Major Research Project (MRP)

Final Report

Title of research project: Fault Tolerant Routing in Wireless Sensor Networks

1. **UGC Reference No. and Date** F. 42-146/2013 (SR) date: 01-04-2013
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5. **Title of research project:** Fault Tolerant Routing in Wireless Sensor Networks
6. **Date of Implementation:** 01-04-2013
7. **Period of report:** from 01-04-2013 to 31-03-2017
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    (DD no: 074642 dated 11-08-2017 drawn in favour of Secretary UGC, New Delhi.)

9. Brief objective of the project:

The proposed research project will address the problem of finding an energy efficient routing and fault tolerance way in which wireless sensor nodes can communicate and gather data. Present problem definition will explore the static as well as mobile sink nodes for network coverage checking redundancy required for geographical coverage and collection of data for processing and communication between the active nodes.

To achieve this, the proposed research project addresses the following goals:

- Generate a dummy field to be used as input to our problem of sensor network
- Propose a method for coverage of the dummy field
- Proposing an algorithm for performance and reliability study of the existing network incorporating the following issues
- ▪ Taking care of static nodes and mobile sink nodes separately for data collection
- ▪ Investigating the effect of mobility on network performance
- ▪ Studying collaborative effect of the static and the mobile nodes on network performance
- Generating a mathematical model for the proposed work and its validation
- Application of proposed model to the real field for its validation

10. Methodology:

The lack of research in the area in which multiple mobile sinks can be used within the same cluster and assigning one of them to be a cluster head and the other sinks will still work within the cluster to collect data from the cluster's static sensor nodes.

It is well known that using mobile sinks in a wireless sensor network will reduce the energy consumption of the static sensor nodes. However the proposed research extends the use of mobile sinks in that it will investigate the effect that results from using multiple sinks within every cluster after portioning the network into clusters. Worth mentioning one of the existing clustering algorithms will be used to group sensor nodes within the network but it will not be further investigated as clustering is not the aim of the proposed research. Also, using multiple and redundant mobile sink nodes will increase the degree of fault tolerance of the system.

The unavailability of a clear pattern according to which mobile nodes should move. The existing research regarding sink mobility uses either random motion or an adaptive. In the proposed research sinks mobility within a cluster will take into consideration the existence of other mobile sinks within the same cluster in case it was decided that the mobile sink acting as a cluster head will be able to move too. Also, when moving a mobile sink, the existence of another sink belonging to another cluster in the intersection area of the clusters must be considered. As a result, the mobile nodes in the wireless sensor network will be moving in zones within their clusters. Therefore, the cluster head will have its own zone to move in and the other mobile sinks will be moving in the part that was not covered by the cluster head.

The unavailability of collaboration between the static sensor nodes and the mobile sinks in terms of sensing, as the previous work assumes that the static sensor nodes have the ability to sense the environment, while the sink is responsible for aggregating the data received from various nodes.

When a mobile sink that is equipped with sensing capability is in the area in which a static mobile node senses and gets information, the mobile sink will sense that region on the sensor node's behalf, while the static sensor node can go to a power saving mode. Thus, further reduction in the energy consumption of the static sensor nodes can be achieved. However, there is still a need for the static sensor nodes in the network to cover the other parts of the cluster which are not covered by the mobile sinks.

11. Work done so far and results achieved and publications, if any, resulting from the work (Give details of the papers and names of the journals in which it has been published or accepted for publication:

In this project, we have found several problems to design a fault tolerance wireless sensor network. We have formulate nine different problems in this project. To solve these problems, we have designed several algorithms. The proposed algorithms have solved these problems and have achieved numerous attracting results through the simulation and field testing. In this report, we provide these results as a final report of this project. The particulars about the proposed algorithms have achieved in our published papers that have attached separately with this report.

Problem 1:

First we have found that the recovery problem of the faulty hardware sensor nodes in WSN. In WSN, if any hardware fault occurs within the sensor nodes, these nodes declare as dead nodes. These nodes are not considered for networking in upcoming network lifetime. Therefore, network lifetime continually degrading in the faulty environments. We have solved this problem in this project.

Solution 1:

We propose efficient fault detection and routing (EFDR) scheme to manage a large size WSN. Cellular automata (CA) based node management technique is used for fault detection in our technique. The proposed CA based rules run on every sensor node and each sensor node set own state with the help of CA. The faulty nodes are detected by neighbor node's temporal and spatial correlation of sensing information and heart beat message passing by the cluster head. On the other hand L-system based data routing scheme is proposed to determine optimal routing path between the cluster head and the base station. The proposed EFDR technique is capable of detecting and managing the faulty nodes in an efficient manner. The simulation results show approximately 86% improvement in the energy loss rate compare to the algorithm proposed by Venkataraman et. al.

Results:

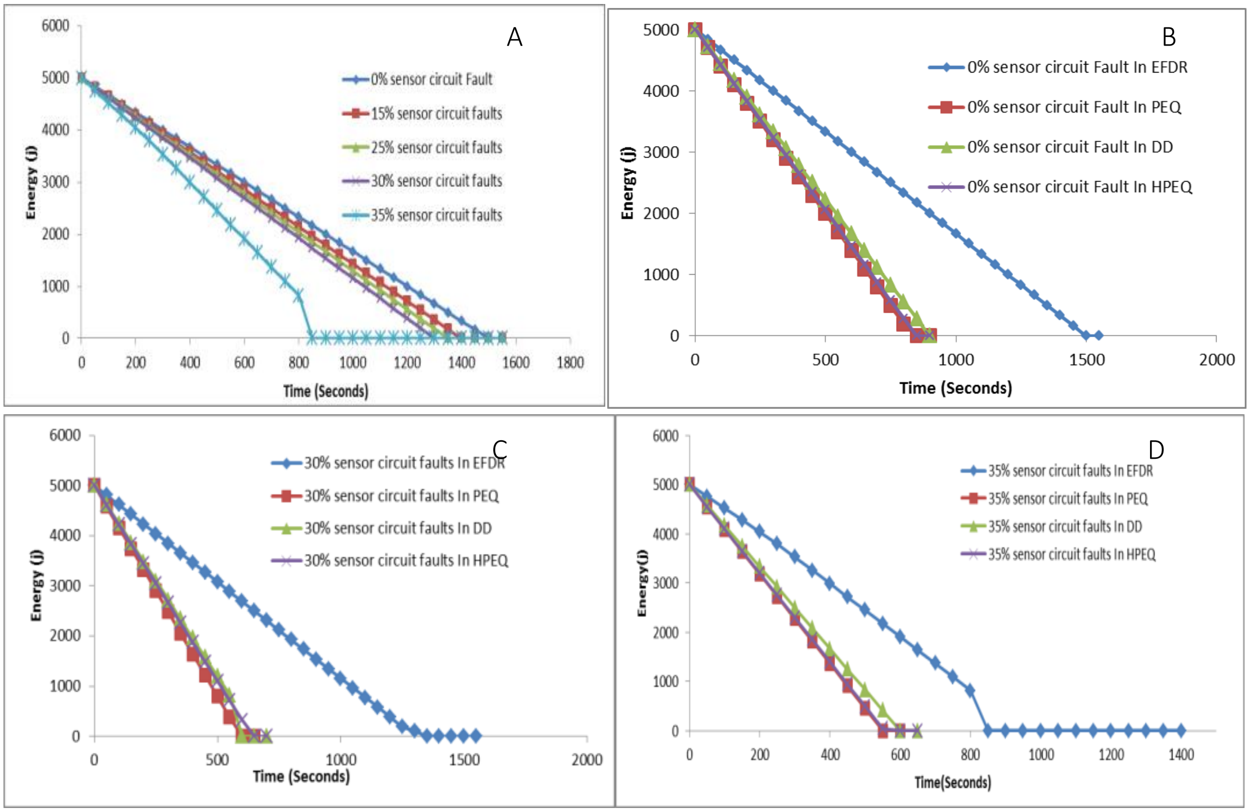
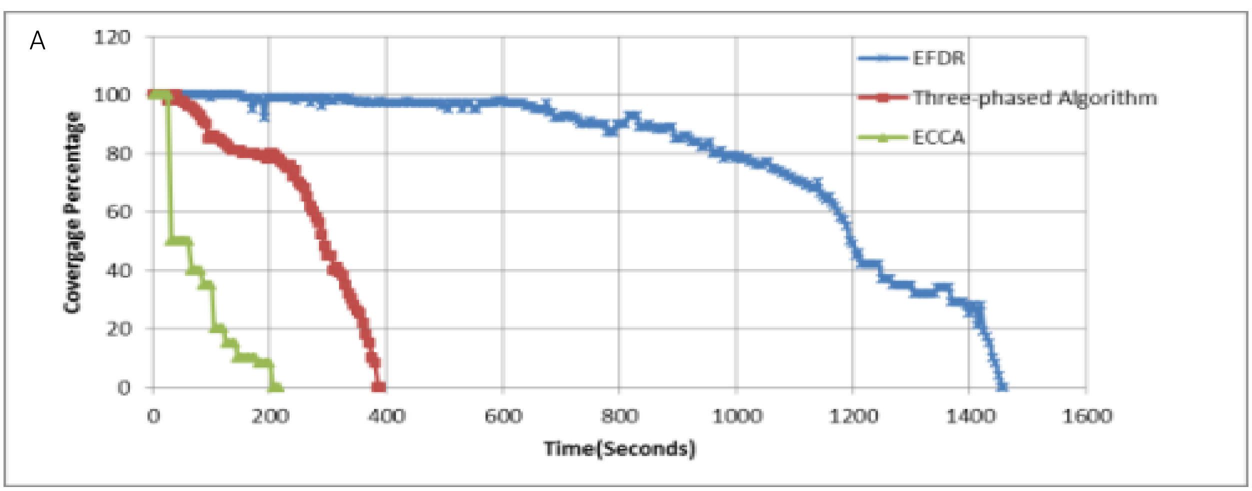


Figure: A) Energy loss in WSN at different percentage sensor circuit fault. B) Energy loss comparison between EFDR, PER, DD and HPEQ at 0% sensor circuit fault. C) Energy loss compression between EFDR, PER, DD and HPEQ at 30% sensor circuit fault. D) Energy loss comparison at 35% sensor circuit fault.



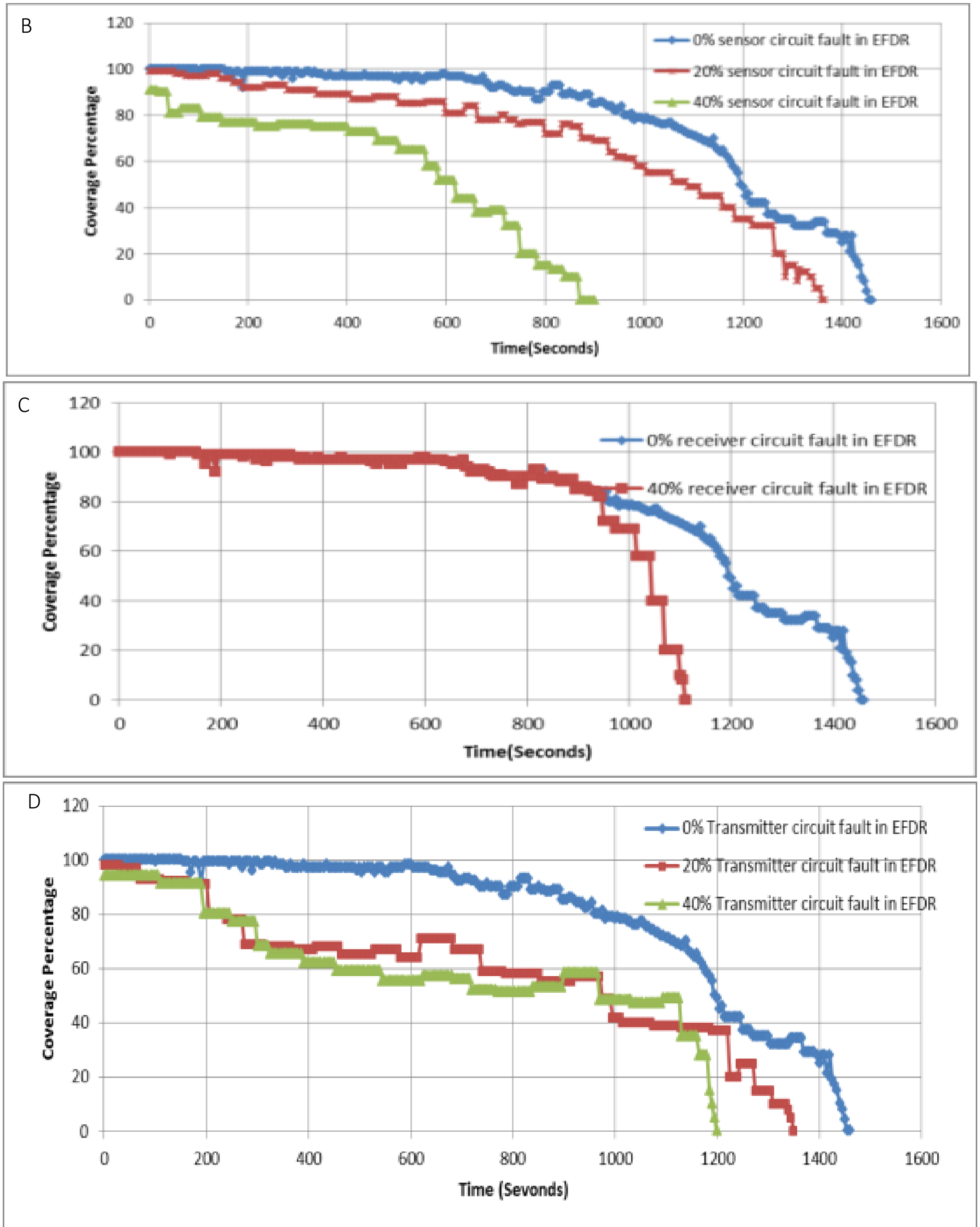


Figure: A) The network coverage compression. B) The network coverage of EFDR scheme at different percentage of sensor circuit fault, C) The network coverage of EFDR scheme at different percentage of receiver circuit fault D) The network coverage percentage of EFDR at different percentage of transmitter circuit fault.

Publication Details of problem 1:

Title = "Effective fault detection and routing scheme for wireless sensor networks ",
Journal = "Computers & Electrical Engineering ",
Volume = "40",
Number = "2",
Pages = "291 - 306",
Year = "2014",
Note = "",
ISSN = "0045-7906",
DOI = "https://doi.org/10.1016/j.compeleceng.2013.04.027",
url = "http://www.sciencedirect.com/science/article/pii/S0045790613001341",
Author = "Indrajit Banerjee and Prasenjit Chanak and Hafizur Rahaman and Tuhina Samanta",

Problem 2:

A standard fault diagnosis and detection scheme can improve the reusability of the fault sensor. Therefore, a fault tolerant WSN demands an efficient fault diagnosis and detection scheme for performance and lifetime enhancement.

