

Fault Tolerance in Wireless Sensor Networks using Stiffed Delaunay Triangulation

*Thesis submitted in partial fulfillment of the requirements for the award of
degree of*

**Master of Engineering
in
Computer Science and Engineering**

Submitted By
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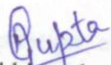
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Acknowledgement **Certificate**

I hereby certify that the work which is being presented in the thesis entitled, "**Fault Tolerance in Wireless Sensor Networks using Stiffed Delaunay Triangulation**" in partial fulfillment of the requirements for the award of degree of Master of Engineering in *Computer Science and Engineering* submitted in Computer Science and Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. Rinkle Rani** and refers other researcher's work which are duly listed in the reference section.

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Wireless Sensor Networks are receiving an enormous attention due to their unlimited capability. Wireless Sensor Networks consist of spatially distributed sensors to monitor environmental conditions such as pressure, noise, humidity etc. Each sensor has heterogeneous processing capabilities. There is a rich body of the algorithms and protocols used for fault tolerance in wireless sensor networks. The thesis contains techniques and protocols used in various coverage algorithms.

In this thesis, Ns2 is used as a network simulation tool for simulating the results of various algorithms like Triangulation and Stiffed Delaunay Triangulation(SDT) in order to make a system fault tolerant and energy efficient both. Ns2 has been largely used as a network simulator. Simulation of Wireless Sensor Networks is a critical & challenging task due to the behavior of its hardware design and utilization of a large number of workstations.

In this thesis, a new fault tolerance technique is introduced that is based on two parameters; edge and vertex of node. This thesis work proposes an algorithm of Stiffed Delaunay Triangulation for less energy efficient wireless sensor networks.

This algorithm is applied on communication networks to optimize energy efficiency and also for good coverage schemes by selecting a backup node from the nodes present in a network.

The technical cores of the thesis covered various coverage strategies to make the system fault tolerant. All the algorithms are proposed in this thesis are practically implemented and tested for fault tolerance by varying number of nodes and coverage schemes of network.

Keywords- Fault Tolerance, Sensor networks, Coverage, Triangulation.

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1.1 Wireless Sensor Networks

Wireless Sensor Network is one of the active field in network research. Wireless Sensor Networks consists of inexpensive miniature devices capable of computation, communication and sensing. It provides a bridge between the real physical and virtual world. It allows the ability to observe the previously unobservable at a fine quality scale over large spatio temporal scales. It has a wide range of potential applications to Area Monitoring, Environmental Monitoring, Industrial Monitoring, Military purposes, Transportation and Security.

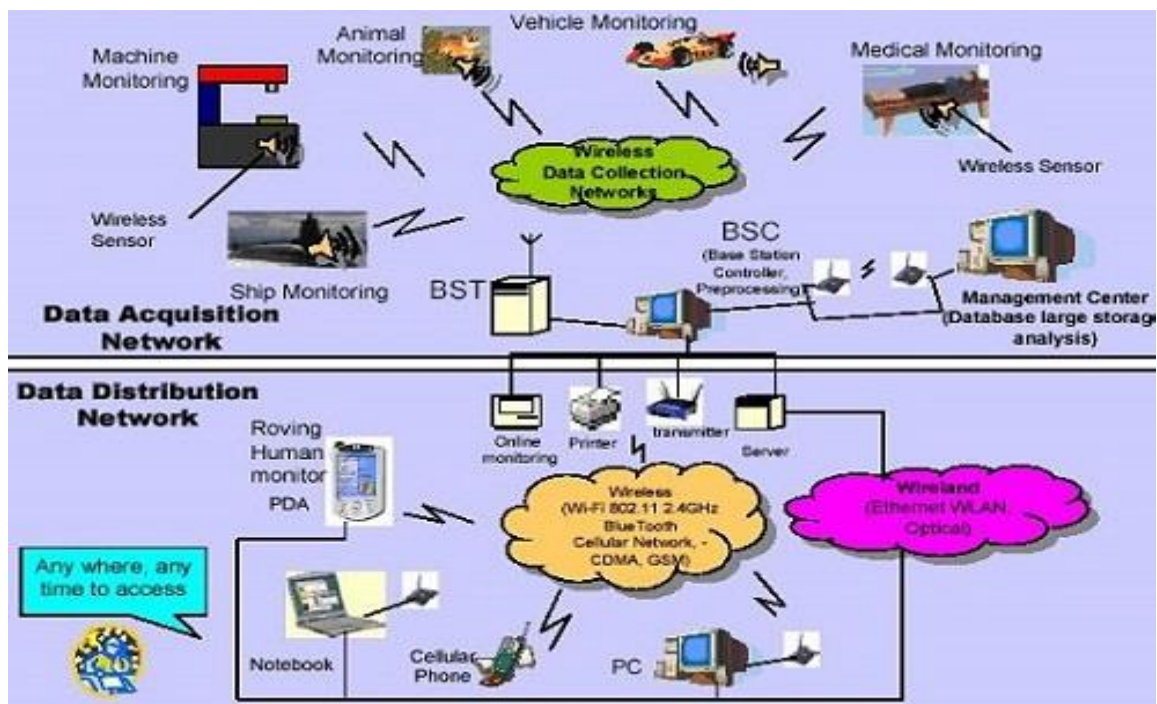
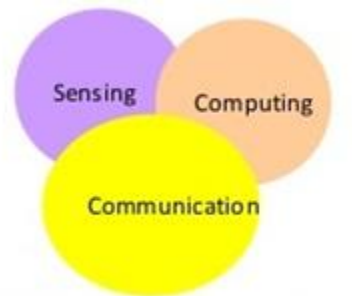


Figure 1.1: A Wireless Sensor Network

To reduce the cost and time of the deployment process, simulation is a preferred job before testing with real hardware. Presently, wireless sensor networks are beginning to be deployed at an accelerated pace. It is not unreasonable to expect that in 7-12 years that the whole world will be covered with wireless sensor networks. This can be considered as

the web becoming a physical network. This new cutting edge technology is excited with unlimited potential for numerous applications. A Wireless Sensor Network is composed by a large number of sensors sensing the self-powered nodes.



Development of sensor nodes can be done with sensing, data processing and communicating abilities in the components at low cost, low memory, low power consumption, low dimension and also at low computational power.

1.1.1 History

The birth of the research on WSNs can be traced to the Distributed Sensor Networks (DSN) code at the DARPA around 1980. By this time ARPANET had been functional for a number of years, with approx. 200 hosts at research institutes and universities. At that time, there were no personal computers; processing was mainly done on minicomputers and Ethernet was just started [3].

A demo application of DSN was a helicopter tracking system using a distributed array of microphones by means of signal and matching techniques, which was developed at MIT. The earliest DSN used were not associated with wireless connections. Recent advances in computing have significantly shifted to WSN research. The storms of research in WSNs begin on around 1998 and have been gaining more and more involvement and attention. Further, the sensor nodes have been tiny in size and low in price, and thus many civilian applications of sensor networks such as Vehicular, Body Sensor Networks have emerged. Again, DARPA acted as an avant-garde by launching an research program known as SensIT which provided the present sensor networks with new abilities such as

multitasking, networking and querying. At the same time, IEEE viewed the low expense and enormous capabilities that sensor networks offer. The organization has defined the standard called as IEEE 802.15.4 for less data rate WPAN. Based on this, ZigBee Alliance has published its own standard which lists a bunch of high level communication protocols which can be used in WSNs. Now a days, the commercialization of WSNs also paced by new formed organizations like Dust Networks, Crossbow etc [5]. .). The usual hardware components of a sensor node include a radio transceiver, an embedded processor, internal and external memories, a power source and one or more sensors.

- **Embedded Processor:** In a sensor node, the functionality of an embedded processor is to schedule tasks, process data and control the functionality of other hardware components. The types of embedded processors that can be used in a sensor node include Microcontroller, Digital Signal Processor (DSP), Field Programmable Gate Array (FPGA) and Application-Specific Integrated Circuit (ASIC). Among all these alternatives, the Microcontroller has been the most used embedded processor for sensor nodes because of its flexibility to connect to other devices and its cheap price. For example, the newest CC2531 development board provided by Chipcon (acquired by Texas Instruments) uses 8051 microcontroller, and the Mica2 Mote platform provided by Crossbow uses ATmega128L microcontroller.
- **Transceiver:** A transceiver is responsible for the wireless communication of a sensor node. The various choices of wireless transmission media include Radio Frequency (RF), Laser and Infrared. RF based communication fits to most of WSN applications. The operational states of a transceiver are Transmit, Receive, Idle and Sleep. Mica2 Mote uses two kinds of RF radios: RFM TR1000 and Chipcon CC1000. The outdoor transmission range of Mica2 Mote is about 150 meters.
- **Memory:** Memories in a sensor node include in-chip flash memory and RAM of a microcontroller and external flash memory. For example, the ATmega128L microcontroller running on Mica2 Mote has 128-Kbyte flash program memory

and 4-Kbyte static RAM. Further, a 4-Mbit Atmel AT45DB041B serial flash chip can provide external memories for Mica and Mica2 Motes

- **Power Source :** In a sensor node, power is consumed by sensing, communication and data processing. More energy is required for data communication than for sensing and data processing. Power can be stored in batteries or capacitors. Batteries are the main source of power supply for sensor nodes. For example, Mica2 Mote runs on 2 AA batteries. Due to the limited capacity of batteries, minimizing the energy consumption is always a key concern during WSN operations. To remove the energy constraint, some preliminary research working on energy-harvesting techniques for WSNs has also been conducted. Energy-harvesting techniques convert ambient energy (e.g. solar, wind) to electrical energy and the aim is to revolutionize the power supply on sensor nodes.
- **Sensors :** A sensor is a hardware device that produces a measurable response signal to a change in a physical condition such as temperature, pressure and humidity. The continual analog signal sensed by the sensors is digitized by an analog-to-digital converter and sent to the embedded processor for further processing. Because a sensor node is a micro-electronic device powered by a limited power source, the attached sensors should also be small in size and consume extremely low energy. A sensor node can have one or several types of sensors integrated in or connected to the node

1.1.2 Wireless Sensor Network Communication Architecture: Protocol Stack

This section describes the Protocol Stack of WSN [4]. The protocol stack used by the cluster head and sensor nodes are shown in Figure 2. It depicts a complete picture of the WSN i.e how it works. It is much like the traditional protocol stack, which consists of five layers: Physical layer, Data Link Layer, Network Layer, Transport Layer, Application Layer. It is similar to TCP/IP protocol suite. The physical layer is responsible for frequency modulation, data encryption etc. The DLL is responsible for multiplexing, error control and also ensures the reliable communication connection. The Network Layer used for routing the data forward

by the transport layer. The Network Layer must consider the power efficiency and data aggregation. The transport layer helps in the reliable delivery of the data.

