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Deploying Backup sensors for Fault Tolerance in Structural Health Monitoring

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Abstract
Wireless sensor networks (WSNs) have wide variety of applications and provide limitless future potentials. Structural health monitoring (SHM) is one of them which pose new challenges to wireless sensor networks. Nodes in WSNs are prone to sudden depletion of energy, hardware error, communication link failure due to irregular shape of the structures, malicious attack, and so on. Therefore, fault tolerance is one of the major issues in WSNs. To make the SHM resistant to the faults, we present an approach, called Backup sensors for Fault Tolerant Structural Health Monitoring to provide guaranteed degree of fault tolerance. Repair points are found out in the network and a set of backup sensors are placed at those points to increase availability of nodes and make the network fault tolerant, thus SHM remains working efficiently even in the event of a sensor faults, prolonging the WSN lifetime under constraints.

Keywords
Wireless sensor networks, Fault-tolerance, Structural Health Monitoring, Backup sensors

I. Introduction

A sensor network is composed of a large number of sensor nodes that can be deployed everywhere from vehicles, buildings, air, war field, animals and even in human bodies. Each sensor will have microcontroller, transceiver, power source and external memory. Sensor networks are widely deployed in environment monitoring, biomedical observation, security and so on. Wireless sensor networks (WSNs), due to the advantage of low-cost and easy deployment have been widely used in many monitoring applications including battlefield surveillance, environmental monitoring and biological detection, Health Monitoring etc.

Structures includes aircraft, bridges, buildings, dams, nuclear power plant, ships, are some complex engineered systems among others that ensure economical and industrial growth and wellness. The structures must follow standardized building codes and designs to ensure safety for public. Incidents such as missing aero-planes, collapse of building and bridge have increased in many parts of the world without little apparent warning, hence it has become paramount importance to develop methods to detect the degradation or damage that result in these events. Sensors work like human brains to analyze abnormal situation and indicate the chances of damage prior by continuously updating state of health and helps in avoiding them. SHM works like any other monitoring system by alerting changes in the system which indicates failure risks.

Structural Health Monitoring (SHM) focuses on developing technologies and systems for assessing the integrity of structures such as buildings, bridges, aero-space structures and off-shore oil rigs SHM is not just that. It involves the integration of sensors, computational power, data transmission and processing ability inside the structures. It makes it possible to reconsider the design of the structure and the full management of the structure itself and of the structure considered as a part of wider systems. SHM will have a set of N sensors deployed which collects data and sends to base station(BS) where analysis of structural physical properties is carried out. The deployed sensors are prone to faults like the sensors may get separated into multiple clusters due to various reasons like quick energy depletion at some nodes, irregular communication distance, and unstable connectivity. In case of any of these faults it's impossible to provide guaranteed fault tolerance. The proposed system uses Ad hoc On-Demand Distance Vector (AODV) routing protocol which is a reactive protocol and detects all the Repair Points (RP) before the sensor network starts its operation and backup sensors are provided at these points fulfilling the requirements. RP's are future possible failure points like a node isolated from network because of energy depletion, node which moves out of coverage region and so on. Backup sensors will be activated when the primary sensors faces issues in transmitting data to BS, thus provides improved availability and Fault tolerant Structural Health Monitoring.

II. Literature Survey

WSN applications can be divided into two categories. The first category is environmental monitoring and WSN applications. Great Duck Island and a Redwood forest is examples of first category and the focus is on networks with low duty-cycle and low power consumption. Applications such as Health monitoring of mechanical machines, Patient monitoring belong to second category requires high fidelity sampling. Over the past a years in research, many algorithms and devices have been developed for structural health monitoring (SHM) of civil engineering structures. Each of these emerging technologies has unique advantages, depending on the specific applications and the desired effect.