Solution 2:

Energy efficient routing is the major goal to design an effective and high performance wireless sensor network (WSN). To design energy efficient routing technique, it is essential to consider load balancing as unavoidable phenomena. We present a new dynamic load balanced routing policy offering a high level of energy efficiency. Unlike existing routing solutions, our scheme is based on a distributed and load balancing scheme. Furthermore, it employs a new fuzzy based node classification scheme to enhance the network lifespan and coverage of the network. Node decides multi-hop data transmission path according to node efficiency. Therefore, proposed policy distributes routing load throughout the network. Extensive analysis and simulation show that our approach improves many important performance metrics such as: network life span, global energy loss, transmission delay, and packet delivery ratio.

Results:

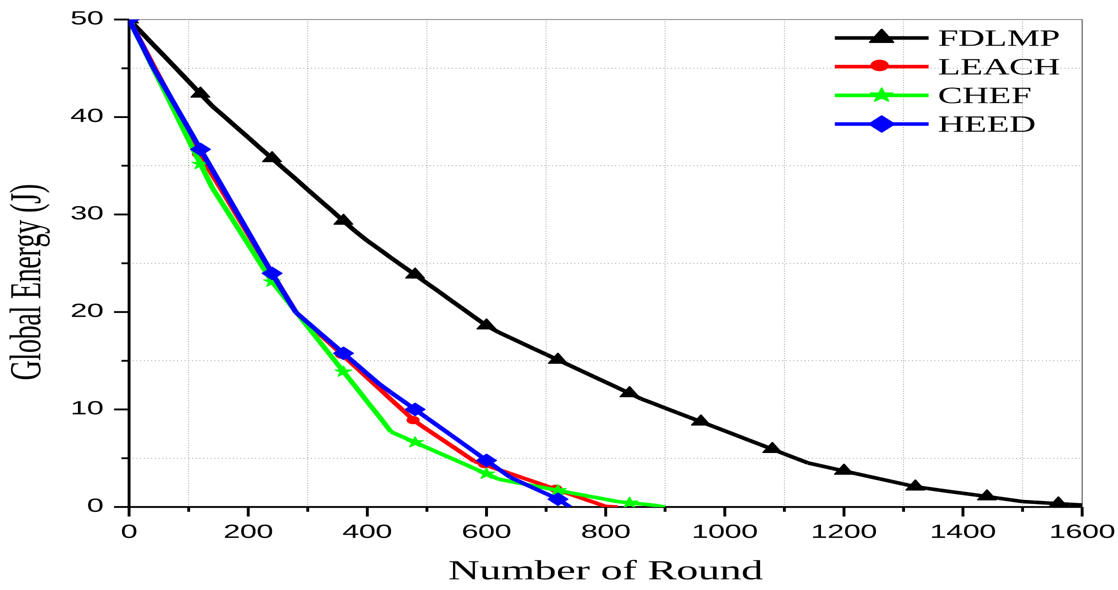
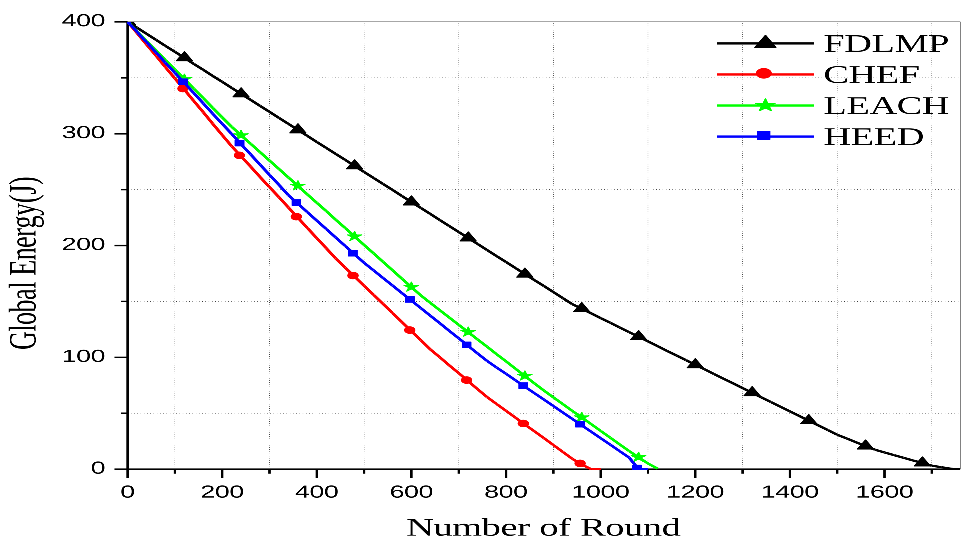
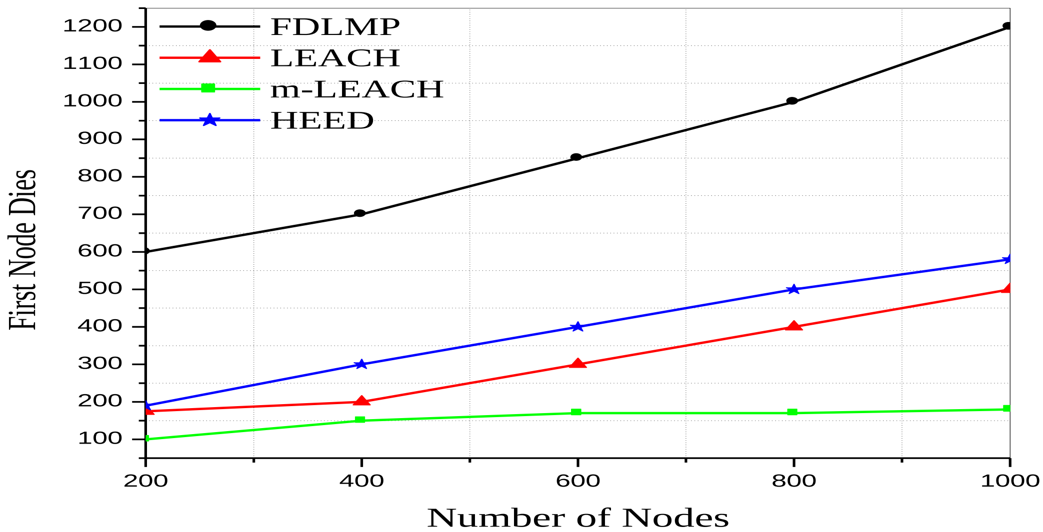


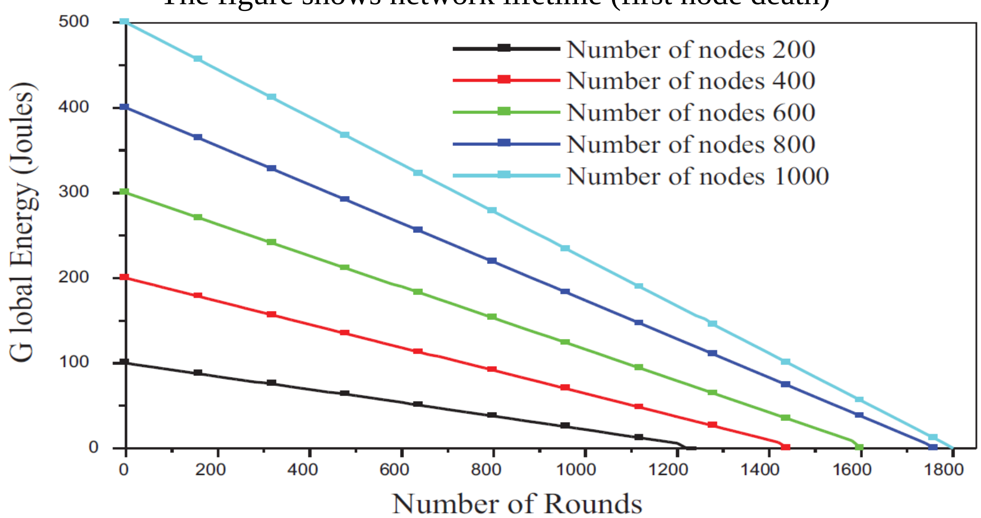
Figure shows global energy loss with 100 nodes



The figure shows global energy loss with 800 nodes.



The figure shows network lifetime (first node death)



The figure shows global energy loss in FNCM scheme for different network size

Publication Details of problem 2:

Title = "Fuzzy rule-based faulty node classification and management scheme for large scale wireless sensor networks ",
Journal = "Expert Systems with Applications ",
Volume = "45",
Pages = "307 - 321",
Year = "2016",
ISSN = "0957-4174",
DOI = "https://doi.org/10.1016/j.eswa.2015.09.040",
url = "http://www.sciencedirect.com/science/article/pii/S0957417415006697",
Author = "Prasenjit Chanak and Indrajit Banerjee".

Problem 3:

A high performance WSN needs an efficient fault tolerant technique that can tolerate the maximum amount of errors which may be occur during data gathering phases. On the other hand, high message overhead is another problem to design an efferent fault tolerant technique.

Solution:

In a wireless sensor network, reliability is the main issue to design any routing technique. To design a comprehensive reliable wireless sensor network, it is essential to consider node failure and energy constrain as inevitable phenomena. In this work we present energy efficient node fault diagnosis and recovery for wireless sensor networks referred as energy efficient fault tolerant multipath routing scheme for wireless sensor network. The scheme is based on multipath data routing. One shortest path is used for main data routing in our scheme and other two backup paths are used as an alternative path for faulty network and to handle the overloaded traffic on main channel. Shortest pat data routing ensures energy efficient data routing. Extensive simulation results have revealed that the performance of the proposed scheme is energy efficient and can tolerate more than 60% of fault.

Results:

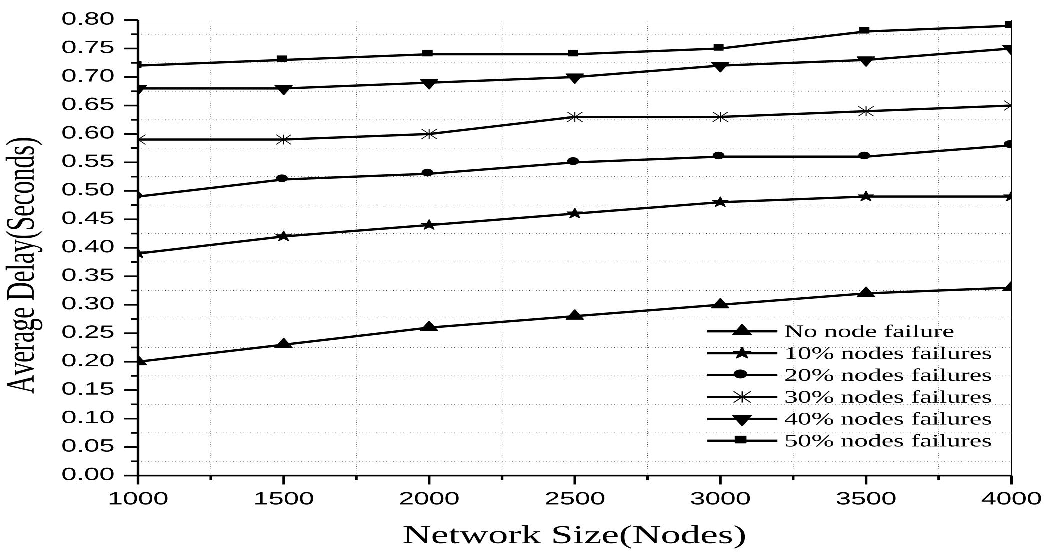


Figure demonstrates an average delay in different percentage of node failures

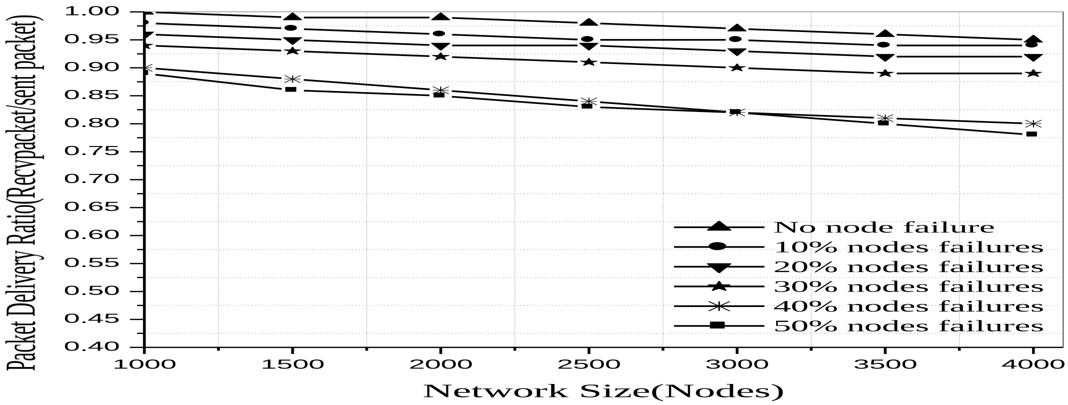


Figure shows average packet delivery in different percentage of node failures

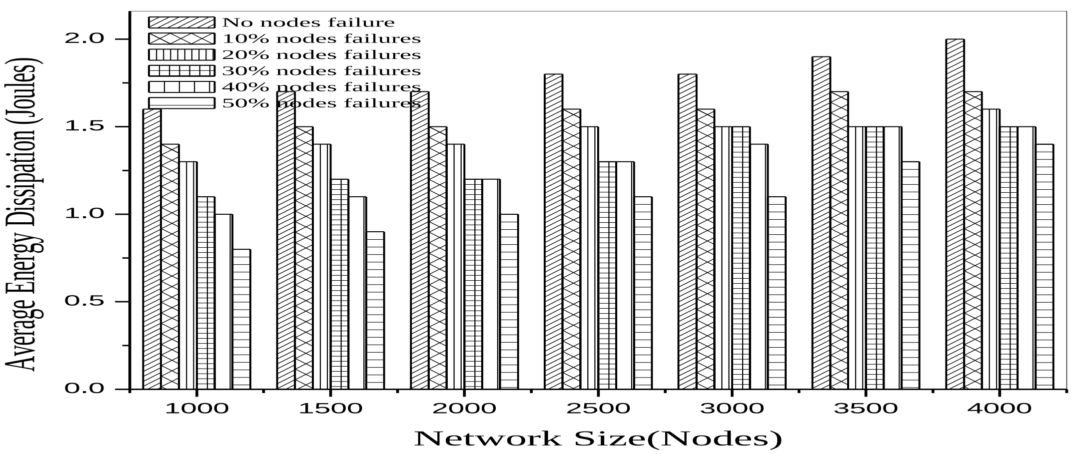


Figure illustrates the average dissipated energy in different percentage of node failures

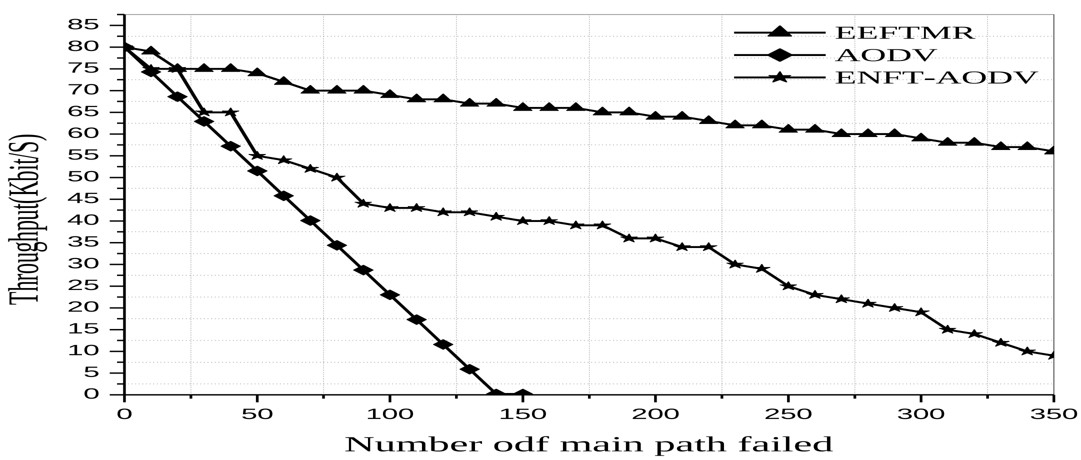


Figure shows throughput with respect to main routing path fault

Publication Details of problem 3:

Title = "Energy efficient fault-tolerant multipath routing scheme for wireless sensor networks",
Journal = "The Journal of China Universities of Posts and Telecommunications",
Volume = "20",
Number = "6",
Pages = "42 - 61",
Year = "2013",
ISSN = "1005-8885",
DOI = "http://dx.doi.org/10.1016/S1005-8885(13)60107-7",
url = "http://www.sciencedirect.com/science/article/pii/S1005888513601077",
Author = "Prasenjit Chanak and Indrajit Banerjee",

Problem 4:

The Obstacles detection technique can reduce the fault occurrence percentage in the wireless sensor networks. Therefore, WSN demands an energy efficient obstacles detection technique for it performance improvement.

