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Sensor node failure detection based on round trip delay and round trip paths in WSN

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Abstract- *In recent years, applications of wireless sensor networks (WSNs) have been increased due to its connection between the physical world to the virtual world. The cost of the wireless sensor nodes have been reduced because of the advancements in the microelectronics manufacturing technology. It is the need to deploy more number of nodes in the network to assure the better quality. The failed node in the network is a huge problem as it affects the operation of entire network. As the number of nodes increases in the network, there is an increase in probability of failed nodes. It is essential to detect such nodes and take corrective measures. In the proposed method, faulty sensor node is detected by measuring the round trip delay (RTD) time of discrete round trip paths and comparing them with threshold value.*

Index Terms— Faulty sensor node, round trip delay, round trip paths, WSNs.

1. Introduction

WIRELESS sensor networks (WSNs) have potential applications in a variety of fields, like surveillance, security, military operations, medical, environmental and industrial. The rapid growth in electronic fabrication technology made it possible to manufacture the sensor node at low cost with better accuracy and sensitivity. Hence large numbers of portable sensor nodes can be deployed in the field to increase the quality of service (QoS) of such wireless sensor networks. The use of large numbers of sensor nodes will increase the probability of sensor node failures in WSNs. Data transmission and reception from such nodes becomes difficult and at times cause major failures in network causing the degradation of QoS. The sensor node in the WSNs can become faulty due to various reasons such as battery failure, environmental effects, hardware or software malfunctions. It is mandatory to detect such nodes in the network. The proposed method of fault detection is based on RTD time measurement of RTPs. RTD times of discrete RTPs are compared with threshold time to determine failed or malfunctioning sensor node. This method is tested and verified on four wireless nodes, implemented by using microcontroller and Zigbee. In order to verify the scalability of this concept, WSNs with large numbers of sensor nodes are implemented and simulated in open source software NS2. Result analysis in hardware and software indicate that RTD time measurement results in both cases are quite equal, validating the real time applicability of this method.

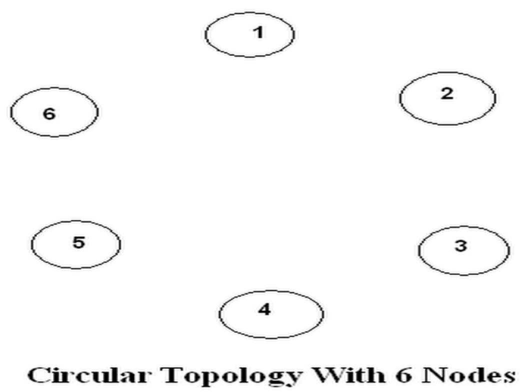

Figure-1: nodes in circular topology

2.0 ROUND TRIP DELAY AND PATHS

Round trip delay time in the network for each node of the RTP will change with different environment. It also changes due to faulty sensor node. This delay time could be more than the threshold value or it could be infinity. The faulty node is decided by comparing the RTD with the threshold. Detection time of faulty sensor node depends upon the numbers of RTPs and RTD time. Therefore, RTD time measurement and evaluation of RTPs is must to minimize the detection time.

2.1 Round trip delay time Estimation

RTD time mainly depends upon the numbers of sensor node present in the round trip path and the distance between them. Selecting minimum numbers of sensor nodes in the RTP will reduce the RTD time. The round trip path (RTP) in WSNs is formed by grouping minimum sensor nodes. The minimum round trip delay time (τRTD) of RTP with three sensor node is given by

$$\tau RTD = \tau 1 + \tau 2 + \tau 3 \quad (1)$$

Where $\tau 1$, $\tau 2$ and $\tau 3$ are the delays for sensor node pairs (1,2), (2,3) and (3,1) respectively. Circular topology keeps the nodes at equidistance. Therefore node pair delays $\tau 1$, $\tau 2$ and $\tau 3$ will be equal. Let 'τ' be the uniform time delay for all sensor node pairs in RTPs i.e. $\tau = \tau 1 = \tau 2 = \tau 3$.

$$\text{i.e. } \tau RTD = 3\tau. \quad (2)$$

This is the minimum RTD time of an RTP in WSNs.