Various sensor deployment methods have been advanced from wired to wireless. Wired sensor network are traditional way for communication in pipeline systems. Even-though they are easy to install and provide power supply for through the network wires they have lot of disadvantages like if any part of wire is tampered the whole network will be affected, unauthorized people can harm network by simply cutting the wire also wired network can be disabled by any intentional o natural reason which leads to partial or complete network error. Some of the wired SHM techniques are Impedance based SHM, Data fusion technique, Vibration control technique, The wireless sensor network will help to overcome problems like it avoids wiring, it can accommodate new devices at any time, it is flexible, and it can be easily monitored from centralized monitor. Few constraints which should be taken care of are comparatively low speed, security of data also it gets

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distracted by devices like Bluetooth. Existing sensor deployment (for habitat monitoring, target tracking, and so on) with grids, or at intersection points.

Fault tolerant is defined in five different levels they are physical layer, hardware layer, system software layer, middleware layer, and application layer. Faults at hardware layer can be caused by malfunction of any hardware component of a sensor node, such as memory, battery, microprocessor, sensing unit, and network interface. Software bugs are a common source of errors in WSNs. One promising method is through software diversity where each program is implemented in several different versions. Link failures refer to Network layer error. Wireless network deployed should have Fault tolerance. It is a research concept that has been studied for almost half a century. Low reliability of individual components created impetus for designing reliable systems by exploiting fault tolerance and redundancy. In particular, Moore and Shannon [Moo56] and in particular von Neumann [von56] built the first systematic approaches for modeling the redundancy techniques. Since then, the reliability of individual components has increased suddenly. However, exponentially increase in levels of integration created a need for fault- tolerant systems, in particular in DRAM.

To tackle fault tolerance, the system should follow fault detection and fault recovery. There are two types of detection techniques: self-diagnosis and cooperative diagnosis. The relay deployment ('RELAY' for short) considers both uniform and random distribution for data collection. The idea is to deploy a set of sensors, which collect sensing data and another set of sensors, to relay the data from the sensors in the first set to the BS. They may not satisfy SHM requirements. Proposed FTSHM attempts to overcome the limitations above by combining engineering requirements, with CS requirements, low communication cost, and fault tolerance

III. System Architecture

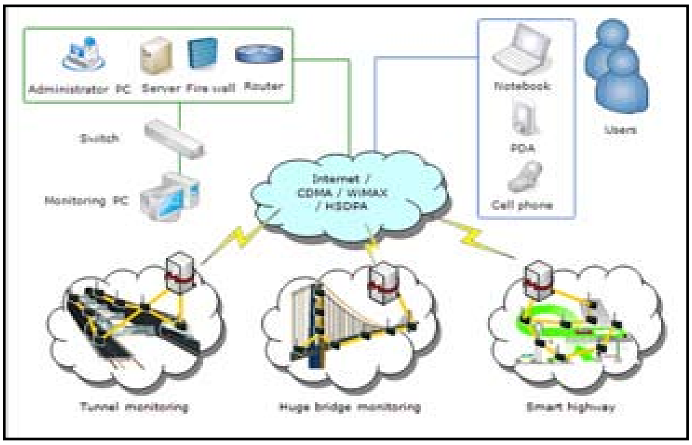

Fig.1: System design of Structural Health Monitoring

Two major categories of SHM are disaster response (earthquake, explosion, etc.) and continuous health monitoring (ambient vibrations, wind, etc.). This work is focused on continuous health monitoring. There are two SHM approaches: direct damage detection (visual inspection, x-ray, etc.) and indirect damage detection (change in structural properties/behavior). We use indirect detection, especially through vibration. In our project we have sensors (Frequency Sensors) deployed to form a Wireless sensor network (802.11), collects data and transfers it to a database. The administrator analyzes, monitors the data and indicates any changes in the structural or geometrical property. To provide fault tolerance to this system we find out the RP's and deploy backup sensors which starts working when the primary sensors fails due to constraints. Deployment of Backup sensors is done at the RP's before the monitoring operation starts.

