round trip time.

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1. INTRODUCTION

Wireless sensor network is a multi-hop ad hoc network system consisting of a large number of sensor nodes randomly deployed in the monitoring area, with low power consumption, low cost, ease of deployment, which is widely used in military, medical, environmental protection and other fields [1, 2]. With the deepening applications of wireless sensor network, different applications business put forward different requirements on the network service, such as some real-time services are sensitive for data latency, and other applications require higher accuracy of data transfer, so the wireless sensor networks need to provide different applications of QoS in order to meet the needs of various applications.

In Wireless sensor networks, sensor node failure is an important cause of reducing quality of service. Wireless sensor networks in which the environment is generally more severe, the wireless communication medium unreliability, nodes, energy constrained and limited bandwidth of the environment, which makes wireless sensor node higher failure frequency, greatly reducing network quality of service, and seriously impact the accuracy of the sensor network detecting data.

In general, we can improve the network quality of service by abandon the failed node [3,4], so detecting and locating the failed node is the basis and prerequisite of the algorithm. However, the characteristics such as distribution, not collaborative, heterogeneous, and traffic characteristics complex of today's networks, make the detection and location of the failed node challenging.

We propose a method to detect and locate the failure node based on round trip time. The method can reduce the number of detected paths by using the discrete method based on the linear round-trip path, so as to shorten the detection time of the failed node, can detect and locate the failed node by measuring path, s round-trip time, and establish a common time model to analyze and compare the discrete method and several other round-trip paths forming method. Under physical environment and NS2 software environment we validate the method, and physical verification and software simulation results consistently show that the practicality and effectiveness of the method on node failure detection and localization.

Existing sensor network node failure detection method can be divided into two categories, one based on the node cooperative detection method, and the other based on the end detection methods. The method based on the node cooperative detection method measures the link status between nodes and reports to the sink. The method is conceptually direct and clear, with high accuracy. But the algorithm requires extra traffic and will consume the scarce node energy, on the other hand may exacerbate congestion of part heavy load node, even impossible when the network load is heavy.

Detection based on end, also known as Network Tomography(NT) technology, according to the measurement information outside of the network to analyze and deduce the internal performance of the network, which is a technology through actively sending probe information or passively collecting the network internal information without the network nodes, cooperation, has become the mainstream of network measurement technology and has a very great prospect in network applications.

It has made a lot of failed node detection and location method currently. Literature [5] proposed an algorithm based on the comparison, which compared between the neighbors based on certain criteria and disseminated the results of the comparison, but it can not detect malicious nodes. Literature [6] proposed the cluster heads failure recovery algorithm which has the data loss problems on detecting the failed node. Literature [7,8] proposed path redundancy techniques to detect the failed node, but redundant paths will increase energy consumption and reduce network lifetime, and excessive redundant paths will slow probe speed. Literature [9] proposed a link failure detection algorithm based on path monitor, which needed to set up a separate wavelength for each path and needed to monitor the node position, which limits the application of the algorithm.

This paper presents the round-trip time detection algorithms based on the existing network tomography technology, which will detect the failed node by using the data transmission time through path. Generally the most important manifestation of the failed node is data transmission error. When there is a failed node in the path, the data transmission time through path will be significantly different from the normal. If a node fail, then the round-trip time in its path will be significantly greater than the normal; if a node sleep or death because of the energy issue, then the round trip time in its path will tend to infinity. Therefore, measuring the round-trip time of the path can determine whether there is a failed node in the path.

