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Topology Control based Fault Management in Distributed Sensor Networks

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Abstract*-Sensor networks finds applications in various fields like military, environmental monitoring, health monitoring and industrial applications because of their reliability, accuracy, flexibility, cost effectiveness and ease of deployment.Energy efficiency and fault-tolerance are the most important issues in the development of next-generation wireless ad hoc networks and sensor networks. Fault tolerance is the ability of a system to deliver a desired level of functionality in presence of faults. Topology control as a low level service governs communication among all nodes and is hence the primary target for increasing connectivity and saving energy. In our scheme we propose fault detection and fault recovery model to achieve fault tolerance by adjusting the topology of the randomly deployed sensor nodes.*

Key words: *Fault tolerance, topology control, fault detection, fault recovery, Distributed Sensor Networks.*

I. INTRODUCTION

Distributed sensor networks are often deployed in hostile and unattended environments. Sensors may fail from impact of deployment, fire or extreme heat, animal or vehicular accidents, malicious activity, or simply from extended use. These failures may occur upon deployment or over time after deployment: extensive operation may drain some of the node's power, and external factors may physically damage part of the nodes. Additionally, hazards may change device's positions over time, possibly disconnecting the network. If any of these initial deployment errors, sensor failures, or change in sensor positions cause the network to be disconnected or lack other desired properties, we need to deploy additional sensors to repair the network. Fault occurrence in a DSN system may exist at hardware layer, software layer, network communication layer, and application layer.

1.1 Topology control

Topology control includes factors like mode of deployment, self-configuration after deployment, deployment of additional nodes etc. Maintaining the topology of sensor network is particularly challenging as sensor nodes are mobile, prone to random failures, subject to harsh physical conditions in the deployment area and often have a nonrenewable energy source. Topology of a Distributed Sensor Network determines the connectivity of the sensor network and profoundly impacts the routing algorithms applied to the network. Topology also influences other important features of the network like resiliency and communication cost between nodes. Current research has established efficient network energy utilization as one of the fundamental research issues in wireless sensor networks. Controlling the topology of the network has emerged as an effective solution to fault tolerance. Like all other aspects of distributed sensor networks, topology control protocols have to be designed and implemented subject to a severe set of computational and energy constraints.

1.1.1 Issues in Topology Control

The two important issues in topology control are

1. Energy efficiency
2. Fault tolerance.

The radio in a sensor node is the primary source of energy dissipation. The radio consumes power in all of its four phases of operation namely listening, idle, transmission and reception. Some common metrics that are used for performance measurement of routing protocols in distributed sensor networks are number of packets dropped, overhead in terms of routing messages, number of hops etc. But, compared to traditional wired and wireless adhoc networks, wireless sensor networks should be primarily evaluated in terms of energy depletion of sensor nodes. Sensor nodes have limited non-renewable battery sources, moreover once deployed there is seldom any means of recharging the battery of a sensor node in a hostile environment. These constraints make energy metric a primary concern. Choosing the approach to selectively switching off the radio of sensor nodes based on the availability of alternate routing paths is one way of optimizing the energy consumption in a distributed sensor network. Switching-off the radio of the sensor nodes is only possible if the topology is configured in such a way that the network is not partitioned due to those inactive nodes. Thus effectively controlling the topology of the network emerges as a solution to the problem of energy conservation for distributed sensor networks. Topology control protocols are designed to exploit node density in the network to extend the network lifetime and provide connectivity. The following criteria have been identified as the key concepts for designing topology control protocols for distributed sensor networks.

- Sensor nodes should be able to self-configureto accommodate changing network dynamics.
- Selection of redundant nodes should be done based on distributed localized algorithms.
- Topology control protocols must ensure minimum connectivity in the network, so that the network is not partitioned.
- Topology control protocols should take advantage of the high node density in large scale distributed sensor networks to reduce the energy dissipated in the network.

1.1.2 Topology Control Algorithms using Fault Tolerance based approach

Extending network operational lifetime seems to be a key factor in the design of network layer or MAC layer protocols for sensor networks. Topology control protocols can be classified into two groups depending on which network layer information is used for identifying redundant nodes:

- Protocols like CEC, GAF, ASCENT, and LEACH use information from the routing layer and above for identifying redundant nodes.
- Protocols like PAMAS, STEM use MAC Layer information to identify redundancy in the network.