Solution:

This work reports an obstacle discovery and localization scheme in wireless sensor network (ODLS). Sometime due to limited knowledge about obstacle, source node's data are unable to reach destination node. Therefore, base station unaware about the source node's monitoring field. On the other hand, without the knowledge of the obstacles end-user is unable to make appropriate decisions. The propose scheme detects obstacle having minimum exposure with graph based triangulation scheme and also detects the approximate location of it by edge based scheme. Experimental results show that the proposed scheme ensures better obstacle detection and localization in wireless sensor network.

Results:

TABLE1: obstacle detection history in different nodes numbers (nodes deployed area 30×30)

Number of Sensor node deployed	**Obstacle detection rate**	**Total energy consumption (Joule)**	**Total time delay (seconds)**	**Average obstacle detection delay**	**Total energy loss percentage for obstacle information routing (joule)**	**Average obstacle information routing delay**
50	0.2	0.260	4	2	0.0041	1.50

100	0.3	1.030	6	2	0.0061	1.50
150	0.4	2.310	8	2	0.0082	1.60
200	0.5	4.100	10	2	0.0122	1.70
250	0.6	6.400	13	2.16	0.0123	1.70
300	0.7	9.210	16	2.28	0.0179	1.80
350	0.8	12.530	20	2.5	0.0204	1.85
400	0.9	16.360	24	2.66	0.0248	1.90
450	1	20.700	28	2.8	0.0275	1.95

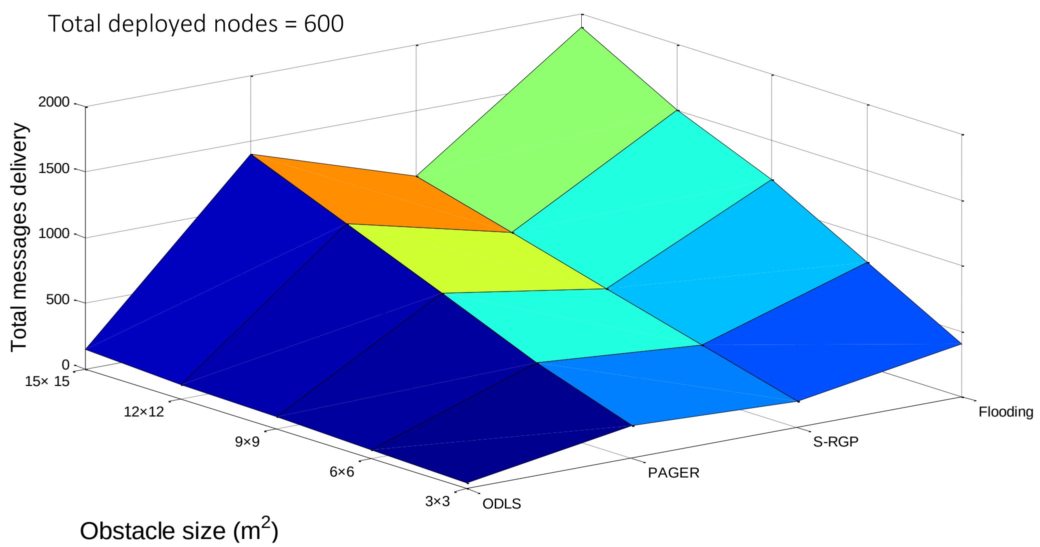
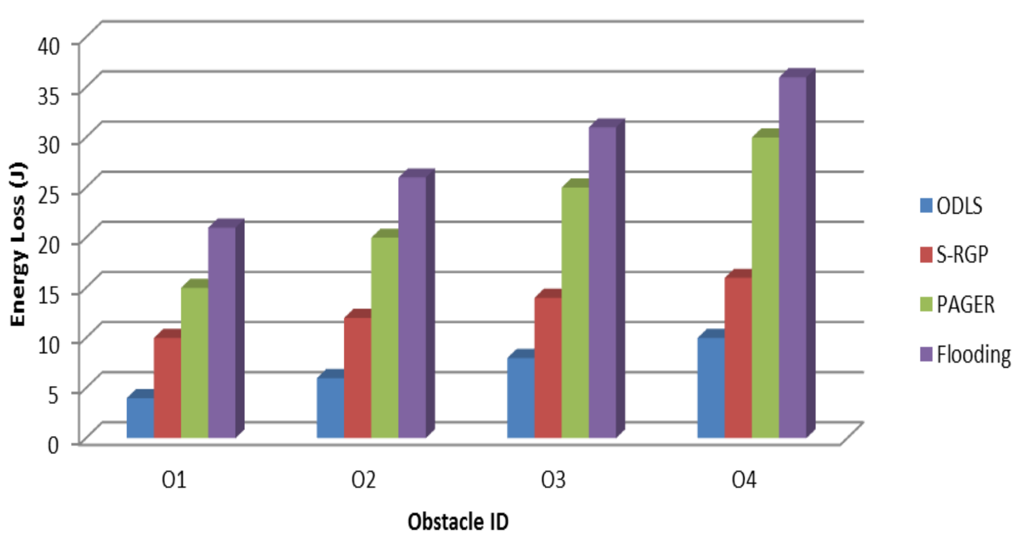


Figure shows total message passing with varying size of an irregular obstacle



The figure displays energy loss for different size of obstacle detection

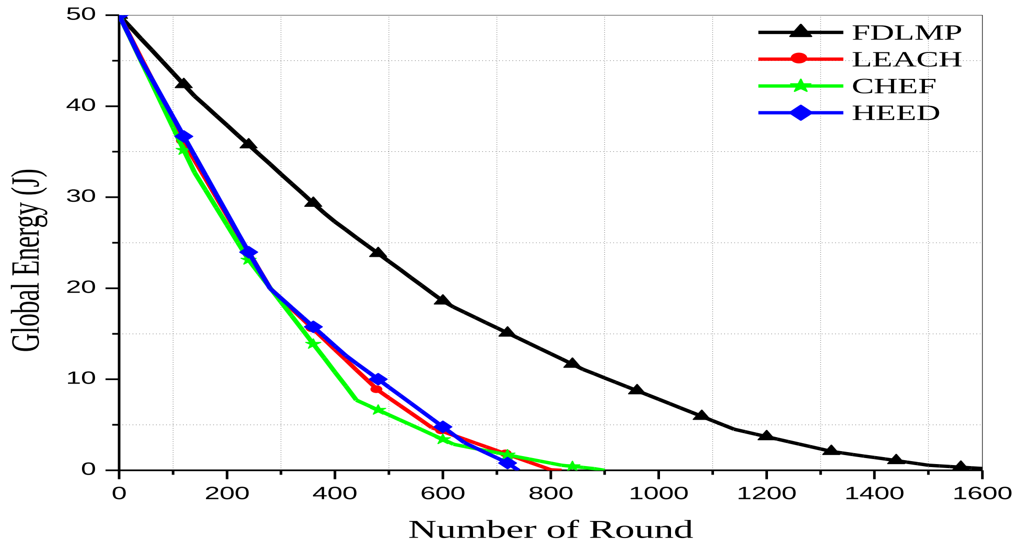
Problem 5:

A load distribution scheme can reduce the fault occurrences possibility within the network lifetime. Therefore, a load distribution scheme is essential to reduce faults within the network.

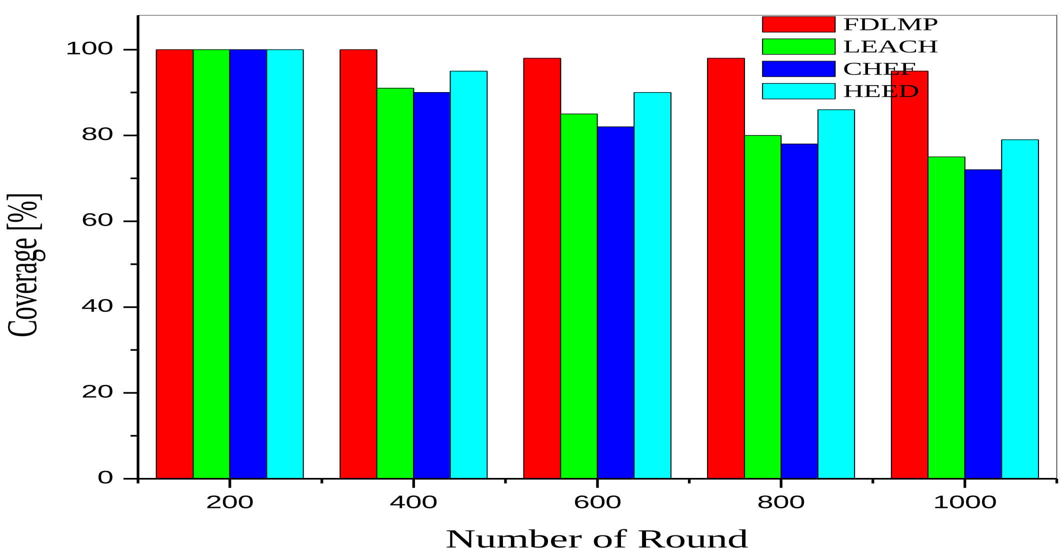
Solution:

Energy efficient routing is the major goal to design an effective and high performance wireless sensor network (WSN). To design energy efficient routing technique, it is essential to consider load balancing as unavoidable phenomena. In this work, we present a new dynamic load balanced routing policy offering a high level of energy efficiency. Unlike existing routing solutions, our scheme is based on a distributed and load balancing scheme. Furthermore, it employs a new fuzzy based node classification scheme to enhance the network life span and coverage of the network. Node decides multi-hop data transmission path according to node efficiency. Therefore, proposed policy distributes routing load throughout the network. Extensive analysis and simulation show that our approach improves many important performance metrics such as: network life span, global energy loss, transmission delay, and packet delivery ratio.

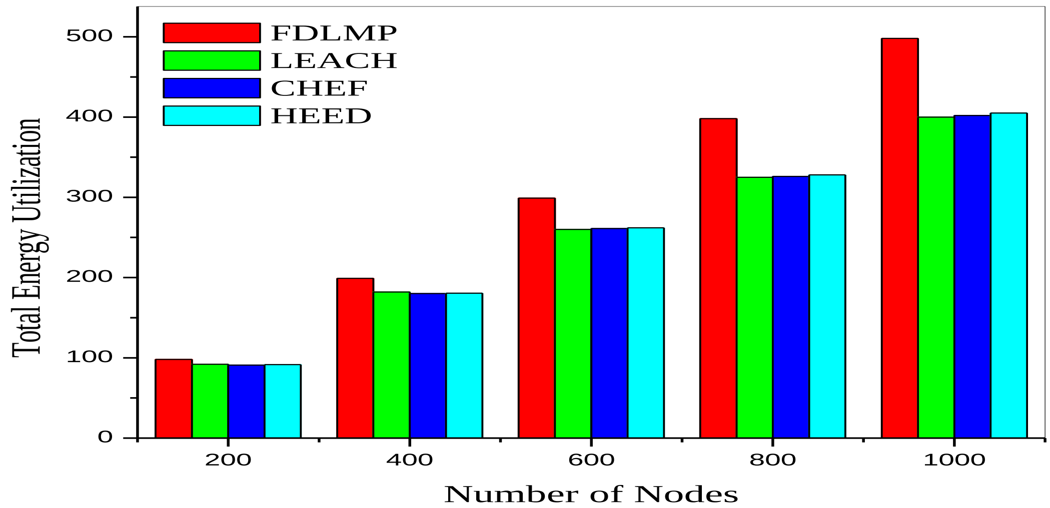
Result:



The figure shows global energy loss with 100 nodes.



The figure shows converges percentage comparison for a network of size 500×700 m^2 with 800 nodes.



The figure shows a comparison of energy utilization for FDLMP, LEACH, CHEF, and HEED.

Publication Details of problem 5:

Title = "Fuzzy rule-based faulty node classification and management scheme for large scale wireless sensor networks ",
Journal = "Expert Systems with Applications ",
Volume = "45",
Pages = "307 - 321",
Year = "2016",
ISSN = "0957-4174",
DOI = "https://doi.org/10.1016/j.eswa.2015.09.040",
url = "http://www.sciencedirect.com/science/article/pii/S0957417415006697",
Author = "Prasenjit Chanak and Indrajit Banerjee".