1.1 Round trip time estimation

Round-trip time refers to the time of data from the source node through a circular path back to the source node. According to definition, path, s round-trip time mainly depends on the number and distance between nodes. The smaller the distance between nodes, the shorter the communication time, the shorter the path, s round-trip time will be. Since the distance between nodes depends on the application and can not be changed, so the path, s round-trip time mainly depends on the number of nodes in the path. The least number of nodes is 3 in the round-trip path, then the round-trip time of the path is:

$$\tau_{RTT} = \tau_1 + \tau_2 + \tau_3 \tag{1}$$

Wherein τ_1, τ_2 and τ_3 are the communication delays of the nodes (S1, S2), (S2, S3) and (S3, S1). Ring network topology of the 6 nodes is shown in Figure 1:

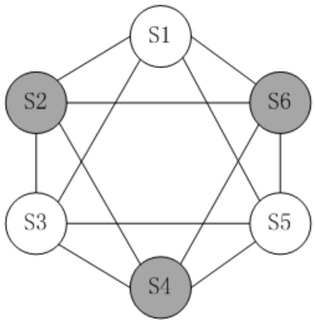

Figure 1 Ring network topology of 6 nodes

In network nodes are sequentially arranged in a ring, you can see in the round-trip consisting of the neighboring three nodes, each node are in an equal position. So, the communication delay τ_1, τ_2 and τ_3 between nodes could be thought equal, making τ as the unified inter-node communication delay. So the path round-trip time formula can be expressed as:

$$\tau_{RTT} = 3\tau \tag{2}$$

This is the minimum round-trip time of the wireless sensor network paths, which depends on the communication time of the neighbor nodes in the path, while the time is related to the nodes, distance and the distances are different at different applications. According to analysis, at the conditions that the node number of the round-trip path is fixed, the detection time can be shortened only by reducing the number of detection path.

1.2 Round-trip path estimation

Using the round trip time to probe failed node, first you should form a circular path according to a certain strategy. When the round-trip path contains more nodes, the formed round-trip path can be less, but at this time a single node will be repeated in the plurality of paths, duplicate detection increases the detection time, and the increasing number of nodes will make the round-trip time of a single paths increasing. In the N nodes network, the number of round-trip path formed by m nodes at most is:

$$P = N(\mathrm{N} - \mathrm{m}) \tag{3}$$

Where P is the number of round-trip path formed in the network, N is the total number of nodes in the network. The total detection time is the sum of all the round-trip paths, round-trip time in the network. If the round-trip time of i-th path is τ_{RTT-i}, then the total detection time is:

$$\tau_{ANL}(\mathrm{M}) = \tau_{RTT-1} + \tau_{RTT-2} + \ldots + \tau_{RTT-p} \tag{4}$$

$$\tau_{ANL} = \sum_{i}^{p} \tau_{RTT-i} \tag{5}$$

When the round-trip path consists of three nodes, namely m = 3, the number of round-trip paths formed in the network is:

$$P = N(\mathrm{N} - 3) \tag{6}$$

From equation 5, at this time the total detection time can be expressed as:

$$\tau_{ANL} = P * 3\tau = N(\mathrm{N}-3) * 3\tau \tag{7}$$

We can see, in the current round-trip path selection algorithm, the failed node detection time changes with polynomial growth according the number of nodes in the network. When the network is large and has a large number of nodes, the algorithm detecting failed node will cost long time. Therefore, we need to optimize round-trip path generation algorithm to reduce the number of the detection path, thereby to reduce the detection time.

2. ALGORITHM DESCRIPTIONS

2.1 Round-trip path optimization

Probing all round-trip in the network will cost a lot of time, in fact, only part of the round-trip path will be able to cover all of the nodes, so it can be optimized to reduce the number of round-trip and improve efficiency.

1) The linear round-trip path

In order to remove the redundant round-trip path, you can make a node as the source node in turn, thereby forming a corresponding round-trip path. At this time, the number of generated round-trip path is equal with the network node, s number, and there is a linear relationship between the two, so the round-trip path created in this way is called a linear round-trip path. In the N nodes network, the number of round-trip path generated by linear method is:

$$P_L = N \tag{8}$$

In which P_L is the number of generated round-trip path, Nis the number of nodes in the network. Then, according to the formula (7), the failed node detection time is:

$$\tau_{ANL}(\mathrm{L}) = \mathrm{N} * 3\tau \tag{9}$$

In the 6-nodes network shown in Figure 1, round-trip paths formed by linear round-trip path method are shown in Figure 2:

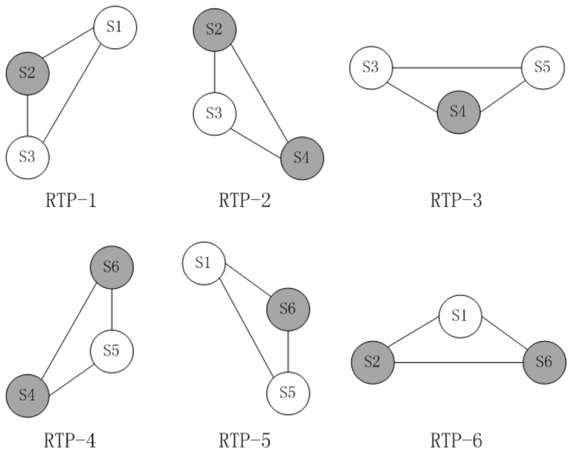

Figure 2 Linear round-trip path

All nodes are contained in the linear round trip paths, so the detection of the linear path can meet the requirements of failed node detection. Compared to all the round-trip paths in the network, linear round trip path have dramatically reduced the number of round trip path. But when the number of nodes in the network is large, it will still cost much more time, so it is necessary to optimize the number of round trip path again to reduce the detection time.

2) Discrete round trip path selection methods

Investigating the linear path method, we found in which there are still many nodes repeated by several round trip path detection, so we can remove the repeated nodes in the path to shorten the detection time. Select the non-adjacent path in turn from the paths generated by linear method as the round trip path, this new path selection method is called discrete method. In N-node network the number of discrete round trip paths is:

$$P_D = Q + C \tag{10}$$

$$Q = \lfloor N / m \rfloor \tag{11}$$

$$C = \begin{cases} 0 & R = 0 \\ 1 & R \neq 0 \end{cases} \tag{12}$$

Where N is the total number of nodes in the network, m is the number of nodes in the round-trip path, Q and R respectively are the integer part and remainder part of N divided by m, C is the additive correction factor. If the remainder R is 0, then C is 0, otherwise C is 1. According to the formula (9), generating round-trip path by using discrete method, the total detection time is:

$$\tau_{ANL}(\mathrm{D}) = (\mathrm{Q} + \mathrm{C}) * 3\tau \tag{13}$$

When the node number in the round trip paths is 3, the detection time is:

$$\tau_{ANL}(\mathrm{D}) = (\lfloor N / m \rfloor + \mathrm{C}) * 3\tau \tag{14}$$

In the network topology shown in Figure 1, the round-trip paths generated by discrete method are shown in Figure 3.

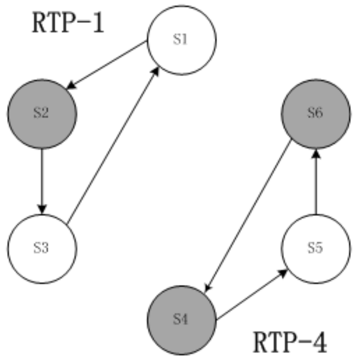

Figure 3 Discrete round-trip path

Discrete method can reduce the number of round trip path based on the linear method, and can significantly reduce the detection time. Table 1 shows the number of round trip path generated by several methods in different nodes network. From the table you can see, the discrete method generates the least round trip paths, especially when in large-scale network and more nodes, the path number generated by discrete method is lower than the other two methods several orders of magnitude, and which failure node detection time will be significantly shorten.

Table 1 The path number generated by different methods in different nodes

Nodes Paths	6	10	20	40	60	80	100
PM=N, N-3,	18	70	340	1480	3420	6160	9700
PL=N	6	10	20	40	60	80	100
PD	2	4	7	14	20	28	34

2.2 Round trip time model

Measure the round-trip time of a path, if the time is greater than the threshold value, we can determine there is failed node in the path. When the source node fails, analyzing additional round trip path can locate the failed node; when the failed node appears in the position of non-source node, using the other two round trip path can determine the location of the failed node.

