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FAULT TOLERANCE IN WIRELESS SENSOR NETWORKS USING CONSTRAINED DELAUNAY TRIANGULATION

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Abstract - Fault tolerance is one of the main issues in Wireless Sensor Networks (WSNs) since it becomes critical in real deployment environment where reliability and reduced inaccessibility times are important. In this paper, we propose a fault–tolerance technique for coverage area of the sensor network that enhances the energy efficiency by reducing the communication, with the help of Constrained Delaunay Triangulation intersect line. Further by applying the above approach, we reduce the energy consumption and congestion in the network. In last, we describe our approach with a case study that our approach is better in fault tolerance and energy saving.

Keywords - *Fault Tolerance, Coverage Approach, Constrained Delaunay Triangulation, Energy Efficiency.*

I. INTRODUCTION

Wireless Sensor Networks (WSNs) consists of a large number of tiny sensors used for monitoring, communication, and computational purposes. Sensor nodes are self governing entities that collaborate with each other to perform sensing operations. Their features of self-organization and dynamic reconfiguration make them a perfect choice for applications to monitor and gather physical data in harsh environments. Sensor nodes provide absolute results in monitoring the region of interest [8].

While sensor nodes have many advantages, they do have some constraints. The tiny size of sensors limits transmission power, bandwidth, and memory space. Also, sensors are energy constrained since they are battery operated. A sensor's primary activities are to sense and to communicate with other nodes to report events to a base station (Sink). The base station processes the data received from sensor nodes and triggers an action for the event monitored. With the constraints possessed by sensors, the following design considerations are essential for better functioning of a sensor network: light weight protocols, reducing the amount of communication, distributed/local pre-computation techniques, complex power saving modes, and large scale networks. Because sensor networks are energy constrained, the primary goal is to maintain energy efficiency of the network.

There are several other problems associated with energy efficiency that play a major role in achieving the goals of a deployed sensor network. One such critical problem is coverage. ***Coverage Approach*** can be described as how well the geographical region is monitored. Coverage can also be defined as the quality of service provided by a sensor network. In sensor networks, coverage is classified in several ways based on different criteria. ***Area coverage*** is one of the classifications. Area coverage deals with the entire geographical region being monitored, and that every location in the region is monitored by at least one sensor node. Each node monitors an area of geographical region within its boundary, also known as the sensing region and the distance from the node to the boundary is known as the sensing radius. It is essential for a wireless sensor network to monitor every location in the region to provide sensing information, proving the importance of coverage in a sensor network. All locations in geographical region are 1-covered when each location in the region is within the sensing range of at least one sensor node.

Sensor nodes deployed in harsh environments are error prone due to noise interference, and obstacles in the geographical region and terrain. Deployment of sensors providing 1-coverage to handle the challenges posed by the errors in the network is inadequate as they lead to failures in event detection and reduction in quality of service provided by sensors. ***Fault tolerant*** mechanisms are essential to handle the error prone nature of a sensor network. K-coverage mechanisms [1] were proposed to provide fault tolerance with degree K. A geographical region is K-covered, provided every point in the region is within the sensing region of K distinct sensors. To solve the coverage problem we have used Constrained Delaunay Triangulations (CDT).

Delaunay Triangulations (DT) and CDT, they have been very influential in solving the coverage problems of Wireless Sensor Networks. DT and CDT are popular tools used for the representation of planar domains. The CDT is an extension of the DT to handle constraints. A CDT can be seen as the triangulation closest to the DT that respects given constraints. Since the Delaunay triangulation is unique for any point set (with the exception of sets with co-circular points), the constrained Delaunay triangulation will most likely contain some edges which are not Delaunay.

The rest of this paper is organized as follows: In section II we present related work on Coverage approach in used Delaunay Triangulation III we describe Coverage approach in used Constrained Delaunay Triangulation for better in fault tolerance and energy saving. Section IV we describe our Simulation Result. Section V we describe our approach with Case Study VI Future work .Section VII concludes our paper.

II. RELATED WORK

Coverage approach in the context of static WSNs; that is the sensor nodes do not move once they are deployed. Sensors have Omni-directional antennae and can monitor a disk whose radius is referred to as sensing range. Coverage classified on various criteria like type, radius, fault tolerance, energy efficiency and others. In this paper we used Area coverage and randomly sensor deployment method.

