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An Energy Aware Fault Tolerance Scheme With Delay Reduction in WSN for Structural Health Monitoring

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ABSTRACT: Civil structures are large-scale systems and they have wide range of applications, hence safety is the supreme issue that needs to be considered during design process. In order to monitor the health status, operations and to detect the changes in structure that affects the performance, Structural health monitoring (SHM) systems are implemented. Wireless Sensor Networks (WSN) are widely used in SHM applications. Nodes in WSN are prone to errors due to several reasons like depletion of energy, link failure, malicious node etc... To make the SHM resilient to fault, FTSHM (fault-tolerance in SHM) is used. FTSHM deploys a set of backup sensors on identification of repair points in distributed manner. To prolong the WSN lifetime, an energy efficient SHM algorithm, called Destruction-Pointer is used, which runs on each sensor and provides a light-weighted indication of damage in a cluster in a decentralized manner, thus improving the life time of WSN under connectivity and providing guaranteed data delivery with reduced delay in the SHM applications.

KEYWORDS: Wireless Sensor Network (WSN), Structural health monitoring (SHM), Fault-Tolerance in SHM (FTSHM).

I. INTRODUCTION

Large civil structures like bridges, tunnels, nuclear power plants, historical monuments etc. need to be monitored periodically. As they are required to withstand the loads, safety is a paramount issue that should be considered while designing these complex structural systems. The deterioration of the civil structures can lead to loss of life and have huge impact on economy. The cost of repair will also increase if not detected on time. Hence Structural health monitoring (SHM) has been a subject of intensive scrutiny. SHM systems are used to monitor the possible changes in the physical structure and provide alert at an early stage to reduce safety risk.

Structural health monitoring involves estimation of structural health that is detection of the structural damage which affects its performance. The major factors that cause structural damage are severity of change and time-scale of change.

Wireless Sensor Networks (WSN) are becoming an enabling technology for SHM that are more prevalent, more easily deployable and require low installation & maintenance expenses than current wired systems. The major requirement of health monitoring is sensor location optimization. Once the set of primary sensors are deployed, the data from each sensor should be gathered by base station for effective SHM. Due to several constraints in WSN like energy, bandwidth, etc. there are more chances that deployed sensors may be prone to faults, which results in incorrect monitoring information.

A technique called FTSHM is used to repair the network before it starts operations to provide specific degree of fault tolerance. FTSHM searches the repair points, which are the prediction of future network failure points in cluster and places secondary or backup sensors at those points, by satisfying the engineering requirements. Identification of repair points are done in distributed manner and the searching is done cluster by cluster.Another requirement of SHM is identifying the destruction points in structure. In order to reduce the energy consumption in WSN, an algorithm called Destruction-Pointer is used, which will transmit only useful information to base station, rather than transmitting all the sensed information.

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The major contribution of this paper includes (1) Placement of secondary sensors along with primary sensors to provide fault tolerance (2) Implementation of Destruction-Pointer algorithm to improve the energy efficiency.

This paper is organized as follows, Section 2 discusses the related work. Section 3 describes Proposed Work. Section 4 includes conclusion and future enhancement.

II. RELATED WORK

Ameer A. Abbasi [1] proposed network connectivity restoration when partitioned due to path length constraints through (a) Node repositioning - reposition some of the healthy nodes in the network to reinstate strong connectivity, (b) Placement of Relay Nodes- restore the network connectivity by efficiently relocating some of the existing nodes.

Soumendu Kumar Ghosh and Raja Datta [2] proposes the extension of service life of a sensor node used in railway bridge health monitoring scheme by, (a) Saving battery consumption of the node using a power efficient, low delay and non-ambiguous event detection scheme, (b)Improving system's tolerability to false events.

A simple, low latency event detection scheme for wireless sensor network are deployed for railway bridge health monitoring. The sensor nodes are activated only when a train is detected. Hence, the life of the sensor nodes depends upon the frequency of trains on a particular bridge. The event detection scheme triggers the system on the basis of a significant number of samples crossing a threshold value thus preventing the system activation in case of false triggering, thereby saving system resources.