1.2 Fault detection and recovery

To tackle faults in a DSN, the system should follow two main steps. The first step is ***fault detection***. It is to detect that a specific functionality is faulty, and to predict it will continue to function properly in the near future. After the system detects a fault, ***fault recovery*** is the second step to enable the system to recover from the faults. Basically, there are two types of detection techniques: ***self-diagnosis*** and ***cooperative-diagnosis***. Some faults which can be determined by a sensor node itself can adopt self-diagnosis detection. For example, faults caused by depletion of battery can be detected by a sensor node itself. The remaining battery of the sensor node can be predicted by measuring current battery voltage. Another example is the detection of link failure. A sensor node may detect some link to one of its neighbors is faulty if the node does not receive any message from the neighbor within a predetermined interval. However, there are some kinds of faults which require cooperative-diagnosis among a set of sensor nodes. A large portion of faults in DSNs are in this category. The most commonly used technique for fault recovery is *replication* or *redundancy* of components which are prone to be failure. For example, DSNs are usually used to periodically monitor a region and forward sensed data to a base station. When some nodes fail to provide data, the base station still gets sufficient data if redundant sensor nodes are deployed in the region. Multiple paths routing is another example. In the case of providing single route, a requested call cannot be set up or be maintained if some nodes / links along the route fail. Keeping a set of candidate routes provides high reliability of the routes for routing. It requires K-connectivity of the network if it is able to tolerate failure of K–1 nodes.

II. LITERATURE REVIEW

The work given in [1] introduces the general concepts, requirements and applications of distributed sensor networks. In [2]& [3] the concept of fault tolerance, different levels of fault tolerance, and sources of fault tolerance, fault detection and fault recovery, basic network topologies in distributed sensor networks is discussed. The work given in [4] explains whether to cache a packet while transmitting it to a faulty node based on analytical models and mathematical evaluations. The work given in [5] explains an efficient *fault-tolerant event query algorithm (FTEQ)* to overcome the faulty data query problem to improve the accuracy of data query. The work given in [6] explains a distributed coverage and connectivity-centric technique for selecting active nodes in wireless sensor networks. The work given in [7] explains repairing connectivity and achieving a certain level of fault tolerance in wireless sensor networks. The work given in [8] presents a new scheduling method called *virtual backbone scheduling(VBS)*.VBS employs heterogeneous scheduling, where backbone nodes work with duty cycling to preserve network connectivity, and non-backbone nodes turn off radios to save energy. The work given in [9] addresses the problem of deploying relay nodes to provide fault tolerance with higher network connectivity in heterogeneous wireless sensor networks, where sensor nodes possess different transmission radii. The work given in [10] considers the problem of deploying or repairing a sensor network to guarantee a specified level of multipath connectivity (k-connectivity) between all nodes. The work given in [11] presents a method for monitoring, maintaining and repairing the communication network of a dynamic mobile wireless sensor network, so that network connectivity is continuously available and provides fault tolerance. The work given in [12] summarizes and compares existing fault tolerant techniques to support sensor applications. The work given in [13] introduces the problem of fault -tolerant topology control for all-to-one and one-to-all communication in static wireless networks with asymmetric wireless links. The work given in [14] addresses the topology control issue. The approach contains three phases: *topology discovery, topology update, and topology regeneration*. A tricolor-based method is proposed to build architecture with high tolerance ability and some security protocols are employed to preclude the hostile nodes in discovery phase. The work given in [15] addresses the issues associated with the steady connectivity which reduces the overall power consumption and a comparison study is made on these issues. The work given in [16] highlights the advantages of data fusion and topology control in wireless sensor networks. The work given in [17] explains ASCENT algorithm and presents analysis, simulation, and experimental measurements. The work given in [18] describes topology discovery algorithm for sensor networks. This paper describes fault tolerance mechanisms for sensor networks for clustered response approach on considering different scenarios that may come to consideration when a node fails; thus ensuring maximum connectivity among operational nodes after the failure of the node. Reverse traverse mechanism has been described in this paper as a part of fault tolerance mechanisms, which ensures that the number of clusters is not increased when a faulty node is repaired and re-connected to the network. The mechanisms described in this paper are distributed and highly scalable. The work given in [19] addresses the topology control issue. This paper describes the relationship between the topology and the network performance by designing three kinds of topology models which are regular hexagon topology model, plane grid topology model and equilateral triangle topology model. The work given in [20] addresses the problem of fault diagnosis for sensor networks. It examines faults that involve an anomalous behavior of the sensor and investigate their diagnosis only through the local interaction between faulty nodes and healthy ones. It also provides heuristics to actively diagnose faults and recover the nominal behavior. The work given in [21] addresses the challenge of designing efficient fault management solutions to recover network systems from various unexpected failures. Fault management process is divided into three phases, such as *fault detection, diagnosis and recovery*. The work given in [22] explains survivability and energy efficiency with the clustering of WSNs to increase the network lifetime. In this work, it presents an easy-to- implement method named *DED (distributed, energy-efficient, and dual-homed clustering)* which provides robustness for WSNs without relying on the redundancy of dedicated sensors, that is, without depending on node density. The work given in [23] addresses fault-tolerant topology control in a heterogeneous wireless sensor network consisting of several resource-rich super nodes, used for data relaying, and a large number of energy-constrained wireless sensor nodes. It explains the k-degree *Any cast Topology Control (k-ATC)* problem, with the objective of selecting each sensor's transmission range such that each sensor is k-vertex super node connected and the total power consumed by sensors is minimized. The work given in [24] explains fault detection and recovery in WSN using clustering. Due to depletion of node energy network will split. To avoid network splitting this paper proposes a fault recovery of corrupted node and Self-healing. The work given in [25] explains Energy efficient Topology Control Algorithm for WSN.