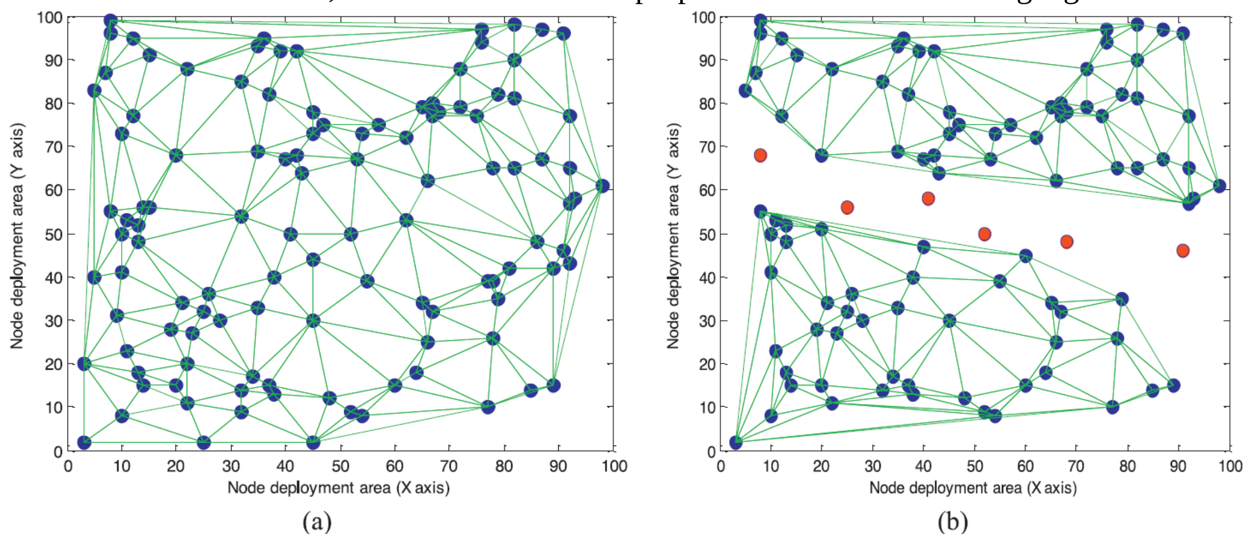
Problem 6:

In a 2D plane of the form of an undirected graph, G = (V, E), where V is the set of all vertices and E is the set of all edges. Each sensor node, $n_i \in V$, periodically senses data from the monitoring area and sends its data to the BS through multi-hop communication. Due to the different types of environmental hazards including interference and deployed nodes failures, network failure can occur within the network. Therefore, a sub set of nodes $V_j = \{n_1, n_2, \ldots\ldots, n_j\}$, ($V_j \subseteq V$) become disconnected from the rest of the network, thus sensed data packets cannot reach the BS. As mentioned earlier, such a network condition can degrade the QoS of WSNs. If these failures can be tolerated during the data routing stage, then sensed information can successfully reach the BS and the QoS of the WSN can be maintained. On the other hand, node failures or link errors frequently change throughout the network lifetime which significantly increases the data routing delay and energy consumption of the deployed sensor nodes.

Solution:

Our main objective is to overcome a network failure condition in a WSN in an energy efficient manner and relay data packets from the source nodes to the BS with minimum time delay. Next we state the problem definition formally.

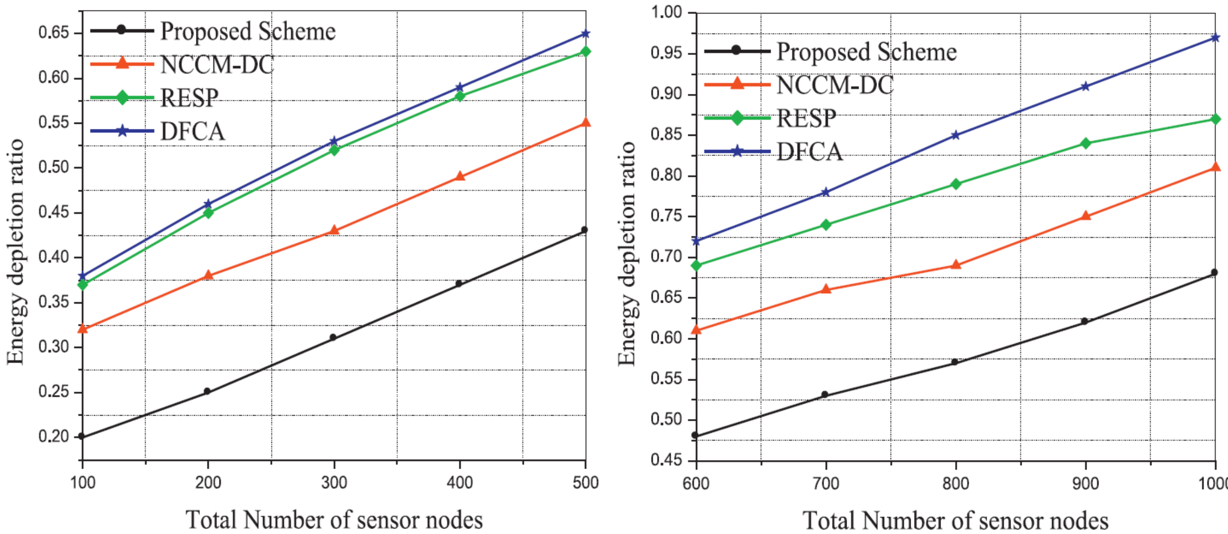
This section describes our proposed three related algorithms: Distributed Energy Efficient Heterogeneous Clustering (DEEHC), k - Vertex Disjoint Paths Routing (kVDPR), and Route Maintenance Mechanism (RMM). The primary goal of the proposed scheme is to consume the minimum energy of the deployed sensor nodes while selecting k disjoint paths. In our proposed DEEHC algorithm, the deployed sensor nodes are organized into different clusters with- out any central control. Therefore, in this section we first propose the DEEHC clustering algorithm.



The figure shows example of network failure due to node failures.

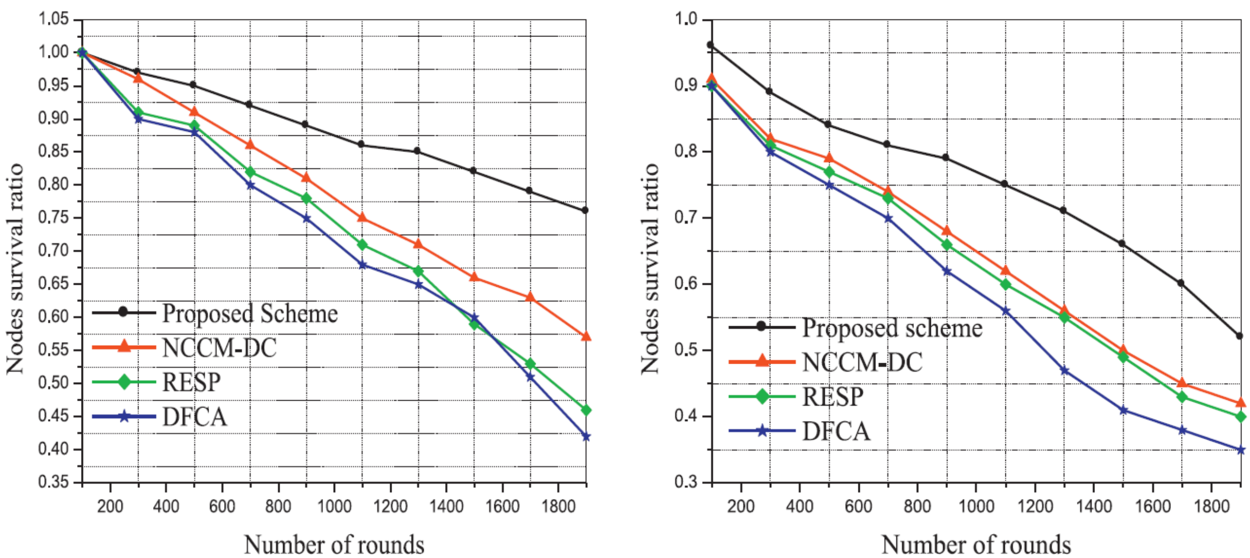
- **Simulation results:**

This work has presented three interrelated algorithms, DEEHC, kVDPR and RRM. The performance of these algorithms are evaluated and compared with the existing algorithms NCCM-DC, RESP, and DFCA in terms of energy depletion ratio, node survival ratio, average success rate, message overhead, number of management packets, and data routing delay. The simulation parameters and their values used in simulation are shown in Table 1 being the same as in the literature. All the algorithms are simulated in a standard network simulator, NS3. The number of disjoint multi paths from each source node to the nearest CH has been set as k = 3. The probabilities of intra-cluster node failure and CH failure are initially set $P_{node\_failure}$ = 0.02 and $P_{CH\_failure}$ = 0.03. To verify the effectiveness, reliability and generality of the proposed algorithms, the simulations were conducted into two scenarios: small scale network, and large scale network. In the small-scale network, the network size is varied from 100 to 500. In large scale network, it is in the range of 600 to 1000.



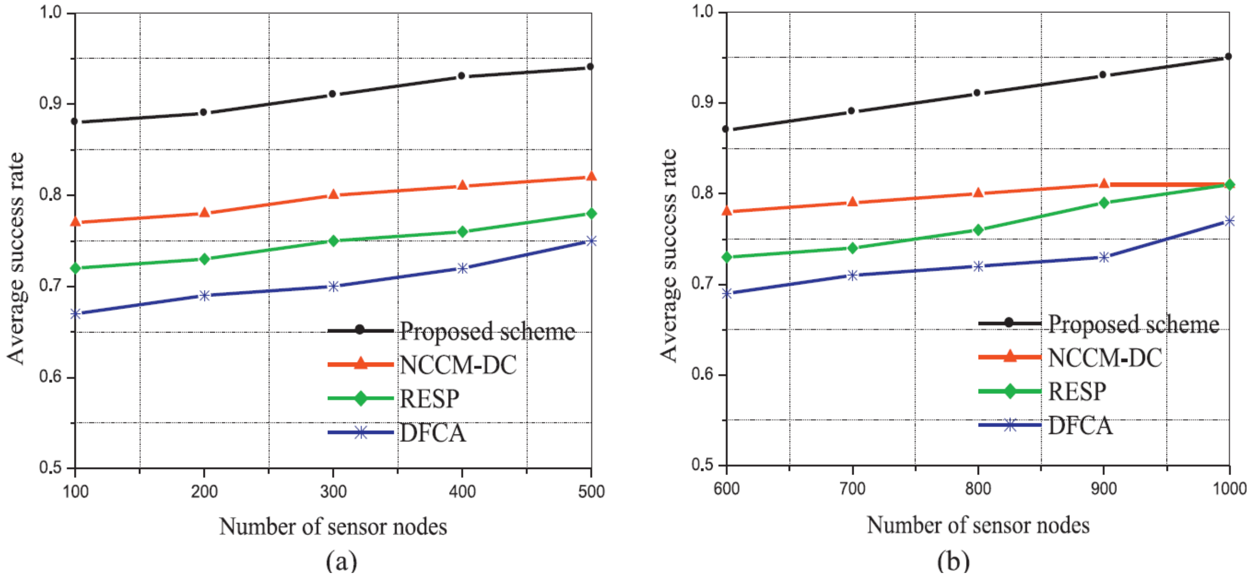
(a) (b)

The figure shows ratio of energy depletion with increasing number of nodes (for k = 3).



(a) (b)

The figure shows node survival ratio per round, a) scenario 1 (100 nodes) and b) scenario 2 (10 0 0 nodes).



The figure shows average success rate of packet delivery using different failure probabilities, a) scenario 1 (*P node_failure* = 0.02) and b) scenario 2 (*P node_failure* = 0.03).

Publication Details of problem 6:

Title = "Energy-aware distributed routing algorithm to tolerate network failure in wireless sensor networks ",
Journal = "Ad Hoc Networks ",
Volume = "56",
Pages = "158 - 172",
Year = "2017",
ISSN = "1570-8705",
DOI = "https://doi.org/10.1016/j.adhoc.2016.12.006",
url = "http://www.sciencedirect.com/science/article/pii/S157087051630333X",
Author = "Prasenjit Chanak and Indrajit Banerjee and R. Simon Sherratt".

Problem 7:

In existing fault detection approaches, most of the energy avail- able to a sensor node is consumed on two major tasks, viz. diagnosis status selection of deployed sensor nodes and localization of faulty nodes within the network. Fault diagnosis strategies depend on the network topology or the location of sensor nodes since fault diagnosis is an important factor that can directly impact the performance and lifetime of the network. In dynamic applications of WSNs, the network structure can frequently change due to rapid fault occurrences within the network. Existing static sink based fault diagnosis approaches lead to large numbers of messages sent over the network (both data and status) in order to adapt to the topological changes. Hence, the available energy of the sensor nodes in the network can be rapidly depleted. In addition, sensors close to the sink suffer from much more traffic being routed through them compared to sensors at the boundary of the network due to the need to route data and status packets from sensors that are far away from the sink (Lau et al., 2014 and Koushanfar et al., 2003). After these sensors fail, communication holes, or energy holes, are created near to the sink node and the network can then become unreliable or even disconnected. In some cases, nodes and link failures may potentially portion an en- tire network into several sub-networks, hence these sub-networks become disconnected from the rest. Then, a Base Station (BS), or network administrator can declare these sub-networks dead due to the lack of available health information and exclude these sub-network nodes from the main network, despite most of the sub- network nodes can still survive for a long period of time. Recently, interesting approaches have been used for MS data gathering that can collect data from deployed sensor nodes in an energy efficient manner (Zahhad et al., 2015 and Mi et al., 2015). These MS based data gathering strategies successfully collected data from different sub-networks in the network portion state. In these approaches, it was argued that MS based WSN management strategies are more effective in improving the performance of the network in dynamic environments. These works motivated us to propose an MS based fault diagnose strategy for WSNs.

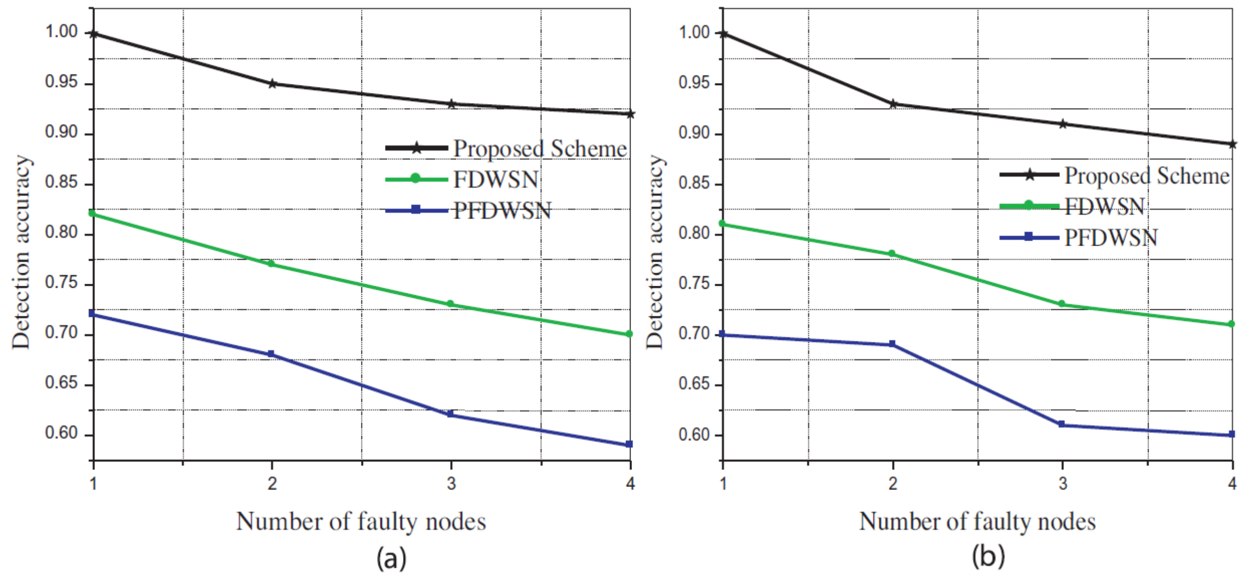
Solution:

To address the above problems, this work proposes an MS based distributed fault diagnosis approach. In our approach, a mobile fault detector starts the fault diagnosis tour periodically from the BS, traverses the network, performs a diagnosis action on each static sensor node using single-hop communication and at the end of each fault diagnosis tour the mobile fault detector transports the entire network health information to the BS. During the fault detection tour, each deployed sensor node is directly diagnosed by the mobile fault detector and hence the current network structure is not affected by the fault diagnosis process. Moreover, if the fault detection tour is well planned, the mobile fault detector can accurately localize the abnormal nodes within in the network thus reducing the fault detection delay. This will give network administrators an up to date status of the network.