3.0 Selection and analysis of Round Trip Paths

Faulty node can be detected by comparing the RTD time of RTP with the threshold. The numbers of RTPs formed with 'm' sensor nodes is given by

$$P = N(N - m) \quad (3)$$

where P is the numbers of RTPs,

N is total number of nodes in the network Analysis time of fault detection method is the time required to measure the RTD times of all RTPs in the WSNs. It is the addition of all RTD times. The equation for analysis time with P numbers of RTPs is given by

$$\tau ANL\ (M) = \tau RTD{-}1 + \tau RTD{-}2 + \cdots + \tau RTD{-}P \quad (4)$$

$$\tau ANL\ (M) = \sum \tau RTDi \quad (5)$$

RTD time of RTP will increase for additional numbers of sensor nodes. All the RTPs in WSNs are formed by selecting only three sensor nodes (m = 3). Then the round trip delay for all RTPs is approximately same.

$$\text{i.e. } \tau RTD = \tau RTD{-}1 = \tau RTD{-}2 = \cdots = \tau RTD{-}P \quad (6)$$

Equation (5) can be written with the equal RTD time as

$$\tau ANL = P * \tau RTD \quad (7)$$

Referring (2), analysis time can be written in terms of sensor node pair delay is as

$$\tau ANL = P * 3\tau. \quad (8)$$

The maximum possible round trip paths PM, created by three sensor nodes per RTP are obtained by substituting m = 3 in (3) and is given by

$$PM = N(N - 3). \quad (9)$$

Analysis time τANL(M), to detect the faulty sensor node using maximum RTPs is obtained by referring (8) and (9) as follows

$$\tau ANL(M) = N(N-3) * 3\tau. \quad (10)$$

The selection of RTPs is a major concern. With the equation (3), it is suitable for networks with small number of nodes. As the number of nodes in the network increases, it becomes difficult to have RTPs. The delay time for such huge RTPs will also increase. The total analysis time increases exponentially with increase in nodes.

3.1 Linear selection of RTPs

To overcome the difficulty of RTP selection, the linear selection of RTPs is imposed. This method will have very less number of RTPs compared to the one given in eq. (3). With this method the number RTPs generated will be

$$P = N \quad (11)$$

which is linear as compared to the eq.(3).

Following table shows the RTP comparison

Table no-1: Comparison of RTPs

	Round trip paths	Number of nodes in RTP			
	m=3	6	10	20	40
1	P=N(N-m)	18	70	340	1480
2	P=N	6	10	20	40

Selection of RTP equal to the number of nodes in the network will reduce the overload. Six linear RTPs created for the WSNs of Fig. 1 is shown in Fig. 2. Individual sensor node is present in three linear RTPs. Hence comparison of such three linear RTPs is sufficient to detect the faulty sensor node.

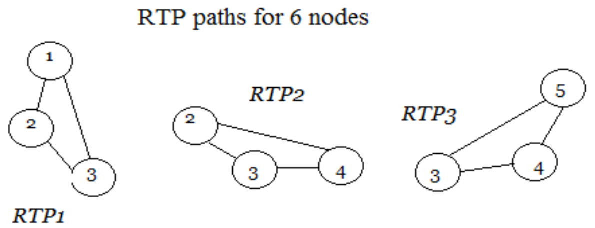

Figure no-2: RTP formed with three nodes

4.0 Algorithm

The algorithm to detect the faulty node is explained below. The network consisting of the N nodes will have the RTP equals to N according to linear selection method. Initially all the sensor nodes are initialized. Considering all the sensor nodes working, the average delay time is calculated. This time is the threshold value. RTP is kept as any value i.e. m=2,3,4,6 etc.

The counter is kept at some value 'x' which is equal to N in this case. The round trip path is assigned amongst the nodes in the network. The RTD of that particular path is calculated and compared with the threshold value. If the time is more than threshold value then the node is considered as faulty. The counter is decremented and the same procedure is carried for each RTP.