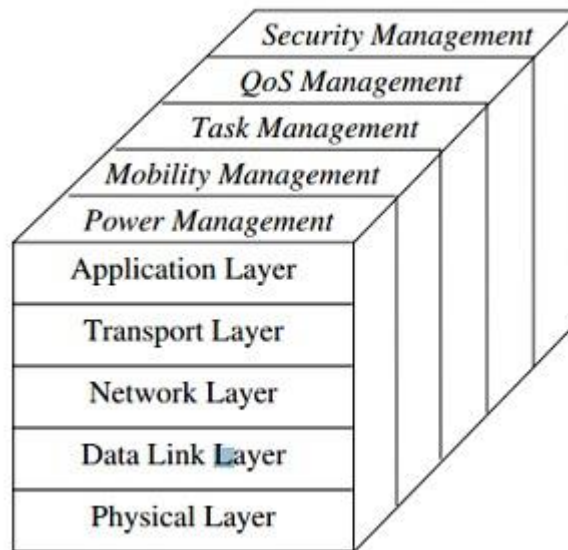


Figure 1.2: Protocol Stack for Sensor Networks

WSNs must also take care of following management services like quality of service, power and security issues in order to function efficiently. The power management fields job is to minimize the power consumption in order to save energy [7]. QoS can be vital if there is real time need with respect to the data services. It also deals with fault tolerance and error detection and control. Security management manages, sniffing and controlling the security behavior of network. But the thesis focuses on the fault tolerance which is held by the QoS.

1.1.3 Features of Wireless Sensor Networks

- Multi hop routing: Wireless routing algorithms are of two types single hop and multi hop. Single hop is simpler than multihop in terms of structure and implementation also the functionality cost is lesser.
- Light Weight Terminals: WSN use the mobile nodes with less CPU processing ability, low memory size and low power storage. These kind of devices need optimized algorithms for implementing the communicating functions.

- **Distributed Operation:** In WSN the control and management services of the whole network are distributed among the terminals. The communicating node themselves acts as a receiver and transmitter as needed.
- **Dynamic Network Topology:** The Network topology may change frequently and randomly because of the mobile nodes. It should adapt to propagation condition and the network traffic. The mobile nodes dynamically establish the routing path as they move to destination.
- **Autonomous Terminals:** Every mobile terminal is an autonomous node, which can function both as a router and a host. But usually the endpoints and switches are same in WSN.

1.1.4 Applications of Wireless Sensor Networks

The original inspirational motivation behind the research into WSNs was military application. Ex. Detection of submarines, ocean surveillance.

Table 1.1: Applications of WSN

Application	Services
Environmental Monitoring Health Monitoring	<ul style="list-style-type: none"> • Flood Detection • Weather Forecasting • Measuring blood pressure • Electrocardiograph can also be knitted into clothes for remote nursing.
Traffic Control	<ul style="list-style-type: none"> • Traffic Monitoring and control • Monitoring the road segments with heavy traffic
Industrial Sensing	<ul style="list-style-type: none"> • Monitoring the equipment failures • Monitoring corrosion using network of wireless corrosion

	sensors
Infrastructure Security	<ul style="list-style-type: none"> • Counter Terrorism Applications • Protection from potential invasions at power plants, airports and military bases.

1.1.5 Challenges facing by WSN

The below mentioned challenges shows the inefficiencies and bottlenecks that have to be overcome in WSN environment [12].

- **Transmission Range:** The range of radio band is limited and the data rate also offers less transmission speed than a wired network. Due to this routing protocols should use bandwidth in the way so that it keeps the overhead as low as possible.
- **Battery Life:** It is one of the major constraints for the wireless nodes. So to overcome this conservation of power using power saving algorithms must be considered.
- **Loss of Packets:** During transmissions, large amount of packets are lost due to the different factors such as high bit error rate, congestion in the network and collisions, attenuation etc.
- **Mobility Induction:** The topology used in WSN is of dynamic nature. So sometimes the ongoing sessions suffers frequent path breaks. Therefore with the presence of high bit error rate in channel it is very much difficult to deliver a reliable delivery to the destination.

1.2 Fault Tolerance in Wireless Sensor Network

A WSN can be defined as a system of independent mobile nodes that interacting using wireless links without any predefined infrastructure.

General definitions of some basic terms as follows:

Fault: A fault is a breach of a system's underlying expectations.

Error: An error is internal data states that give back a fault.

Failure: A failure is an externally seen departure from requirement.

Fault tolerance is the ability to maintain the delivery of conventional services despite of the presence of fault caused errors in the system. A fault tolerant service finds the errors and recovers from them without involved in the external agents such as human beings [15].

1.2.1 Problem in implementing fault tolerance in Wireless Sensor Network

- Asymmetric links: All the wired networks rely on the symmetric links which are fixed, but the nodes are mobile in WSN as they constantly changing their positions in a network.
- Dynamic Topology: It is also a major bottleneck in WSN, because the topologies are not constant here. The nodes might move and their characteristics will be change.
- Hindrance: Transmission between the different nodes might created the interference with the another transmission which leads to the corruption of the overall transmission.
- Failure of nodes: In WSNs, nodes often change their locations which lead to some chances of node failures in the networks, so some backup nodes would be generated to handle that failure.

1.3 Classification of Faults

With respect to time, three types of faults can occur in the networks [20]

- **Permanent:** These faults occur by fortuitously cutting a wire, breakup of power and so on. It is easy to yield these faults. It can cause disruptions and also some part of the system may not be functioning as expected.
- **Intermittent:** These faults appear occasionally. Every time, these faults are neglected while testing the system and only visible when the system goes into operation. Therefore it is very difficult to predict the damages these faults can cause.

- **Transient:** These faults are caused by some hereditary faults in the system. But these faults can be corrected by retrying like rebooting the system or retransmit the message. These faults are very common in the systems.

1.3.1 Behavior of Failed Machines

The types of faults mentioned above cause the system to behave in a different manner. Three kinds of behavior are feasible in a system after a fault occurs. They are [22]:

- **Fail-stop System:** The system doesn't produce any data once it has failed. It instantly stops transmitting any messages and doesn't respond to any of the messages.
- **Byzantine System:** The system doesn't stop producing output after a fault occurs, instead behave in a unexpected manner. It may send out wrong data, or respond lately to a message.
- **Fail-fast system:** The system behaves like a Byzantine system for a time but switch over to fail-stop mode after a short span of time. It doesn't matter what kind of fault has caused to change its behavior but system doesn't perform any work once it has failed.

2.2 Coverage

The most active research field in WSNs is coverage. Coverage usually depicts as how well a sensor network will monitor a field of interest. We can think it as a measure of quality of service. It can be measured in so many ways depending on the application. It is very important for a sensor network to maintain connectivity. Connectivity can be defined as the ability of the sensor nodes to reach the data sink [27]. If no route is there from sensor node to the data sink then the data collected by the given node cannot be processed. Based on type protocols of coverage can be classified into Target and Area Coverage.

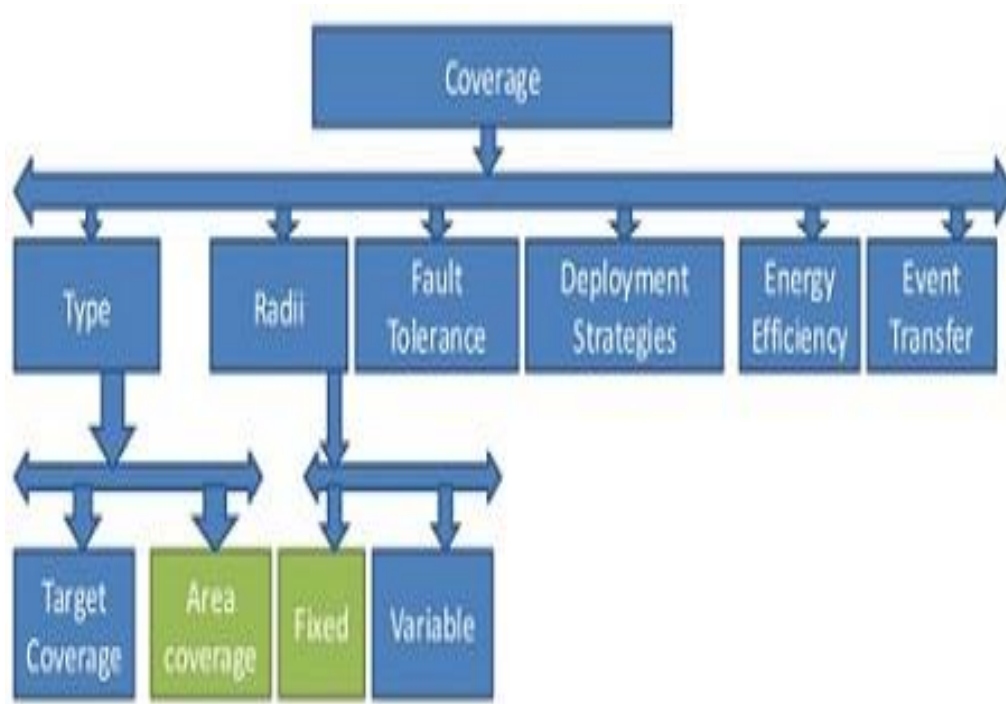


Figure 2.2: Various Attributes of Coverage

Target Coverage: In this coverage, targets are essentially observed in a given region of deployment. Its complexity takes many folds with an increase in number and versatility of targets.