Md Zakirul Alam Bhuiyan, Guojun Wang and Jiannong Cao [3] proposed Local Monitoring and Maintenance for operational WSN, where two important issues of monitoring probable anomalies/faults of the nodes, and link failures were addressed. They also proposed on how to perform monitoring from remote place.

Guiling Wang, Guohong Cao, and Tom La Porta [4] proposes on how to maximize the sensor coverage with less time in movement assisted sensors and also discusses about deployment quality.

Although sensor deployment for SHM is one of the fundamental requirement, the deployment problem is seldom considered.

III. PROPOSED WORK

The proposed approach involves effective deployment of sensors in the structure using a set of secondary sensors near the repair points for each cluster. It also focus on fault tolerance, improvement of data delivery, delay reduction and energy conservation, by swapping the secondary sensor with the primary sensor, when the energy of primary sensor reduces below the threshold. For further improvement of network lifetime, destruction pointer algorithm is used, which will transmit only the useful information to the base station. The following modules are used to achieve fault tolerance and improve energy efficiency.

A. *Sensor Placement and Clustering*

The available sensors for deployment will be categorized as primary and secondary sensors. The primary sensors will be deployed in optimal locations. The optimal locations will be specified by the structural engineers. The deployment should follow the below rule

$$\mathbf{T = P + S;\ S < P}$$

Where

T is Available Sensors,

P is primary sensors and

S is secondary sensors.

Once all the primary sensors are deployed, all the nodes will provide energy update. The cluster formation begins based on the coverage area, then the cluster head will be elected based on the transmission range and energy of the node. The transmission range of cluster head will be more than member nodes. The base station will be predetermined and will be away from the sensing region. The data transmission to the base station, happens through the cluster head.

B. Secondary Sensor Placement

After deployment of primary sensors, the secondary sensors will be deployed in the predictable failure points to provide fault tolerance and keep the network connected for data transfer. The expected failure points will be separable points, critical mid points and isolated points.

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ALGORITHM: 1

If RS > 0; for each Cluster do //If remaining secondary sensors greater than zero
Call SP1 (S1 ⟵ S) //Find separable point and place secondary sensors
Call SP1 (S2 ⟵ S) //Find critical middle point and place secondary sensors
Call SP1 (S3 ⟵ S) //Find isolated point and place secondary sensors
RS ⟵ |(S–(S1+S2+S3))| //Remaining secondary sensors

B.1 Finding Separable Points

A separable point or sensor in a cluster is the one, which is the only connecting point between multiple sensors. Example – A sensor, 'w' is said to be separable sensor, when w is present in every path between sensor u and v. Failure or removal of one or more separable point, results in a disconnected cluster and this module involves finding separable points in each cluster.

ALGORITHM : 2 (SP1 – FIND SEPARABLE POINT)

If (P is a separable node) //Find Separable point
Place secondary sensor S1

B.2 Finding Critical Mid Points

The Critical Mid-Point is the middle point between two sensors that are having the longest and irregular transmission distance between them. Example sensors x and y have longest transmission distance (dxy) .Reasons for unreliable communication between x and y can be the presence of interference and obstacles during communication and this module involves finding the critical mid-point in each cluster one by one.

ALGORITHM : 3 (SP2 – FIND CRITICAL MID-POINT)

If (P is a critical node) //Find Critical Mid-point
Place secondary sensor S2

B.3 Finding Isolated Points

An isolated point or sensor, is the one which is not part of any cluster and is present outside the coverage area. During the sensor deployment especially in an irregular shape, few sensors act as isolated sensors. When the isolated sensors communicate directly to the base station, their energy will be exhausted quickly and to avoid the energy depletion, they are made to communicate through Cluster Head.

