



**Addis Ababa University**  
**Addis Ababa Institute of Technology (AAIT)**  
**Department of Electrical and Computer**  
**Engineering**

**Performance and energy management for multi-hop  
traffic in wireless sensor networks (WSNs) towards  
railway track failure monitoring application**

**By**  
**Fantaye Haileyesus**

**A thesis submitted to the School of Graduate Studies of Addis Ababa  
University in partial fulfillment of the requirement for the Degree of  
Master of Science in Electrical Engineering (Railway)**

**Advisor**  
**Dr. Yalemzewd Negash**

**June 2015**  
**Addis Ababa, Ethiopia**

**Addis Ababa University**  
**Addis Ababa Institute of Technology (AAIT)**  
**Department of Electrical and Computer**  
**Engineering**

**Performance and energy management for multi-hop  
traffic in wireless sensor networks (WSNs) towards  
railway track failure monitoring application**

**By**  
**Fantaye Haileyesus**

Electrical and Computer Engineering Department

**Approval by Board Examiners**

|   |                    |               |
|---|--------------------|---------------|
| -----<br>Chairman, Department Graduate<br>Committee | -----<br>Signature | -----<br>Date |
| -----<br>Advisor                                    | -----<br>Signature | -----<br>Date |
| -----<br>Internal Examiner                          | -----<br>Signature | -----<br>Date |
| -----<br>External Examiner                          | -----<br>Signature | -----<br>Date |

**Declaration**

I declare that this thesis was done by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification.

Fantaye Haileyesus

-----

Name

Signature

Addis Ababa, Ethiopia

June 2015

Place

Date of submission

This thesis has been submitted with my approval as a university advisor

Dr. Yalemzewd Negash

-----

Advisor

Signature

## **Acknowledgment**

I want to give thanks to the almighty God who is typically helped me to see about the significance of Wireless Sensor Networks technology towards railway application within my project. The good insight of my advisor, family and friends are put their own remarks in order to accomplish this paper. God bless you all. *No void ≈ No miracles. Ask God to fill your voids!*

## **Table of Contents**

### **Acknowledgement**

|  |                |
|--|----------------|
| <b>Table of content</b> .....                              | <b>(i-iii)</b> |
| <b>Abstract</b> .....                                      | <b>(vi)</b>    |
| <b>1. Introduction</b> .....                               | <b>(1-3)</b>   |
| 1.1. Background.....                                       | (4)            |
| 1.1.1. System overview.....                                | (5)            |
| 1.1.1.1. Base station.....                                 | (5)            |
| 1.1.1.2. Data storage.....                                 | (5)            |
| 1.1.1.3. User interface.....                               | (5)            |
| 1.1.1.4. Overall requirement.....                          | (5-6)          |
| 1.2. Wireless Sensor Networks design issues.....           | (6)            |
| 1.2.1. MAC protocols.....                                  | (6-7)          |
| 1.2.2. Routing protocols.....                              | (7-8)          |
| 1.2.3. Transport protocols .....                           | (8-9)          |
| 1.3. Performance modeling of Wireless Sensor Networks..... | (9)            |
| 1.3.1. Performance metrics.....                            | (9-10)         |
| 1.4. Statement of the problem.....                         | (10)           |
| 1.5. Objectives of the study.....                          | (10)           |
| 1.5.1. General objectives.....                             | (11)           |
| 1.5.2. Specific objectives.....                            | (11)           |
| 1.6. Significance of the study.....                        | (11)           |

