HEAL Method for Structural Health Monitoring

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ABSTRACT

Wireless sensor network (WSN) is an effective approach for a wide variety of applications such as environmental monitoring, scientific exploration, and target tracking. Structural health monitoring (SHM) systems are implemented for these structures to monitor their operations and health status. HEAL method for Structural Health Monitoring can be used in bridges and railway tracks. HEAL is Hole detection and Healing used to detect the abnormalities around the sensor location and system connectivity which affects system performance. It searches the nodes that reaches the threshold level in clusters and replaces it by a set of backup sensors at those points before it gets failed. It is also an efficient scheme for restoring the network connectivity in partitioned Wireless Sensor Networks. When two sensors is about to fail at the same time this condition is called rendezvous point and the system heals it by electing the backup sensor by itself. By using critical middle point algorithm, the coverage requirements in WSN based SHM system is achieved.

Keywords/ Index Term— Backup sensor placement, Critical middle point algorithm, Coverage, deployment, Rendezvous point, Structural health monitoring, Wireless sensor network.

1. INTRODUCTION

A wireless sensor network (WSN) comprises of sensor hubs or sensor nodes capable of collecting information from the environment and through wireless transceivers it will communicate with each other. The gathered information will be conveyed to one or more sinks, by and large through multi-bounce correspondence. The sensor nodes are normally anticipated that would work with batteries. It can be troublesome or difficult to supplant the batteries of the sensor nodes. The sink on the other hand is typically rich in energy. Since the sensor energy is the most precious resource in the WSN, to prolong the network lifetime efficient utilization of the energy has been the focus of much of the research on WSN.

Sensor nodes are deployed to gather information and desired that all the nodes works continuously and transmit information as long as possible. This addresses the lifetime problem in wireless sensor networks. Sensor nodes spend their energy during transmission of data, receiving and relaying packets. So one of the important consideration is designing routing algorithms which will maximize the life time until the first battery expires. In some applications the network size must be larger. Energy conservation in wireless sensor networks has been the primary objective. Other objectives include scalable architecture, routing and latency.

In many of the applications of wireless sensor networks delivering information of each individual node as fast as possible to the base station becomes an important issue. It is important to guarantee that data can be successfully received to the base station the first time instead of being retransmitted. Data gathering and routing are the challenging tasks in wireless sensor networks due to their dynamic and unique properties. In event detection environment nodes are idle most of the time and active at the time when the event occurs.

Sensor nodes send the gather information periodically to the base station. Structural Health Monitoring (SHM) involves in surveying the integrity of structures such as buildings, bridges etc. It also involves the joining of sensors, computational power, transmission of information and processing ability inside the structures. WSN are enabling technology for SHM application. The deployed WSN for SHM may be about to have faults for various reasons: communication irregularity, unstable connectivity, quick depletion of energy of some sensors.

If faults occur in WSN two problems arise continue monitoring information is difficult, guarantee sensor fault tolerance in SHM is difficult. SHM will have asset of N sensors deployed that collects data and sends to base station (BS) where the analysis of structural physical properties. The deployed sensors may have faults like sensors may get separated into multiple clusters due to various reasons like quick energy depletion at some nodes, irregular communication distance and unstable connectivity.

The proposed system uses Ad hoc On-Demand Distance Vector (AODV) routing protocol which is also a reactive protocol that detects all the Repair Points (RP) before the sensor networks 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, nodes which move out of coverage region and so on .When the primary sensor faces issues in transmitting data to base station then backup sensors will be activated.

2. STRUCTURAL HEALTH MONITORING (SHM)

The main objectives of SHM are to estimate the health status (i.e. damage, which is the changes around a sensor location) of a structure, and provides both long-term monitoring and rapid analysis in response to critical events like earthquakes, load, etc. In reality, it is often difficult to achieve these objectives in WSN-based SHM, due to requirements of SHM and severe limitations of WSNs. Civil structures, including bridges, buildings, tunnels, aircrafts, nuclear plants, among others, are complex engineering structures that ensure society's economic and industrial prosperity. Structural health monitoring (SHM) systems are implemented for these structures to monitor their operations and health status. 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. WSNs are becoming an useful technology for SHM that are more prevalent and more easily deployable than current wired systems. Examples include the bridge monitoring in India, and Guangzhou new TV tower (GNTVT) in China.