So, for the round-trip path with the length of m, the total round trip path needed by detecting and locating the failed node is:

$$P_T = P_D + L \tag{15}$$

P_D is defined in equation (10), L is the number of nodes of the round-trip path except source node, namely, $L = m - 1$. According to equation (10), substituting P_D is,

$$P_T = \lfloor N / m \rfloor + \mathrm{C} + \mathrm{m} - 1 \tag{16}$$

According to the formula (10), we know the required detection time is:

$$P_T = \{\lfloor N / m \rfloor + \mathrm{C} + \mathrm{m} - 1\} * m\tau \tag{17}$$

Using Equation (17) we can calculate the required time detecting and locating failed node in the corresponding state.

According to the formula (7), (9) and (17) we can know the relationship between the algorithm's time complexity and the number of nodes in the network. The time detecting all the round trip path is proportional to the square of all the nodes in the network, namely the detecting time $\tau_{ANL} = o(\mathrm{N}^2)$; the detecting time of linear round trip path is $\tau_{ANL} = o(\mathrm{N})$, namely the detecting time is linear relationship with the number of nodes in the network; the detection time of discrete method is proportional to the number of nodes in the network, namely $\tau_{ANL} = o(\mathrm{N})$. The detection time of Linear path method and Discrete method both are proportional to the number of nodes in the network, but the discrete method will complete the detection in less time, with a higher efficiency than linear path method, consume fewer nodes, energy while saving time.

Table 2 lists the needing detection time of 100 node-scale network when m, the number of nodes is different. From Table 2, you can see that when the round trip path contains three nodes, detecting and locating the failed node will cost the least time.

Table 2 Detection time lists of different path lengths

N	m	$Q = \lfloor N/m \rfloor$	R	C	L=m-1	$P_T = Q + C + L$	$\tau_{ANL} = P_T * 3\tau$
100	3	33	1	1	2	36	108 τ
100	4	25	0	0	3	28	112 τ
100	5	20	0	0	4	24	120 τ
100	6	16	4	1	5	22	132 τ
100	7	14	2	1	6	21	147 τ
100	8	12	4	1	7	20	160 τ
100	9	11	1	1	8	20	180 τ
100	10	10	0	0	9	19	190 τ

2.3 Algorithm flow

Using round trip path detecting failed node can be divided into two phases, the first phase is to determine the threshold value, and the second phase is the detection analysis. In the first phase, all the nodes is normal in the initial work, forming the round-trip path and measuring the round-trip time method using a linear method, and make the longest round-trip time in which as a threshold value.

In the second stage, comparing the round-trip time of each path with the threshold value, when finding the round trip time of a path is greater than the threshold, it indicates existing failed node in the path, then we will determine the failed node through detailed analysis. Locate the failed node work can be divided into three steps. For the example of the round-trip path length is 3, for the detecting round trip path, in which the three nodes are represented as SX, SX+1, SX+2, and the round-trip path using SX+1 and SX+2 as the source node are respectively SX+1--SX+2--SX+3 and SX+2--SX+3--SX+4. Then the round-trip time of the three-round trip path are respectively RTT-X, RTT-X+1, RTT-X+2.

The first step of the algorithm is to compare RTT-X and RTT-X + 1. If the RTT-X + 1 is less than or equal to the threshold value, and the RTT-X is greater than the threshold value, then it shows that in the round trip path SX + 1 is working properly, and the node SX is not normal. If the RTT-X tends to infinity, then you can determine the node SX is dead; if the RTT-X is significantly greater than the threshold, then you can determine the node SX fault.

The second step of the algorithm is to compare RTT-X + 1 and the RTT-X + 2. If the RTT-X + 1 is greater than the threshold value and the RTT-X + 2 is less than or equal to the threshold, then it shows node SX + 1 fails. If the RTT-X + 1 tends to infinity, then you can determine the node SX is dead, otherwise the node is failed.