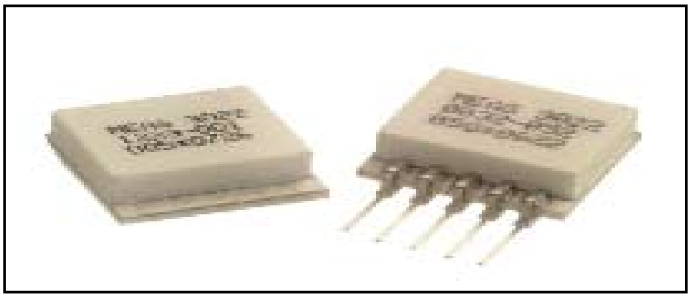

Fig. 2: Vibration sensors Model 3022

The Vibration sensors also called piezoelectric sensor measures any change in the pressure, acceleration, stress or force by converting them into electric charge. Piezoresistors located in the beams change their resistance as the motion of the suspended mass changes the strain in the beams.

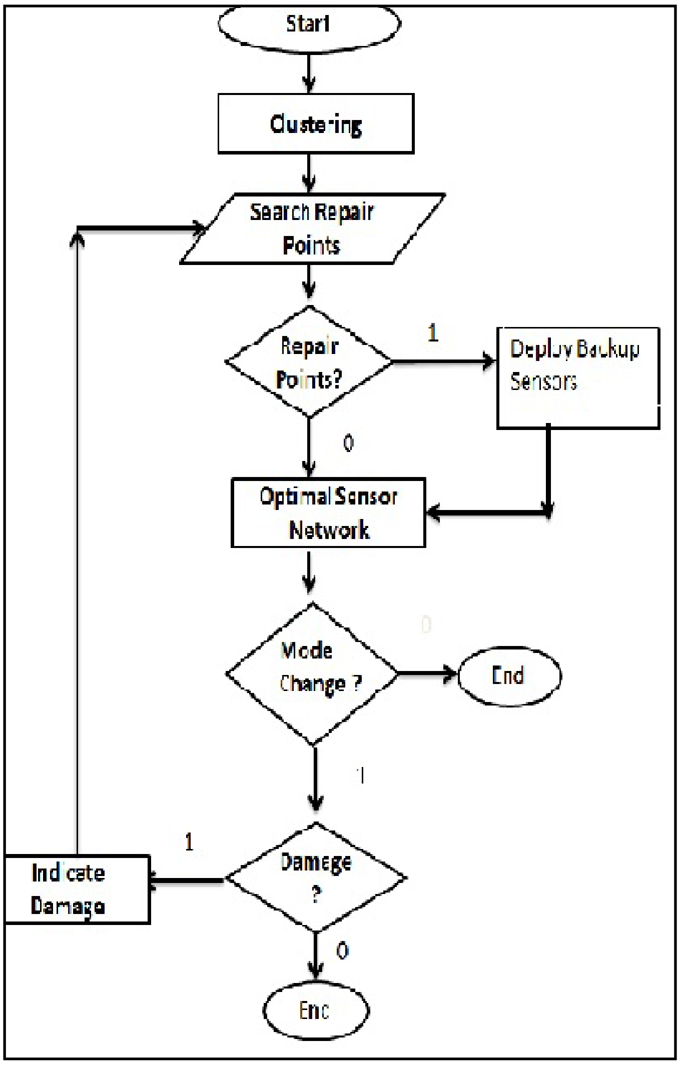

Fig. 3: Flowchart showing the flow of events in the system

Set of sensors are deployed satisfying the requirements. These sensors are grouped into clusters and a cluster head is elected this process is called as clustering. Cluster heads reports sensed