3. LITERATURE SURVEY

WSN can be divided into two categories. The first category involves environmental monitoring and wireless sensor network applications. Redwood forest, Great Duck Island is example for first category and applications such as mechanical machines and patient monitoring belong to second category.

Various sensor deployment methods have been progressed from wired to wireless. Wired sensor network are easy to install and provide power supply through the network wires and have lot of disadvantages like if any part of wire is affected then the whole network will be affected, unauthorized people can harm network by simply cutting the wire and it can also be disabled by any natural disaster.

The failure of nodes may partition the network into disjoint blocks and violate the connectivity goal. The Least Disruptive topology repair (LeDiR) will be aware of entire network topology and thus can build the shortest path routing table(SRT) for every pair of nodes prior to its failure. SRT can be populated when on-demand routing protocol AODV is employed. In case of failure detection, sensor will periodically send heartbeat messages to their neighbour. Missing heartbeat messages can be used to detect the failure of nodes [1].

Sensing coverage is a fundamental design problem in wireless sensor networks. In order to address this problem a fuzzy based self-healing coverage scheme determine the uncovered sensing areas and then to minimize the coverage hole the best mobile nodes are selected to be moved. Additionally it distributes the sensor nodes uniformly taking into account of Euclidean distance and coverage redundancy among the mobile nodes. This method is efficient both in terms of maintaining the coverage ratio dynamically and consumtion of energy [3].

LoMoM a new approach of Local Monitoring and Maintenance for a WSN, which combines monitoring operations for the WSN with the operations of a mobile event monitoring, which is both energy and latency-efficient. LoMoM includes a two-part monitoring architecture: a WSN and a 3G network. The main interest is in the WSN-part, where two important issues are addressed: monitoring probable faults of the nodes and link failures. To achieve event monitoring efficiently, LoMoM involves in local maintenance when such fault occurs. The Fault and event detection status reports are observed by a 3G network using the remote monitoring center. During the event monitoring, if there are any faults in the WSN, they are detected in such a way that requires low energy cost and latency in the WSN and repaired online. To achieve this, author designed a two-part monitoring architecture that includes two network infrastructures: a lower part includes sensor nodes, coordinator nodes, and a sink and an upper part includes the sink, a 3G network, the Internet, and a monitoring center (MC). The disadvantage is that the delay latency will be higher. Network lifetime will be lower. Energy consumption of node will be high [6]..

4. SYSTEM DESIGN

The Fig 1, below shows the block diagram of structural health monitoring

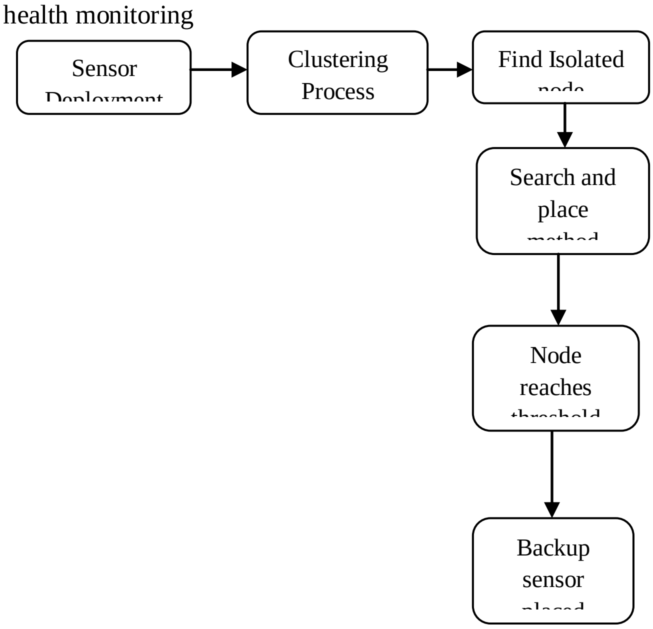

Fig.1. Block diagram of SHM

Proposed system utilize an approach, called HEAL method for Structural health monitoring, to repair the network before it starts operations, so as to guarantee a specified degree of fault-tolerance. HEAL is Hole Detection and Healing, here the hole detection specifies the detection of future failure points or repairing points.

HEAL method for SHM searches the repairing points or locations in clusters, and places a set of backup sensors at those points by satisfying engineering requirements.