The third step of the algorithm is to compare RTT-X, RTT-X + 1 and RTT-X + 2. If the round trip time of the three paths is greater than the threshold, then it shows node SX + 2 ineffective. If the round trip time RTT-X + 2 tend to infinity, then it shows that node SX + 2 is dead, otherwise node SX + 2 is fault.

The algorithm flow is described with pseudo-code as follow:

for node Sx from WSN with N sensor nodes, X=1,2, 3, N (S1, SX, SN)
for RTP-X formed by SX-SX+1-SX+2.
call subroutine RTT
RTT Subroutine,
I, if SX+1=SN then
replace SX+2 by S1
else if Sx+1>SN then
 replace SX+1 by S1 and SX+2 by S2
II, measure RTT of RTP-X
III, return.
if $\tau_{RTT-X} = \tau_{THR}$ then
increment SX by 3
if SX+3>SN then
reset SX+3 to SN and go to step 2
else go to step 2

else call subroutine RTT to measure RTP-X+1

if $\tau_{RTT-X+1} = \tau_{THR}$ then

go to step 7

else if $\tau_{RTT-X} = \infty$ then

SX is dead

otherwise SX is malfunctioning

go to step 4

call subroutine RTT to measure RTT of RTP-X+2.

if $\tau_{RTT-X+2} = \tau_{THR}$ then

go to step 10

else if $\tau_{RTT-X+1} = \infty$ then

SX+1 is dead

otherwise SX+1 is malfunctioning

go to step 4

if $\tau_{RTT-X+2} = \infty$ then

SX+2 is dead

otherwise SX+2 is malfunctioning

if SX+2>SN then

go to step 4

stop.

3.THE SIMULATION

In this section we will use the physical and software methods to simulation verification to the failed node detection method based on round trip time.

3.1 Physical simulation

At physical simulation, we, ll use an ATMEGA16l microcontroller and XBEE S2 wireless sensors to make a wireless network, use six sensor nodes to compose the network topology as shown in figure 1, use X-CTU software to configure the round-trip path of the wireless sensor networks, in which distance between nodes is 50 cm and form a ring topology.

Initially, all nodes in the sensor network is working properly, generating two round-trip paths using the discrete method, the round-trip time of the two paths are respectively 3.371s and 3.383s, both are close to 3.4s, so set the threshold of the path, round-trip time to be 3.4s.

To validate the algorithm, in the experiment we, ll make the node S1, S2 and S3 as the failed node of the round-trip RTP 1 and measure the round-trip time for the respective paths using each node as the source node which are shown in Figure 4.

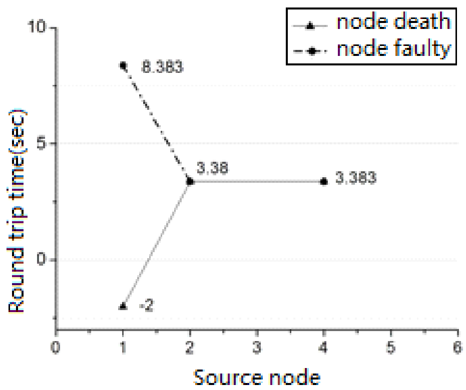

Figure 4 Round trip time figure when the source node is failed

We measured path round-trip time as shown in Figure 4 when node S1 is failed. In the figure the abscissa is the source node, the ordinate is the round-trip time of the corresponding path. When the round-trip time is infinite indicated in value of -2.

Can be seen from the figure, the round-trip time of the node S1, s corresponding path RTP_1 is greater than the threshold value, indicating that there is failure node in the path has RTP_1. The round-trip time of the node S2, s corresponding path RTP_2 is less than the threshold value, indicating that the node S2, S3 and S4 in the path are working properly. It can be determined that node S1 is the failed node. Round-trip time approaching infinity indicats node S1 death, otherwise node S1 is faulty.