|   |             |
|---|-------------|
| <b>2. Related works</b> -----   | <b>(12)</b> |
| 2.1. Introduction-----  | (12)        |
| 2.1.1. Classification of routing protocols for Wireless Sensor Networks----   | (13-14)     |
| 2.1.2. Low Energy Adaptive Clustering Hierarchy protocol (LEACH) -----        | (15-16)     |
| 2.1.3. A Stable Election Protocol (SEP) -----                                 | (16-17)     |
| 2.1.4. Routing challenges in Wireless Sensor Networks -----                   | (17)        |
| 2.2. Heterogeneous Wireless Sensor Networks-----                              | (18)        |
| 2.2.1. Types of heterogeneous resources-----                                  | (18)        |
| 2.2.2. Impact of heterogeneity on Wireless Sensor Networks-----               | (19)        |
| 2.2.3. Performance measures-----  | (19)        |
| 2.3. Wireless sensor network models-----                                      | (20)        |
| 2.3.1. Network model-----   | (20)        |
| 2.3.2. Radio energy dissipation model-----                                    | (21-22)     |
| 2.3.3. The verification of optimal number of clusters-----                    | (22-24)     |
| <b>3. Methodology</b> -----   | <b>(25)</b> |
| 3.1. Design of the project -----  | (25)        |
| 3.1.1. Hierarchical Adaptive Balanced energy-efficient Routing Protocol ----- | (26)        |
| 3.1.2. HABRP network model -----  | (27-28)     |
| 3.1.3. Gateway selection algorithm-----                                       | (29)        |
| 3.1.4. Cluster head selection algorithm-----                                  | (29-31)     |
| 3.1.5. Summary of HABRP-----  | (31-32)     |
| 3.2. Simulation-----  | (33)        |

|   |                |
|---|----------------|
| 3.2.1. Parameter settings-----  | (33)           |
| 3.2.2. Simulation metrics-----  | (34)           |
| 3.2.3. Simulation results-----  | (35)           |
| 3.2.3.1. Energy consumption analysis-----                             | (35-36)        |
| 3.2.3.2. Network lifetime-----  | (37)           |
| 3.2.3.3. Variation of the base station location-----                  | (37-38)        |
| 3.2.3.4. Percentage of node death-----                                | (39)           |
| 3.2.3.5. Stable region in heterogeneous Wireless Sensor Networks----- | (40)           |
| 3.2.3.6. Heterogeneity in large-scale networks-----                   | (41)           |
| 3.2.3.7. Improvement of stability period-----                         | (42)           |
| <b>4. Result analysis-----</b>  | <b>(43)</b>    |
| <b>5. Conclusion and future work-----</b>                             | <b>(44)</b>    |
| 5.1. Conclusion-----  | (44-45)        |
| 5.2. Future work-----   | (45)           |
| <b>6. References -----</b>  | <b>(46-48)</b> |

## List of Tables

|   |      |
|---|------|
| Table 1. Classification of routing protocols in WSNs-----     | (13) |
| Table 2. Simulation parameter-----                            | (33) |
| Table 3. Improvement of HABRP compared to LEACH with a=1----- | (42) |

## List of Figures

|  |      |
|--|------|
| Figure 1. The basic components of Wireless Sensor Networks node-----   | (2)  |
| Figure 2. System overview-----   | (4)  |
| Figure 3. Network model with clustering-----   | (16) |
| Figure 4. Heterogeneous model for wireless sensor network-----   | (20) |
| Figure 5. Radio Energy Dissipation Model-----  | (21) |
| Figure 6. The HABRP network model-----   | (27) |
| Figure 7. Time line showing HABRP operation-----   | (27) |
| Figure 8. The lifetime $t$ of the network-----   | (28) |
| Figure 9. Time line showing set-up phase-----  | (28) |
| Figure 10. Cluster head would transmit to base station through gateway if<br>$E_{CH-to-Gat} + E_{Gat-to-BS} < E_{CH-to-BS}$ -----                  | (32) |
| Figure 11. Energy analysis comparison of HABRP, LEACH and SEP in Homogeneous<br>WSN (100m*100m, 100 nodes, 0.5J/node, a=0(Homogeneous WSNs)) ----- | (35) |
| Figure 12. Energy analysis comparison of HABRP, LEACH and SEP (100m*100m,<br>100nodes, 0.5J/node, m=0.2, a=3 (Heterogeneous WSNs)) -----           | (36) |
| Figure 13. Number of alive nodes per round with (100m*100m, 100nodes,<br>0.5J/Normal node, 1J/Advanced node, m=0.2, a=1, BS (50,50))-----          | (37) |