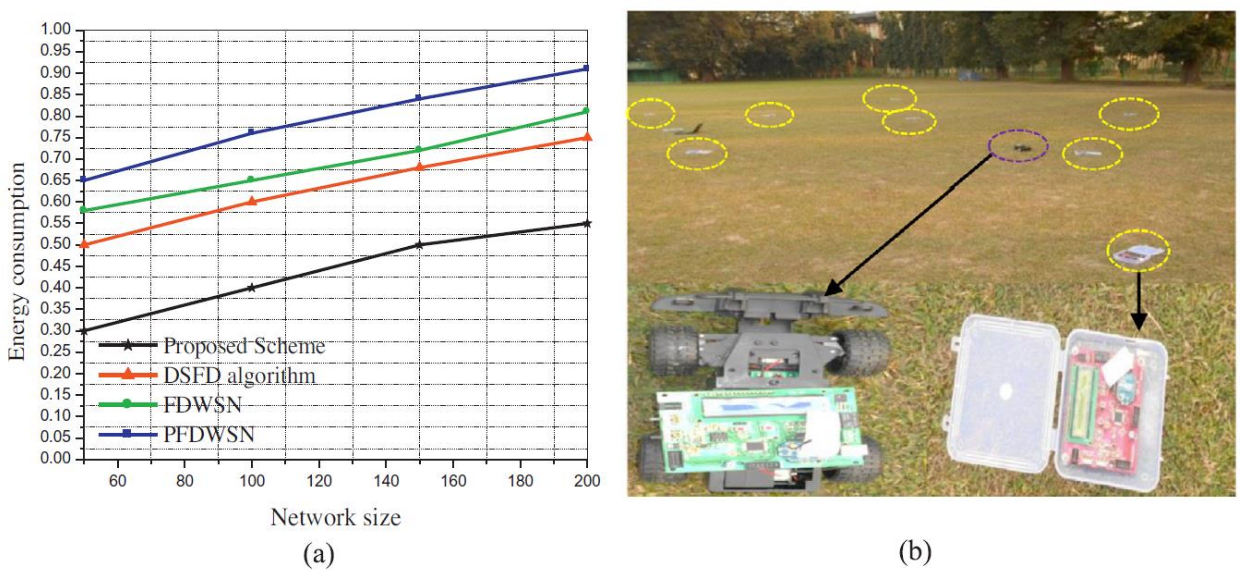
The major contributions of this work can be summarized as follows:

1. We propose a Mobile Sink based fault detector to perform fault diagnosis in WSNs. It reduces the message overhead and is resilient to network topology changes during the fault diagnosis process.
2. We propose a hardware fault detection mechanism where each hardware component of the deployed sensor nodes is diagnosed by the mobile fault detector. Therefore, network administrators find the exact causes of any faults within the network. The proposed detector may also help to maintain the network.
3. We focus on the problem of minimizing the length of each fault diagnosis tour by excluding faulty sensor nodes from the WSN, improving QoS.
4. We carry out extensive simulations and real life experiments. The effectiveness of the proposed scheme is verified by comparing our method with other fault detection approaches in the literature. In addition, the real time applicability of the proposed scheme is confirmed by the real life experimental results.

- **Experimental results:**



The figure shows fault detection accuracy in the outdoor test: (a) hardware failure, (b) hardware and software failure.



The figure shows (a) Energy consumption rate during the fault diagnosis process. (b) Network topology in the outdoor test.

Publication Details of problem 7:

Title = "Mobile sink based fault diagnosis scheme for wireless sensor networks ",
Journal = "Journal of Systems and Software ",
Volume = "119",
Pages = "45 - 57",
Year = "2016",
ISSN = "0164-1212",

DOI = "https://doi.org/10.1016/j.jss.2016.05.041",
url = "http://www.sciencedirect.com/science/article/pii/S0164121216300620",
Author = "Prasenjit Chanak and Indrajit Banerjee and R. Simon Sherratt".

Problem 8:

Fault tolerance of network can be achieved through the load distribution of cluster head. Load distribution reduces the overhead of cluster head. Due to reduction of this overhead, the fault occurrence diminishes. Fault tolerance can also be enhanced by node authentication and secure transmission of data. If authentication is not performed, then some unknown sources may generate a bulk amount of data which if received by the cluster head, probability of system failure will be on the rise.

Cluster formation and Cluster head detection: Cluster is formed according to the co-ordinate values of the sensor nodes as shown in Fig 1a (for uniform distribution) and Fig 1b (for non-uniform distribution). The cluster head is selected in the centre of the cluster for both uniform and non-uniform deployment of nodes. In case of non-uniform deployment, if there is no node in the centre, then choose nearest node from the centre as cluster head. After the selection of cluster head, the load of cluster head is distributed among its two neighbouring nodes.

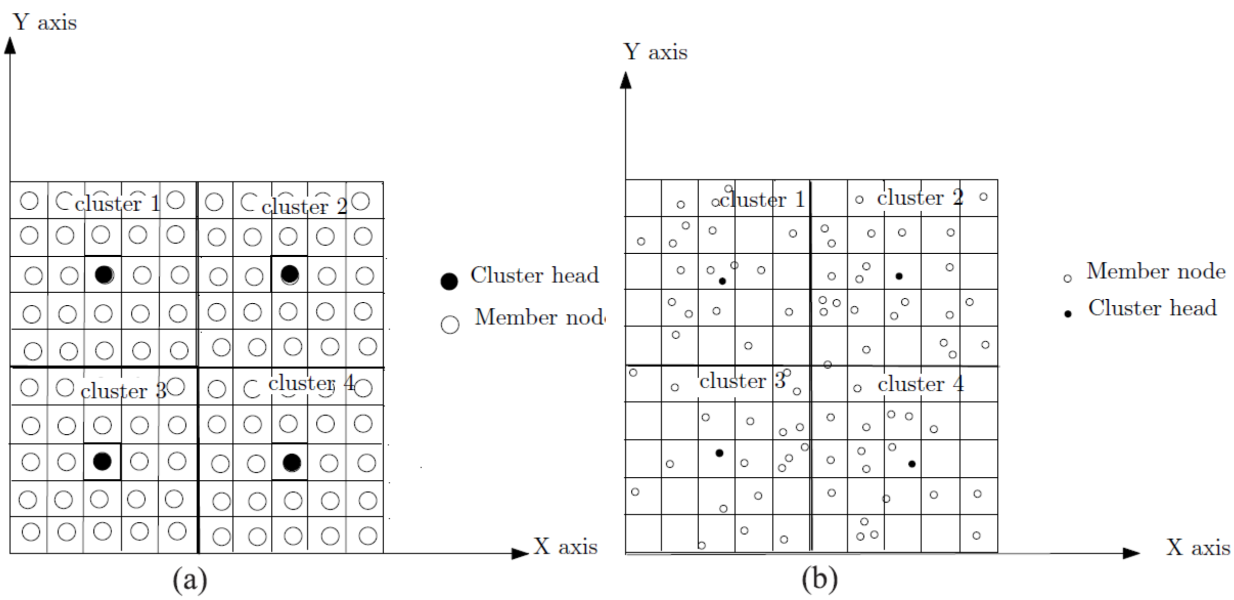


Figure (1a) Cluster formation for uniform distribution of nodes. (1b) Cluster formation for uniform deployment.

Fault tolerant data transmission: One neighbouring node of cluster head performs authentication and another one transmits data. Through cluster head and transmission head only the authenticated nodes are allowed to transmit data to the base station.

Solution:

In this paper we will mainly concentrate on the distribution of the load of a cluster head to its neighbouring nodes. The functions of the cluster head are as follows:-

a) **Data receiving and Data aggregation:** Cluster head collects data from its member nodes which are within the respective cluster and then aggregates the received data.
b) **Authentication:** Authentication is required to prevent cluster head from malicious attacks if in case they receive unauthorized data from unknown source.
c) **Data transmission:** Cluster head transmits the aggregated data to the base station.
d) **Routing:** For those cluster heads which reside far from the base station and cannot directly send data to it, require routing. They send data to another cluster head which is within the transmission range of the former and also nearer to the base station.

The node lying in the centre position of a network is eventually selected as the cluster head as shown in Fig 2. The cluster head performs the most important role of selecting the transmission & routing head and authentication head among the neighbouring nodes and it itself performs data receiving and data aggregation.

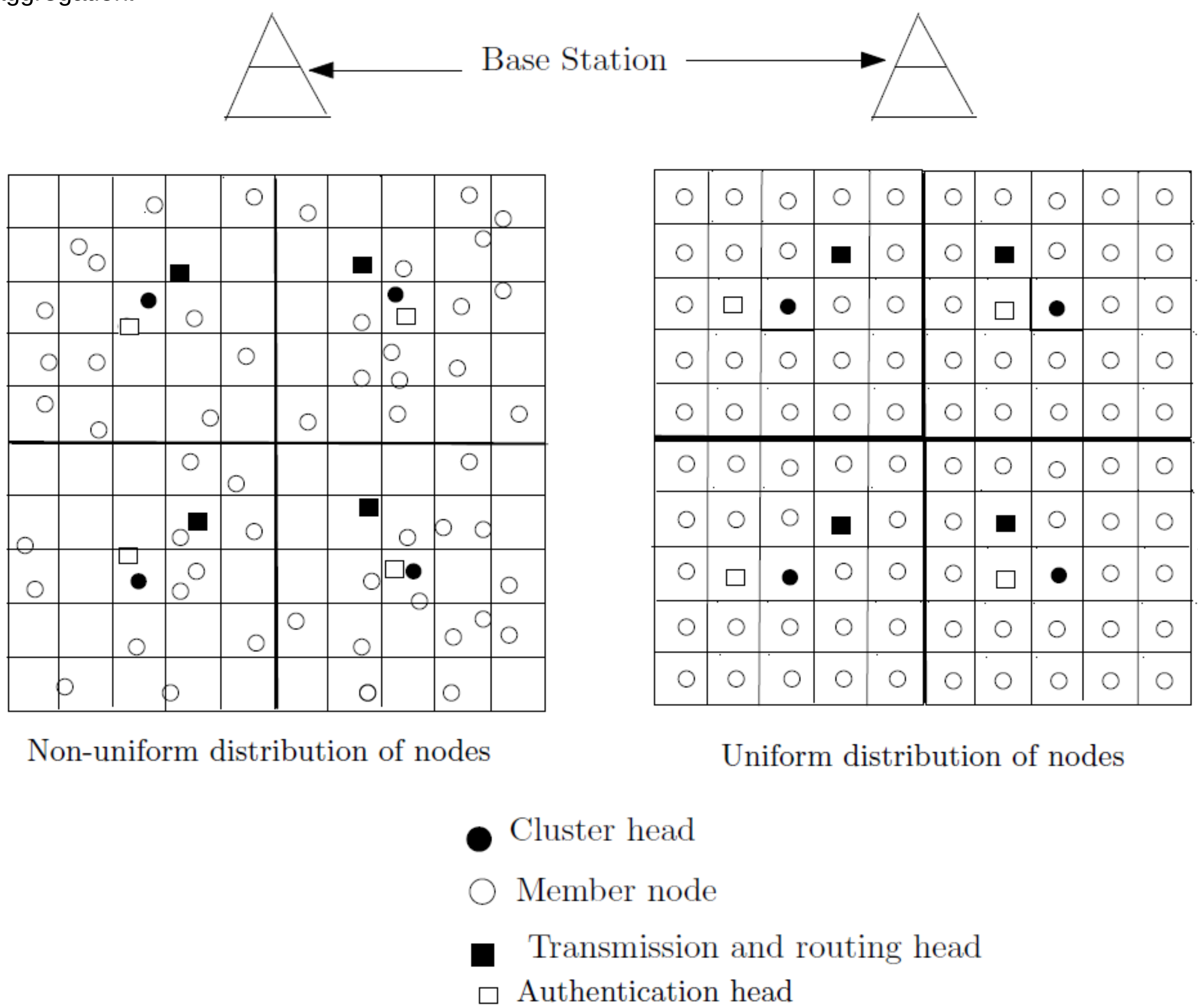


Figure (2) Cluster head and its neighboring nodes position in a cluster.

We have proposed the algorithm for both uniform and non-uniform deployment of nodes. We consider the whole network as a grid. For uniform distribution each grid consists of one node. But for non-uniform each grid may or may not consist of nodes.

In Algorithm 1 (Main Algorithm) cluster head is selected for the first time. For selection of transmission & routing head and authentication head_trans head and authen_head functions are respectively called. Energy loss due to data transmission, data receiving, data aggregation and node authentication is calculated. When residual energy of cluster head is less than the threshold, then we use the cluster_head function. If the residual energy of transmission and routing head is less than the threshold then trans_head function is called. The authen_head function is called if the residual energy of the authentication head is less than that of the threshold. This whole process gets repeated until the first node dies.

In Algorithm 2, alternate cluster head is selected when residual energy of the previous cluster head is less than the threshold value. The new cluster head is selected among the neighbouring nodes of first cluster head. Also, those nodes which have not been previously chosen, can also be considered.

In Algorithm 3, transmission & routing head is selected between those nodes which are in the neighbourhood of cluster head and it has minimum distance from the base station.

In Algorithm 4, authentication head is selected out of the neighbouring nodes of cluster head and it has minimum distance from the cluster head.

- **Simulation results:**

Our simulation results show that the proposed algorithm can reduce the overhead of cluster head and provide an energy efficient mechanism.