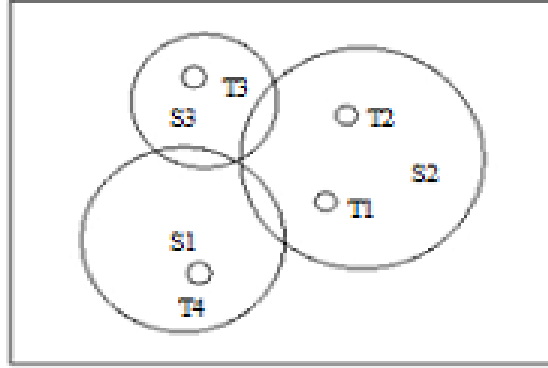


Figure 2.3: Target Coverage

Area Coverage: It is also the one of the research area in coverage problems. These problems are not restricted to sensor networks, but its utilization range from MANET and other areas to computational geometry. It compromises in observing the entire physical space with the set of installed sensor nodes.

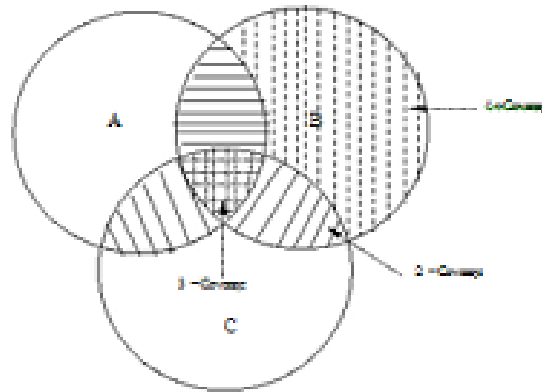


Figure 2.4: Area Coverage

Figure 2.4 illustrates, area covered by sensor nodes and depicted with dashed lines has coverage degree 1, common region covered between two nodes and depicted with straight lines has coverage degree two and finally the region within 3 nodes and depicted as a mesh has coverage degree three [35]. The representations are also shown mathematically below.

$$\begin{aligned}
 \text{1 - coverage} &\longrightarrow A \cup B - ((A \cap B) \cup (B \cap C)) \\
 \text{2 - coverage} &\longrightarrow A \cap B - ((A \cap C) \cap (B \cap C)) \\
 \text{3 - coverage} &\longrightarrow (A \cap C) \cap (B \cap C)
 \end{aligned}$$

Attributes of Coverage are:

- **Type:** It tells about the type of coverage used like Area or Target Coverage
- **Radii:** Radii shows us the radius coverage is going to cover whether it is fixed or variable. Sensors having the same sensing and transmission radii and not able to vary its sensing radii can be called as sensors observing the region with fixed sensing and transmission radii and vice –versa is known as variable sensing and transmission radii.
- **Deployment Strategies:** Different deployment strategies used for maximize the coverage. In deterministic deployment, the nodes are statically deployed in a particular region and have static locations. It can be uniform and for more sensitive regions a weighted deployment can be deployed, but the sensors are to be manually positioned. In general this type of deployment is not feasible practically for applications in sensor networks. In stochastic deployment the sensor nodes are distributed in a random fashion in a particular region. It can be uniform, Gaussian, Poisson or any other distribution [39].

2.2.1 Types of Coverage

A sensors main function is to sense the environment for happening of the event of interest. Therefore it is one of the main concerns in WSN. It is also a key for evaluating the quality of service. Optimal resource management and assuring reliable Quality of Service are two of the most fundamental requirements in ad hoc wireless sensor networks. Sensor deployment strategies play a very important role in providing better Quality of Service, which relates to the issue of how well each point in the sensing field is covered. However, due to severe resource constraints and hostile environmental conditions, it is nontrivial to design an efficient deployment strategy that would minimize cost, reduce computation, minimize node-to-node communication, and provide a high degree of area coverage, while at the same time maintaining a globally connected network is nontrivial. Challenges also arise because topological information about a sensing field is rarely available and such information may change over time in the presence of obstacles. Many wireless sensor network applications require one to perform

certain functions that can be measured in terms of area coverage It can be divided into three classes:

- Area Coverage:- Area coverage tells that how to cover an area with the sensors.
- Point Coverage:- Point Coverage interacts with coverage for a set of points of interest.
- Barrier Coverage:- To achieve a static arrangement of sensor nodes that minimizes the probability of undetected penetration through the barrier Lessen the problem of undetected penetration is the main concern in barrier coverage.

2.2.2 Coverage Strategies

This section reviews the strategies used in solving coverage problems which are implied during deployment stage. They are divided into 3 categories force based, computational geometry based and grid based [9].

- **Force Based:** These types of strategies rely on the sensors mobility. The sensors will keep running until equilibrium state is achieved.



Figure 2.5: Category Wise Representations of Coverage Strategies

- **Grid Based:** Grid Points are used either to measure coverage or to determine sensors positions.
- **Computational Geometry Based:** It is used in WSN coverage optimization. The most common approaches used are Voronoi diagram and Delaunay Triangulation.

2.2.3 Comparison of the Various Available Coverage Approaches

Table 2.1: Comparison of Coverage Approaches

Coverage Approach	Coverage Type	Problem Objective	Sensor Deployment	Range Sensing	Comm. Range	Algorithm Characteristics
Minimally constrained heuristic	Area	Energy efficiency, Max n/w lifetime by reducing no of working nodes	Random	Yes/No		Centralized
Disjoint dominating sets heuristic	Area	Energy efficiency, Max n/w lifetime by reducing no of working nodes	Random	Yes/NA		Centralized
Node self scheduling algorithm	Area	Energy efficiency, Max n/w lifetime by reducing no of working nodes	Random	Yes/NA		Distributed Localized
Probing based density control algo.	Area	By controlling the working of nodes density	Random	Yes/NA		Distributed Localized
Optimal Geographical Density Control Algo	Area	By reducing the no. of working node	Random	Yes/NA		Distributed Localized
Coverage Configuration Protocol	Area	By reducing the no. of working node	Random	Yes/NA		Distributed Localized
Delaunay Triangulation Coverage Strategy for WSN	Point	Energy efficiency, Connectivity provides active network & less no of ideal nodes	Random	Yes/NA		Distributed Localized
Maximal Support Path Algorithm	Barrier	Worst and Best case coverage paths	Random	Yes/NA		Distributed Localized

2.2.4 Why Coverage Strategies?

- Coverage is a basic fundamental concept in the design of wireless sensor networks.
- It is one of the measures of QoS.
- Due to the large diversification of sensors and applications, coverage is subject to a vast range of interpretations.
- In various sensing utilities a full sensing coverage is one of the vital requirements which want that every location would be covered by at least one sensor.
- Traditionally, sensors used in a field were distributed randomly in most of all the networking protocols but in spite of this the deployment techniques don't provide unoccupied coverage.
- Coverage strategies discussed so far do not open doors for fault tolerance and energy efficiency together.
- Wireless Sensor Networks are energy forced as they are battery operated, but to provide fault tolerant coverage, the energy efficiency of the network must be maintained.
- K-coverage strategies proposed are not energy efficient as several sensors reported together, leading to more energy consumption, congestion and collisions in the network, which reduces the quality of service and network performance [18].

2.2.5 View Points of Coverage

- **Worst Case Coverage:** In this case of coverage several attempts are made to calibrate the QoS by finding the areas of minimum view ability from sensor nodes and also break regions.
- **Best Case Coverage:** In this case coverage, finding areas of maximum view ability from sensors nodes and identify the best guidance regions are of our main concern.

2.2.6 Issues in Coverage of Wireless Sensor Networks

There are several factors that must be considered when developing a plan for coverage in a sensor networks. Many of these will be dependent upon the particular application that is

being addressed. The capabilities of the sensor nodes that are being used must also be considered. Most researchers focus on a single deployment model but there are papers that attempt to develop a more general algorithm that can be used in many types of deployment.