data to the Base station. BS usually will have high memory and more power supply and processing power. It can be a switch or gateway which is in turn connected to a database. Some of the nodes in the network are marked as RP's based on criteria such as energy level, distance between nodes and handoff region range. The nodes which have less energy level than the threshold value, the nodes whose distance between them is very irregular and longest hopping distance and nodes which cross the handoff region are all identified as RP's. Backup sensors are deployed at these points. The SHM starts its operation and collects data from all the end-users (sensors). If there are any changes in the values sensed by the vibration sensors it will be indicated to the administrator and if the nodes encounters failure at RP's then the backup sensors will be activated and starts working exactly as the primary sensors.
Some of the issues that must be considered during design phases are explained briefly. The sensors selected should fulfill the requirements and installed in calibrated with appropriate instructions and supervision. The data stored in database and backup sensors must be provided with authorized access. The integrity of the data collected must not be tampered as the data assessment is directly dependent on the result. The probability of the risk associated with a design is assessed by the SHM system designer along with owner. The output of the risk analysis will give the list of possible events and degradations that can possibly affect the structure. The severity of the risk is also analyzed by system engineer. Some of the examples of the risks are unavoidable natural calamities, intentional intrusion, poor material quality used in construction of structures and so on.

IV. Implementation

Our proposed system is implemented as three modules they are deploying sensors (End users, Gateway, Handover nodes) Repair points and Backup sensors

A. Deploying Sensors

End users:
They refer to the sensors which are deployed to sense the structural information. The sensors are vibration sensors which measure and analyze displacement, any changes in the mass due to the stress, linear velocity, and acceleration. Some of the examples are ADIS16223, *MiniSense-100* and VR001. These sensors are chosen considering sensitivity, frequency, and temperature range, power requirements and environmental conditions based on the application. The sensors are grouped into clusters and the node with high power is chosen as cluster head. All the nodes send the data collected to the cluster heads. The nodes are connected using 802.11 protocol. The information routing is done using AODV protocol which is a reactive protocol i.e. routing table is created only on demand. We use AODV because of its many advantages like on-demand, changes are informed only to the affected nodes instead of unnecessary broadcast and significantly less overhead.
Handover or Handoffs
Since we are talking about wireless network the nodes have no fixed position. Handover or handoff refers to change in channel. Nodes have their own region of transmission when any nodes moves out of region of transmission the data from that particular node will be lost to avoid these handoff's should be done. In this module switches or selected nodes will be configured with a range and specific number of end users. When any node moves from this range handoff will be done to an adjacent switch and the end-user will starts data transmission to base station via new switch and thus data is not lost.
Base station or Gateway nodes
Gateway nodes are the nodes in the network which acts as entry point to other network. It collects all the information from the nodes in a network and forwards it to the servers.BS will have 2 main hardware components that are powerful computer and radio which provides features such as alternate operate frequency. The software part has database (SQLite 3) base module and user interface.

B. Repair points

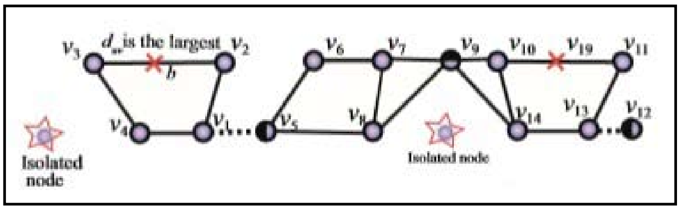

Fig. 4: Repair points

RP's indicate the future possible failure points. It can be a node whose energy level is very low and posses the risk of separation or isolation in the network. The second kind of repair points are marked to the nodes which is moves out of range of the cluster head and chances of failure to handoff to the adjacent node

C. Backup Sensors

The RP's identified are provided with the backup sensors of similar configuration as primary sensors. It improves the stability of the network by making system fault tolerant. The search for repair points runs continuously through all the clusters till all the RP's are provided with backup sensors

V. Conclusion

In this paper, our intention was to demonstrate that it is worthwhile to place a small number of backup sensors around the repair points in the WSN to have a better performance. We believe that idea of the backup sensor placement should be used in generic WSN applications. Through extensive simulations, we validated the effectiveness of our approach. The validation shows that structural health monitoring using WSNs can be meaningless, if the requirements of WSNs such as fault tolerance, energy efficiency are not seriously considered.
This work leaves the area of research like deciding number of backup sensor making sure that it does not increase overhead too much which in turn will affect performance of the system . Another issue to develop scheduling algorithms for backup sensors to activate at the event of failure

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