Area coverage problems are not limited to sensor networks, but its applications range from ad hoc wireless networks and other areas to computational geometry. Area coverage deals in monitoring the entire physical space of interest with the set of deployed sensor nodes. Applications in sensor networks vary in the critical levels of monitoring depending on the requirements. Wireless sensor networks deployed in harsh environments are error prone due to noise interference and terrain. This clearly demonstrates the requirement for fault tolerance in WSN to provide quality monitoring services by the coverage protocol in event detection. Fault tolerant sensor networks have higher a coverage degree to handle the challenges in WSN. The coverage degree of a sensor network can be defined as the minimum sensors monitoring every location in a given region. Figure 1 illustrates, area covered by senor nodes and represented with Light turquoise color has coverage degree one, common region covered between two nodes and represented with turquoise color has coverage degree two and finally the region within three nodes and represented as a Indigo color has coverage degree three. The representations are also shown mathematically below.

1- Coverage --- $A \cup B - ((A \cap B) \cup (B \cap C))$

2- Coverage --- $A \cap B - ((A \cap C) \cap (B \cap C))$

3- Coverage -- $(A \cap C) \cap (B \cap C)$

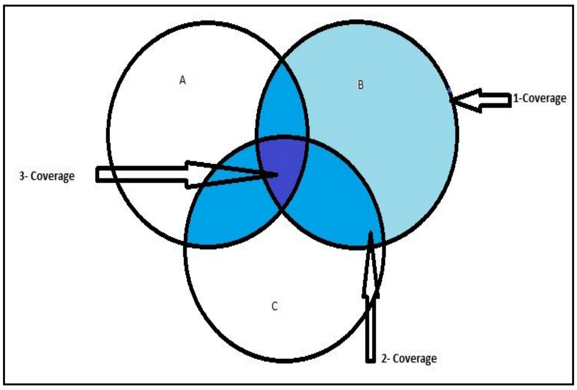

Fig. 1 : Area Coverage

Considering the above challenges, we propose a coverage Approach to provide fault tolerance and event reporting with improved energy efficiency. In order to measure the performance of the protocol, we choose the following standard metrics [6, 7].

A. Coverage Ratio

Coverage ratio is measured as the percentage of the area covered by the subset of nodes performing the sensing and communication operations to the number of nodes deployed.

$$CR = \frac{Ns}{Nt} \times 100\,\%$$

B. Active Node Count Ratio

Active node count ratio is measured based on the subset of nodes performing monitoring services from the number of nodes deployed.

$$ANCR = \frac{Ns\,(ms)}{Nt} \times 100\%$$

C. Energy Consumed

To identify the energy efficiency of the proposed protocol, the total energy consumed in the network is calculated for the number of nodes deployed. The lower the energy consumption value, the better the energy efficiency of the protocol. To evaluate the quality of service provided by the protocol, we measure the number of events sensed by sensors and the number of events reported at the sink.

D. Coverage approach in used Delaunay Triangulation

Delaunay triangulation is constructing in computational geometry, which is a dual of Voronoi diagram. Figure 2, it can be generated by joining the vertices of neighboring sites of an example of a Delaunay triangulation of a set of P points in a 2D plane. Delaunay triangulation of a set of points can be produced in different methods like incremental, divide and conquer, sweep-line, and flip algorithms [4]. Delaunay triangulations have a major influence in WSNs as neighborhood information can be easily extracted by considering the neighboring sites and the shortest Euclidean distance between two nodes of the triangulation.

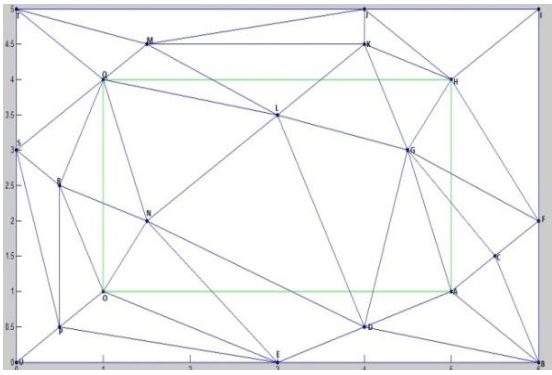

Fig. 2: Delaunay triangulation

III. DESCRIBE COVERAGE APPROACH IN USED CONSTRAINED DELAUNAY TRIANGULATION

Use Constrained Delaunay Triangulation intersect line for better in fault tolerance and energy saving.