- Coverage Types: The first step in deploying a wireless sensor network is determining what it is exactly that you are attempting to monitor. Typically you would monitor an entire area, watch a set of targets, or look for a breach among a barrier. Coverage of an entire area otherwise known as full or blanket coverage means that every single point within the field of interest is within the sensing range of at least one sensor node [5], [7], [9]. Ideally you would like to deploy the minimum number of sensor nodes within a field in order to achieve blanket coverage.
- Deployment: A sensor network deployment can usually be categorized as either a dense deployment or a sparse deployment. A dense deployment has a relatively high number of sensor nodes in the given field of interest while a sparse deployment would have fewer nodes. The dense deployment model is used in situations where it is very important for every event to be detected or when it is important to have multiple sensors cover an area. Sparse deployments may be used when the cost of the sensors make a dense deployment prohibitive or when you want to achieve maximum coverage using the bare minimum number of sensors.
- Node Types: The set of nodes that are selected for a sensor network can be either a homogeneous or heterogeneous group of nodes. A homogeneous group is a group in which all of the nodes have the same capabilities. A heterogeneous group is one in which some nodes are more powerful than other nodes. Usually you would have a smaller group of more powerful nodes known as cluster heads which would gather data from the less powerful nodes. Examples of homogeneous and heterogeneous nodes are given in figures 3 and 4.
A homogeneous set of nodes is required for the algorithms in [1] and [15]. Each of these solutions requires the nodes to be placed at a precise distance in relation

to each other that is dependent on the sensing ranges of every node being identical. The authors in [12] assume homogeneous sensors but repeat their experiments with different uniform sensing ranges in order to prove the efficacy of their algorithm. Several algorithms for best coverage using homogeneous nodes are presented in [16].

- **Constraints:** Perhaps the most important factor to consider in the development of a coverage scheme is that of energy constraints. Sensor nodes usually depend upon a battery for their energy source and in most deployments battery replacement is not feasible. It therefore becomes very important to conserve energy and prolong battery life. There are several methods available to do this. Placing unneeded sensors into a low energy sleep mode is a popular method to conserve energy. Another method is to adjust the transmission range so that the sensor nodes only use enough energy to transmit to a neighbor node. When sensors are arranged in a hierarchical network then cluster heads can be used to aggregate data and reduce the amount of information sent up to the sink. This will relieve some of the burden on the nodes that are along the transmission path and increase their lifetimes. Improving the efficiency of data gathering and routing is also used to conserve energy. If multiple sensor nodes are collecting the same information the network is expending energy unnecessarily. Eliminating the redundancy will allow the network to be more efficient.
- **Centralized/Distributed Algorithms:** Once sensor is deployed an algorithm is run to determine if sufficient coverage exists in the area. This can be either a centralized or distributed algorithm. A centralized algorithm is run on one or more nodes in a centralized location usually near the data sink. A distributed or localized algorithm is run on nodes throughout the network. Distributed algorithms involve multiple nodes working together to solve a computing problem while localized algorithms imply that many or all of the nodes run the algorithm separately on the information each has gathered. They both spread the workload out more evenly than the centralized algorithm; however since it is being run on many more nodes throughout the network the distributed/localized algorithms may be more complex than the centralized algorithms.

One example of a centralized method is given by Cardei, Thai, Li, and Wu in [3]. They employ a central data collector node known as a base station to collect data and determine which sensors to deactivate in order to conserve energy and preserve k-coverage. The authors in [4] also use a central data collector node to gather information from the other sensor nodes to decide which sensors to put into sleep mode.

Chapter3

Problem Statement

WSNs are primarily set up with minute sensors to observe a particular region. All the applications in WSN are belongs to area controlling services. Deployments are either stochastic or deterministic to provide coverage area. Deterministic deployments are not feasible in rusty environments. In a stochastic deployment, the required number of sensors is unknown in priori and therefore condensed deployment is necessary for sensors placed in stochastic to avoid natural regions [18]. For a better QoS, every event happening in the environment needs to be detected and reported to concerned station/base station. The current resources restrict a difficult task in reporting the events to base station. Thus with resource constrained sensor nodes, energy efficient tools are required. This call for the need for fault tolerant coverage tools with event reporting and efficiency of energy [26].

Current fault tolerant components proposed in the literature support area coverage with degree K . It also doesn't give the detailed information of the problem connected to node failures in the network also decrease the event reporting stamina of network due to thick environment [37]. All the protocols mentioned in the literature provide packet level reliability for traffic from upstream. These protocols are not energy efficient.

In this thesis, we propose a protocol which supports the fault tolerant coverage and reporting of the events with better energy efficiency by considering a backbone support structure to traditional 1-coverage nodes. It come in to action when 1-coverage nodes unable to detect the event. It also improves the efficiency of energy by decreasing the no. of transmissions. In the next part, we identify the challenges and arrange the key to challenges using our support structure [40].

- Link Failures: There are so many reasons for packets getting disappear. Attenuation and interference don't allow packets to be transmitted to the destination. When 2 nodes send the packets simultaneously, packets collide and dropped. In order to overcome this, the protocol needs to recover packets in case of failures.
- Minimal Connected 2-Cover: Sensors in dense environments are densely positioned randomly. Due to redundancy, several sensors transmit data simultaneously, causing congestion and more energy consumption in network. Therefore why there is a need for strategy which reduces redundancy by finding minimum no. of nodes required for region to fully covered [32].
- Energy Efficient: Most of all the sensors are battery operated and energy forced. All the nodes lose their energy due to communication in network. In designing energy efficient strategy, these wastage of energy must be taken care of and reduced to some extent.
- Recovery of Loss packets: Packets lost due to congestion, failures etc can be recovered in wired networks only using TCP/IP mechanism, but not in WSNs. As all the transmissions in WSN are hop by hop, packets lost can be recovered at the

link layer only. This needs strategy that confirms better packet delivery at the base station for better event reporting.

- Scalability: Sensor network consists of so many nodes, network should be scalable to provide coverage. Strategies need to be distributed naturally so that it reduces the overhead caused in big networks.

Speculate the above problems; we propose a coverage strategy which provides fault tolerance and reporting of event with energy efficiency. We set the following standards in order to measure the performance of strategy

- Coverage Ratio: It is measured as the percentage of area covered by the subset of nodes participating in the transmission operations to nodes deployed.
- Energy Consumed: To know the energy efficiency of the strategy, the overall energy utilized in the network is determined for the no of deployed nodes. Lower the consumption, the greater the energy efficiency.

3.1 Backup Coverage

We chose a minimal subset of n/w nodes which provide 2-coverage for fault tolerance, but the selection of it has already proven to be NP-hard, as it generalizes for 1-coverage. Nodes for backup improves energy efficiency by reducing the exchange of information as they only report when 1-coverage collapse to detect the event [41].

The selection process of setting up of nodes at different phase for WSN to provide quality observing services.

- Selecting nodes for 2-coverage
- Delaunay Triangulation over 2-coverage set
- Picking 1-coverage subset and nodes for backup from picked 2-coverage subset.

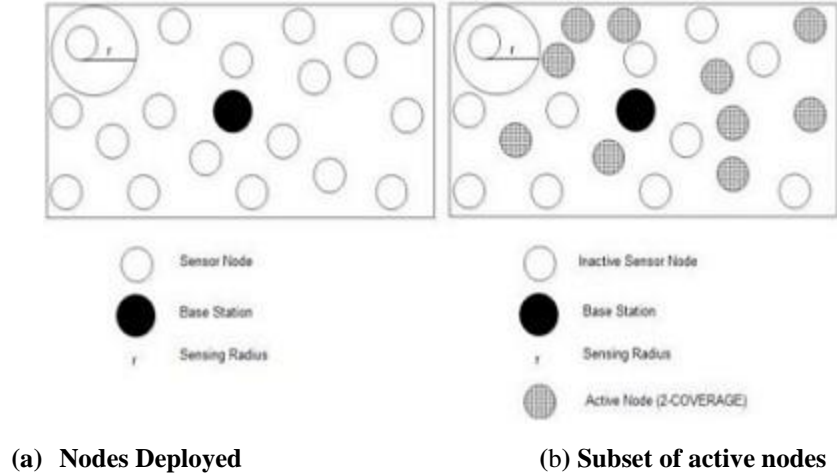


Figure 3.1: Subsetting of nodes

3.1.1 Two Coverage

Consider the initial set of nodes S in a region, subset of 2-coverage is chosen. For selection, we used the distributed greedy algorithm for K -coverage and used it to provide 2-coverage. Firstly a random node A is chosen from the set S and identified by 2-coverage. A now transmits a control message Node-Dbl-Status to its one neighboring hop to select the 2-coverage node. The Node-Dbl-Status message is used to query the one hop neighbours if they already chosen as 2-Coverage nodes. After receiving, the neighbor hop reply to message received from A with message YES/NO. Nodes broadcast A with YES if they already chosen and NO if not. This maintains the 1-hop connectivity b/w the sensor nodes so that they transmit messages and report the events to base station. Once whole region covered, the chosen 2-coverage nodes are active and take part in communication [10]. The remaining would be inactive nodes.

Algorithm 3.1 Distributed Greedy Algorithms

Procedure COV-2($N[]$)

$N []$ is the set of sensor nodes deployed

$stc[]$ is the set of sensor nodes providing COV-2

Where A is the area to be covered

- (a) snode = N[x] : x is randomly selected node
- (b) while (A is not covered)do
- (c) stc[i] = snode
- (d) snode = broadcast()
- (e) snode = recv()
- (f) snode = maxWeight()
- (g) i = i+1
- (h) end while
- (i) end func

3.1.2 Delaunay Triangulation

Delaunay Triangulation is very powerful in solving the coverage problems in WSN. It is one of the construct in computational geometry, which is dual of Voronoi diagram. It can be created by linking the vertices of neighboring sites of voronoi diagrams that share a common edge. Delaunay Triangulation of a set of points in a plane maximizes the smallest angle and no point in set is inside the circumcircle of any triangle in triangulation [2].

