CHAPTER 5

SELF HEALING NETWORK PARTITION (SH-NP)

Given the aspect that sensors are tiny and subject to physical damage easily, fault resilience against sudden node failures is an important requisite for WSNs. This is usually achieved through the deployment of a high density of sensors to increase node redundancy, or through restructuring the topology by repositioning the nodes if they are able to move. However, a majority of these works have assumed that node failures are random and individual, and typically happen at different times which can be tolerated or fixed easily. In reality this may not always be the case for WSNs which can be deployed in cacophonous encompassment, and thus, it is not bizarre that the network may suffer a medium or large scale damage that involves many nodes at the same time.

Focusing on the usage of sensors in the industries, the main application where they are used are the places where human beings cannot reach or is not safe for them, for example, in nuclear power plants. Similarly it finds application in places where a constant monitoring of pressure, humidity, velocity, rate of work etc., are needed.

Therefore, a mechanism to provide the self-detection of partitioning and redefining of nodes is needed, given that WSNs are operated unattended and there is no central node which can detect such damage immediately. In addition, since such self-recovery will be critical in many applications, repopulating the affected parts of the area with additional sensors may be
infeasible or at least cannot be completed in a timely manner. Therefore, a temporary solution that will maintain the network operation is required, until a permanent solution is found.

Partition detection and route recovery has been used to improve the energy efficiency, lifetime, coverage and connectivity of different wireless networks. In WSN, local partition detection algorithm to find out the exact position of the partition in the network and the severity of it is discussed by Vemulapalli (2010). Movement of sensors to re-establish connectivity is also proposed by him. This can be used for large scale failures but the movement of the sensors may affect the lifetime of the network. And also finding the appropriate no of nodes to be moved to achieve good results is difficult.

The overall drawbacks of the above stated works are that they are either costly or don’t confide to the needed energy efficiency levels or affect the lifetime of the system. Further there is no guarantee in terms of route recovery that multiple routes can be found. The drawback in relocation is that the relocation of nodes over a longer distance may lead to significant fall in energy. So in order to provide a mechanism to detect partitions and to avoid it mechanisms which not only detects the partitions, using local information, but also redefines the behaviour of the nodes have been discussed.

5.1 SELF HEALING FOR MULTIPLE NODE FAILURE AT THE SAME TIME AND AT SAME PLACE

In addition to the assumptions made in section 3.3 it also assumed that the failures happen at the same time and at the same place.

5.1.1 Problem Definition

The problem can be defined as follows: "Given WSN with n nodes which are connected to a sink node, assume that FN number of nodes such
that $1 < FN < n$ nodes die within a particular region at the same time creating a hole. The scenario assumed is shown in Figure 5.1.

The problems to be solved to maintain connectivity are

1) To determine whether any hole due to the dyeing node creates partitioning in WSN.

2) To formulate how WSN could redefine the behaviour of the nodes to recover the routes to sustain the data gathering.

![Figure 5.1 Assumed scenario for our problem.](image)

**5.1.2 Redefining the Nodes for Recovery from Multiple Node Failures**

When there is damage such as a storm or fire in the WSN, a particular sensor is not able to send its reading to its next hop neighbour (i.e., next hop in its routing table). The network may be partitioned in this case and the data cannot be sent from source to destination.
5.1.2.1 Partition detection

When there is damage in the WSN and when a particular sensor cannot be able to send data to the next hop neighbour nodes then it can decide that its upstream neighbour has failed. This can be easily determined at the MAC layer when the packet is not ACKed until a certain timeout period. After single path failure, the node will try to find another path to the sink by using the genetic algorithm method in section 3.4.1. To find such a path, the node starts querying its direct neighbours. During this search, if a node which has a valid path to the sink is found, a reply will come back to the original node so that it can setup a new path to the sink. Otherwise, the node will conclude that no paths are found. Normally, the search will be limited by some TTL value.

If a node cannot reach its next hop neighbour, it starts looking for another node which knows alternative path to the sink. During this process, the invalidation of all the routes of the previous hop neighbours of that node is done so that they will not falsely respond to queries asking for a path. Therefore, the node issues an INVALIDATE message for this purpose.

In addition to invalidation, the previous hop neighbour’s nodes also need to be notified (i.e., VALIDATE message) when a valid path is found. In such a case, each node is responsible for informing its previous hop neighbours, starting from the very first node which initiated the detection process.