A constrained Delaunay triangulation is a generalization of the Delaunay triangulation that forces certain required segments into the triangulation. Because a Delaunay triangulation is almost always unique, often a constrained Delaunay triangulation contains edges, Figure shows CDT 3 that do not satisfy the Delaunay condition. Thus a constrained Delaunay triangulation often is not a Delaunay triangulation itself [5].

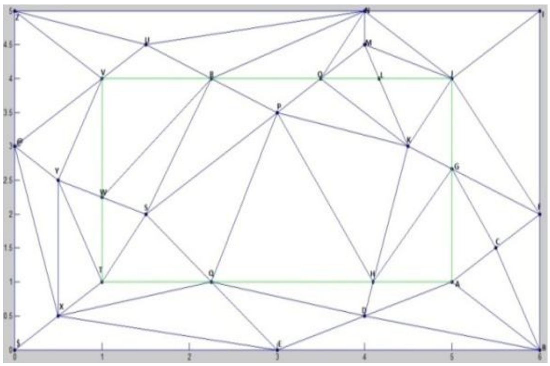

Fig. 3: Constrained Delaunay triangulation

We chose the distributed greedy heuristic provided in [3] to identify the minimal subset, as it caters to cover the entire region, maintains connectivity between sensor nodes, and also performs better in comparison with other coverage mechanisms proposed.

To improve energy efficiency of the network while maintaining fault tolerance from the subset of 2-coverage nodes previously chosen, the subset is further divided into 1-coverage nodes and backup nodes. Backup nodes provide additional support to the 1-coverage nodes in event detection and maintain fault tolerance. Backup nodes improve energy efficiency by reducing the communication as they only report when 1-coverage nodes fail to detect the event [9-10].

The selection process of sub setting of nodes is performed in different stages as part of the preprocessing of WSN to cater quality monitoring services.

In the first stage, we chose the subset D containing nodes providing 2-coverage that is each and every location is monitored by at least two nodes. In stage two, we use the properties of Constrained Delaunay triangulation and perform a local Constrained Delaunay triangulation over the chosen subset D providing two-coverage. In the final stage, we further divide subset D into two subsets with the knowledge obtained from Constrained Delaunay triangulation in stage two. One subset provides 1-coverage and the other subset provides additional support or backup. Details of how the selection process is performed are presented in further sections below.

Considering a set of S nodes in a given region, choosing the set D of minimum number of nodes, providing 2-coverage from S can be represented as below:

$$D \subseteq S$$

Further dividing the set D into sets A and B, providing 1-coverage nodes and Backup nodes can be shown as below.

$$A \subseteq D$$
$$B \subseteq D$$
$$A \cup B \equiv D$$

A. Selection of 2-coverage subset nodes

Considering an initial set of sensor nodes S in a given region, a subset of nodes providing 2-coverage is chosen. The selection of a minimum number of sensors from a set S to provide 2-coverage for a given region is NP-hard, as mentioned before. To select the minimal number of nodes providing 2-coverage, we used the distributed greedy technique for K-coverage proposed in [3] and adapted it to provide 2-coverage. In the distributed greedy heuristic, a minimal number of nodes are selected from the deployed set. Initially, a random node, say A, is chosen from the deployed set S and is identified as 2-coverage node. A now Broadcasts a control message NODE-DBL-STATUS to its one-hop neighbors to select the potential 2-coverage node. The NODE-DBL-STATUS control message is used to query the one-hop neighbors if they are previously chosen as 2-coverage nodes. Upon receiving the NODE-DBL-STATUS message, the one-hop neighbors' reply to the message received from A with a control message YES/NO. The nodes notify A with YES if they have been previously chosen and NO if not chosen. Each and every node replies to the YES/NO control message three times to essentially make sure at least one of the control messages would make it to the node if other control message are dropped due to collisions.