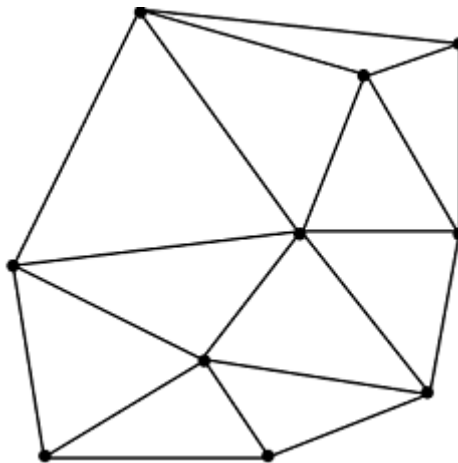


Figure 3.2: Delaunay Triangulation

A stiffed Delaunay triangulation is a triangulation with stiffed edges which tries to be as much Delaunay as possible. Stiffed edges are not necessarily Delaunay edges, therefore a stiffed Delaunay triangulation is not a Delaunay triangulation. A Stiffed Delaunay is a triangulation whose faces do not necessarily fulfill the empty circle property but fulfill a weaker property called the stiffed empty circle. To state this property, it is convenient to think of stiffed edges as blocking the view. Then, a triangulation is stiffed Delaunay if the circumscribing circle of any of its triangular faces includes in its interior no vertex that is visible from the interior of the triangle [24].

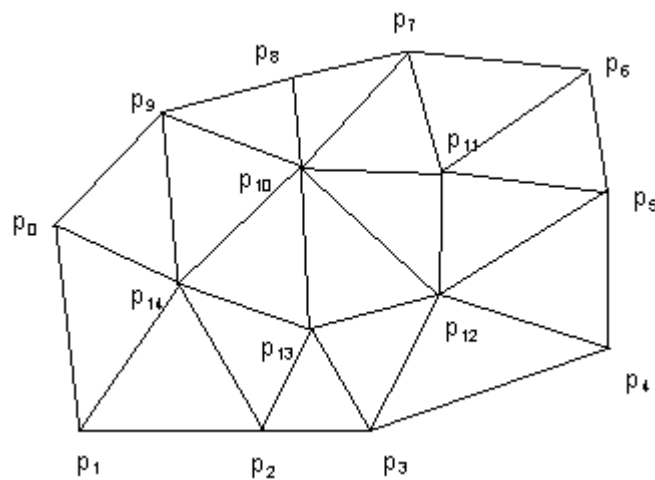


Figure 3.3 Stiffed Delaunay Triangulation

Algorithm 3.2 Stiffed Delaunay Triangulation

- (a) Construct a triangulation, fix color of every node to white and broadcast all its 1-hop neighbor data using the Neighbour_Packet [9].
- (b) Nodes having minId among its 2-hop neighbors' set their color to black.
- (c) Every black node chooses a set N of nodes from its 1-hop neighbors using the following procedure.
 - (i) N=empty

```

(ii) N1 =distant neighbor
(iii) N=NU n1
(iv) For i=2,3,.....
{
ni= select ith farthest neighbor
if ni covers greater than 60 degree angle with n1,n2,.....,ni-1
then N=NU ni
}
(d) Every black node adds the stiffed edges to the nodes in N and broadcasts these stiffed
edges data using the MSG Stiffed_Packet.
(e) Every white node fix its color=Brown if it is other end of any stiffed edges rec using
Stiffed_Packet.
(f) Every Brown node broadcast its stiffed edge data using the control packet
Stiffed_Packet.
(g) All white and Brown nodes delete edges connected to it which crosses stiffed edges,
this data is broadcasted using edge_cross_Packet.
(h) Every Black node places a new edge from the White nodes, from which the edge was
removed in last step to from new triangles

```

3.1.3 Selection of Backup Nodes

We can select the backup nodes after finding the 2-coverage and the Delaunay Triangulation. We can identify backup nodes in two phases. In first phase, all nodes treats itself as a backup node if region is covered entirely by its neighborly triangles, which are previously opted as backup nodes. To demonstrate the selection of backup node in figure3.3, in which node a broadcasts a control query message NODE-PRIMARY-STATUS to all its one hop neighbors B, C, D, E &I. They all check their status and acknowledge to node A if they were already chosen as primary nodes or not. After receiving control reply messages NODE-PRIMARY-STATUS-REPLY from 1-hop neighbors C,D,B,E,I, the node A checks if the nodes replied are part of the triangulation

in which node A is vertice. In the Delaunay neighbors, if node D is considered as backup node, then it is not going to be a part of computation [31].

Algorithm 3.3 Backup Node Selection

Procedure: BK Select(stc[])

stc[] is the set of sensor nodes providing COV-2

Neighbours[] is the set of triangle neighbours of each node

- (a) i=0;
- (b) while i!stc.end()do
- (c) if stc[i].A()= Neighbours[].A() then
- (d) backup[j]= stc[i]
- (e) PriPot[]= nearest(Neighbours[],backup[j])
- (f) PriPot[]= median(Neighbours[], backup[j])
- (g) i=i+1
- (h) end if
- (i) end while
- (j) while i!PriPot.end() do
- (k) if PriPot.A()= Neighbours[].A() then
- (l) backup[]= PriPot[i]
- (m) delete(PriPot[i])
- (n) end if
- (n) end while
- (o) end func

Only left nodes can be a part of computation. Once backup node is selected, it sends a circular control message NODE-PRIMARY-STATUS-NOTIFY to the nearest and distant neighbors. This process is repeated on all nodes to selecting primary as well as backup nodes.

For the reduction of redundancy from primary nodes, backup nodes are again selecting as per the same processes of phase one. Treating node D as primary node, it transmits a NODE-PRIMARY-STATUS message. Upon getting acknowledge from neighbors A, G, C, H, I and E primary node calculates the area covered by itself and by the primary nodes. If the primary nodes has covered the whole region covered by node D, node D would be treated as backup node.

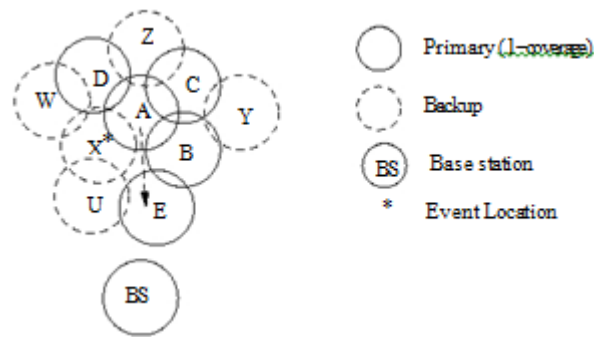


Figure 3.4: Backup Node Functionality

3.2 Functions of Backup Node

For sensor nodes observing in dense environments, various events go undiscovered due to obstacles, interference, attenuation etc. To provide additional support, backup nodes escort 1-coverage deployed nodes in discovering that event [13].

3.2.1 Event Exposure: It support 1-coverage nodes in enhancing the fault tolerance of network by discovering the events concurrently with 1-coverage nodes and reporting the same if they know that 1-coverage neighbors fails to discover the event.

3.2.2 Backup Reporting: Connectivity errors and traffic jam in the network leads to packet lost and disturb the event reporting procedure. Backup nodes escort 1-coverage nodes in sending of packets to its successor for reporting of events to base station to improve the reporting mechanism. After sending the neighboring

backup nodes which are within one hop overhear the packet broadcast and cache the packet. Those cache packets are sending in a different route when the transmission is failed.

3.2.3 Event Reporting: In WSN events happened at different locations and these events not only must be discovered but also reporting to the base station. The primary pattern of traffic is from sensor to sink in reporting of events i.e sensor nodes transmit the messages to base station. When 2 or more nodes detecting an event concurrently, leads to a complex case of sensor to sink traffic pattern called as spatially correlated argument. This problem in stochastic type of deployment leads to battle and congestion are as follows:

- Many nodes discovering and reporting events to common successor.
- Channel /medium approach issues
- A node and its successor discovering the event.

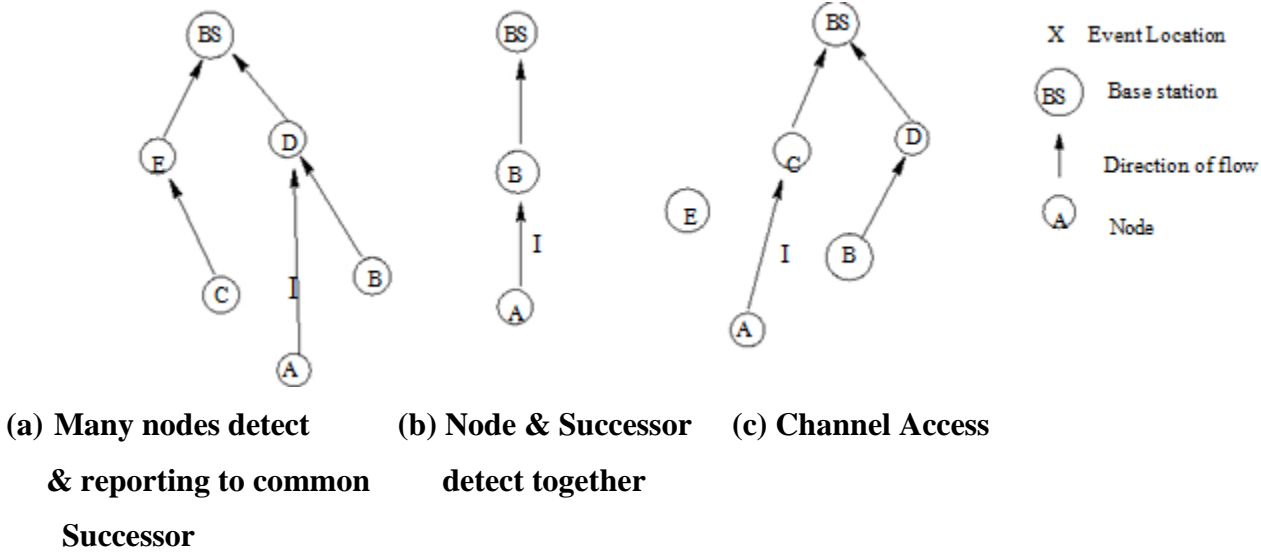


Figure 3.5: Event Reporting

To better demonstrate event reporting in WSN, figure 3.6, an event happening at location ‘I’, sensor nodes A, B & C discover the event.

