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Monitoring the health status of civil structures by deploying backup sensors with scheduling scheme

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ABSTRACT- *Sensor networks are used for Structural Health Monitoring (SHM). Wireless Sensor Network (WSN) is an effective and economically viable solution used in variety of applications for sensing the temperature, pressure and sound. The SHM is a technique to determine the condition of a civil structure, provide spatial and quantitative information regarding the structural damage and predict the performance of the structure. It is used to monitor the operation and health status of the civil structures even in the presence of sensor fault. Sensor deployment and decentralized computing are the two challenges that are addressed in the WSN. Communication errors, unstable connectivity and sensor fault affect the performance of SHM. To make WSN resilient to failures Fault Tolerance in SHM (FTSHM) approach is used. It searches the repairing points in cluster in a distributed manner and places a set of backup sensors by Backup Sensor Placement (BSP) algorithm. The proposed Fault tolerant Node Scheduling (FNS) algorithm activates the set of backup nodes for each active node if failure occurs. It consists of two phases sensing phase and scheduling phase. All nodes are scheduled to be in active mode broadcasts the Bandwidth REQuest (BREQ) message which contains its ID. This will decrease security issues, enables stable connectivity and maximize network lifetime. The performance is evaluated in OMNeT++ and the system level simulations are performed in C++ to demonstrate the effectiveness and efficiency of the scheduling scheme for a set of backup sensors.*

Keywords - structural health monitoring, sensor deployment, wireless sensor network, bandwidth request, decentralized computing.

1. INTRODUCTION

Wireless Sensor Networks (WSNs) are used in environmental monitoring, structural health monitoring [1], military operations, and event detection. The SHM is the process of implementing damage detection for engineering structures. The objective of SHM is to monitor the integrity of structures such as buildings, dams, bridges, and to detect and to pinpoint the locations of any damage [2]. The WSN consist of several nodes connected to several sensors. Radio transceiver is used for transmission of data. A micro controller is used for communicating with the sensors and for energy harvesting battery source is used. Sensor node is also known as mote [3]. It is used for processing the information and communicating with other connected node in the network. The Fig 1 shows the structure of Wireless Sensor Network.

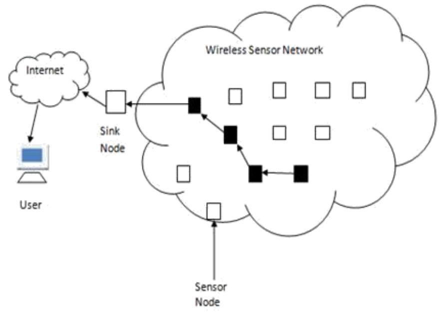

Figure.1 Wireless Sensor Network

The ideal wireless sensor network is scalable, consumes little power and software programmable. A WSN has a base station that can communicate wireless sensors via a radio link to transmit the information. Sensor deployment and decentralized computing are the two challenges have been implemented [4]. Communication errors, unstable connectivity, sensor faults damage the performance of SHM. The flexibility to WSN is provided by the Fault Tolerance in SHM (FTSHM) approach. It repairs the WSN with clusters in a distributed manner and set the backup sensors [5]. The repairing points include separable point, critical middle point and isolated point. Search and place algorithm is implemented for finding locations around the repairing point based on Effective Independence (EFI) method with larger values. FTSHM includes energy efficient online damage indication algorithm called damage indicator suitable for decentralized computing to optimize WSN resources and guaranteeing that the WSN for SHM is connected. It prolongs the WSN lifetime for stable connectivity and data delivery constraints [6].

1.1 Backup Sensor Placement

Structural health monitoring is used to determine health status of a structure and provides long term monitoring, rapid analysis in response to unusual incidents. Sensor location optimization method is identifying the sensor based on EFI method [7]. This method is used to deploy a set of N wireless sensors called primary sensors in a set of locations of a structure and analysis of structural physical properties is carried out at Base Station (BS). The deployed WSN for SHM is prone to faults for various reasons like physical structure modeling constraint, irregular communication or unstable connectivity, sensor debonding faults, quick energy depletion of some sensors. Two problems arise if any of the fault type occurs in WSN like continue monitoring information and guarantee sensor fault tolerance in SHM [8].