When node S2 is failed we measured the round-trip time of the path as shown in Figure 5. Can be seen from the figure, the round trip time of the path RTP_1 is greater than the threshold value, indicating that there is failure node in the path. The round-trip time of node S2, s corresponding path RTP2 is greater than the threshold value, the round-trip time of node S3, s corresponding path RTP_3 is less than the threshold value, indicating the node S2 failure.

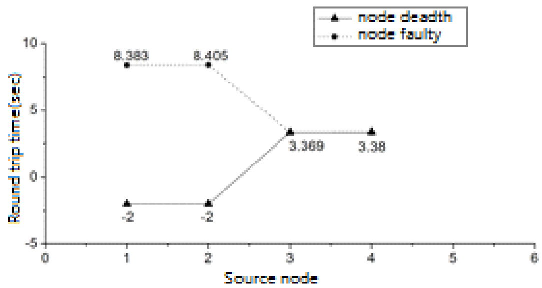

Figure 5 Round trip time chart when the node S2 is failed

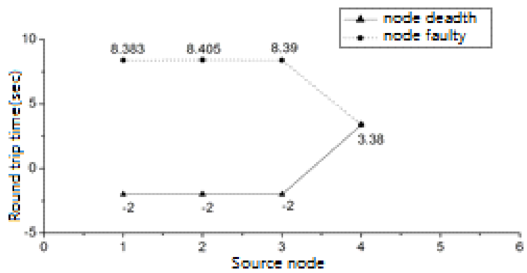

Figure 6 Round trip time chart when the node S3 is failed

When node S3 is failed we measured the round-trip time of the path as shown in Figure 6. The round trip time of RTP 1, RTP 2 and RTP_3 are greater than the threshold and the round trip time of RTP_4 is less than the threshold, indicating node S3 is the failed node.

Physical Experiment results show that using the path round-trip time to detect and locate the failed node is effective. When the network nodes number is large it is difficult to do physics experiment, in the following we, ll use NS2 simulation software to simulate verifying the performance of the algorithm when nodes are more.

3.2 Software simulation

In the wireless sensor network nodes form in a ring topology, and the adjacent three network nodes interconnected form a round trip path. Table 3 lists the simulation parameters.

Table 3 The simulation parameters

Name	Value
Nodes	6, 10, 20, 30, 40, 50, 100
Node distribution area	20m*20m
Routing Protocol	RTT
Communication distance	1m
Traffic model	CBR
Packet Size	20bytes

Initially all nodes are working normal, respectively simulating the sensor network of nodes 6,10,20,30,40,50, and 100, and we measured the path, s round-trip time of different network size as shown in Figure 7. Calculated that the path, s average round-trip time are between 14 and 22 milliseconds. Thus, the threshold value of path round-trip time is determined 22 milliseconds.

When a node is dead the path, s round-trip time is approaching infinity, unified identity -0.2 in the figure.

Figure 8 and Figure 9 respectively show the path, s round trip time when node 16 is failed and the network scale is 100 nodes and 30 nodes. In the figure the abscissa is the source node, the ordinate is the corresponding round trip time of each path. Node 16 is the source node of the round-trip path RTP_16, RTP_16, s round trip time is greater than the threshold, and the round-trip time of RTP_17 is less than the threshold, which can determine that node 16 is ineffective. RTP_16, s round-trip time tends to infinity, indicating the node 16 dead, otherwise indicating node 16 is faulty.

Figure 10 shows the path, s round-trip time when the network has 30 nodes and node 17 is failed. In the figure the abscissa is the source node, the ordinate is the corresponding round trip time of each path. Seen from the figure, the round trip time of path RTP_16 and RTP_17 are greater than the threshold, and the round trip time of RTP_18 is less than the threshold, which can determine that node 17 is ineffective. RTP_17, s round-trip time tends to infinity, indicating the node 17 dead, otherwise indicating node 17 is faulty.