III. PROPOSED WORK

3.1 System Model

Failures are inevitable in distributed sensor networks due to inhospitable environment and unattended deployment. Therefore, it is necessary that network failures are detected in advance and appropriate measures are taken to sustain network operation. The fault model of our proposed system is as shown in fig 3.1

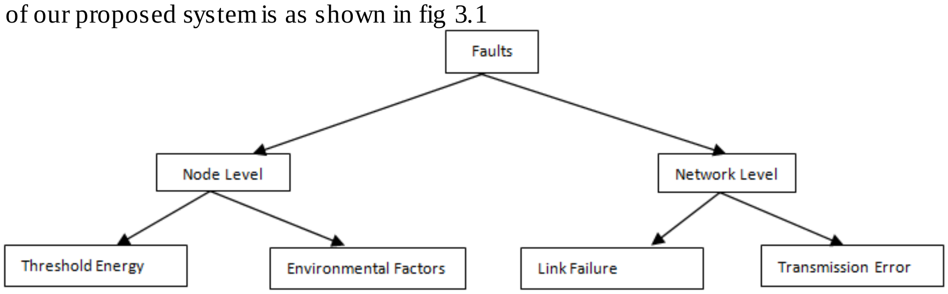

Fig.3.1 Fault Model

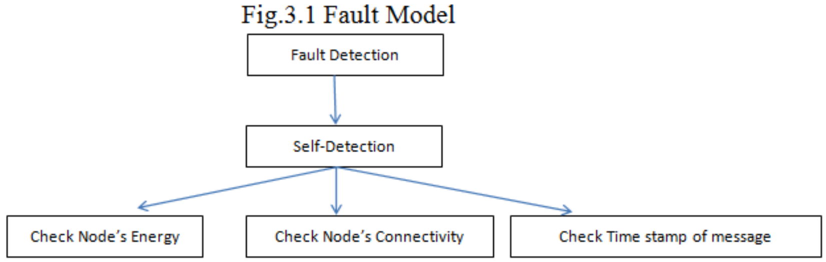

Fig.3.2 Fault Detection Model

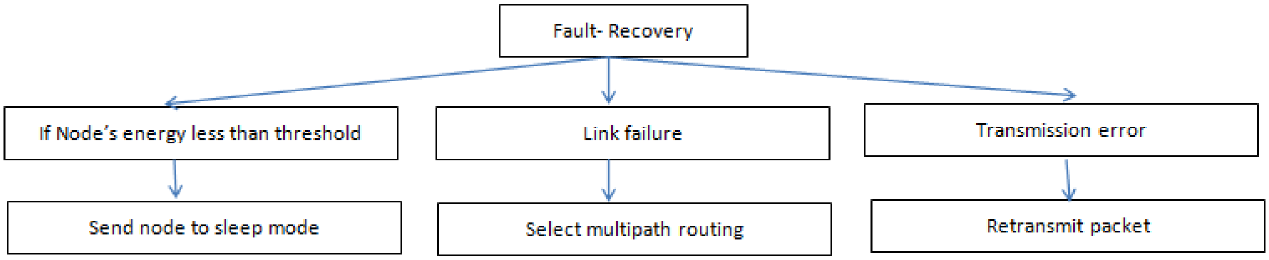

Fig.3.3 Fault Recovery Model

The proposed work schemed out for fault tolerance is divided into two phases
1. Fault detection
2. Fault recovery

Fault Detection:

Figure 3.2 shows the fault detection model of our proposed system. Fault detection is done at two levels for three parameters.

1. At node level

When the node's residual energy is less than the threshold energy (<0.05 J per node)

2. **At network level**

- Link failure between nodes
- Transmission error

The first parameter is measured by measuring the energy level of a node. If energy level of nodes is above threshold energy then they are selected for routing messages from source node to sink node. Nodes with energy level less than threshold are sent to sleep mode. When node A wants to send packets to node B, first it will measure the energy level of nodes that are in the path between A and B. If the energy of nodes in path between A and B are greater than the threshold energy then packets are forwarded from node A to node B. Suppose if any of the node's energy level is below threshold then it is sent to sleep mode and the next nearest node is selected for forwarding the packets provided that its energy level is greater than threshold.