This algorithm is best suited for minimum number of nodes in the round trip path. When the network is initialized, it is mandatory to check whether all the nodes are working properly as this delay time will be used as the threshold time. This threshold time according to the number of nodes in the RTP. Total analysis time will depend on the number of nodes in the network.
Following steps explain the algorithm

Steps:
1) Initialize all the nodes
2) Select 'n' sensor nodes for round trip path (e.g. m=2,3,4,5)
3) Determine number of round paths in WSN
4) Set the counter for round trip paths
5) Select the round trip path
6) Calculate the Round Trip Delay of the selected RTP e.g. $\tau RTD= \tau(1,2)+ \tau(2,3)+ \tau(3,1)$
7) Compare the RTD time of each RTP by with the threshold value
8) If the time is more than threshold then declare the node as 'faulty' else go to step 9.
9) Go to step 4, decrement the counter for RTD path and repeat till step 7 for all paths in the WSN.
10) Stop.

5.0 HARDWARE ANALYSIS

Wireless nodes are designed using the PIC controller PIC16F73 and the ZigBee S2 module. The network implemented with four nodes is as shown in the figure 3. The communication takes place between any two nodes at a time. The base node acts as a monitoring node. It displays the delay taken by the nodes for its communication. The TTL to USB connector is used to display the data on the monitor. The 9 voltage batteries are used for each node. Figure 3 shows the experimental set of the four nodes with the base node.

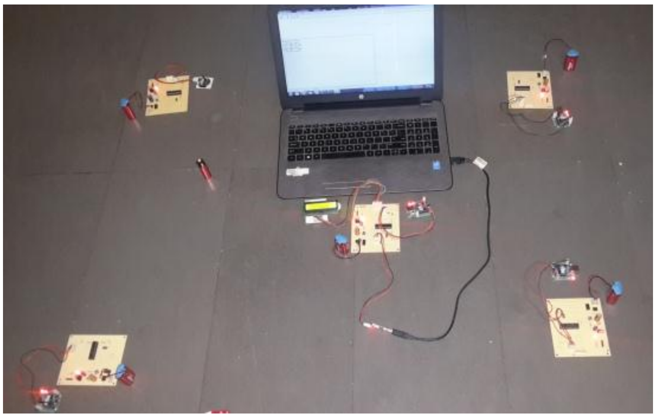

Figure no-3: Hardware implementation

The delay between two nodes is calculated at a time and is displayed on the monitor and LCD as well. Hyper terminal is used to display the serial data from the base station. Due to this serial connection, some delay is added to the actual delay between the nodes. Following table shows the delay of each RTP.

The nodes are deployed in the area of 30*30 hall. All the nodes are kept at equidistance to each other. Considering all the nodes in the network are working properly, the threshold value is calculated. The serial data transmission at the base station takes some time to display it on monitor. To compensate this, the average delay time for serial data transmission is calculated and added to the actual delay time. This delay time observed is around 800 to 900 milliseconds. Therefore the delay of 1 second is added to compensate this time.
Following table shows the average delay time of the RTPs in the network.

Table no-2: Hardware RTD time

	Round trip path (RTP)	RTD time (msec)	Threshold	Delay due to serial connection (msec)
1	RTP1	1002.36	3	1000
2	RTP2	1002.15	3	1000
3	RTP3	1001.15	3	1000
4	RTP4	1002.28	3	1000

The threshold time kept in the analysis of hardware is 3 seconds. The average time taken by one round trip path considering two nodes in the RTP is around two seconds. Therefore the threshold value kept is just above that value. The source node in RTP sends the data and will wait for maximum of 3 seconds. If the source node does not receive any response from the receiver, it will declare the path as faulty.

6.0 SOFTWARE ANALYSIS

In this the protocol is formed and simulated using the NS2 simulator tool. The round trip path is assigned and a packet is routed in between these sensor nodes of RTP. It is routed in the round trip d path by assigning the addresses of source, forwarding and destination senor nodes. The parameters selected for this simulation are listed in Table 3. The circular topology of WSNs with six sensor nodes (N = 6) implemented and simulated in NS2 is shown in Fig.3. The sensor nodes in circular topology are placed at the same distance.