To identify a potential 2-coverage node, A performs a computation over the received reply of YES control messages. In this computation, the source node tries to identify the potential 2-coverage node of maximum benefit. The maximum benefit function provided in [3] is a generalized solution for K-coverage. We adapted this approach and found the maximum benefit for 2-coverage. The maximum benefit is calculated based on the maximum overlapped area from the neighboring nodes so as to provide 2-coverage. Once the potential 2-coverage node is chosen from the maximum benefit computation, a sends a control message DBL-STATUS-NOTIFY to notify the identified node as a 2-coverage node. This process continues until the entire geographic region is covered, Explain with the help of a pseudo code below. The above procedure is chosen for identifying the subset providing 2-coverage as it ensures the entire region is 2-covered. It also maintains the one-hop connectivity between the sensor nodes in the network so that the nodes can transmit messages and report events to the base station. Once the entire region is covered, the chosen 2-coverage sensor nodes are active and are involved in the sensing and communication activity of the network. The remaining nodes are inactive nodes [1].

Algorithm 1: Distributed Greedy Algorithm

```
Procedure 2-COVERAGE (S [ ])
S [ ] is the set of sensor nodes deployed
R is the region to be covered
   Snode ← S[x]   *x is randomly selected node
   while (R is not Covered) do
   dbl[i]← snode
   snode← broadcast()
   snode ←recv()
   snode ←maxBenif it()
    i ←i+1
  end while
end procedure
```

B. Selection of 1-coverage subset and backup nodes from selected 2-coverage subset.

Backup nodes are selected after finding the 2-coverage nodes and the Constrained Delaunay triangulation over a 2-coverage subset. Identification of backup nodes is performed in two stages [2]. Each and every node identifies itself as a backup node if the region it covers is covered entirely by its triangle neighbors, which are not previously chosen as backup nodes.

To illustrate the backup node selection, in Figure4, node A sends a query control message NODE-PRIMARY-STATUS to all of its one-hop neighbors B, C, D, E, and I.

The one-hop neighbors check their status and reply to node A if they were previously chosen as primary (1-coverage) nodes or not. Upon receiving reply control messages NODE-PRIMARYSTATUS- REPLY from one-hop neighbors B, C, D, E, and I, node A checks if the nodes that replied are present in the triangulation in which node A is a vertex [10]. In this illustration, nodes B, C, D, and E are Delaunay neighbors in which node A is also part of the triangles. Node A computes if it is a valid backup node by checking if the region it covers by itself is completely covered by the Delaunay neighbors. In the set of Delaunay neighbors, if node D is a backup node, then it is not considered in the computation.

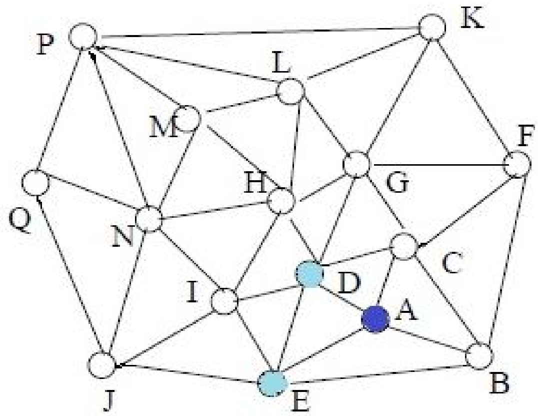

Fig. 4: Selection of Backup node from Double Coverage set Node A Backup, Node D, E Primary (1- Coverage)

Only non-backup nodes are considered for computation. If the area is completely covered, then node A sets itself as a backup. Once a node is identified as a backup node, it sends a notification control message NODE-PRIMARY-STATUS-NOTIFY to the nearest and median distant neighbors, which are D and E in the illustration. To provide a better selection of 1-coverage nodes in the topology, nearest and median nodes are chosen [9]. Nodes receiving the NODEPRIMARY- STATUS-NOTIFY message will identify themselves as primary nodes providing 1-coverage. Nodes receiving the NODE-PRIMARY-STATUS-NOTIFY notification message would ignore the message if the node was previously identified as either a backup node or primary node. This process is performed in all nodes to identify backup and primary nodes. All the above processes are performed in stage one.