The Repairing Points (RPs) are searched for the prediction of network failure. The highly possible RPs is searched in a distributed manner because it involves only communication between neighbors in a cluster and limits searching to clusters. A fundamental requirement of SHM is structural damage identification. In that each sensor works actively for a long period of time to severe constraint on radio bandwidth and energy usage [9-10]. Mode shape of the structure of the structure is determined based on the engineering driven methods. It includes structural mode shapes, sensor deployment procedure, limitations of deployment methods, the number of sensors have been deployed

[11]. Mode shape is mechanical structures that have a number of specific vibration patterns at specific frequencies.

Effective Independence method is used for sensor deployment. It uses mode shapes and noise measurement and then provides Fisher Information Matrix (FIM), a determinant to calculate EFI values [12]. The noise measurement is used to identify the malfunctioning nodes in the sensor network and an iterative algorithm is used to evaluate the candidate location of each *i*th sensor based on EFI values and each value corresponds to a candidate location [13]. Sensors should be deployed at optimal locations because sensor cannot be deployed anywhere for SHM. A specified degree of fault tolerance should be guaranteed before the WSN formally starts the operation. Small numbers of backup sensors are placed after the deployment of N primary sensors to repair possible failure points in WSN [14].

1.2 Clustering

Clustering is detecting possible repairing points in the WSN and repair by placing backup sensors through clusters. Clustering in SHM (C-SHM) approach is used to obtain dynamic vibration characteristics of each cluster area and carries out structural modal analysis [15]. In SHM perspective C-SHM is distributed and it outperforms centralized approach and carries out excessive modal analysis at the cluster level. In WSN perspective C-SHM is resource consuming and Cluster Head (CH) needs a lot computation, delay and transmission to modal analysis [16]. Each cluster as a sub graph G' of the WSN G= (V, E). V is the set of deployed sensors and E is the set of edges.

After clustering the objective is to detect RPs and provide fault tolerance for the RPs and for the data packet loss in the cluster. The level of fault tolerance is the failure of up to k-1 sensors to achieve a k-connected cluster [17]. The backup sensor placement is performed through each cluster. BSP algorithm is relatively simple, it finds the location to place the backup sensors and improves unstable or weak k-connected clusters into strongly k-connected clusters. The algorithm places backup sensors until all RPs are found. This algorithm has three steps.

In Step 1 BSP algorithm calls the three sub algorithms like separable point algorithm, critical middle point algorithm and isolated algorithm. The separable point is the only connecting point of several sensors which is critical to communicate and whose removal results in a disconnected cluster. Finding this RPs and placing backup sensors around the RPs guarantees to monitor every sensor location. The critical middle point is a RP that have longest and irregular transmission distance and the link between two sensor nodes is vulnerable.

The isolated point does not have a path or communication to another sensor in any cluster and may receive broken messages. When running three algorithms, if there is no RP in any cluster the algorithm stops searching and goes to step 2. The Step 2 considers still available backup sensors to be placed. The total number of RPs can be less or more than backup sensors.

If backup sensor is less than the number of RP then finding the RPs will be discarded. In Step 3 BSP algorithm calls a connectivity maintenance algorithm, k-connectivity recovery. The purpose of this algorithm is to improve connectivity of the WSN in an event of sensor failure.

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2. PROPOSED SYSTEM

This section provides the description of concepts on which the proposed framework is based. Backup node selection is described as follows.

2.1 Backup node selection

In WSNs the network lifetime of sensor nodes have a direct impact on battery resources. To improve energy efficiency in sensor node, scheduling methods are used to keep only a minimum number of sensor nodes in active mode. The Fault tolerant sensor Node Scheduling algorithm, called FNS that consider not only sensing coverage but also sensing level. Only a minimum number of sensor nodes operate in active mode and others are kept in sleep mode for reducing unnecessary power consumption [4]. Because of unexpected failure the active node is unable to perform its sensing or communication function. The active nodes are replaced for a set of backup nodes if failure occurs. It consists of two phases: the scheduling phase and sensing phase. The network lifetime is divided into several rounds as shown in Fig 2.