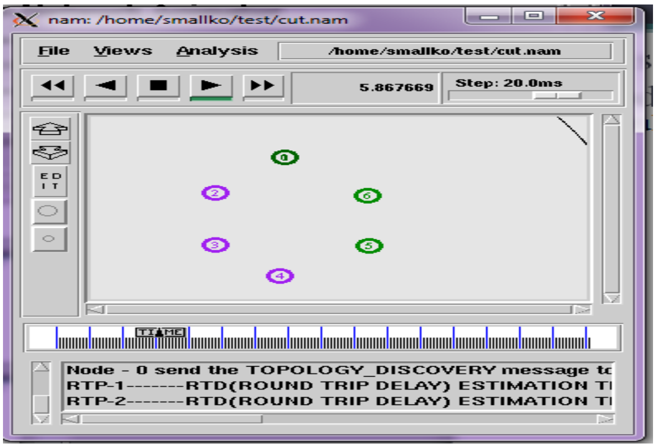

Figure no-4: Simulation of 6 nodes

The simulation is done for different number of nodes in the network. The results are observed for N= 4, 6, 30. The number of nodes in the round trip path is also changed and the result is analyzed.
Following table enlist different parameters used for the simulation.

Table no-3: Parameters selected in NS2

	Parameter	Value
1	Number of nodes	4, 6, 30
2	Simulation area	150*120, 150*120, 1500*1500
3	Simulation time (seconds)	30, 100, 100
4	Routing protocol	RTP
5	Transmission distance between nodes	1 feet
6	Traffic type	CBR
7	Initial node energy	100J
8	Packet size	1024byte

7.0 RESULT ANALYSIS

The simulation is done for 4,6,30 nodes and the resultant delay is plotted on the graph using the Xgraph tool. The more number of nodes in RTP more is the delay. 4 nodes have been simulated with RTP=2, 6 nodes have been simulated with RTP=3, 30 nodes have been simulated with RTP= 3, 4, 5. The result of simulation is being listed in table 4. The 6 node simulation result with the faulty node is plotted on the graph as shown below in figure 5.

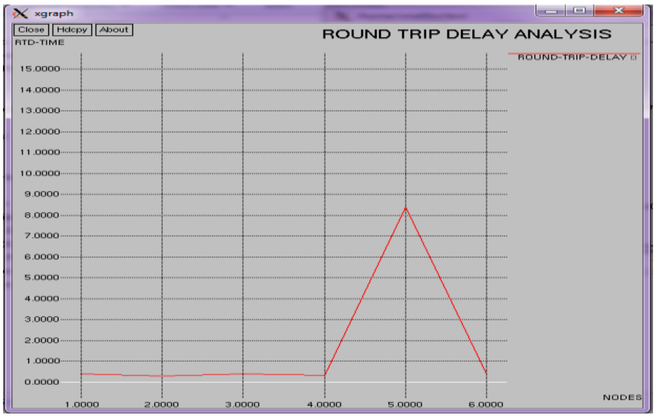

Figure no-5: Output graph of fault node with its delay time

As it can be seen from the graph that the node number 5 takes more time to deliver the data, it is concluded that this node is faulty. The threshold time kept for comparison is 5 seconds and in the simulation of 6 nodes, node 5 takes 8 seconds to deliver the data.

Following table shows the difference between having different number of nodes in RTP for different number of nodes in the network.

Table no-4: comparison with different number of nodes in RTP

	No of nodes in network	No of nodes in RTP	Avg. delay (seconds)	Threshold (seconds)
1	4	2	0.22	5
2	6	3	0.36	5
3	30	3	0.39	5
4	30	4	0.47	5
5	30	5	0.58	5

The average delay is increasing with increase in number of nodes in RTP. The threshold value kept for each simulation is 5 seconds. This time is evaluated considering all the nodes are working properly.

Table 5 shows the comparison of hardware and software results for four nodes and RTP=2.

Table no-5: Comparison of Hardware and Software

	Parameters	Software	Hardware
1	No of nodes	4	4
2	RTP	2	2
3	Distance between nodes	1 feet	1 feet
4	Avg RTD time	0.22 sec	1002.21 msec
5	Threshold	5(sec)	3 (sec)
6	Transmit power	1.5W	0.8 W

10.0 CONCLUSION

The proposed method is implemented in software with multiple numbers of nodes. The RTPs are changed and the results are observed for different number of nodes. The simulation with less number of nodes in RTP is excellent. Round trip delay time increases in case of more number of nodes in RTP resulting in increase of total analysis time. For real time applicability, performance of the proposed method is tested with hardware as well. It is seen that the results of software and hardware are identical.

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