To reduce the redundancy from primary nodes, backup nodes are again identified based on the same guidelines in stage two. Considering node D as the primary node, it broadcasts a NODE-PRIMARY-STATUS message. Upon receiving replies from neighbors A, C, E, G, H, and I, primary node D computes the area covered by itself and the area covered by the primary nodes C, E, G, H, and I, which have replied to node D's NODE-PRIMARY-STATUS message. If the primary nodes C, E, G, H, and I cover the region covered by node D, then node D identifies itself as backup node. For illustration purposes, C and E are considered primary nodes and A as backup node in stage 2. The procedure of selection for backup nodes is also presented in the form of an algorithm [1].

Algorithm 2: Selection of Backup Nodes

```
Procedure BK SELECT (dbl [ ])
dbl [ ] is the set of sensor nodes providing 2Coverage
Neighbors [ ] is the set of Triangle Neighbors of each
node

i ←0
   while i    dbl.end() do
      if dbl[i].area()    Neighbors [ ].area() then
          backup[ j] ← dbl[i]
          PotPri[] ←nearest(Neighbors[],backup[ j])
          PotPri[] ←median(Neighbors[],backup[ j])
          i ← i+1
      end if
end while
while i    PotPri.end() do
    if PotPri.area()    Neighbors [ ].area() then
       backup[] ←PotPri[i]
       erase(PotPri[i])
    end if
 end while
end procedure
```

IV. SIMULATION RESULT

To evaluate the performance first the proposed approach is compared with 1- coverage and 2-coverage in terms of standard metrics Active node, fault node, total node deployed show on Figure 5 Active node count vs. Number of node Deployed shows that, the subset of active nodes chosen to provide 2-coverage, 1- coverage and backup is consistently maintained from nodes greater than 300. This behavior is observed with nodes greater than 300 for the given geographical region, since the selection of minimal number of 2-coverage nodes from the distribution is not influenced by the location of the nodes as the network is over-provisioned. As the 1-coverage and backup nodes are chosen as subsets from 2-coverage set, similar behavior for both the subsets is expected. The difference between the number of active nodes in 1-coverage, backup, and 2-coverage for network size below 250 nodes is due to an insufficient number of nodes to choose to cover the entire region. The gap between the number of nodes providing 1-coverage and backup nodes for deployment of nodes greater than 300 is due to: (a) the influence of the random nature in the selection of 2-coverage nodes, (b) the selection of 1-coverage nodes as backup nodes and vice versa, (c) the division of 2-coverage nodes into exact halves is not possible as there could be an odd number of nodes chosen. After that fault node count vs. number of node deployed .The lower part of the Figure 5 shows that no of faulty nodes with respect to the no of nodes deployed, are always high in 1-coverae protocol as compared to the 2-coverae protocol.

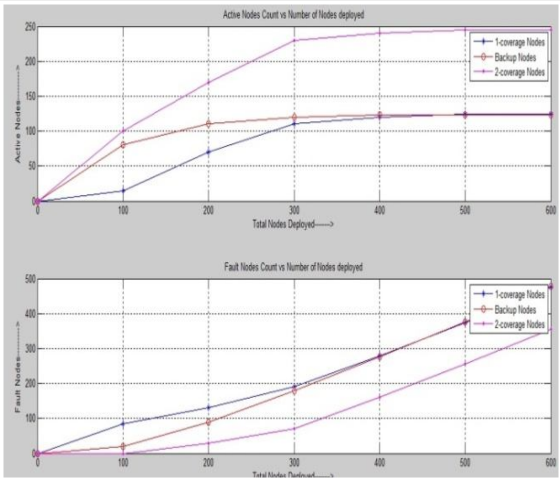

Fig. 5: Active node count vs. Number of node Deployed and fault node count vs. number of node deployed.

The behavior of energy efficiency of the coverage protocol is studied as it is a primary concern for a wireless sensor network. To maintain energy efficiency, backup coverage only reports events when the 1-coverage nodes fail to detect the event. Energy consumption of the network is calculated for the transmission and reception of packets and for idle listening. The behavior of energy consumed for both low and high power settings is observed for a packet size of 64 bytes at high and low network loads of 0.2 and 0.6 packets/sec, respectively. From Figures 6, we can 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.