Figure 14. Number of alive nodes per round with (100m\*100m, 100nodes, 0.5J/Normal node, 2J/Advanced node, m=0.2, a=3, BS (50,200)) ----- (38)

Figure 15. Number of alive node per round with (100m\*100m, 100nodes, 0.5J/Normal node, 2J/Advanced node, m=0.2, a=3, BS (50,300)) ----- (38)

Figure 16. Node death percentage per number of rounds with (100m\*100m, 100nodes, 0.5J/node, a=0) ----- (39)

Figure 17. Node death percentage per number of rounds with (100m\*100m, 100nodes, 0.5J/Normal node, 1.0J/Advanced node, m=0.2, a=1) ----- (39)

Figure 18. Length of stable region for different values of energy heterogeneity with (100m\*100m, 100nodes, 0.5J/node, a=1) ----- (40)

Figure 19. Sensitivity of HABRP and LEACH to degree of heterogeneity in large scale networks with 900 nodes in an 300m\*300m field. ----- (41)

## **Abstract**

Wireless Sensor Network (WSN) is an innovative ad-hoc network with distributed sensing and processing capacities made up of collection of sensor nodes. The sensors transmit information to the sink. The routing protocols for WSNs are based mostly on efficiency of energy and some deal with real-time requirements. In this paper, a comparative study between Low Energy Adaptive Clustering Hierarchy (LEACH), Stable Election Protocol (SEP) and Hierarchical Adaptive Balanced energy-efficient Routing Protocol (HABRP) would be conducted being heterogeneous sensors are employed in order to attain an energy-efficient routing protocol in the sensor network field. The paper typically discusses an energy management of routing protocol in order to attain the safety analysis of a railway track monitoring. A sensor network in mesh topology has been used to detect the cracks with incorporated camera embedded along the railway track for proper end-to-end data delivery with minimum communication energy. The simulation has been done by MATLAB software environment. On the design process of railway track failure monitoring our desired routing protocol HABRP satisfies an improvement compared with LEACH by 76%. This system furnishes a cheap, reliable, flexible, and intellectual alternative for the existing system.



## **1. Introduction**

Railway being the most convenient and low cost mode of transportation in coincidence to other modes and plays a prominent role in economic prevailing of the country. Relying upon recent advancements high-speed rails is dominantly used. In the field of transportation railway plays a vital role. The rail carries both freight and passengers. Railway accidents can have worse impact in comparison to any other type of transport accidents, while the most of the goods and passenger travel by the railways.

One major cause of the railway accidents is track failure. Railroad cracks have been found out to be prominent origin of derailments and can introduce a major harm to the economy. Railroad safety is the paramount concern and hence the crack detection process is required for its safety. In order to have an effective means of transport, proper surveillance system is necessary for railroad crack analysis. The root of the issue is that 60% of total railway accidents occur due to derailments, out of which 90% of them happened due to crack. The most awaited problem in railroad maintenance is the shortage of cheap and efficient technology to detect track flaws [22]. An effective track surveying system is the need of the day for regularity in monitoring the predefined issue. The approach which is in trend today is manually (i.e. by human beings) to detect the cracks. This manual approach is lengthy, subjective and cumbersome and lacks objectivity. To overcome the problem regarding manual approach an automatic system has been needed which is capable of scrutinizing cracks on a continuous basis without human intervention, for getting regularity in monitoring procedure. Proper maintenance of tracks leads avoidance of destructive flaws that can results in major accidents.

The proposed system is accurate, intellectual, reliable, and effective means for analysis of cracks present on a railway track without human efforts. The proposed system deal about routing protocol which is suitable for crack detection where being a uniformly distributed sensor nodes within the sensor network field identify the track failures and sends the data to the base station and manage accordingly.