In fact, searching the RPs is a prediction of future network failure points (e.g., separable points, isolated points, and critical middle points), which is a promising idea (to search such points and tackle them in advance).

Rendezvous point can be solved that is if two or more sensors fails at the same time then the system will elect the nearest highest energy level node as the backup sensor by itself.

Critical midpoint analysis is used to solve the connectivity issue to a greater extent. It is done using the critical midpoint formula.

4.1 Topology formation

Random node deployment is the deployment method used in the HEAL method of Structural Health Monitoring.

4.2 Clustering

Depending upon network structure, routing protocols in WSNs can be coarsely divided into two categories

1. Flat routing
2. Hierarchical routing

In a flat topology, all nodes perform the similar tasks and have the similar functionalities in the network. Data or information transmission is performed hop by hop usually using the flooding. The typical flat routings in WSNs include Flooding and Gossiping, Sensor Protocols for Information via Negotiation (SPIN), Directed Diffusion (DD), Greedy Perimeter Stateless Routing (GPSR), Trajectory Based Forwarding (TBF), Energy-Aware Routing (EAR), Gradient-Based Routing (GBR), Sequential Assignment Routing (SAR).

In small-scale networks flat routing protocols are relatively effective. However, in large-scale networks it is undesirable because resources are limited, but every sensor node generates more data processing and bandwidth usage.

In a hierarchical topology, nodes perform various tasks in WSNs and are organized into many clusters according to specific metrics. Each cluster comprises a head referred to as cluster head (CH) and other member nodes (MNs) and the CHs can be organized into further levels. In general, nodes with higher energy act as CH and perform the work of processing the data and information transmission, while nodes with minimum energy act as MNs and perform the work of information sensing.

The advantages of clustering are

- More Scalability
- Less Energy Consumption
- Load Balancing
- Fault-Tolerance
- Collision Avoidance
- More Robustness
- Guarantee of Connectivity
- Energy Hole Avoidance
- Maximizing of the Network Lifetime

4.3 Isolated node and Repair node

Suppose that a cluster is weakly k -connected, or sensor connectivity in a cluster area is unstable. This means there are one or more separable points in a cluster. A separable point or sensor of a cluster is a Repair node, that is, the only connecting point of several other sensors, which is critical to communication, and whose removal results in a disconnected cluster (see the half black or dashed line in Fig 2). Sensor failure is expected to be quite common due to energy depletion. Failure of one or more sensors reduces the number of multi-hop paths, and also can cause a cluster which has actually not failed to become separated from the rest.

When a sensor does not have a path or communication to another sensor in any cluster, or may receive messages that are broken, the sensor is an isolated sensor. Isolated sensor is also considered as repair point.

Missing Route Request (RREQ) messages can be used to detect the failure of sensors. After that it just check whether the failed node is critical node or not, critical in the sense whose removal result in disconnected cluster.

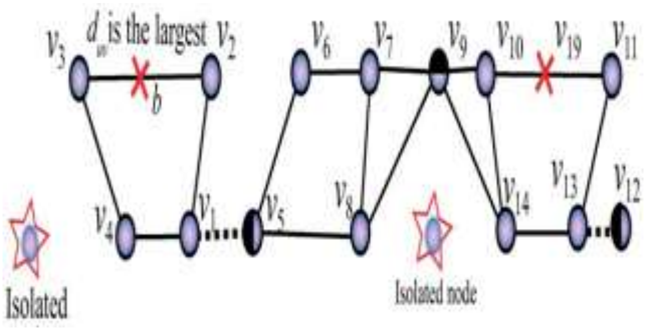

Fig.2. Types of Repair Points

As in the Fig 2 the star shaped node is the isolated node which does not have path to another sensor in any cluster.

4.4 Search and Place method

Under any of the fault occurrence in a practical SHM, an undiscovered fact is that both faulty and non-faulty sensors can generate variated signals or decisions. This indicates that there is a possibility of both structural damage and sensor fault occurring at the same time. The faulty sensors may cause undamaged location to be found as damaged (false positive) or damage location as undamaged (false negative) diagnosis. Search and Place algorithm is used to locate the faulty or repair sensors and place the backup sensor for the continuing the connectivity of the network.