Different parameters for this simulation are given in Table 1

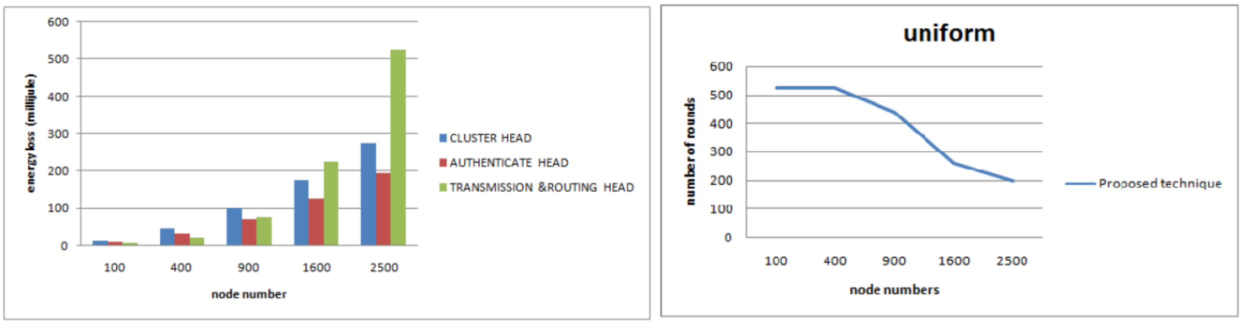
Parameter	Values (uniform)	Values (non-uniform)
Size of the network	$400m^2$ to $10000m^2$	$400m^2$ to $6400m^2$
Number of nodes	100 to 2500	110 to 2060
Size of grid	2m×2m	2m×2m
Transmission range of sensor node	40m	40m
Data packet size	800 bits	800 bits
Initial energy	.5J	.5J
Energy loss by transmitter electronics circuit(α_1)	50nJ/bit	50nJ/bit
Dissipated energy by transmit op-amp(α_2)	10pJ/bit/m^2	10pJ/bit/m^2
Energy loss due to Data aggregation	5nJ /bit/message	5nJ/bit/message

Table 1: **PARAMETERS CONSIDERED FOR SIMULATION**

In our proposed algorithm all the nodes are static. All sensor nodes are divided into a number of clusters, and each cluster executes the algorithm independently. We have assumed that all the nodes within one cluster are homogeneous. The communication environment is contention and error-free; hence sensors do not have to retransmit any data. To evaluate the performance of our algorithm for both uniform and non-uniform deployment of nodes, simulation is carried out using C in Linux.

A. Simulation Results for Uniform Sensor Node Distribution

We consider the nodes are distributed uniformly. Each cluster consists of 25 nodes.



(a) (b)

Figure (a) Energy loss due to load distribution of cluster head. (b) No of rounds before first node dies

B. Simulation Results for Non-uniform Sensor Node Distribution

We consider the nodes are distributed non-uniformly. Each cluster consists of 25 grids.

As the nodes are distributed non-uniformly, we repeat the simulation 10 times and take the average result for each set of node numbers

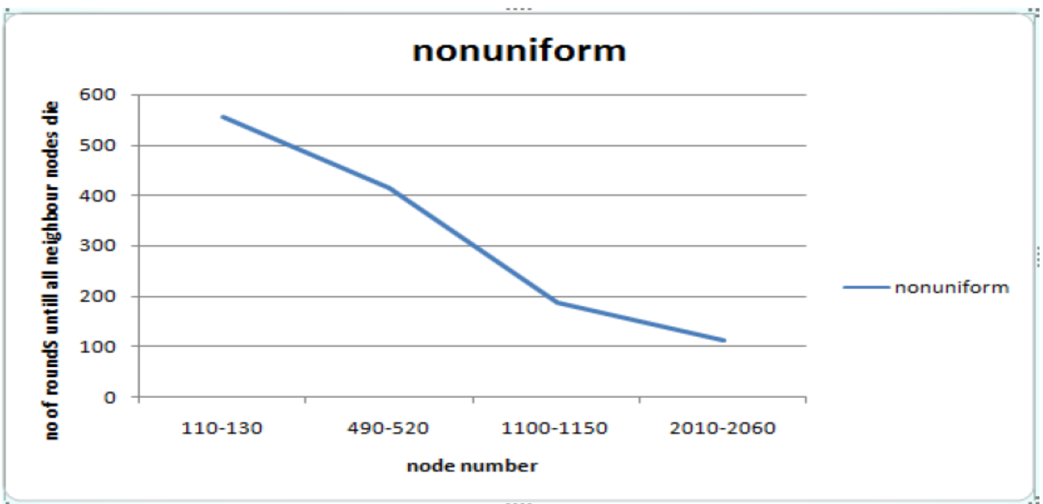


Figure: No of rounds before first node dies

C. Fault Rate Calculation

The system works better if the fault rate is under control. In our proposed algorithm, the cluster head distributes its work load to the neighbouring nodes. This directly results in less energy dissipation leading to the increase in network lifetime. So fault rate gradually decreases with the increasing number of nodes. Fault rate varies from 13 % to 23 %.

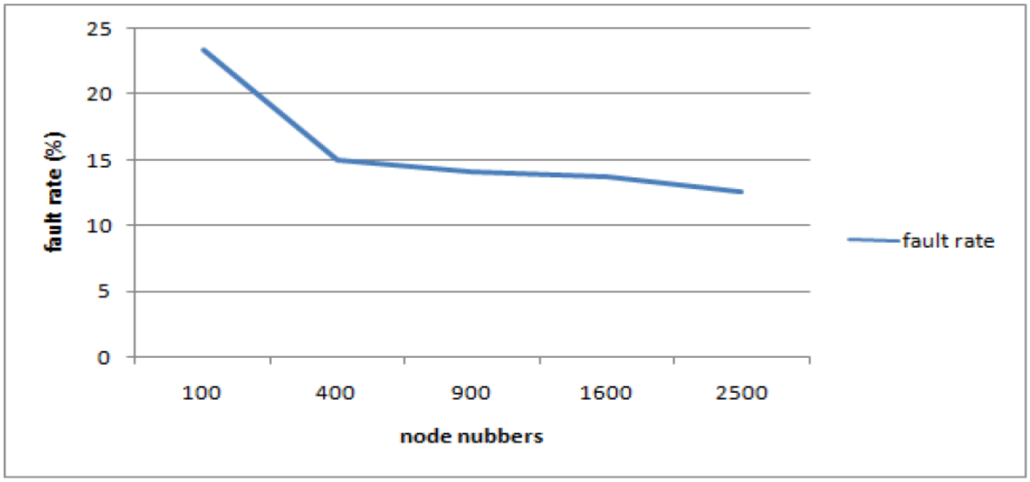


Figure: Fault rate calculation

D. Comparison with Other Existing Algorithms

Now we compare the energy loss by the cluster head after the load distribution. It is depicted that the energy loss by the cluster head for the proposed technique is almost 90 % to 92% less than the existing techniques like LEACH, EEE LEACH(Energy Efficient Extended LEACH). We take the energy consumption value by the cluster head up to 5th iteration.

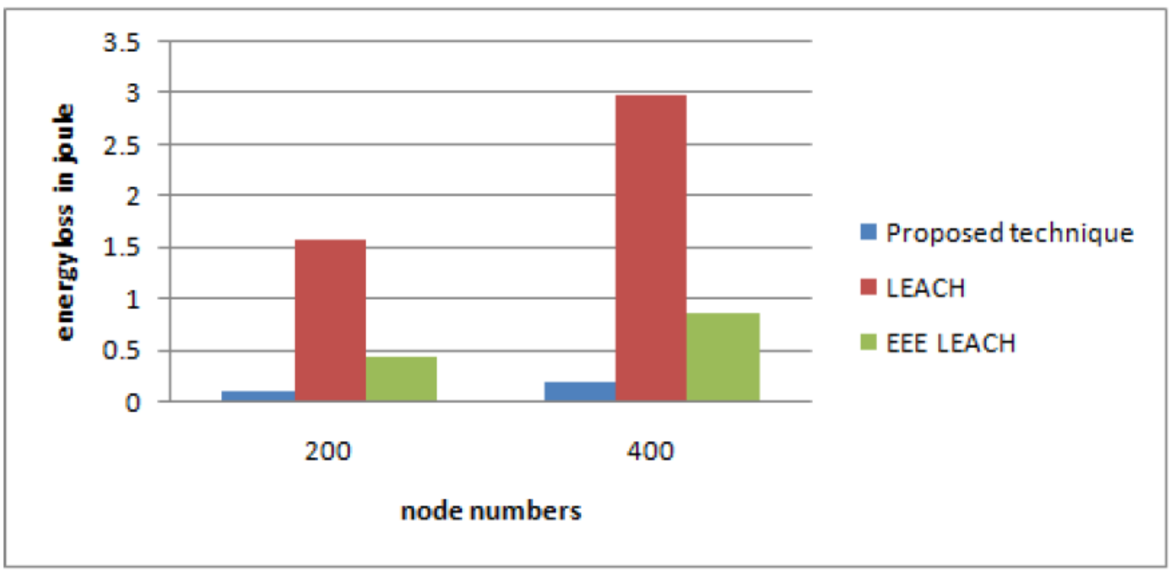


Figure: Energy loss by the cluster heads

In our proposed algorithm, load is distributed, so energy consumption is less than the existing techniques (LEACH, EEE LEACH) where cluster head performs all the tasks. For this reason, running time of the cluster head as well as the number of rounds (i.e. the time when the first node dies) is much higher in our method as compared with the existing ones (LEACH, EEE LEACH).

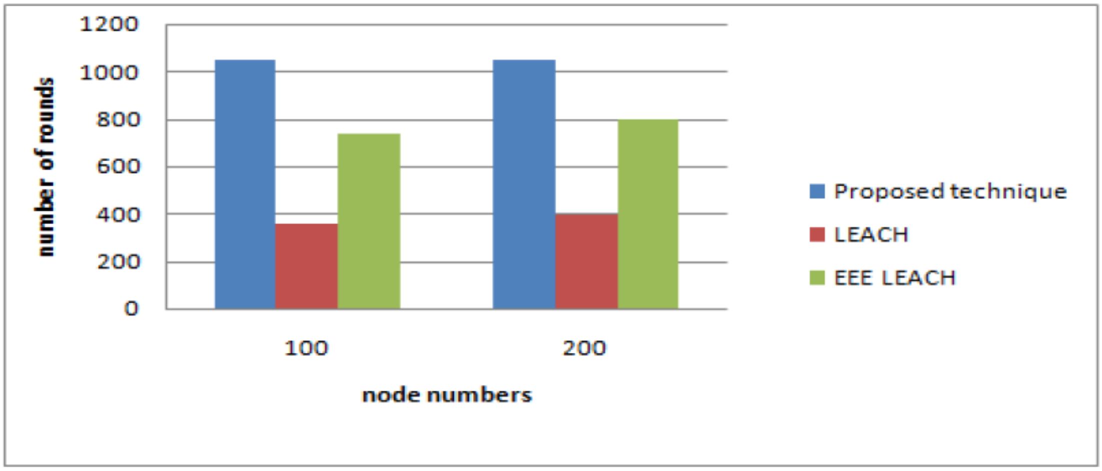


Figure: No of rounds before first node dies

Publication Details of problem 8:

Author= {M. Samanta and I. Banerjee},
Book title= {Electrical, Electronics and Computer Science (SCEECS), 2014 IEEE Students' Conference on},
Title= {Optimal load distribution of cluster head in fault-tolerant wireless sensor network},
Year= {2014},
Pages= {1-7},
DOI={10.1109/SCEECS.2014.6804505},
Month= {March}

Problem 9:

In recent years, ZigBee has been proven to be an excellent solution to create scalable and flexible home automation networks. In a home automation network, consumer devices typically collect data from a home monitoring environment and then transmit the data to an end user through multi-hop communication without the need for any human intervention. However, due to the presence of typical obstacles in a home environment, error-free reception may not be possible, particularly for power constrained devices. A mobile sink based data transmission scheme can be one solution but obstacles create significant complexities for the sink movement path determination process. Therefore, an obstacle avoidance data routing scheme is of vital importance to the design of an efficient home automation system.

Home automation networks are a significant application of Wireless Sensor Networks (WSN) where WSN and Consumer Electronics technology work together efficiently to construct a smart home. In a home automation network, smart consumer sensor nodes collect data from monitoring field and then transmit the data to the Base Station (BS) through multi-hop communication without any human intervention. Different types of physical obstacles may be present in and around the home environment, e.g. walls, furniture, human body, etc. These physical obstacles can hamper the data transmission path between sensor nodes and the BS. Therefore, data reception faults or data inconsistency faults have been occurring in home automation networks. An obstacle avoidance data routing scheme can alleviate and minimize reception faults and improve the performance of the home monitoring network.

Solution:

This paper presents a mobile sink based obstacle avoidance routing scheme for a home monitoring system. The mobile sink collects data by traversing through the obstacle avoidance path. Through ZigBee based hardware implementation and verification, the proposed scheme successfully transmits data through the obstacle avoidance path to improve network performance in terms of life span, energy consumption and reliability. The application of this work can be applied to a wide range of intelligent pervasive consumer products and services including robotic vacuum cleaners and personal security robots.

A. SYSTEM DESCRIPTION

The proposed automatic smart home monitoring system for this research which consisted of static sensor nodes and a robot-type mobile sink. Static sensor nodes are scattered in different locations in the home. These nodes collect data from the monitoring environment and then transmit data to the mobile sink. The mobile sink moves along different paths by avoiding obstacles and collects data from the static sensor nodes to transmit to the BS. Static sensor nodes are coupled to each other through IR based signal transmission for detecting the presence of obstacles between them. Similarly, the mobile sink also transmits an IR signal to the static sensor nodes for detecting the presence of obstacles on its moving path. Each static node detects the emitted IR signal. The BS is used to send the sensed information to another networks. The Zigbee standard is used for communication between the static nodes and the mobile sink.

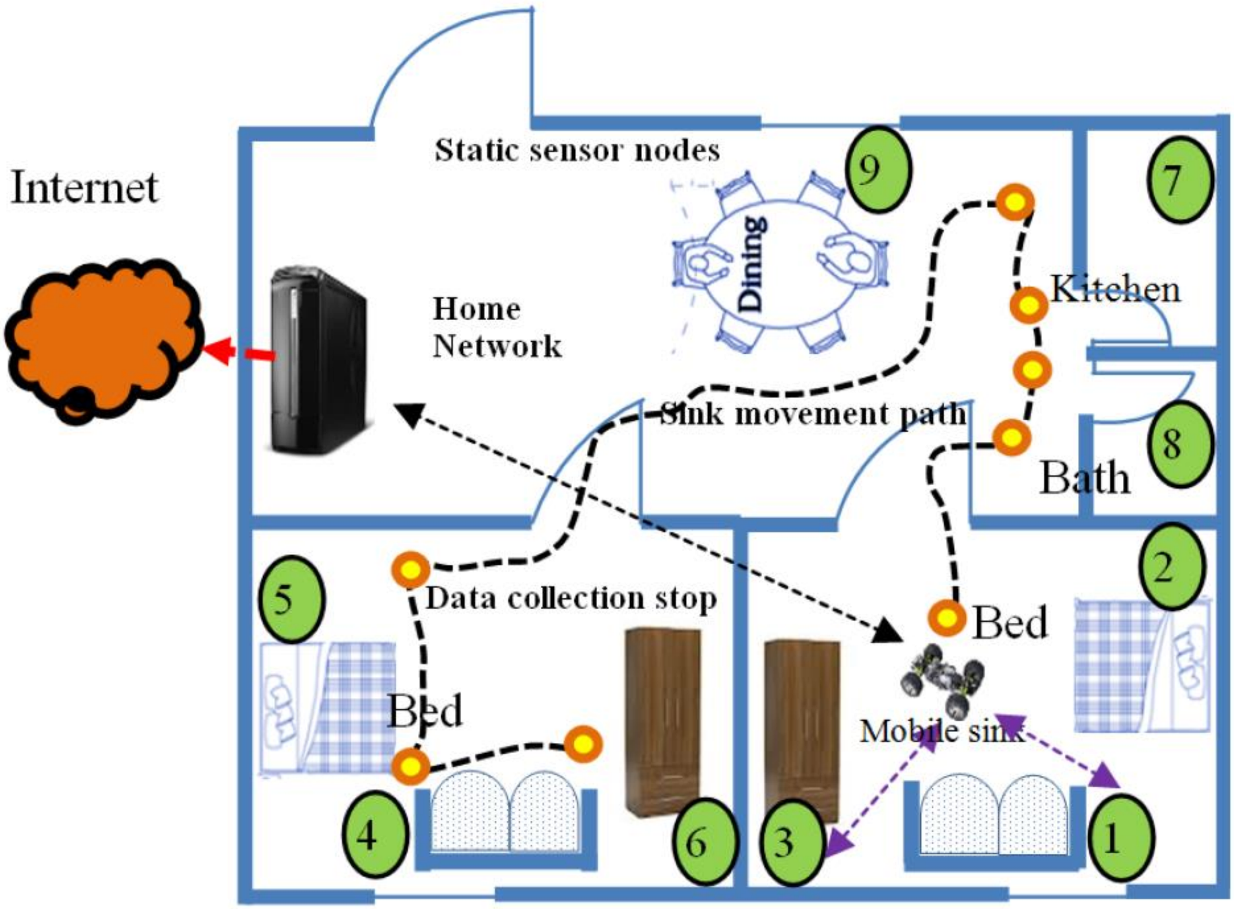


Figure: The proposed home monitoring layout.