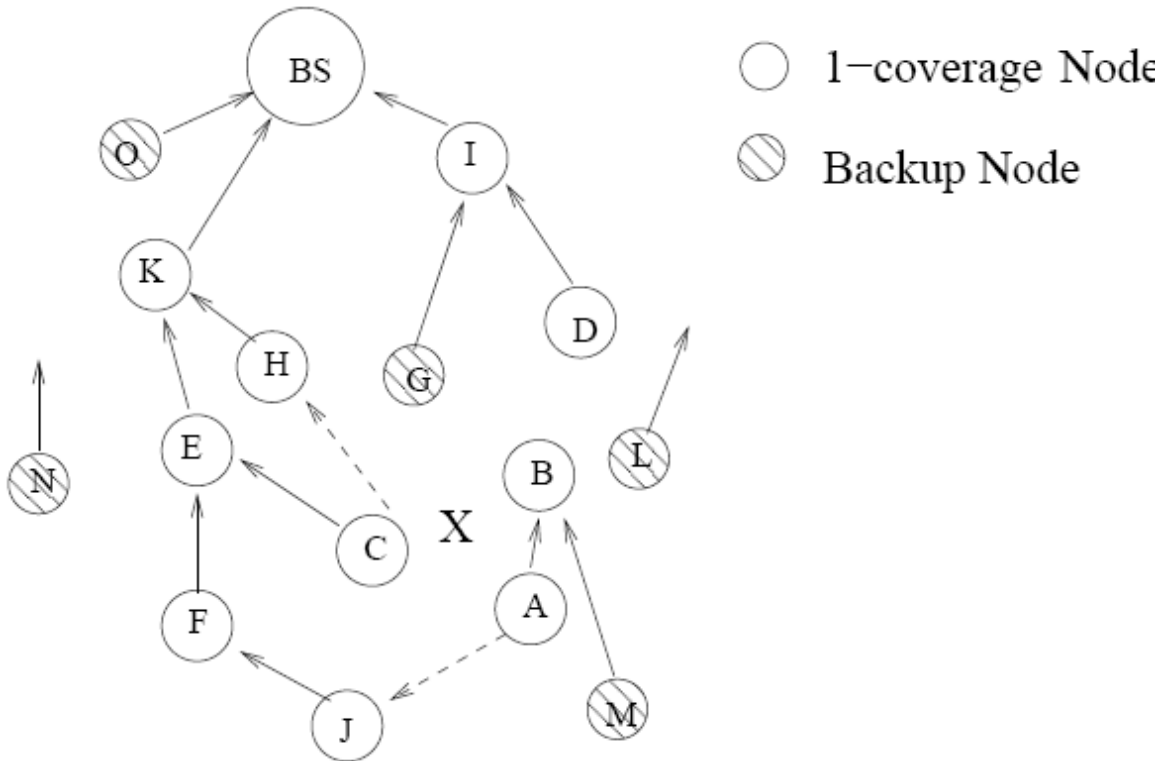


Figure 3.6: Sensor to Sink Correlated Argument

Node B, being the one hop nearest node to base station, reports first. Node A & node C report depends on time in an different path with another successor as shown. If nodes A & C do not able to find any alternate sender to forward data, they send data to the backup node to report event to base station [36].

Chapter4

Results and Analysis

To analyze the performance, the proposed algorithm is implemented using ns-2 simulator. Thorough experiments were accompanied in order to test the performance of the proposed coverage algorithm. First approach is compared with 1-coverage and then with 2-coverage in terms of standard measures, such as energy consumption, coverage ratio etc. Secondly, it is tested for event reporting and fault tolerance.

The simulations were tested with the simulation parameters as described in Table 4.1 and Table 4.2, in an dimension of 1000x1000, radius of 195m. All the sensors deployed stochastically.

4.1 Fault Tolerance

The coverage protocol classified for the act of fault tolerance in sensor networks. In sensor networks, if we want to provide fault tolerance, we need to ensure that the entire area is covered and discovering the events happening in the region. To study the reaction of fault tolerance of WSN, the event detection ratio, active node, coverage ratio are used.

Table 4.1: Parameters for Low Power

Parameter	Value
Bandwidth(Kbps)	2.4
Transmit power(mW)	14.88
Receive power(mW)	12.50
Idle Power(mW)	12.36

Table 4.2: Parameters for High Power

Parameter	Value
Bandwidth(Kbps)	100
Transmit power(mW)	660
Receive power(mW)	395
Idle Power(mW)	350

To evaluate the performance in terms of coverage ratio and active nodes count, simulations are run by altering the number of sensors which was distributed stochastically in the region from 20 to 50 nodes on a 1000mx1000m region.

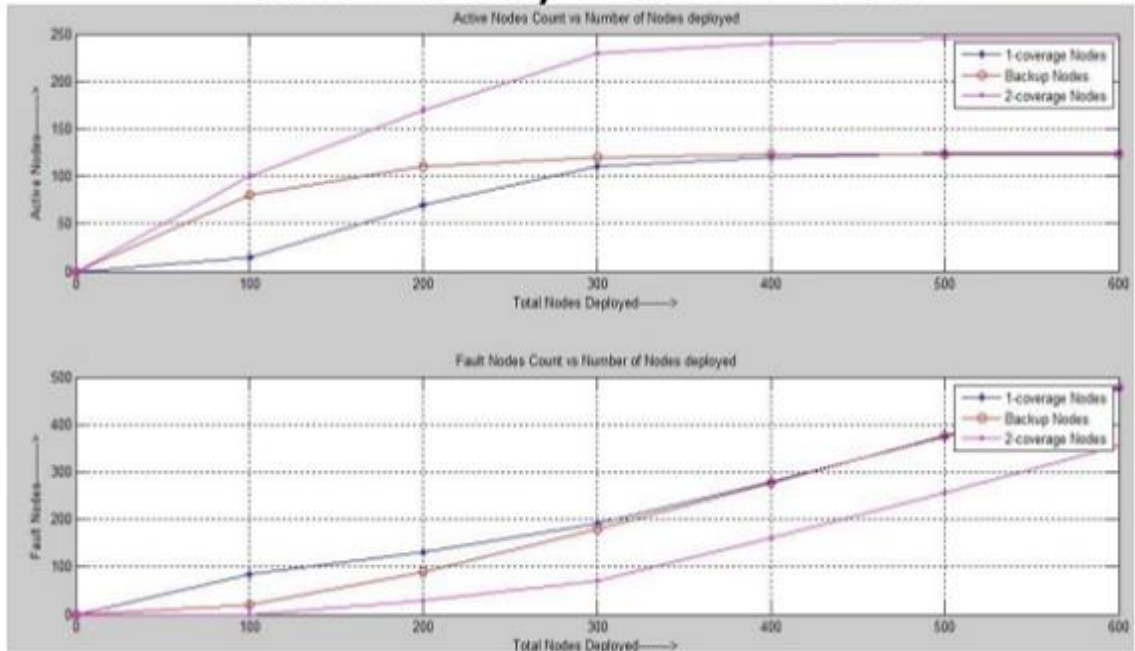


Figure 4.1: Active Fault Node Count vs Number of Nodes Deployed

Figure 4.1 displays, the subset of active nodes which are providing 1-coverage, 2-coverage and backup. As we chose the 1-coverage and backup from subsets of 2-coverage, we expect the same kind of behavior. The difference between the no. of nodes providing 1-coverage and backup for deployment must be greater than 400 and only due to the following:

- (a) The selection of 1-coverage nodes as backup nodes or vice-versa.
- (b) The influence of the random nature in selected the 2-coverage nodes.
- (c) Division of 2-coverage nodes into two equal parts is not feasible as there could be odd number of nodes.

4.2 Parameters Used

The following parameters were used for the analysis of various coverage protocols

- **Throughput (Low):** Throughput is the average rate of successful message delivery over a communication channel. The data may be delivered over a physical or logical link, or pass through a certain network node. It is usually

measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot.

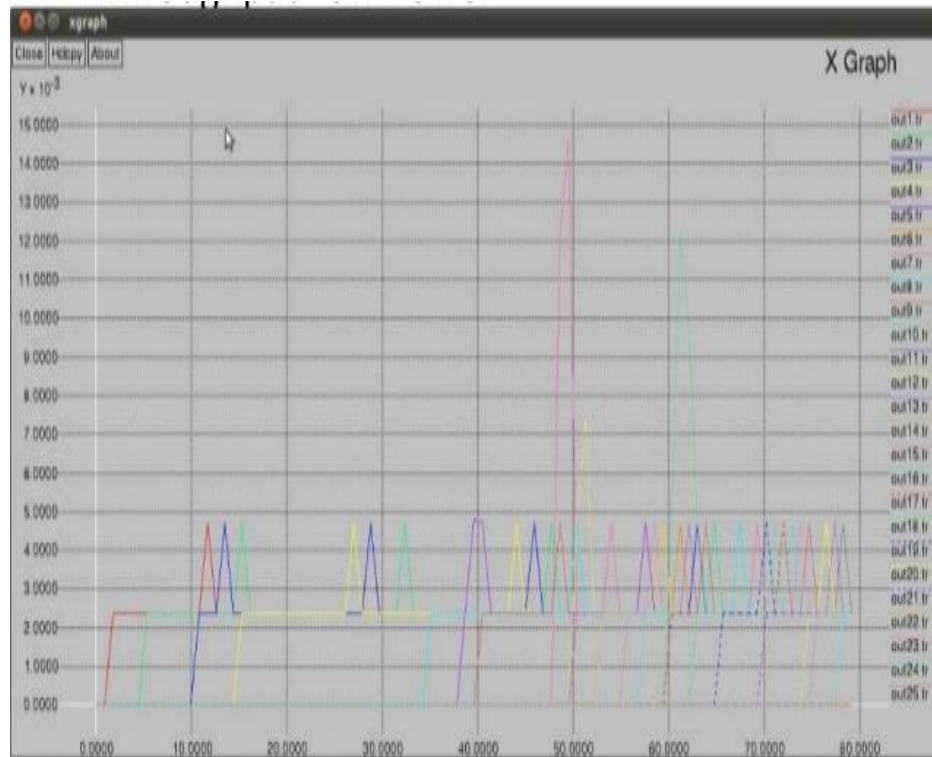


Figure 4.2: Throughput (Low Power) vs. Coverage Protocols

- Throughput (High): The maximum throughput can be defined as the minimum load in bit/s that causes the delivery time (the latency) to become unstable and increase towards infinity.

