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Protocol Based On Round Trip Delay and Paths for Sensor Node Failure Detection

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Abstract: The usage of Wireless Sensor Networks (WSNs) has been increased nowadays due to its vast advantages of being used in the industrial environment. Also the reduction in the cost of semiconducting devices has increased the usage of WSNs. The important thing to be noted while using the wireless sensor networks is to maintain its Quality of Service (QoS). Many sensors can be used in a WSN to increase its quality of service. But the increase in the number of sensors will have a danger of increase in the failure of sensor nodes, which indeed affects the quality of service of that particular sensor network. In order to maintain the quality of service of a WSN a protocol called Round Trip Delay protocol has been proposed here. The suggested protocol is experimented in WSN with six sensor node designed using ARM processor and Zigbee. Also this method is verified by simulating the WSN with large number of sensor nodes in NS2

Keywords: Quality of Service, WSN, ARM, Round Trip Delay.

I. Introduction

In the wireless sensor networks (WSN) more number of sensor nodes can be used to increase the quality of service (QoS). But the exercise to use large number of sensor nodes will increase the probability of sensor node failure. The output data from these faulty sensors is incorrect or else it will deviate vastly from the original value. This will eventually degrade the quality of service (QoS) of that WSN [5]. In any WSN the various reasons for the failure of sensor node are the failure of the battery, environmental effects or hardware or software malfunctions. So in all these circumstances a better Quality Of Service (QoS) can be achieved by discarding data from the faulty sensor nodes during the analysis [6], [7]. In order to do that an efficient and accurate detection of faulty sensor node is needed.

II. Literature Review

The faulty sensor nodes identification suggested in [8] is based on comparisons between neighboring nodes and dissemination of the decision made at each node. Algorithm proposed in this method can't detect the malicious nodes. Cluster head failure recovery algorithm used in [9] to detect the faulty node has data loss problem, occurring due to transfer of cluster head. Path redundancy technique to detect faulty sensor node is suggested in [10] and [11]. Redundancy increases the energy consumption and reduces the number of correct responses in network lifetime. Excessive redundant paths in WSNs will slow down the fault detection process. In [12], link failure detection based on monitoring cycles (MCs) and monitoring paths (MPs) is presented. Three-edge connectivity in the network, separate wavelength for each monitoring cycle and monitoring locations are the limitations of this method.

III. Proposed System

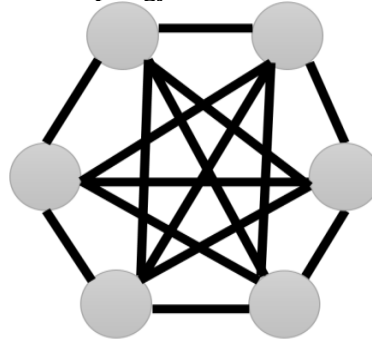
The proposed method of fault detection is based on RTD time measurement of RTPs. RTD times of discrete RTPs are compared with threshold time to determine failed or malfunctioning sensor node. Initially this method is tested and verified on six wireless sensor nodes, implemented by using ARM processor 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. Generalized model to determine the fault detection analysis time for WSNs by using discrete RTPs is suggested. Various experiments are performed in hardware and software based on RTD time measurements. Analysis time in all cases of fault detection is determined with the help of generalized model. 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.

A. Round Trip Delay and Paths Analysis:

Round trip delay time of the RTP will change due to faulty sensor node. It will be either infinity or higher than the threshold value. Faulty sensor node is detected by comparing the RTD time of RTPs with threshold value. The sensor node common to specific RTPs with infinity RTD time is detected as failed. If this time is higher

than the threshold value then this sensor node is detected as malfunctioning. Detection time of faulty sensor node depends upon the numbers of RTPs and RTD time.