Link failure between nodes is detected as follows. If node A does not receive packets from its nearest neighbors whose energy level is greater than threshold within predetermined time interval then it assumes that link from those nodes to node A are failed.
Packet error rate can be used to monitor the network's health and help debug potential problems. If errors do occur a pattern can be identified. This can help isolate and solve problems before the system fails. Packet errors are node specific i.e., nodes only check their own packets and ignore all other packets. In case of packet error, the time stamp field in message is checked. If it is zero then there is packet error.

Fault recovery:

Faulty recovery process (Fig.3.3) is carried out as follows.

- Once fault is detected, the nodes with low energy are sent to sleep mode.
- In case of link failure, the next nearest node with energy level greater than threshold is selected for forwarding the packets
- In case of transmission error, the time stamp field is checked. If it is non-zero then there is no packet error. Otherwise packet error has occurred and the packet has to be retransmitted to the desired node through alternate path.

Flowchart of proposed system:

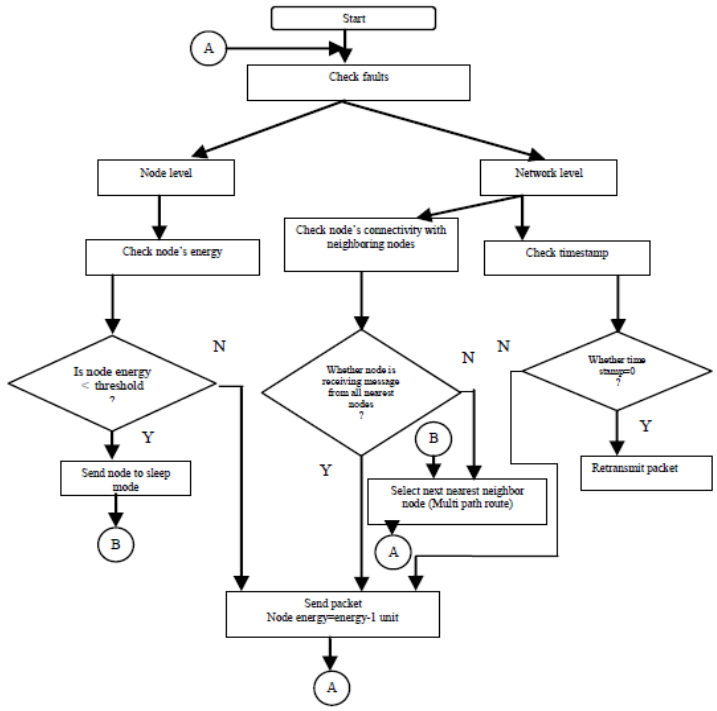

Fig.3.4. Flow-chart of proposed system

IV. SIMULATION

NS-3 simulator has been used to perform simulation. Simulation model consists of 'N' number of nodes deployed randomly in Distributed Sensor Networks connected in various topologies like star, bus, tree and mesh topology.