4.5 Backup Sensor Selection

Find Critical midpoint, which is the middle point between two sensors of a cluster whose distance is too long to communicate and irregular transmission takes place between those sensors. Search and place algorithm is implemented to place backup sensor in a network.

As shown in Figure 3.3 the nodes v2 and v3 have a very large distance which is difficult for the sensors to communicate with each other. So the middle point is known as critical midpoint and place the backup sensor for better connectivity.

The backup sensor will be placed where ever the repair points are found. When the energy of a particular sensor gets depleted and the sensor becomes a faulty sensor the backup sensor moves towards it to heal it.

5. RESULT ANALYSIS

The proposed HEAL method for Structural Health Monitoring is an efficient system than the existing Structural Health Monitoring systems. It provides more efficient connectivity and coverage to the nodes so that the nodes can transmit the required information continuously without any interruption. As the connectivity and coverage is provided in an efficient manner and the network lifetime is also increased.

5.1 Hello message update

Hello packet update from each node to each neighbour as shown in Fig 3. . Through this hello packet update the energy of every node can be updated. Now the entire network will know each other's node energy. The green color rings represent the hello message updation. This updation will occur repeatedly after a time interval of 0.5sec.

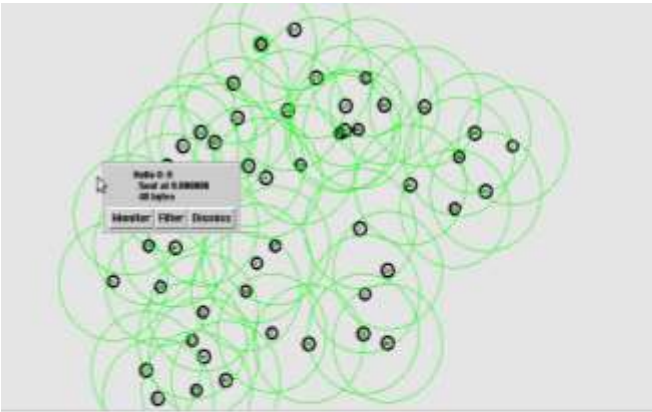

Fig.3. Hello message update

5.2 Cluster head request

Initially no Cluster Head is formed in clusters. All nodes update Cluster Request message to its neighbour which is indicated by purple color as shown in Fig 4.

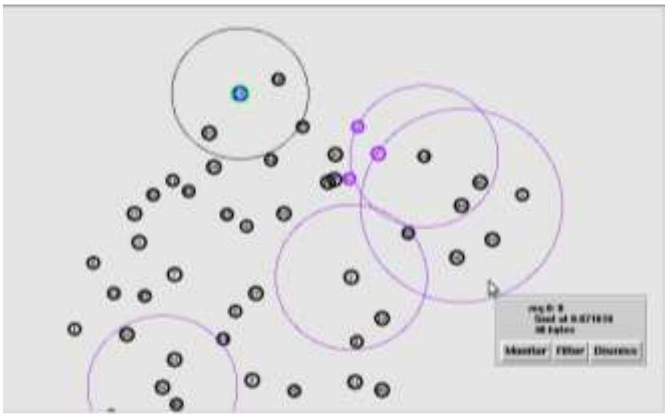

Fig.4. Cluster head request

After getting Cluster Request all nodes update energy level to neighbour. The node with higher energy level and coverage will be elected as Cluster head.

5.3 Cluster head advertisement

The elected Cluster Head is shown as blue color node in Fig 5 and will give a black ring which indicates the Cluster Advertisement. After receiving the cluster advertisement, every node in a cluster will know about the presence of cluster head. Only the cluster head will have a direct dealing with the base station. The nodes in clusters other than cluster head will send the information to the cluster head to reach the BS.

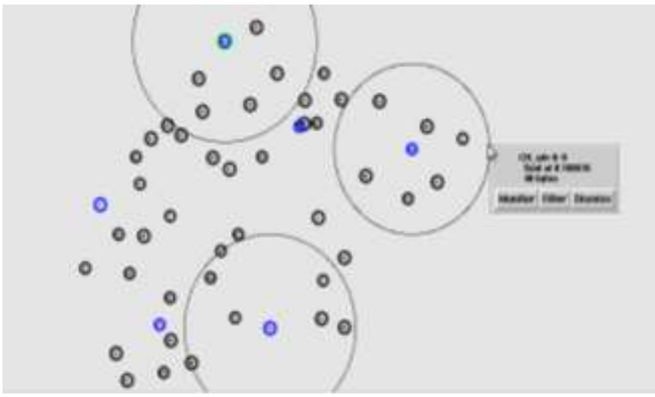

Fig. 5.Cluster head advertisement

5.4 Data Transmission

Nodes 6, 17, 35, 38, 44 illustrated in Fig 6 are the cluster heads elected because of its higher energy level than other nodes in a cluster. The data transmission is been carried out from each node to the cluster heads and all the cluster heads to the base station node 26 after 3ms.