Fig.1 Circular topology WSN with six sensor nodes



B. RTD Time Estimation:

RTD time mainly depends upon the numbers of sensor node present in the round trip path and the distance between them. Proposed fault detection technique accuracy can be increased by reducing the RTD time of RTP. It can be decreased only by reducing the sensor nodes in RTP because the distance between sensor nodes in WSNs is determined by particular applications and can't be decided. 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 three sensor nodes [13]. Hence the minimum round trip delay time (τ_{RTD}) of RTP with three sensor node is given by,

$$\tau_{RTD} = \tau_1 + \tau_2 + \tau_3 \quad (1)$$

where τ_1 , τ_2 and τ_3 are the delays for sensor node pairs (1,2), (2,3) and (3,1) respectively [14]. Circular topology with six sensor nodes is shown in Fig. 1. Three consecutive sensor nodes in each RTP are almost at equidistance because of circular topology. As a result sensor node pair delays τ_1 , τ_2 and τ_3 will be equal. Let ' τ ' be the uniform time delay for all sensor node pairs in RTPs i.e. $\tau = \tau_1 = \tau_2 = \tau_3$. Round trip delay time for RTP with uniform sensor node pair delay is obtained by referring equation (1) as,

$$\tau_{RTD} = 3\tau \quad (2)$$

This is the minimum RTD time of an RTP in WSNs. It is determined by the sensor node pair delay (τ), which is decided by particular application of WSNs, as it depends upon the distance between the sensor nodes. Hence the efficiency of proposed method can be improved only by reducing the RTPs in WSNs.

C. Evaluation of Round Trip Paths:

Faulty sensor node is detected by comparing the specific RTPs to which it belongs. More numbers of sensor nodes in the round path will reduce the RTPs created. But due to this individual sensor node will be present in more RTPs. While detecting faults, comparisons of all such RTPs become necessary. This will delay the fault detection process. 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. 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,

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

$$\tau_{ANL} = \sum_i^P \tau_{RTD-i} \quad (5)$$

RTD time of RTP will increase for additional numbers of sensor nodes. Referring (2), optimum value of RTD time of RTP is obtained by considering only three 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.

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

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

$$\tau_{ANL} = P \times \tau_{RTD} \quad (7)$$

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

$$\tau_{ANL} = P \times 3\tau \quad (8)$$

Minimum numbers of sensor nodes used to form RTP will create substantial numbers of RTPs. 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,

$$P_M = N(N - 3) \quad (9)$$

Analysis time $\tau_{ANL}(M)$, to detect the faulty sensor node using maximum RTPs is obtained by referring (8) and (9) as follows,

$$\tau_{ANL}(M) = N(N-3) \times 3\tau \quad (10)$$

The fault detection analysis time will increase exponentially with increase in numbers of sensor nodes N in WSNs. Also the maximum numbers of RTPs produced are not required for comparison to detect the fault. Such selection of RTPs is not an adequate solution to speed up fault detection. Hence optimization of RTPs in WSNs is essential to speed up the fault detection.

D. Optimization of Round Trip Paths:

Fault detection by analyzing RTD times of maximum numbers of RTPs will require substantial time and can affect the performance. Therefore essential numbers of RTPs has to be selected for comparison purpose. Optimization of RTPs can be done by either linearly selecting the RTPs or by discretely selecting the RTPs.

D.1. Linear Selection of RTPs:

In order to reduce the RTPs in the fault detection analysis, instead of considering maximum numbers of RTPs, only few paths corresponding to the number of sensor nodes in WSNs are sufficient. We can select the RTPs equal to the numbers of nodes in WSNs to reduce the analysis time. RTPs selected in this way are called as linear RTPs because of the linear relationship between N and P . Individual sensor node is present in three linear RTPs. Hence comparison of such three linear RTPs is sufficient to detect the faulty sensor node. The linear RTPs in WSNs with N sensor nodes can be written as

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

where P_L is the number of linear RTPs. Measurement of RTD times of such paths is essential. Referring (8) and (11), the analysis time $\tau_{ANL}(L)$ for linear RTPs is given by,

$$\tau_{ANL}(L) = N \times 3\tau \quad (12)$$

Linear RTPs selected will be higher for large value of sensor nodes N . This will not optimize the fault detection time in case of large size WSNs. Therefore, further reduction in the numbers of RTPs is must to increase the efficiency of proposed method.