Figure 11 shows the path, s round-trip time when the node 18 is failed. In the figure the abscissa is the source node, the ordinate is the corresponding round trip time of each path. Can be seen from the figure, the RTP_16, s round trip time is abnormal which source node is node 16, and round-trip time of RTP_17, RTP_18 both are greater than the threshold value, thereby determining node 18 ineffective. RTP_18, s round-trip time tends to infinity, indicating the node 18 dead, otherwise indicating node 18 is faulty.

NS2 simulation results are consistent with the results of physical tests, indicating that the round trip path resulted by discrete method is efficient and effective, which can complete detecting and locating the failed node in a relatively short period.

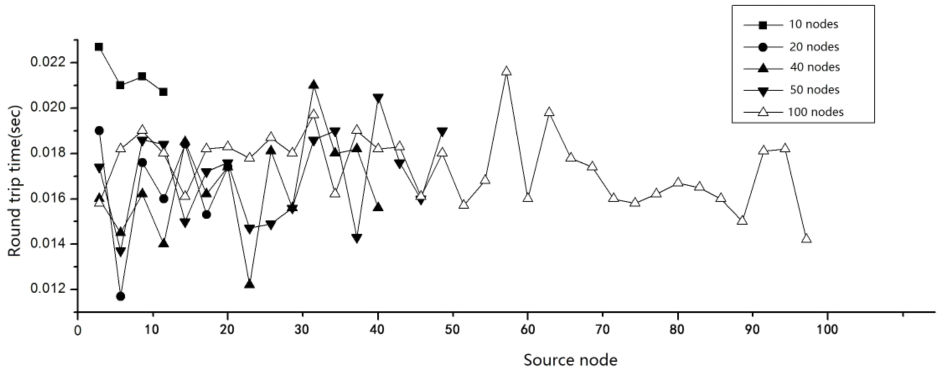

Figure 7 Round trip time chart when different nodes

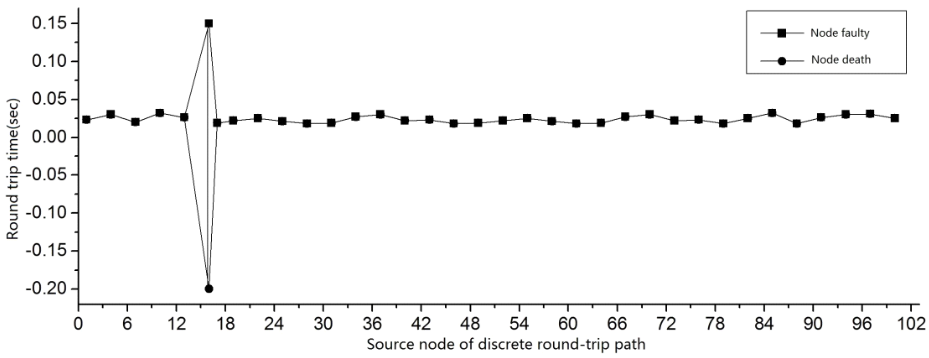

Figure 8 The round trip time chart when 100 nodes and node 16 failed

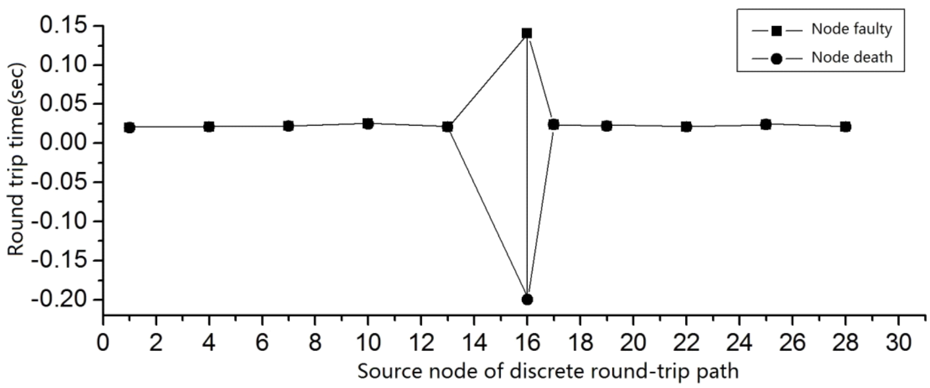

Figure 9 The round trip time chart when 30 nodes and node 16 failed

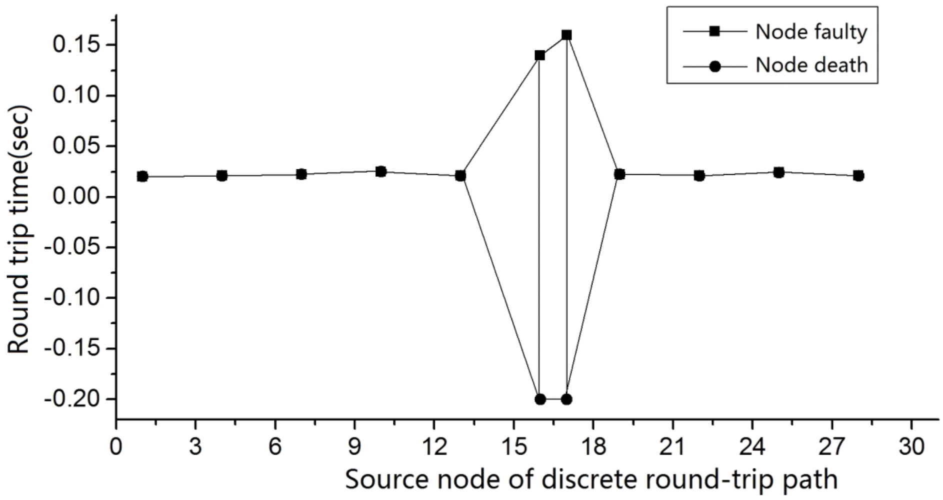