Figure 5.2 shows the assumed scenario, where a portion of the network has been damaged by some natural calamities.
5.1.2.2 Redefining nodes

After the partition detection process, there may be multiple nodes without any valid routes to the sink node. To recover the routes, increasing the transmission capacity of some of the nodes have been proposed.

Selection of Node

When there are problems in WSN the network will be partitioned. The mobile agent which is moving from node to node, checks whether that particular node has a one hop neighbour and a path to the sink. If no path has been found to the sink, that node will be chosen to increase the transmission range, so that any node within the increased range can be reached. To increase the transmission range the mobile agent is used.

Selection of Transmission Range

The node that has no one hop neighbour, sends a NEWPATH message to the next hop neighbour. If there is no reply from that neighbour, that particular node will send the message to the next hop neighbour. Like this, the NEWPATH message will travel k hops before it stops. In this way if
the sensor within k hops hears the NEWPATH message of a node. The location of the node and the transmission power required to be increased to reach the node that is in k hops (k may be 2 hops) is decided and the agent will increase the transmission power of that node.

**Figure 5.3 Redefinition of Nodes**

Figure 5.3 shows that in a partitioned network the agent decides to increase the transmission power, to achieve the connectivity between nodes.

**Figure 5.4 Network after connectivity**
Figure 5.4 shows, the network after being connected with the
nodes, and a path has been established.

5.1.2.3 Reliable transmission

For redefining the node, the neighbour node is searched, which is in
one hop or two hops or three hops. During this search when a suitable node
has been found, a path will identified by using genetic algorithm method in
section 3.4.1 to send the data to sink. So, after increasing the transmission
range of the nodes, the nodes will send the data to the sink using the new path
established.

5.2 PERFORMANCE EVALUATION

5.2.1 Performance Metrics

Network lifetime can be defined as the time elapsed from the
network operation starts until the network fails.

5.2.2 Energy Model for Multiple Node failures at same time and at
same place.

The expected average lifetime from section 3.4 is

\[
E[Anlt] = \frac{E_{tint} - E_{wa}}{P_{con} + \eta (E_{E_c} + E_{H}(E_{E_t} + E_{E_r}))}
\]  \hspace{1cm} (5.1)

The Average Network Lifetime can be extended by redefining the
transmission range of the nodes. Once a network is going to be dead, then it
will be redefined until there is no way of extending it.

So the overall lifetime is
\[ E[\text{NL}] = \sum_n \frac{E[E_{\text{trt}}]_n - E[E_{\text{wa}}]_n}{p_{\text{con}} + \eta(E[E_c] + E[H](E[E_c] + E[E_r]))_n + \lambda E[E_f]_n} \] (5.2)

Here \( E[E_f] \) is the expected amount of energy spent for increasing the transmission range to recover from multipath failures, and \( \bar{E}_n \) is the average amount to nodes where transmission energy is increased. For each \( n \), \( E_{\text{trt}} \) is calculated by

\[ E[E_{\text{trt}}]_n = \sum_{i=1}^{n} [E_{\text{wa}}]_n \text{ For all } E_{\text{wa}} > E_{\text{th}} \] (5.3)

So, by the above formula (5.2) the overall Average Network Lifetime can be evaluated.

### 5.2.3 Analysis of Energy Model

The Energy model is analyzed by varying the Initial Energy, Number of Nodes to reach the destination by evaluating the Average Network Lifetime with the radio parameters used in Table 3.2. Comparison is done between Basic Routing, SH-SNF, SH-MNF and SH-NP. SH-NP is the one which concentrates on multiple node failures that occur at same time at same place.

![Theoretical Analysis of Network Lifetime based on Energy](image)

**Figure 5.5 Comparison of expected lifetime based on Initial energy**
The graph in Figure 5.5 depicts the theoretical analysis of Average Network Lifetime based on energy for basic routing, SH-SNF, SH-MNF and SH-NP. It clearly depicts that average network lifetime is greater in SH-NP when compared to basic routing, SH-SNF and SH-MNF with the same initial energy. An important fact is also that there is only a slight variation in lifetime for SH-NP for all initial energy.