ALGORITHM: 4 (SP3 – FIND ISOLATED POINT)

If (P is an isolated node) //Find Isolated point
Place secondary sensor S3

B.4 Find and Rescue Algorithm

Once all the backup sensors are placed, set the threshold energy limit. When the energy of the primary sensor reaches the threshold, the transmission will continue through the secondary sensor. When multiple primary sensors start disconnecting, and if the available replacement sensors is less, any node within the cluster that has more energy can replace the primary sensor, to rescue the operation.

ALGORITHM: 5 – FIND AND RESCUE

Set threshold (T) for NE ; //Set threshold limit for node energy
If NE < T
Swap primary sensor with secondary sensor
Continue data transfer through secondary sensor

B.5 Destruction Pointer

In order to conserve the energy of sensor nodes and to enable the base station to easily identify the damage, the cluster head will transmit only the damage information and when no damage information is present in the cluster, it just maintains the connectivity with the base station and does not transmit any information. The damage is identified by comparison of mode shape. Each mechanical structure has number of specific vibration patterns at specific frequencies. These vibration patterns are called mode shapes. A reference mode shape is a mode shape estimated by using a set of measured vibrations when the structural health condition is normal or not damaged. Reference global mode shapes are calculated by the base station. The damage indication happens at 2 areas

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ALGORITHM : 6 – DESTRUCTION POINTER

For Cluster Head
If (RFS < > MS) // If mode shape is not equal to Reference mode shape
{Transmit data to base station}
For Member node
If (RFS < > MS) // If mode shape is not equal to Reference mode shape
{Transmit data to cluster head}

IV. ENERGY AND PERFORMANCE ANALYSIS

Experiment result analyzes the overall performance using Network Simulator-2 and it consists of 50 nodes which are deployed randomly. The bandwidth allocated for each medium is 3 Mbps. The energy assigned for each node in the Wireless Sensor Network is 100 joules the transmission power is 1.5 joule and the receiving power is 0.8 joule. The transmission packet is 1000 bytes per second, the interval point is 0.01 s and the simulation time is 200 s. The communication starts at point 3 and at time 6, the failure notification occurs. For the proposed model, the backup node movement occurs at the point 6 and data transfer continues.

Fig 1: Delay Rate

Figure 1 shows the comparison of delay in establishing recovery from failure and data transfer through backup sensor. It is defined as the difference between the Time at which data transfer resumed and the failure time. The proposed method has less delay compared to existing one. The delay rate is represented in mille-seconds.

Fig 2: Packet Delivery Rate

Figure 2 shows the packet delivery rate. It is defined as the rate at which the data packets are transferred with respect to time. The proposed method maximizes the packet delivery rate. The data rate is represented in kilobytes per second.

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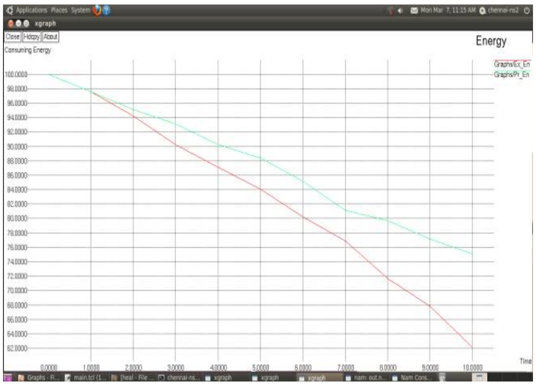

Fig 3: Energy Consumption

Figure 3 shows the energy remaining after data transfer. It is defined as the available energy with respect to time. In the graph above, the proposed model has consumed only 25% of energy compared to existing which has consumed 35% of energy. Thus proposed model conserves more energy.

V. CONCLUSION AND FUTURE ENHANCEMENT

FTSHM provides reliable data communication and transmitting only the damage information to base station improves the energy efficiency. Avoids data loss by placement of secondary sensors, in the predicted repair points and ensuring the effective data transmission with reduced delay. In future, this approach can be implemented in multi domain and development of algorithms for application-specific SHM.

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BIOGRAPHY

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