We have considered the following parameters to perform simulation.

Number of nodes=100, sensor area=1000*1000m, energy of each node= 2joules, number of sink nodes=1(static), transmission range=100m, packet size=64,128,512 bits and so on. Threshold energy =0.05 J, mobility of sensor nodes is considered.

Results and Discussions:

The following performance parameters are considered for evaluation.

a) **Probability of fault detection:**
It defines the ability of the system to identify the faults at node level and network level. Fig 4.1 shows the probability of fault detection for various faults.

b) **Probability of fault recovery:**
It defines the ability of the system to operate normally in the presence of faults. Fig 4.2 shows how the probability of fault recovery varies with number of nodes for different types of faults.

c) **Topology Control:**
It explains how the topology of the network is controlled in order to achieve fault tolerance. For example, if nodes between sink and transmitter are energy depleted, then those nodes are sent to sleep mode and alternate path is selected for data transmission. This is achieved by controlling the topology of the network. Refer Fig 4.3.

d) **Average Delay:** It defines the time required to recover from various faults and operate normally for various types of faults (Fig 4.4).

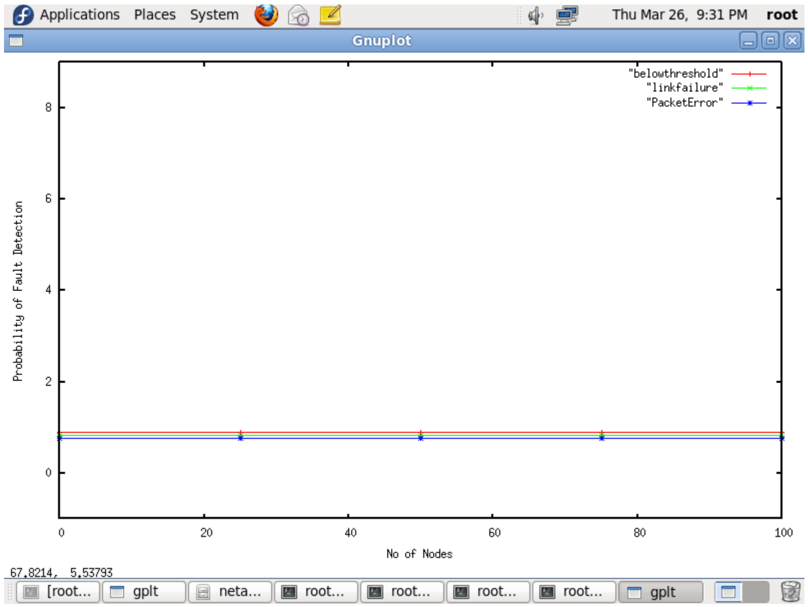

Fig.4.1 Probability of Fault Detection v/s Number of Nodes for energy depletion, link failure and packet error

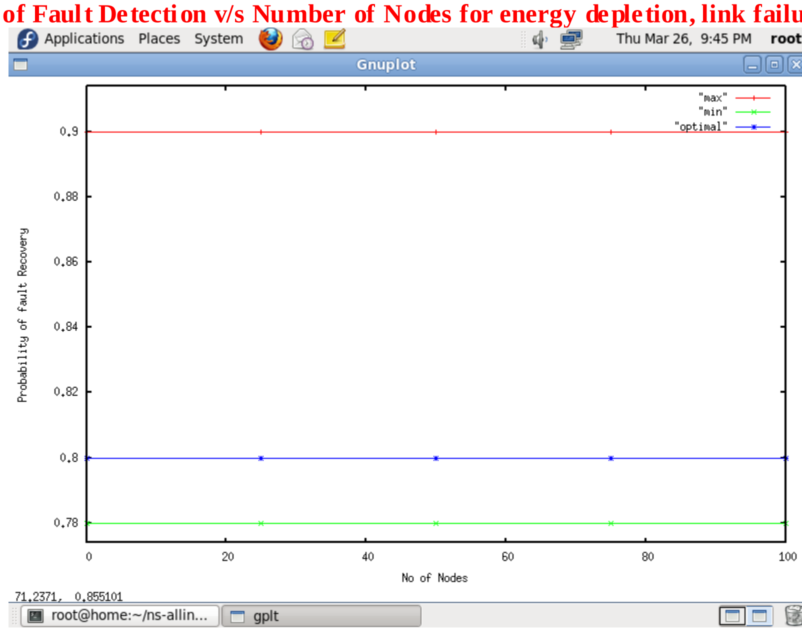

Fig. 4.2 Probability of Fault Recovery v/s Number of Nodes for energy optimization for energy depletion, link failure and packet error