D.2. Discrete Selection of RTPs:

In the first level of optimization the analysis time is curtail up to certain limit. Still the numbers of RTPs are high. For WSNs with large numbers of sensor nodes the fault detection time is significantly high. So again there is need to minimize the RTPs in WSNs. In the second level of optimization, numbers of RTPs are reduced by selecting only discrete paths in WSNs. Discrete RTPs are selected from sequential linear RTPs only. They are selected by ignoring the two consecutive paths, after each selected linear path. In this way RTPs are selected in discrete steps of three as each RTP consists of three sensor nodes. The equation to select the discrete RTPs in WSNs is given by,

$$P_D = Q + C \quad (13)$$

Q and C in above equation are expressed as below,

$$Q = [N/m] \quad (14)$$

$$C = \begin{cases} 0 & \text{if } R = 0 \\ 1 & \text{otherwise} \end{cases} \quad (15)$$

where Q is the quotient, m is the numbers of sensor nodes in RTP, R is remainder, N is numbers of sensor nodes in wireless sensor networks and C is correction factor to be added. Correction factor will be 0 if remainder is 0 otherwise it is 1. Analysis time $\tau_{ANL}(D)$ required for detecting fault in discrete RTPs is obtained by referring (8) and (13) as follows,

$$\tau_{ANL}(D) = (Q + C) \times 3\tau \quad (16)$$

The numbers of sensor nodes used in RTP are three only i.e. $m = 3$. Equation (16) can be written in terms of N and m as

$$\tau_{ANL}(D) = ([N/3] + C) \times 3\tau \quad (17)$$

Analysis of particular selected discrete path will be sufficient to monitor the fault. Selection of discrete RTPs will save the analysis time to a large extend.

D.3. Comparisons of RTPs:

After analysis time of discrete RTPs with variable numbers of sensor nodes from 3 to 10 for WSNs with 100 sensor nodes, it's been found that the numbers of discrete RTPs required are only 34% as compared to linear selection. Hence analysis time curtail in discrete RTPs is up to 66% w.r.t linear RTPs. The efficiency of fault detection method is improved by considering the discrete RTPs.

E. Generalized RTD Time Model:

After optimization of number of RTD paths, the quick detection of fault is done by using discrete RTPs. Fault present at source node in round trip path is identified by discrete plus one RTPs analysis. Along with discrete

RTPs in WSNs, additional two RTPs are essential to locate the fault present at second and third level respectively. Hence total numbers of RTPs used to detect fault are given by,

$$P_T = P_D + L \quad (18)$$

where P_T is number of total optimized RTPs and L is the numbers of sensor nodes excluding source node used in formation of RTP i.e. $L = (m - 1)$.

The equation (18) can be written in terms of N and m by referring (13) and (14) as,

$$P_T = [N/m] + C + (m - 1) \quad (19)$$

Analysis time of the proposed method depends upon the RTD times of RTPs used to examine. Generalized model of analysis time by selecting discrete RTPs in WSNs having N sensor nodes and RTP created by grouping 'm' sensor nodes is given by,

$$\tau_{ANL}(G) = \{[N/m] + C + (m - 1)\} \times m\tau \quad (20)$$

After creating the RTPs and calculating the analysis time related to it by referring equation (20), for various numbers of sensor nodes (m) selected per RTP in WSNs with 100 nodes it is found that analysis time is lowest in the case of least numbers of sensor nodes i.e. $m = 3$. Thus the selection of sensor nodes per RTP equal to three will be better to enhance the detection efficiency of the proposed method. Deciding the specific RTPs (discrete RTPs) in WSNs with unique source node is a novel approach, which will enable the parallel analysis of such RTPs to improve the efficiency of suggested method.

F. Algorithm to Detect Faulty Sensor Node:

The algorithm to detect the working as well as faulty sensor node is explained below. The discrete RTPs with three sensor nodes are used to determine the fault in WSNs. Algorithm is executed in two phases, first phase is used to decide the threshold value of RTD time and fault is detected in the second phase. In the first phase all sensor nodes in WSNs are considered as working properly. Discrete RTPs are selected by incrementing the source node value by three and their respective RTD times are measured by using the subroutine. The highest value of RTD time measured during the execution of first phase is selected as the threshold RTD time for all discrete RTPs in WSNs.