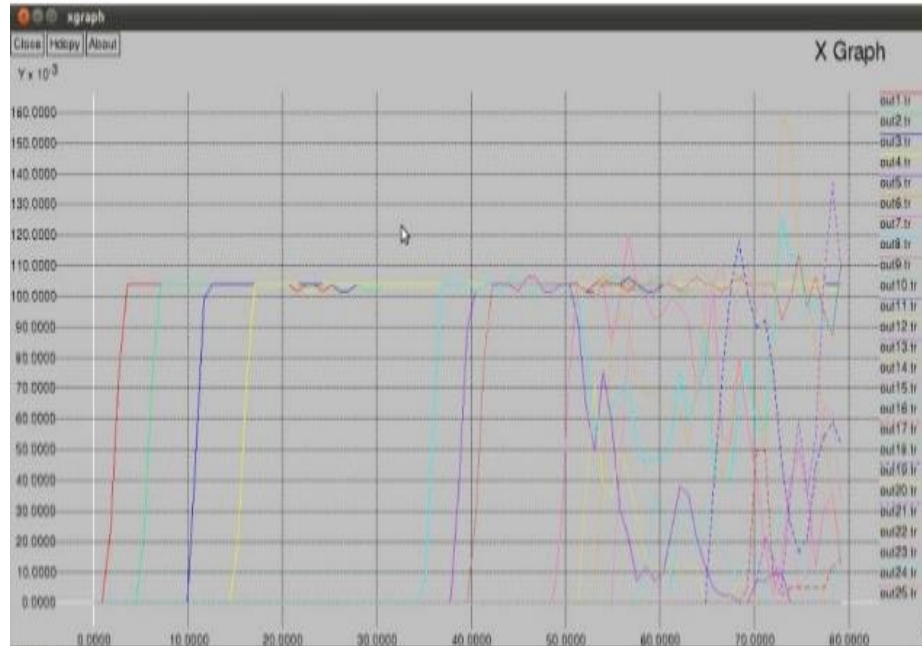


Figure 4.3: Throughput (High Power) vs Coverage Protocols

- Packet Lost Rate (Low): Packet loss occurs when one or more packets of data sending across a computer network fails to reach their destination. Packet loss is defined as one of the three main error types encountered in digital communications; the other two being bit error and spurious packets caused due to noise.

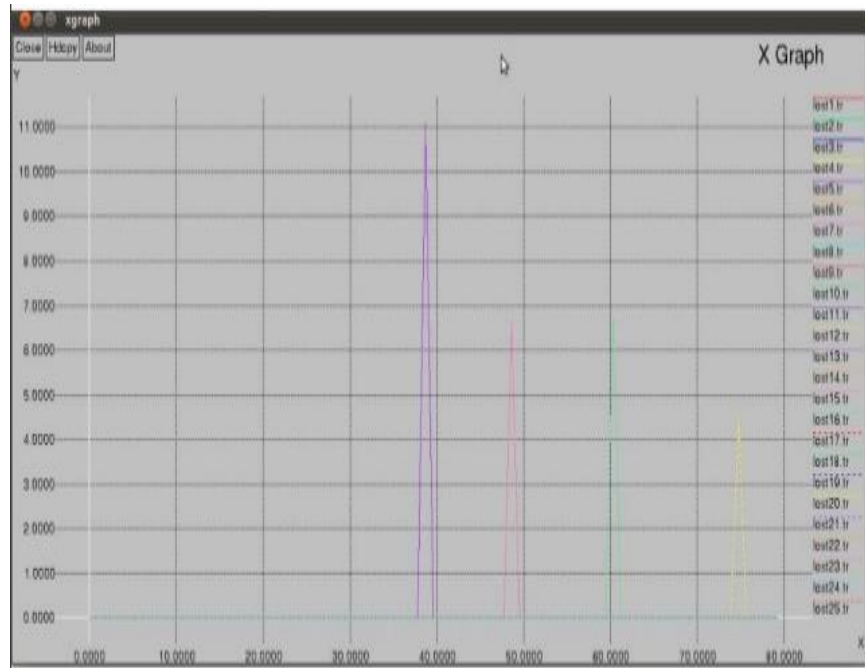


Figure 4.4: Packet Dropped Rate (Low) vs. Coverage Protocols

- Packet Lost Rate (High): Packet loss can be caused by a number of factors including signal degradation over the network medium due to multi-path fading.

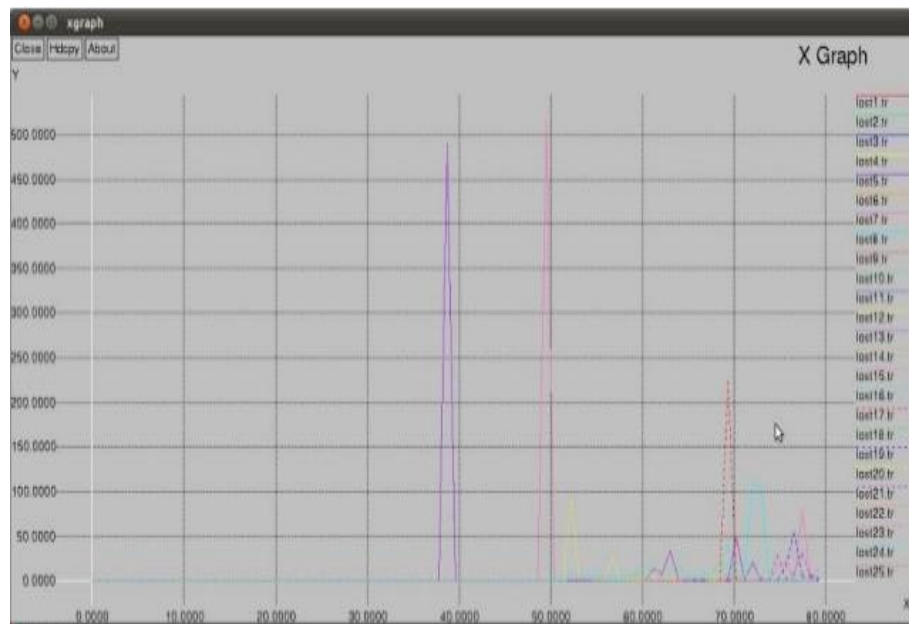


Figure 4.5: Packet Dropped Rate (High) vs. Coverage Protocols

- Average Packets End to End Delay (Low): Packet End-to-End delay refers to the time taken for a packet to be transmitted across a network from source to destination.

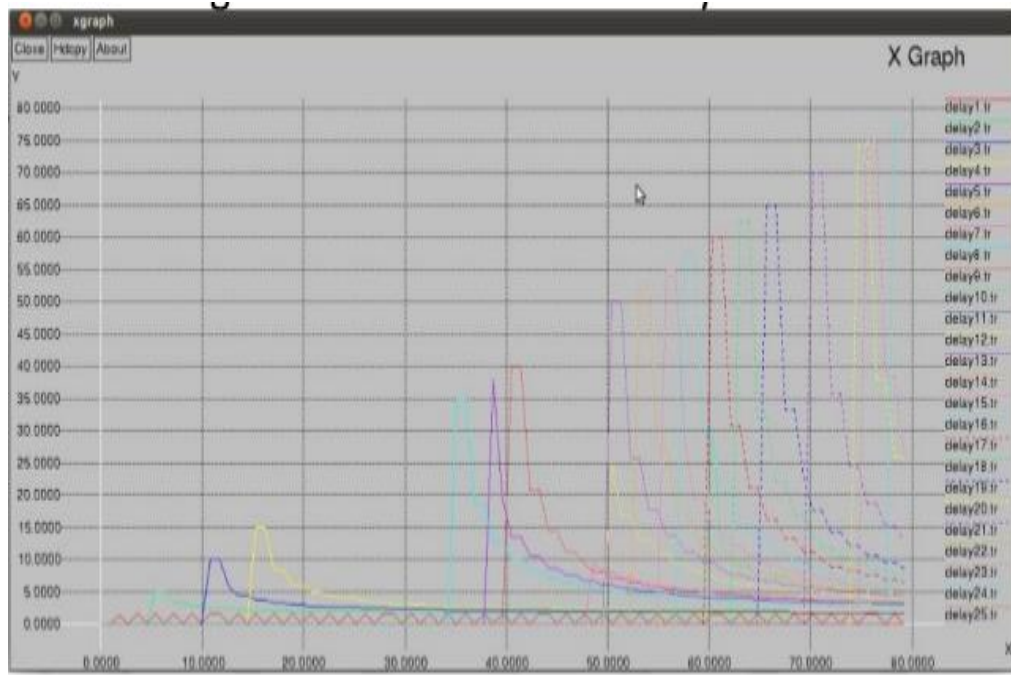


Figure 4.6: Average Packets End to End Delay (Low) vs. Coverage Protocols

- Average Packets End to End Delay (High): Average packet End-to-end delay is the time it takes a packet to travel across the network from source to destination. Delay jitter is the fluctuation of end-to-end delay from packet to the next packet.