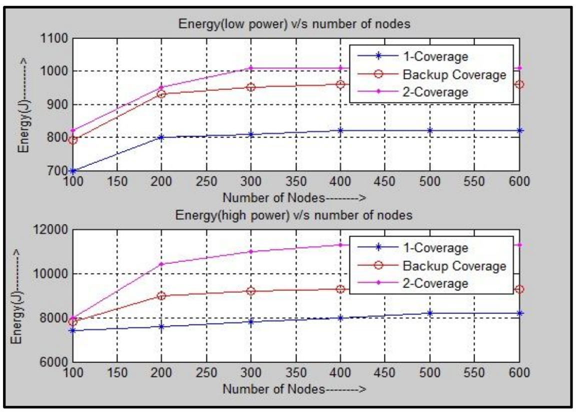

Fig. 6 : Energy(low power) vs. number of nodes and Energy(high power) vs. number of nodes.

V. CASE STUDY

For sensor nodes monitoring in harsh environments, several events go undetected due to noise interference, terrain, signal fading, obstacles, and etc. In order to provide additional support, backup nodes assist deployed 1-coverage nodes in detecting the event that occurred in a region. To illustrate the backup node functionality, we represent the network in Figure 7. Circles with Light turquoise color are nodes providing 1-coverage, circles with turquoise color are backup nodes, and BS is base station.

Backup nodes support 1-coverage nodes in improving the fault tolerance of the network by detecting events simultaneously with 1-coverage nodes in the network and reporting the event detected

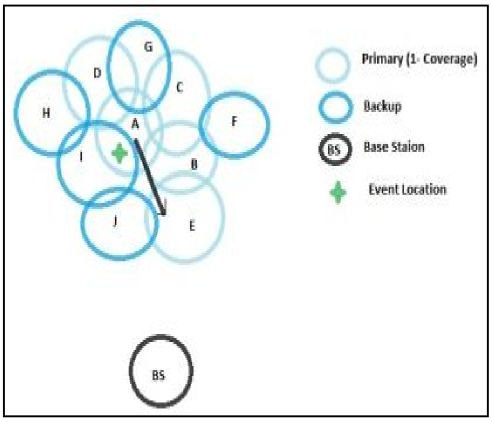

Fig. 7 : Backup Functionality

When they know that the 1-coverage neighbors failed to detect the event. In the current literature, coverage protocols have assumed that all the events are successfully detected without considering the error-prone nature of the network. When an event is detected, 1-coverage nodes transmit messages to its forwarder to report the event to the base station. Backup nodes observe the packet transmissions for a time of td, which is the transmit time of a packet for one-hop to determine if the event was successfully detected by 1-coverage nodes. Backup nodes can overhear the packet transmissions, which is used to determine if the event was successfully detected. When 1-coverage nodes do not transmit packets for the event detection within the time td, the backup nodes classify the event detection as unsuccessful and transmit packets to its forwarder to report the event to the base station.

To illustrate the process of event detection in the WSN from Figure 7, consider that an event has occurred at location '*'. Node A and X have the event within their sensing region, and sense the event. Node A transmits packets to node E for reporting the event to the base station. Node E is the forwarder for node A, and forwards the packet received from A to the base station. Node X, as a backup node, will observe for a time td to overhear the packet transmission from node A. Node X, upon overhearing the transmission from node A, considers the event to be successfully detected. If an unsuccessful detection occurs, X would transmit the packet to its forwarder and report the event to base station.

VI. FUTURE WORK

In the future, we would like to investigate for better mechanisms in choosing the minimal number of nodes for our coverage-based protocol. This way will enrich in the set of nodes chosen, will be reduced, thereby lowering the contention in the network and perform better event reporting operations.

VII. CONCLUSION

Wireless Sensor Networks are mainly deployed in harsh environments to provide quality services. In such environments, errors in WSN like noise interference, terrain, and obstacles pose problems in detecting the event and thereby degrade the event detection capability of the network. There is a need to provide fault tolerance to detect the events occurring in the geographical region. With current fault tolerant mechanisms, many nodes detect the same event and forward data to the base station, which increases the number of transmissions and congestion in the network. With an increase in the number of transmissions, the energy consumption of nodes increases and the event reporting capability due to collisions in the network is reduced. A decrease in the number of events reported to the base station reduces the quality of service provided by the coverage protocol. Also, as sensor nodes are energy constrained, maintaining energy efficiency is one of the primary concerns of sensor networks.

So to provide quality service by coverage protocols, there arises a need for developing protocols to provide fault tolerance, event reporting, and maintain energy efficiency.

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