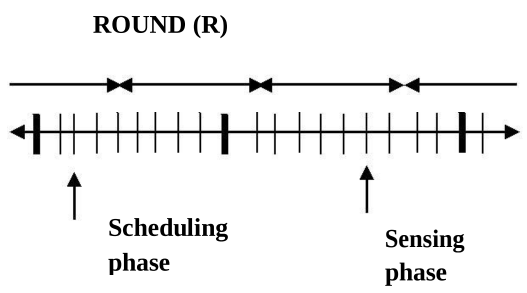

Figure. 2 Network Lifetime

Each node in sleep mode keeps not only information on the ID, location and heartbeat period of its neighboring active nodes but also information for the backup node function [18]. At the end of the scheduling phase, each node that is scheduled to be in active mode broadcasts a Bandwidth REQuest (BREQ) message to initiate the sensing task. If a node that is scheduled to be in sleep mode receives a BREQ from its neighboring active node and its evaluates that it is located within the sponsored coverage of the node and broadcasts a Bandwidth REPly (BREP) message after a random back off time. BREP message contains the ID and position information of the node. The ID and position of the node that sends the BREP message involves sponsored coverage information [17]. The node that is scheduled to be in sleep mode receives both a BREQ message and a BREP message from its neighbor nodes evaluated to be located within the sponsored coverage of the node that sent the BREP message [19].

If it is included in the sponsored coverage of the node that sent the BREP message it loses a chance to be selected as a backup node for the node that sent the BREP message. If not it is selected as a backup node for the node that sent the BREP message. In the sensing phase, each backup node wakes up periodically and checks the heartbeat packets from the active nodes that is backed up for. If any of the active nodes does not send a heartbeat packet within its heartbeat period, it decides that some fault occurs in the active node and switch itself to active mode. It maintains the minimum sensing level even in the presence of sensor

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node failures and can provide an efficient way to deal with the sensor node failures requiring a small number of backup nodes and a small amount of control messages. In scheduling phase, each sensor node decides to be in active mode or sleep mode through a predetermined process. The transition diagram of a backup node FNS algorithm is shown in Fig 3.

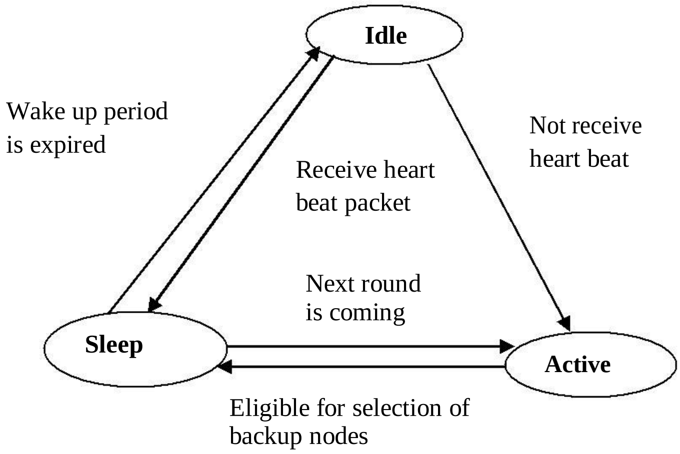

Figure.3 State Transition Diagram of a Backup Node in FNS

The backup mode selection strategy is represented,

$$\cos\theta = \frac{c^2 + a^2 - b^2}{2ac} \quad \theta = \arccos\left(\frac{c^2 + a^2 - b^2}{2ac}\right) \qquad (1)$$

The union of sponsored coverage of the backup nodes includes the set of backup nodes for an active node and sensing area of the activation node. To provide larger sponsored coverage the number of backup nodes should be minimized by selecting those nodes.

3. PROPOSED FAULT TOLERANT NODE SCHEDULING ALGORITHM

This paper proposes a new scheduling algorithm for backup sensor nodes. The proposed algorithm for scheduling is summarized as follows:

Step 1: Set the timer as T_a.

Step 2: Broadcast the BREQ message to the neighboring nodes if T_a is expired.

Step 3: After receiving BREQ message the sponsored angle is computed to prepare a BREQ message and set the timer as T_d.

Step 4: Compute angle if BREP message is received before T_d is expired and broadcast BREP message and set itself as a backup node.