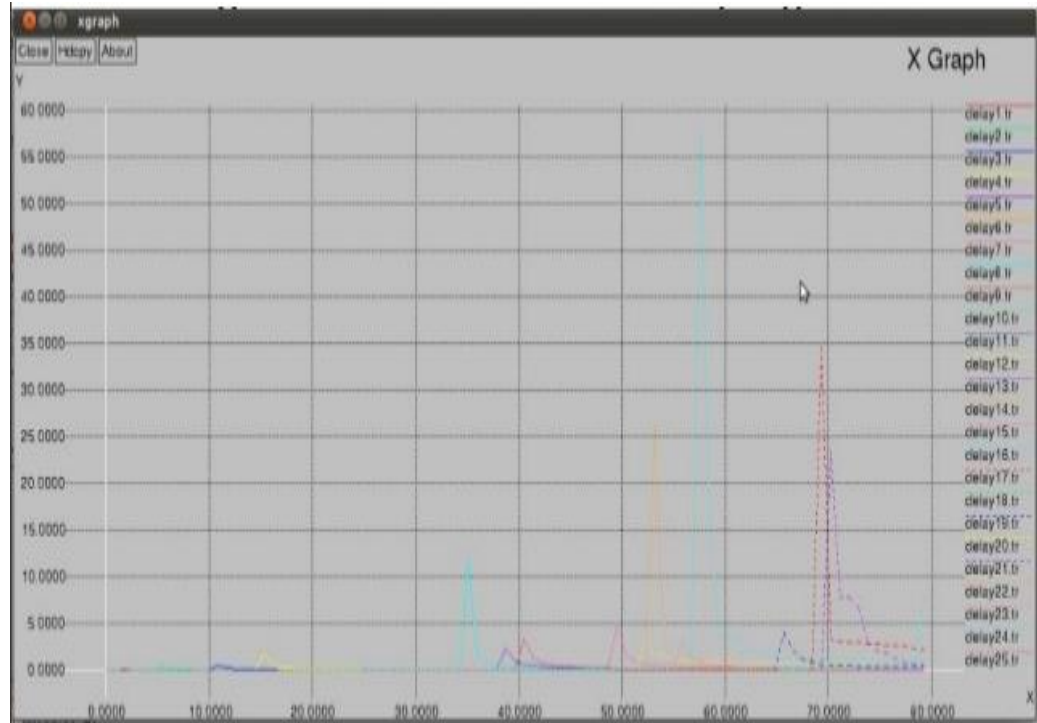


Figure 4.7: Average Packets End to End Delay (High) vs. Coverage Protocols

4.3 Energy Efficiency

Energy efficiency is the goal to reduce the amount of energy required to provide products and services. For example, insulating a home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature. The act of energy efficiency is evaluated as it is a major issue for a wireless sensor network. To maintain backup, energy efficiency when reports in 1-coverage nodes fail to detect the event. Consumption of energy is estimated for transmission and receiving of packets and for idle listening. The act of energy consumed for both high and low power settings is of 0.2 and 0.6 packets/sec for low and high network loads for a packet size of 64 bytes.

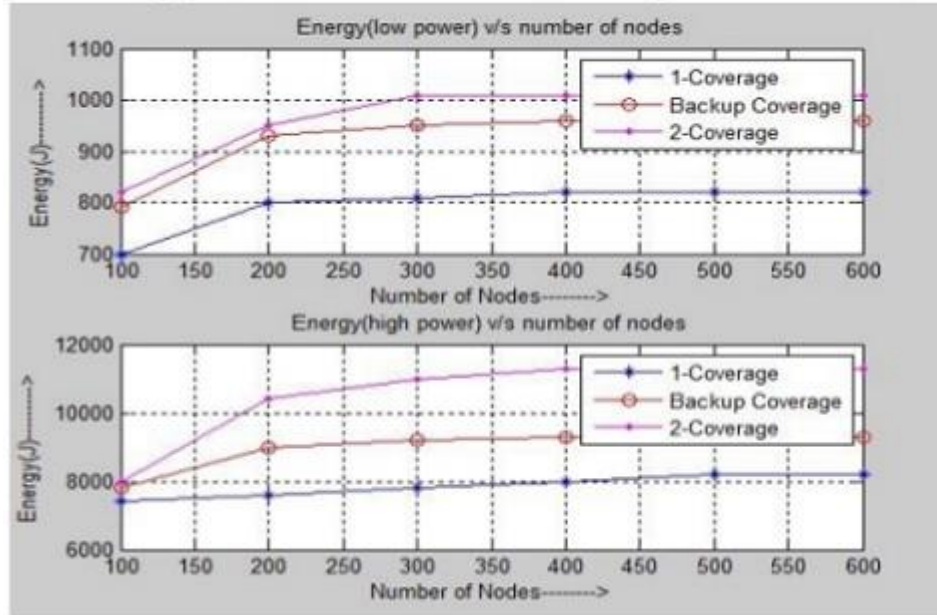


Figure 4.8: Energy (low power) vs. Number of nodes and Energy (high power) vs. Number of nodes

For various network loads, the energy consumed differs for both low and high parameter settings. The energy consumption is more at a high network load of 0.2 packet/sec in both low and high parameter settings in comparison with low network loads 0.6 packets/sec as more number of packets are transmitted. This addition in energy consumption is due to the more number of transmissions, as network loads increases.

In low power settings or high power settings with an increase in network loads (i.e. from 0.6 packets/sec to 0.2 packets/sec), the gap between energy consumed by backup coverage and 2-coverage has decreased. This behavior is because of traffic and transmissions in the network are high with 2-coverage than backup coverage and also due to an scaling in the network load. Also, in 2-coverage, packets dropped due to traffic before they reach the base station reduces the energy consumed, and backup nodes handling packet lost with the help of the cross-layered network design of the coverage protocol to improve event reporting in backup coverage, the energy consumed is increased.

In high power settings, the difference between 2-coverage and backup coverage is much larger when compared to low power settings. Also, with high power settings, there is an improved event reporting for all 1-coverage, backup, and 2-coverage techniques and less congestion in the network. With low congestion in the network, there is more energy consumption for 2-coverage, and less consumption for backup coverage. Similar behavior differences in energy consumption between 2-coverage and backup coverage for an increase in network load is shown in Figures 4.7, 4.8, and 4.9, with respect to low power settings.

From Figures 4.7, infer the following: At higher loads with low power, the energy consumption of backup coverage is closer to the energy consumption of 2-coverage, whereas at low loads with high power the energy consumption of backup coverage is closer to the energy consumption of 1-coverage. This behavior with high network loads and low power settings is because of the decrease in energy consumption due to packet drops for 2-coverage and increased energy consumption of backup coverage for handling packet losses. In low network loads with high power settings, less congestion and better event reporting aid backup coverage and 1-coverage protocols for lower energy consumption, whereas energy consumed by 2-coverage is increased due to more transmissions.

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

Wireless Sensor Networks usually deployed in astringent environment to provide Quality of Service. In these kinds of environments, defects like interference, contour and barriers create problems in discovering the event and thereby reduce the ability of event detection in network. Therefore the need arises to provide fault tolerance to discover the events.

In legacy fault tolerant strategy, so many nodes discover the same event and forward the same data to base station, which raise the number of transmissions and traffic in the network. With raise in the number of transmissions, the energy utilization also increases and event reporting capability reduced due to congestion in network. This also decreases the Quality of Service provided by coverage algorithm/protocol.

As sensor nodes are energy stiffed, handling the energy efficiency is one of the main concerns of wireless sensor networks. To accommodate the quality of service by coverage algorithms used, it originates a need for making protocols which provides fault tolerance, reporting of the events and retains energy efficiency.

To fit all these requirements, the thesis proposed a coverage algorithm by considering a set of some nodes as Backup nodes.

Conclusions drawn from the work done are as follows.

- The proposed coverage protocol supports to fault tolerance and better event reporting.
- Among all types of coverage's, backup coverage as compare to 1-coverage utilize more energy, but Quality of Service provided is much better.

- Number of events discovered by backup coverage is almost similar to 2-coverage, but the backup coverage has consumed very less energy and outstanding event reporting.
- The proposed technique is effectively done in maximizing the coverage of wireless sensor networks by sensor positioning.

5.2 Future Scope

Following extensions can be done in future.

- The proposed technique maximizes the coverage in centralized environment. This work can be extended for other environments also like distributed, localized etc.
- The presented work is fulfilling the criteria for fault tolerance only. The work can be extended in this aspect to achieve a mutual global solution.
- This work can be extended to investigate for better mechanism in selecting the minimal number of nodes for our coverage strategy and also how to decrease the latency rate and contention in the network.

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List of Publications

1. Abhinandan Gupta and Rinkle Rani, "Simulating Wireless Sensor Networks Using OPNET", *International Journal on Information and Communication Technologies* , Vol.6 , no.01, pp. 366-371, March 2013.
2. Abhinandan Gupta and Rinkle Rani, "Fault Tolerance in Wireless Sensor Networks using Stiffed Delaunay Triangulation", *International Journal of Computer Science and Engineering Technology (IJCSET)*, Vol. 4, no. 6, pp. 654-662, June2013.