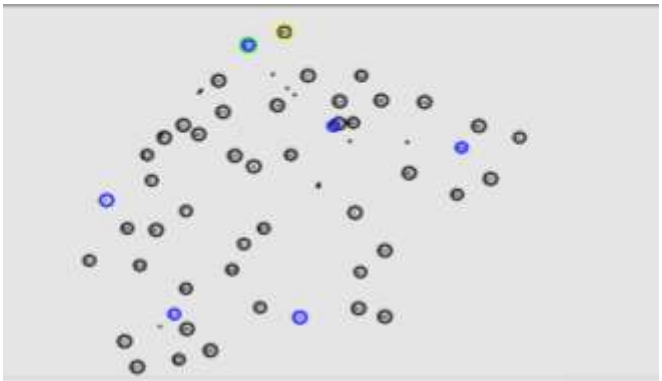

Fig.6. Data Transmission

5.5 Route Request Message

In Figure 7, the route request will be sent by all the cluster heads to find the route to the desired destination. The route request will be broadcasted to search for the correct route to the destination.

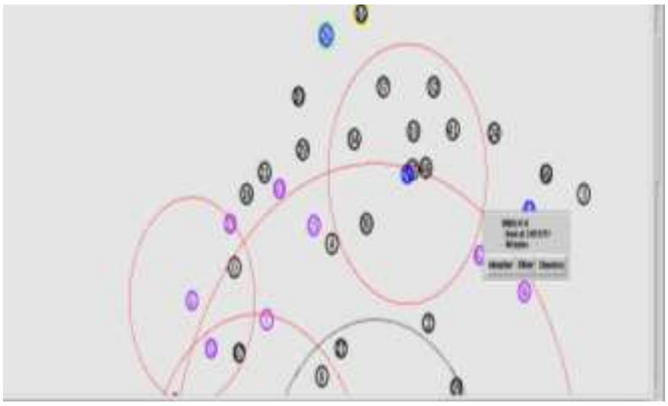

Fig.7. Route Request Message

5.6 Route Reply Message

The corresponding route reply will be in unicast direction through the correct route that it has identified.This process is shown in Figure 8.

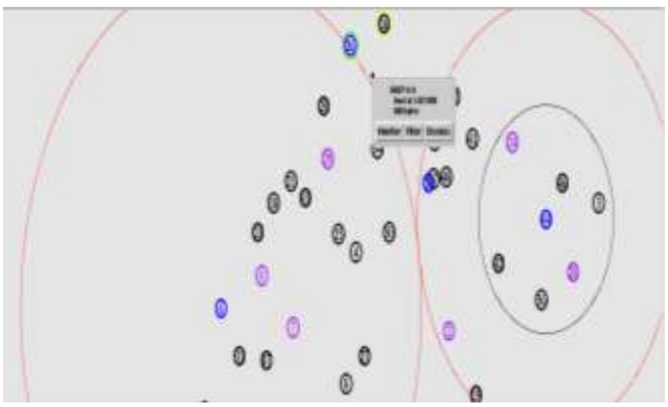

Fig.8. Route Reply Message

5.7CH Reach Threshold Energy Level

In Figure 9 the node 17 is found to be repaired node as it reached the threshold energy level say 40 and is indicated by red color.