The main goal of this research was to detect obstacle avoidance by forming an optimal sink movement path under a smart home network. The optimal sink moving scheme can efficiently improve network performance and lifetime. However, another goal is to design a mobile sink based obstacle avoidance routing scheme, which can maximize the reliability of the network.

B. IR BASED OBSTACLE AVOIDANCE DETECTION

In IR based obstacle detection systems, each sensor node couples with its neighbour nodes through IR transmission for the obstacle detection. If any sensor node is unable to detect the IR signal from its neighbour node, it considers that there is the presence of obstacle between them. Once an obstacle has been detected, the node transmits this information to the BS and in this work ZigBee is used. Detailed description of both the static sensor node design and the mobile sink system is described below.

- Static Sensor Node Design

Static nodes are designed using a simple 8-bit microcontroller with a ZigBee RF baseband and protocol stack for node-to-node communication. An IR emitter is used for infrared coupling. A local timer is used for generating accurate time delays and additional terminals are provided for triggering or resetting events. A PIN diode and preamplifier are assembled on lead frame. The epoxy package is designed as an IR filter. The demodulated output signal can be directly decoded by the microprocessor.

- Mobile Sink Design

The mobile sink contains a robotic based chassis, a motor board, static sensors and an IR based transceiver. The mobile sink movement is controlled by the motor board according to the path information.

Figure: The proposed mobile sink – a classical vehicular robot design.

EXPERIMENTAL RESULTS

Nine static sensors are deployed into three rooms for the home environment monitoring. One robotic based mobile sink is used for data collection. The experiment tests the feasibility of the proposed scheme on real life implementation using a mobile robotic vehicle emulating such devices as security robots or robotic vacuum cleaners. In the experiments, all static sensor nodes are initially the same and each sensor node communicates to its neighbour nodes through single-hop communication. Each node verifies the presence of an obstacle through IR signal coupling. Each static sensor periodically transmits an IR signal to its neighbour nodes for obstacle verification. If any obstacle presents between the nodes, IR signals are unable to reach neighbouring nodes. In that condition, the node detects an obstacle between them.

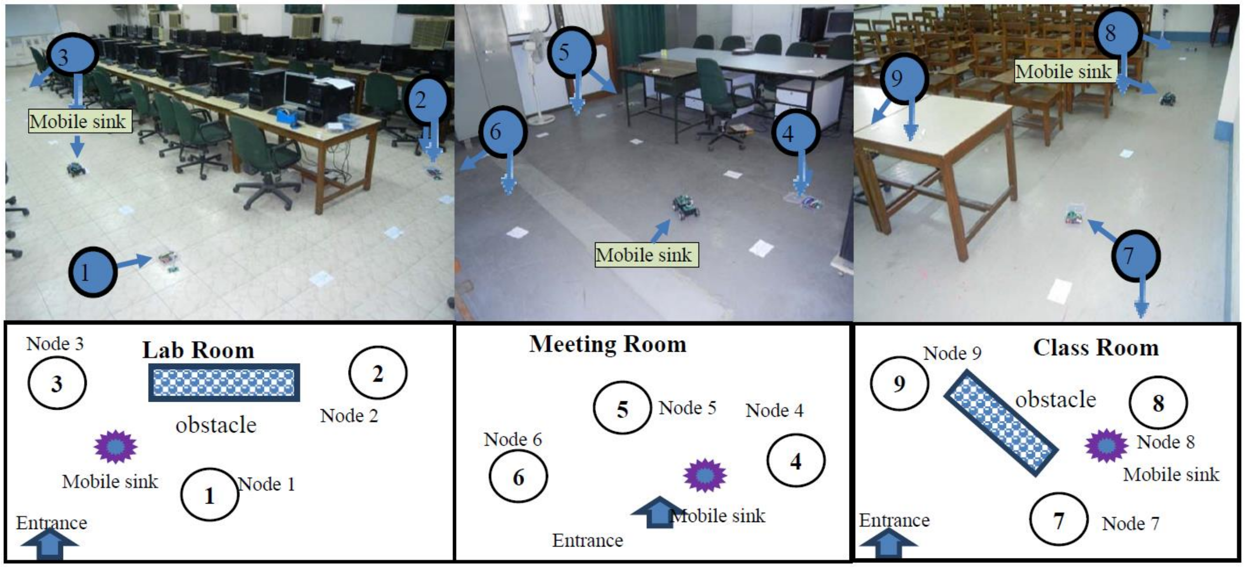


Figure: Mobile sink based data collection experiment, static sensor nodes are deployed in three rooms and these three rooms are connected through a common corridor.

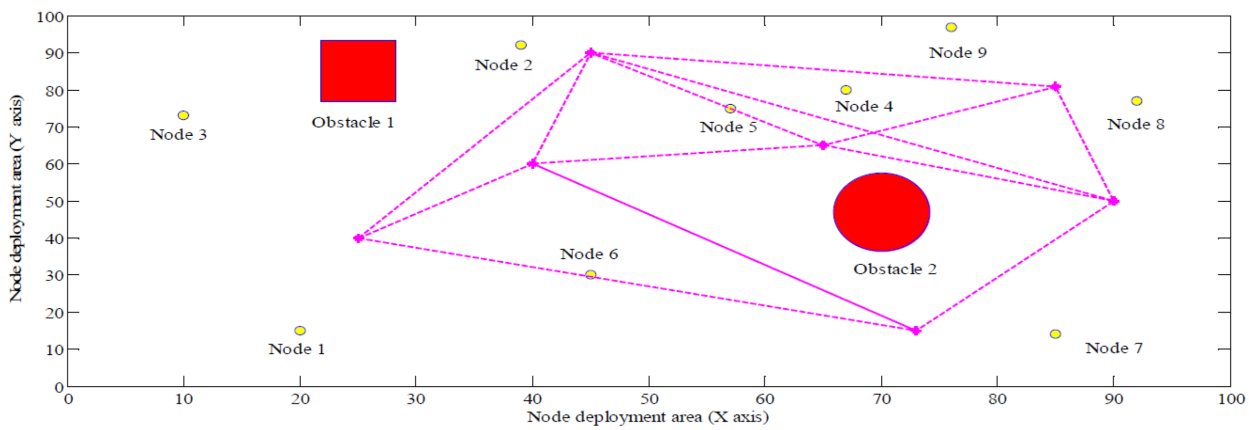


Figure: Data collection point set and all possible paths between them (through simulation).

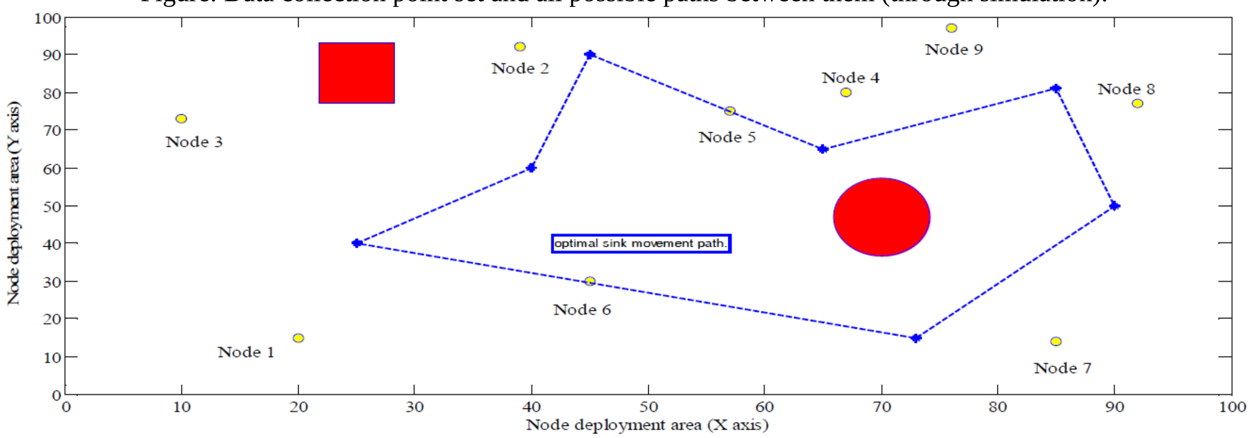


Figure: Optimal sink mobility path (after optimization).

The proposed scheme derived from this research performs significantly better compared to the M-RGP scheme primarily due to the optimal sink mobility that reduces the energy loss of the static sensor nodes. The network lifetime comparison results between the static sink based data collection scheme and the mobile sink based data collection scheme. The proposed sink mobility based data collection scheme has resulted in an increased network lifetime of 30% compared to the static sink based data collection scheme. Therefore, the network lifetime is increased as a result of using the mobile sink based data collection scheme.

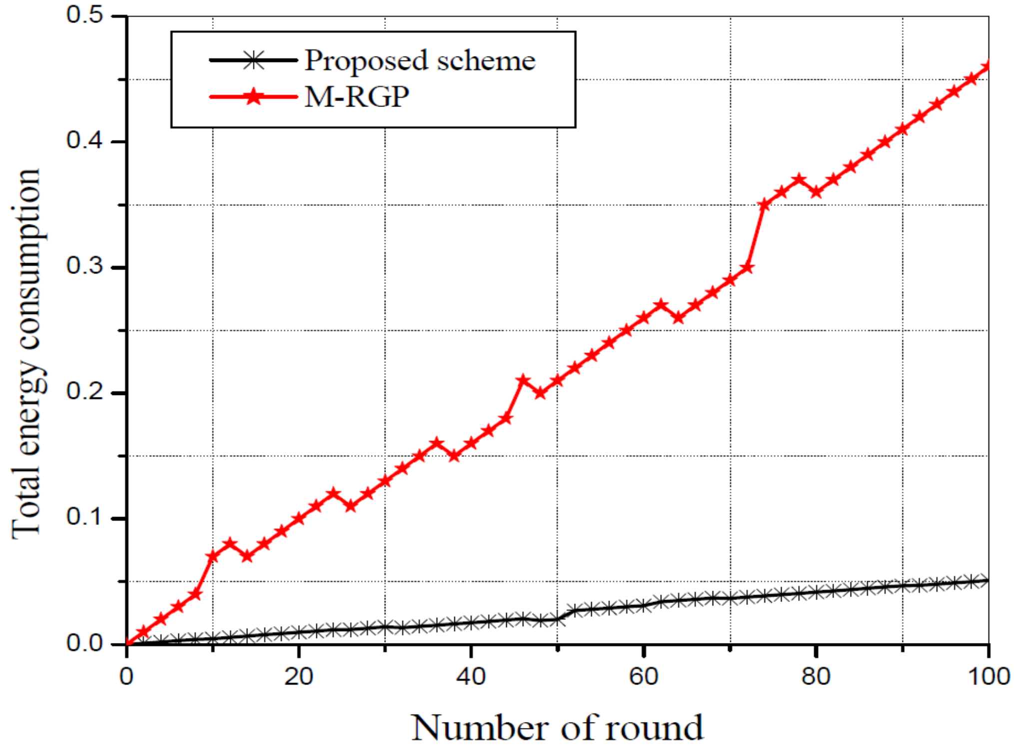


Figure: Total energy loss comparison.

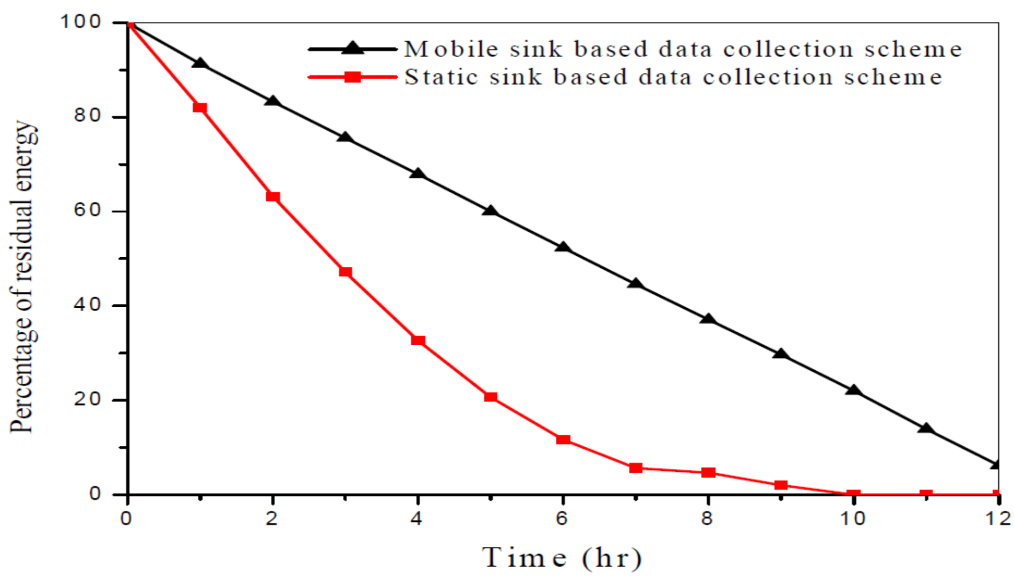


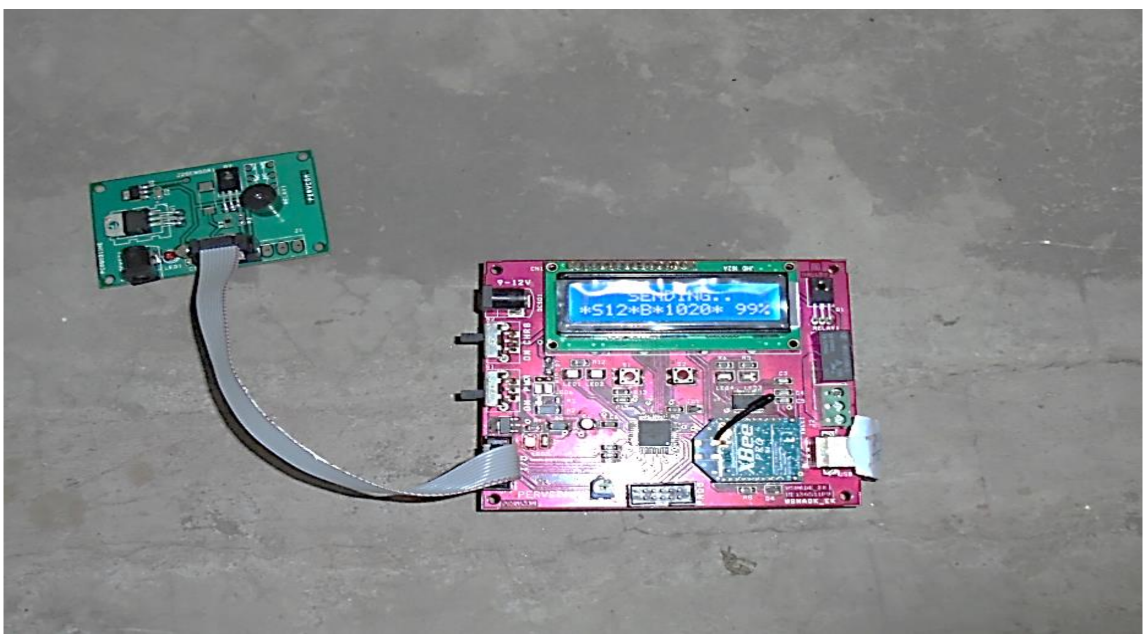
Figure: Network lifetime comparison.