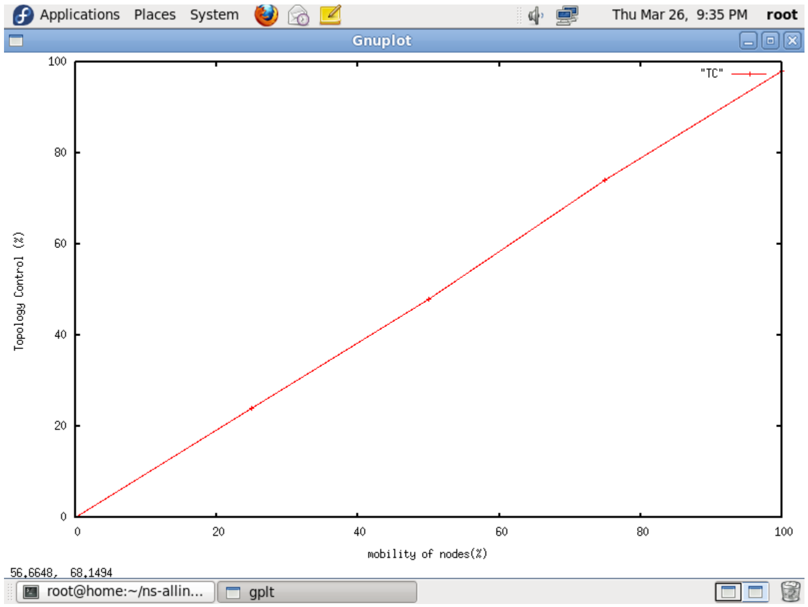

Fig. 4.3 Topology Control v/s percentage of Mobility of nodes

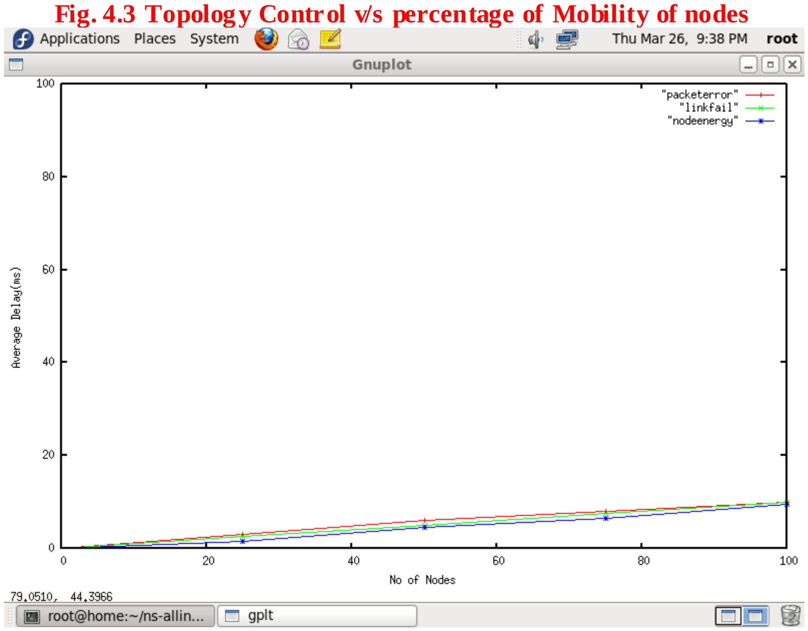

Fig.4.4 Average Delay v/s Number of Nodes for energy depletion, link failure and Packet error.

V. CONCLUSION

The proposed fault tolerant mechanism is energy-efficient and responsive to network topology. It includes faults at node level and network level. Our proposed system detects energy depletion of a node, link failure between nodes and packet error. Simulation results shows that mesh topology of our proposed system is more efficient than the star, bus and tree topology. Future scope includes presence of more than one sink node, mobility of sink node, energy optimization techniques.

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