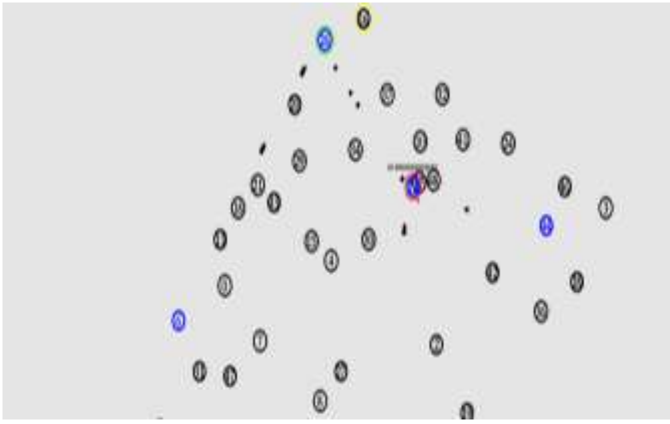

Fig.9. CH Reach Threshold Energy Level

The node nearest to base station will be depleted in energy because all other nodes may transmit their information through this node. Example of such node is node 17 through which node 35 and node 44 transmit

5.8 Backup Sensor Placement

After the cluster head node 17 reaches the threshold energy level other nodes in the cluster sends the new cluster head request to find the new cluster head. Then backup sensor which has the highest energy level will be elected as the cluster head and will move to replace energy depleting node. In Figure 10, node 16 that is the backup sensor shown. Backup sensor sends a cluster head advertisement to inform the other nodes in the cluster about the new cluster head elected as illustrated in Figure 10

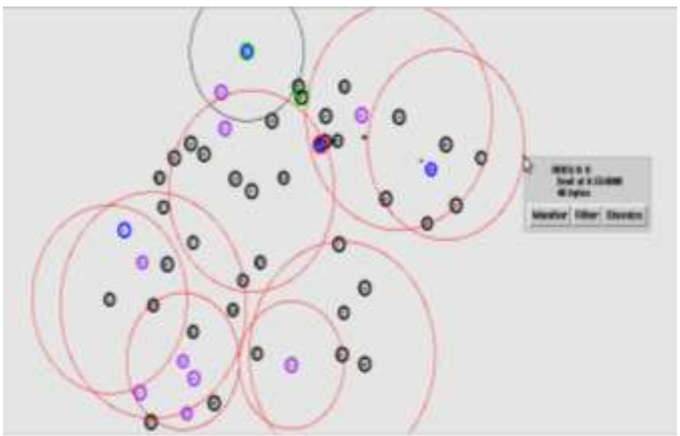

Fig.10. Backup Sensor Placement to Low Energy CH

5.9 Rendezvous Point

If other node also reaches the threshold energy level at the same time then this condition is called rendezvous point as shown in Figure 11, at this condition a node with higher energy will be elected as CH by itself for easy transmission of data.

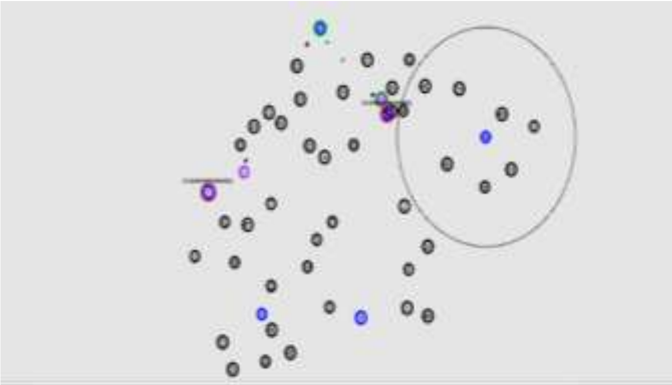

Fig.11. Rendezvous Point

5.10 Critical Midpoint Analysis

The backup sensor is set to heal the future failure node and kept the threshold energy level to minimum to get depleted fast and get back to the same place where it was before. So the distance between that particular area where the future failure node was available and the other cluster head available was very large so the concept of critical middle point is been implemented the cluster request is sent to find the nearby cluster head which is the node 0. And node 44 is also moved a little nearby to the node 0 for easy transmission.