In the second phase of fault detection, instantaneous RTD time of discrete RTPs is compared with the threshold time. Discrete RTPs whose RTD time is found to be greater than threshold time is then analyzed in detail. This particular discrete RTP is examined in three stages to locate the exact position of fault. Let S_X be the source node of this particular discrete RTP with sequence of sensor nodes as $S_X - S_{X+1} - S_{X+2}$. Faulty sensor node in the WSNs can be present at position S_X or S_{X+1} or S_{X+2} in RTP. Hence RTPs formed by these sensor nodes have to be examined to locate the fault. RTPs formed by second and third node in this particular discrete RTP have the sensor node sequence as $S_{X+1} - S_{X+2} - S_{X+3}$ and $S_{X+2} - S_{X+3} - S_{X+4}$ respectively. The RTD times of these RTPs are measured sequentially. On the basis of this RTD time, these RTPs are compared to detect the faulty sensor node. Detected faulty sensor node, which can be either failed or malfunctioning, is verified by comparing the RTD times of respective RTPs with threshold time. Execution of second phase in three stages to locate the fault is as follows.

In the first stage RTP_X and RTP_X+1 are compared. If RTD time of RTP_X+1 is equal to threshold, provided that RTP_X time is greater than threshold value, then sensor node S_X is determined as faulty. Here if the RTD time of RTP_X is infinity then S_X is concluded as failed (dead) otherwise it is malfunctioning.

RTP_X+1 and RTP_X+2 are compared in second stage, provided that RTD time of RTP_X is greater than threshold time. If the RTD time of RTP_X+1 is greater than threshold and RTP_X+2 is equal to threshold value, determines that S_{X+1} is faulty. In this case if RTD time of RTP_X+1 is infinity then S_{X+1} is concluded as failed (dead) otherwise it is malfunctioning.

Similarly RTP_X, RTP_X+1 and RTP_X+2 are compared in third stage. RTD times of RTP_X, RTP_X+1 and RTP_X+2 higher than threshold time determines that S_{X+2} is faulty. Infinity value of RTD time of RTP_X+2 indicate that S_{X+2} is failed (dead) otherwise it is malfunctioning. Finally the S_{X+2} sensor node value is compared with the last node S_N in the WSNs, if it is found to be less, then algorithm is executed again for the next discrete RTP. This process is continued till the examination of last discrete RTPs in WSNs.

IV. Experimental Analysis

A. Hardware implementation:

The hardware implementation is done using six sensors, ARM LPC2148 and XBEE S2 wireless module. The statuses of the sensors are received on the other end using Zigbee device and it displayed using a LCD Device. First the threshold RTD time is detected. And then to test the suggested protocol one of the sensor is made faulty and the malfunctioning sensor is detected.

While performing the experiment for failed (dead) state detection, one sensor node is made faulty by switching off its power supply. Infinity (∞) value of RTD time in simulation is indicated by '-2' value in all cases. For detecting malfunctioning state, a delay of 5s is added to the RTP of particular sensor node in WSNs.

Implementation of WSNs with large numbers of sensor nodes in hardware will be complicated. Hence to verify the scalability of investigated method, WSNs with large numbers of sensor nodes are implemented in software NS2.

Fig.2 ARM LPC 2148 Board



B. Software implementation:

Circular topology WSNs having different sensor nodes (N) are implemented by using the open source software NS2. In the proposed method round trip paths are formed by combining the adjacent three sensor nodes. RTD protocol is developed and implemented to measure the RTD time of such RTPs. Appropriate threshold RTD time is estimated by considering initially all sensor nodes in WSNs as working properly.

Specific sensor node in WSNs is declared as faulty in order to test and verify the suggested method. Faulty sensor node can be either failed or malfunctioning; hence two cases have to be evaluated separately. Failed (dead) sensor node detection is done by declaring the particular node as dead in tcl script. Similarly malfunctioning behavior is detected by adding certain delay in the RTPs of particular sensor node.

V. Conclusion

The protocol proposed here is successfully implemented and tested on both hardware and software. The faulty sensor node is detected by comparing the RTD time of discrete RTPs. This proposed protocol is verified in hardware using the ARM processor and in the software using the NS2. This protocol can be used in any topology Wireless Sensor Networks. From the experiments conducted it has been clear that the efficiency of this RTD protocol will be good when we consider RTPs with three sensor nodes. Since only circular topology has been considered here, in the future work this suggested protocol can be applied in other topologies like NJ-LATA, circular and triangular.

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