Figure 10 The round trip time chart when 30 nodes and node 17 failed

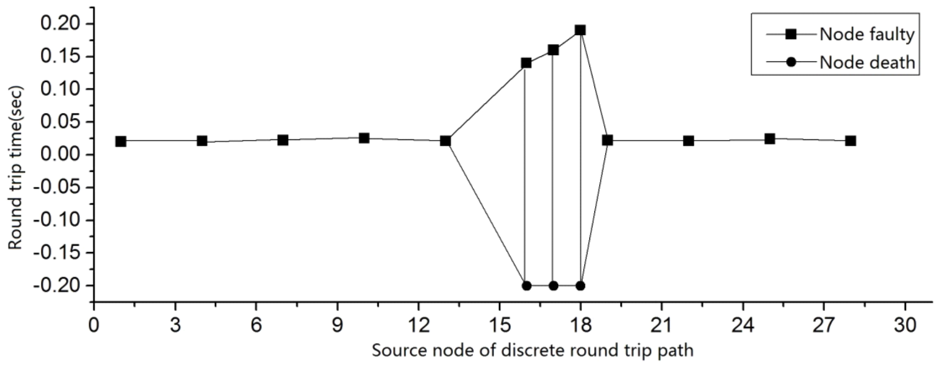

Figure 11 The round trip time chart when 30 nodes and node 18 failed

4. CONCLUSION

In wireless sensor network node failure problem has become an important reason for QoS decline, to detect and locate the failed node is the foundational technology to improve the network quality of service. In this paper, we study detection and localization of the failed node in the wireless sensor network, on the basis of the existing network tomography techniques, we propose a node failure detection method based on round-trip time, which method generates a circular path with a discrete method, compared with the linear path and other methods, the discrete method can significantly reduce the number of detected paths, and the discrete method can effectively reduce the node failure detection time , compared to other methods in the detection time model. With physical experiments and software simulation consistently demonstrate that the method based on round-trip time in the detection and localization of node failure is effective and practical.

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