![Theoretical Analysis of Network Lifetime based on Nodes](image)

**Figure 5.6 Comparison of expected lifetime based on Nodes**

The graph in Figure 5.6 depicts the theoretical analysis of Average Network Lifetime based on nodes for basic routing, SH-SNF SH-NP and SH-MNF. It clearly depicts that the average network lifetime is greater in SH-NP when compared to basic routing, SH-MNF and SH-SNF having same number of nodes. The longest Average network lifetime having 60 nodes in SH-NP is about 31 seconds whereas it is only 25 seconds in case of SH-MNF which is lesser than lifetime value of SH-NP with 50 nodes. The average network lifetime is increasing with the number of nodes in all the four methods.
5.2.4 Simulation Results

The proposed scheme of this research work is implemented using ns-2 simulator. Performance analysis is done for both the basic routing and SH-SNF, SH-MNF, SH-NP. The results shown are the mean value calculated from 100 independent runs. In each simulation run, the number of nodes are varied and randomly placed in the regions with varying initial energy. The base station is located at the centre of the network. All sensor nodes are at fixed location throughout the lifetime. The parameters are chosen based on the Table 3.2. The transmission range can be increased for Average Network lifetime by battery power management.

Based on the simulation a comparison graph has been drawn.

![Experimental Analysis of Network Lifetime based on Energy](image)

**Figure 5.7 Comparison of lifetime based on Energy**

The graph in Figure 5.7 depicts the experimental analysis of Average Network Lifetime based on energy for basic routing, SH-SNF, SH-MNF and SH-NP. It clearly depicts that average network lifetime is greater in SH-NP when compared to Basic routing, SH-MNF and SH-SNF at all initial energy levels. There is an increase in Average network lifetime from SH-
MNF by approximately 2 seconds at different initial energy values. Basic routing has the least average network lifetime and remains constant throughout even though initial energy is increased.

![Experimental Analysis of Network Lifetime based on Nodes](image)

**Figure 5.8 Comparison of lifetime based on Nodes**

The graph in Figure 5.8 depicts the experimental analysis of Average Network Lifetime based on nodes for basic routing, SH-SNF, SH-MNF and SH-NP. It clearly depicts that the average network lifetime is greater in SH-NP when compared to basic routing, SH-MNF and SH-SNF when they have same number of nodes. The longest average network lifetime having 60 nodes in SH-NP is around 32 seconds whereas the average network lifetime for SH-MNF is around 26 seconds which lesser than the average network lifetime having 50 nodes in SH-NP. The average network lifetime is increasing with the number of nodes in all the three cases.
Figure 5.9 Comparison of lifetime based on Energy (Experimental and Theoretical)

The graph in Figure 5.9 depicts the comparison of Average Network Lifetime theoretically and experimentally simulated for SH-NP, SH-SNF, Basic Routing and SH-SMNF based on Energy. Experimental simulation value for SH-NP is the longest average network lifetime calculated compared to the other methods and is almost constant from 30 joules to 60 joules as per the graph. The results from theoretical analysis for SH-SNF, and experimental simulation for SH-MNF have constant average network lifetime even when the initial energy is increased.

The graph in Figure 5.10 depicts the comparison of Average Network Lifetime when theoretically and experimentally simulated for SH-SNF, Basic Routing, SH-NP and SH-SMNF based on Nodes. Experimental simulation value for SH-NP is the longest average network lifetime calculated compared to the other methods and increases proportionally with the increasing number of nodes. In all the cases there is a proportional increase of average network lifetime with the increase of number of nodes.
5.3 SUMMARY

In this chapter, a route recovery scheme for multiple node failures that happen in industries at same time as the result of an accident is been proposed. Considering the possibility of network partitioning where the sensors are not able to transmit their readings to the sink, the proposed approach first detects such a partition and then strives to fix the partition by redefining some of the sensor nodes for network connectivity.

This helped the industrial operations to resume immediately and ensure safety of the industry and people and avoided loss. This showed a better performance and has a significant impact on all metrics evaluated. Based on the mathematical formula and by simulation experimental results it shows a better performance after the recovery of nodes from network failures. Although SH-NP the network lifetime has been increased by increasing the transmission range, it can’t handle the failures at a wider area where increase in transmission range cannot be done. So in order to elevate the network failures in this case some other mechanism should be done.