Publication Details of problem 9:

Author= {P. Chanak and I. Banerjee and J. Wang and R. S. Sherratt},
Journal= {IEEE Transactions on Consumer Electronics},
Title= {Obstacle avoidance routing scheme through optimal sink movement for home monitoring and mobile robotic consumer devices},
Year= {2014},
Volume= {60},
Number= {4},
Pages= {596-604},
DOI= {10.1109/TCE.2014.7027292},
ISSN= {0098-3063},
Month= {Nov}

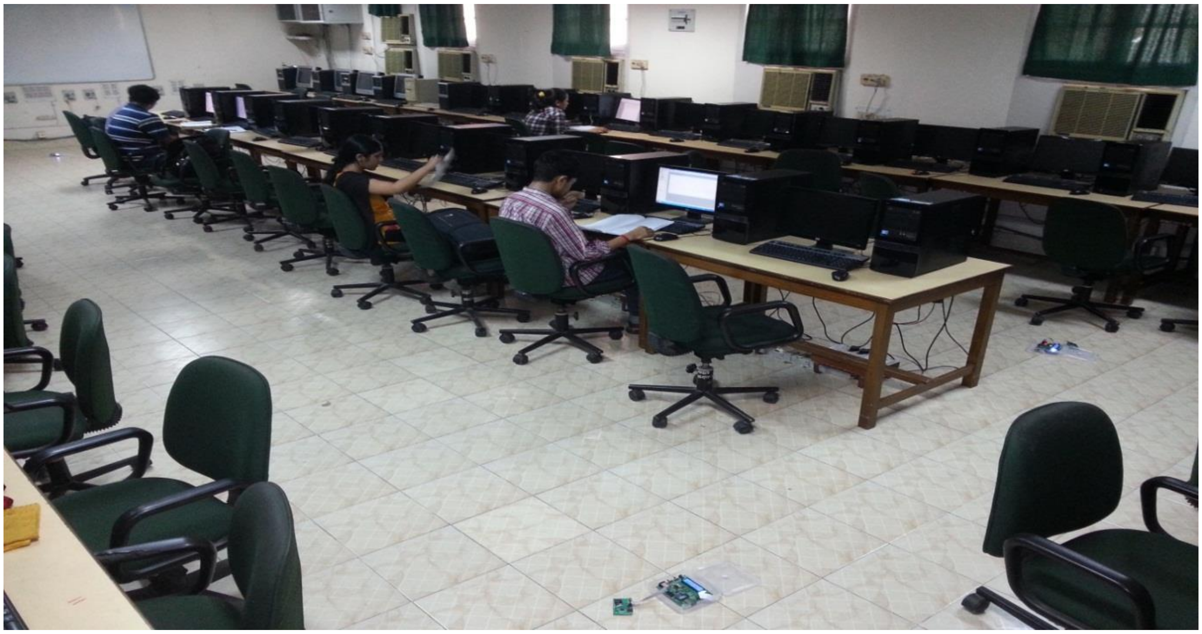
Some field testing results and excremental Setup:

Practical implementation is an essential phenomenon to verify the efficiency of the proposed schemes. Therefore, we have prepared a real life hardware setup to verify our proposed schemes. This section shows some practical implementation images that demonstrate how the proposed schemes are working in the real life environments.

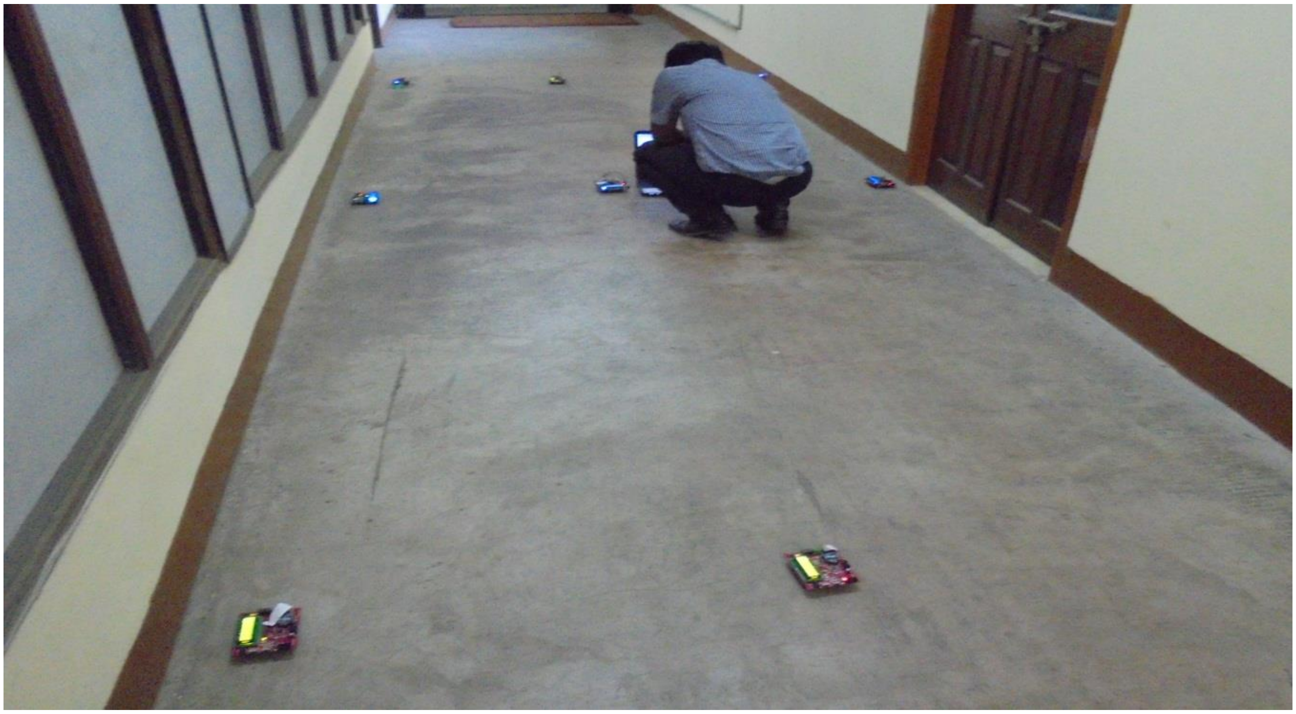


The figure shows a hardware component of a sensor node that use of the data acquisition process in our field experiment

The figure shows a base station (BS) that collects data from the deployed sensor nodes



The figure shows a real life data gathering process in our laboratory



The figure shows a network setup formation phase within our institution

Conclusion:

These nine proposed schemes are simulated using the standard simulation software. Throughout the simulation we have archived numerous impressive results that can prove our proposed schemes are more efficient compared to the existing schemes. On the other hand, some results of the proposed schemes also proved that the proposed schemes are essential innovation for some particular problem. The real life experiments prove the efficiency of the proposed schemes.

12. Whether Project work was delayed if yes, specify reasons

The proposed project has been completed successfully.

13. Please indicate the approximate time by which the project work is likely to be completed
N/A

14. Please indicate the difficulties, if any, experienced in implementing the project

Under the scope of this project, we have done a real field application with the help of sensor network hardware. However, for embedded system design and implementation the research fellow is very essential what we don't have in our sanctioned project.

15. Collaboration, If any (with Department, University, Industry etc)

We have done an international collaboration with Eur Ing Professor Simon Sherratt, Professor in Biosensors, University of Reading, UK.

16. Ph.D Enrolled, If yes, Details

1. **Number of Ph.D student Enrolled: 06**
2. **Number of PhD student completed: 01**

17. Publication related to the project in 2013-2017

[1]. Prasenjit Chanak, Indrajit Banerjee and R. S. Sherratt, Energy-aware distributed routing algorithm to tolerate network failure in wireless sensor networks, Ad Hoc Networks 56, 158-172, 2017.

[2]. Rupam Some, Tuhina Samanta, Indrajit Banerjee, Energy Aware Cluster Head Load Balancing Scheme for Heterogeneous Wireless Ad Hoc Network, ACM ICDCN, 2017, pp 43

[3]. Mrinmoy Sen, Indrajit Banerjee, Mainak Chatteijee, Tuhina Samanta, A node deployment mechanism accounting into received signal strength and frequency diversity for a wireless sensor network, SENSORS, 2016 IEEE, pp 1-3.

[4]. Prasenjit Chanak, Indrajit Banerjee, R Simon Sherratt, Mobile sink based fault diagnosis scheme for wireless sensor networks, Elsevier Journal of Systems and Software 119, 45-57, 2016.

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[6]. Shuvajyoti Pal, Indrajit Banerjee, DAPR: Delay-Aware Priority Based Routing Scheme to Alleviate Congestion in Wireless Sensor Networks, Information Technology (ICIT), 2015, pp 31-36.

[7]. Prasenjit Chanak, Indrajit Banerjee, Fuzzy rule-based faulty node classification and management scheme for large scale wireless sensor networks, Elsevier Expert Systems with Applications, Vol 45, pp 307-321. 2015

[8]. Riddhiman Sett, Indrajit Banerjee, An overhearing based routing scheme for Wireless Sensor Networks, IEEE Advances in Computing, Communications and Informatics (ICACCI), 2015 , pp 2076-2082.

[9]. Prasenjit Chanak, Indrajit Banerjee, J. Wang, and R. S. Sherratt, "Obstacle Avoidance Routing Scheme through Optimal Sink Movement for Home Monitoring and Mobile Robotic Consumer Devices," IEEE Transaction on Consumer Electronics, 2014

[10]. Indrajit Banerjee, Prasenjit Chanak, Hafizur Rahaman, Tuhina Samanta, "Effective fault detection and routing scheme for wireless sensor networks," Computers & Electrical Engineering, Elsevier, vol.40, no.2, page 291-306, 2014.

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[12]. Indrajit Banerjee, Suriti Chakrabarti, Arunava Bhattacharyya, Utsav Ganguly, "An Energy Aware Routing Design to Maximize Lifetime of a Wireless Sensor Network with a Mobile Base Station," International Conference on Advances in Computing, Communications and Informatics (ICACCI), 2014, pp. 2135-2141.

[13]. Prasenjit Chanak, Indrajit Banerjee, "Path Discovery for Sinks Mobility in Obstacle Resisting WSNs," Advanced Computing, Networking and Informatics, India, 2014, pp. 39-50.

[14]. Prasenjit Chanak, Indrajit Banerjee, "Load reduction with multiple mobile sinks in wireless sensor networks," IEEE Students' Technology Symposium (TechSym), IIT-Kharagpur, India, 2014, pp. 21-125. (Best Paper Award).

[15]. Nimisha Ghosh, Indrajit Banerjee, Tuhina Samanta, "Energy efficient coverage of static sensor nodes deciding on mobile sink movements using game theory" Applications and Innovations in Mobile Computing (AIMoC), Kolkata, India, 2014, pp. 118-125.

[16]. Moumita Samanta, Indrajit Banerjee, "Optimal load distribution of cluster head in fault-tolerant wireless sensor network," IEEE Students' Conference on Electrical, Electronics and Computer Science (SCEECS), 2014, pp. 1-7.

[17]. Prasenjit Chanak, Indrajit Banerjee, "Fuzzy Based Dynamic Load Management Policy for Wireless Sensor Networks," IEEE High Performance Computing and Communications (HPCC), China, 2013, pp. 1665-1670.

[18]. Prasenjit Chanak, Tuhina Samanta, Indrajit Banerjee, "Cluster head load distribution scheme for wireless sensor networks," IEEE Sensors, USA, 2013, pp. 1-4.

[19]. Prasenjit Chanak, Tuhina Samanta, Indrajit Banerjee, "Quad-tree approach for obstacle discovery and tracking in wireless sensor networks," IEEE Sensors, USA, 2013, pp. 1-4.

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[21]. Prasenjit Chanak, Indrajit Banerjee, "Energy efficient fault-tolerant multipath routing scheme for wireless sensor networks," The Journal of China Universities of Posts and Telecommunications, Elsevier, vol. 20, no. 6, pp. 42-61, 2013.

18. Any other Information which would help in evaluation of work done on the Project:

We have published numbers of SCI indexed Journal paper and sufficient amount of International conference paper out them many has awarded as best paper of the conference.

19. Financial Assistance Provided/ Expenditure incurred:

sl. no	Items	Amount Approved	Amount Received 1st installment	Amount Received 2nd installment	Expenditure incurred so far
1	Books & Journal	30000.00	475000.00		28607.00
	Equipment	445000.00			418021.00
	Honorarium				
	Contingency	150000.00	165000.00	60000.00	120788.00
	Travel/fieldwork	30000.00		12000.00	41426.00
	Chemicals & Glassware				
	Hiring Services	100000.00		40000.00	117032.00
	Overhead	25000.00			25000.00
	Any other items (please specify)				
	Honorarium to PI (from____________ to____________)				
	Staff (date of appointment) (from__________to ___________) (Please give details of staff appointed in the prescribed format annexure IX as per XI plan guidelines of Major Research Project)				
	Total	780000.00	640000.00	112000.00	750874.00

It is certified that the grant of Rs._7, 52,000.00__ (Rupees Seven lakhs fifty two thousand only) received from the University Grand Commission under the Scheme of support for Major Research Project entitled __Fault tolerant routing in wireless sensor network _____vide UGC Letter No. F. ________ 42-146/2013 __ date___ 14th March 2013 ___has been utilized for the purpose for with it was sanctioned and in accordance with the terms and conditions laid down by the University Grants Commission.

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