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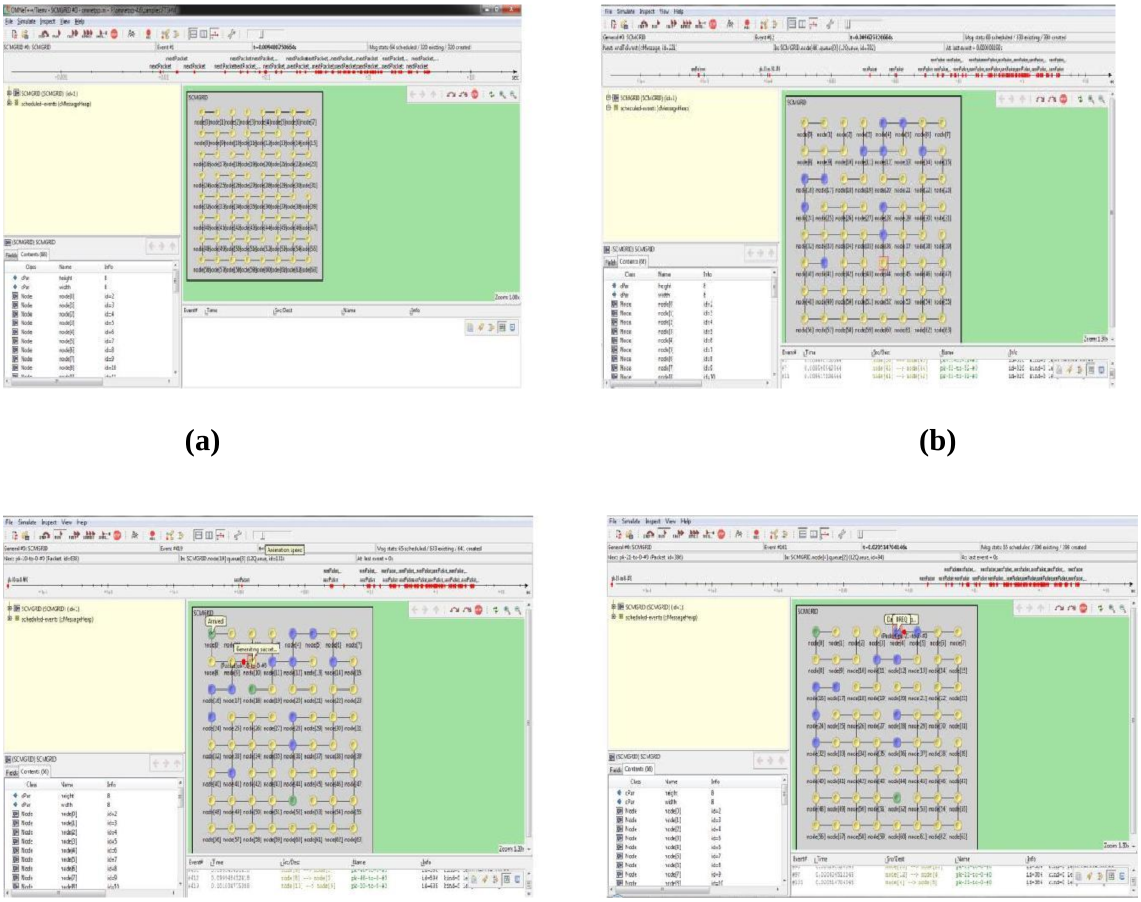
4. RESULTS



(a) (b) (c) (d)

Figure.4. Results for Backup Sensor Placement: a) Design of Fault Tolerance in Structural Health Monitoring (FTSHM). b) Backup Sensor Placement (BSP) at Repairing Points. c) Fault tolerant Node Scheduling (FNS) algorithm. d) Bandwidth REQuest (BREQ) Message for Active Nodes.

5. CONCLUSION

In this paper, Wireless Sensor Network (WSN) deployed for Structural Health Monitoring (SHM) remains connected even in the presence of sensor fault. It requires small number of backup sensors around the repairing points in the WSN to have a better performance by using the Fault tolerance in SHM (FTSHM) that uses Backup Sensor Placement (BSP) algorithm. It also increases the lifetime of sensor under connectivity and data delivery constraints. The specific scheduling scheme called Fault tolerant Node Scheduling (FNS) algorithm is used to set the backup node for the active node if an active node fails in the sensing area. It can provide the efficient way to deal with the sensor node failures, requiring a small number of backup nodes as well as a small amount of control messages. It is the efficient way to recover from sensor node faults and fault detection is still made using the existing heartbeat packet based scheme. The performance of FTSHM is shown by the simulation results and in future the specific sensor fault detection algorithm can be used that collects local decision signal for the faulty sensor. It detects the fault in the sensor node that receives wrong diagnosis and recovers it from receiving wrong signal.

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