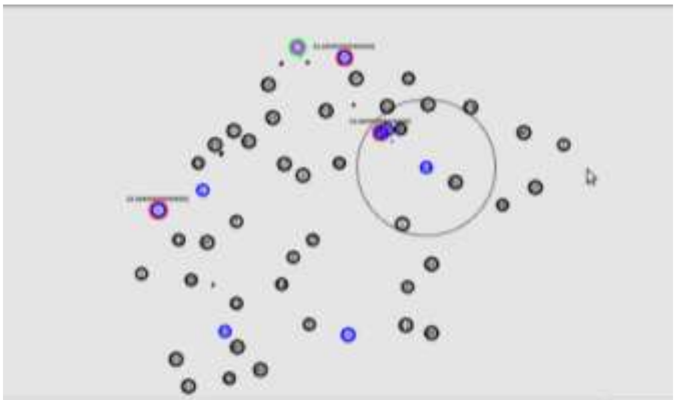

Fig.12. Critical Midpoint Analysis

5.11 XGRAPH

XGRAPH is a x-y data plotter with interactive buttons for panning, zooming, printing, and selecting display options. It can plot data from any number of files on the same graph and can handle unlimited data-set sizes and any number of data files.

Fig.13. Delay Graph between Existing System and Proposed System

Fig.13 shows the Xgraph between existing system and proposed system. Delay is the time during which some action is awaited. By showing this graph the delay in existing system is more compared to the delay in proposed system.

Fig.14 shows that the PDR of proposed system. PDR (Packet Delivery Ratio) is the ratio of number of packets received to the number of packets sent. PDR is the size of a packet and it is found that proposed system delivers more packets than existing system.

Fig.15 shows Xgraph between energy saving between existing system and proposed system, it shows that the proposed system consume less energy compared to existing system.

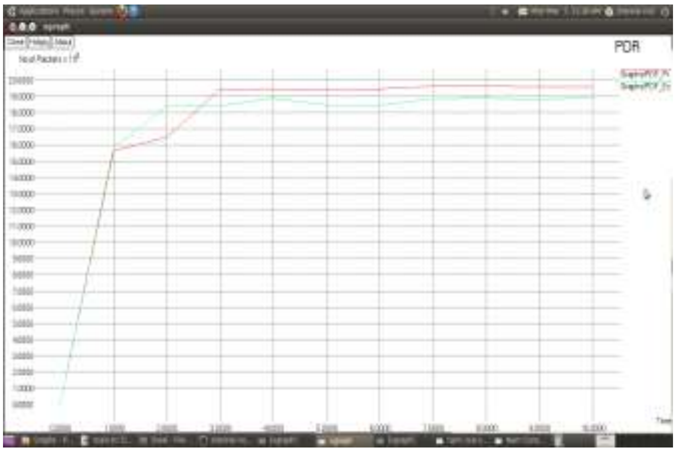

Fig.14. Packet Delivery Ratio Vs Time

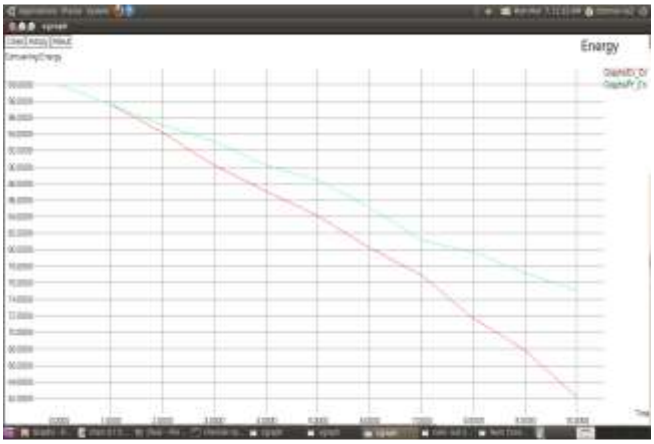

Fig.15. Remaining Energy Vs Time

Fig.16 shows the throughput analysis of existing system and proposed system. Throughput is the rate of successful message delivery over a communication channel. The graph shows that the proposed system has more throughput than existing system.

Fig.16 Throughput Analysis of Existing System and Proposed System.

6. CONCLUSION

The proposed HEAL method for SHM sends the hello message update to update the energy of each node. Now the entire network will know each other energy level. Before the sensor fails that is when the sensor reaches the threshold level the backup sensor will heal the repair node by using backup sensor placement algorithm. If another future failure point is about to occur, the algorithm designates one of the backup nodes by itself to initiate the connectivity restoration process. This process involves repositioning of a set of sensors in order to restore the connectivity. By using critical middle point algorithm the coverage requirements in WSN based SHM system is achieved. The network life time is increased finally.

In future, security will be given priority because the mobility of Backup sensor may not be secure to the network. Any malicious backup may gather all information from the cluster head which may be vulnerable to the network.

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