The project intended to discuss about wireless sensor networks (WSNs) which are able to compose homogeneous and/or heterogeneous sensor nodes with limited resources. Routing techniques are the most important issue for networks where resources are limited [3]. WSNs technology's growth in the computation capacity requires these sensor nodes to be increasingly equipped to handle functions that are more complex. Each sensor is mostly limited in their energy level, processing power and sensing ability. Figure 1 depicts that the basic components of WSNs node as:

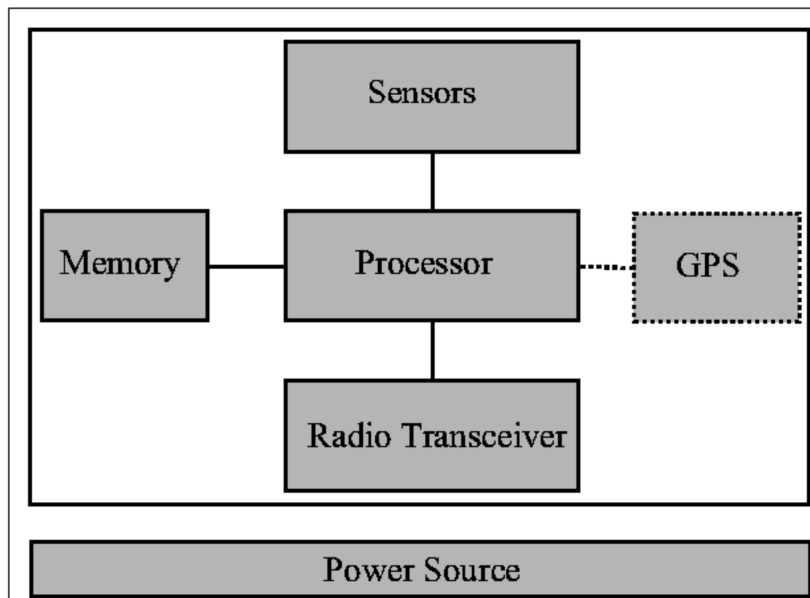


Figure 1. The basic components of Wireless Sensor Networks node

Thus, a network of these sensors gives rise to a more robust, reliable and accurate network. It is noted that, to maintain a reliable information delivery, data aggregation and information fusion that is necessary for efficient and effective communication between these sensor nodes. Only processed and concise information should be delivered to the sinks to reduce communications energy, prolonging the effective network lifetime with optimal data delivery.

An inefficient use of the available energy leads to poor performance and short life cycle of the network. To this end, energy in these sensors is a scarce resource and must be managed in an efficient manner. In this project I propose Hierarchical Adaptive Balanced energy efficient Routing Protocol (HABRP) to decrease probability of failure nodes and to prolong the time interval before the death of the first node (stability period) and increasing the lifetime in heterogeneous WSNs, which is crucial for many applications. We study the impact of heterogeneity of nodes, in terms of their energy, in wireless sensor networks that are hierarchically clustered. In these networks some high-energy nodes called NCG nodes (Normal node |Cluster Head |Gateway) are elected "cluster heads" to aggregate the data of their cluster members and transmit it to the chosen "Gateways" that requires the minimum communication energy to reduce the energy consumption of cluster head and decrease probability of failure nodes and properly balance energy dissipation. Simulation result shows an improvement in effective network lifetime and increased robustness of performance in the presence of energy heterogeneity.

The organization of this project is as followings: we briefly review related work in section 2. In section 3, we discussed the design and simulation using our HABRP protocol for rail crack monitoring in terms of energy consumption, Length of stable region for different values of heterogeneity, number of alive nodes per round, variation of the Base station location, sensitivity to degree of heterogeneity in large-scale networks, improvement of stability period. In section 4, we present the result analysis. Finally, in section 5, we present the conclusion and future work of the project.

## 1.1. Background

In wireless sensor network the scattered distributed micro-sensors, which are cubic centimeters in size, and each such node comprises of processor, memory type, a RF transceiver, an energy source, and huge sensors & actuators. These nodes converse wirelessly and order themselves into networks [6]. Moreover, they are capable of sensing data from their location, perform trouble-free computations, and transmit the data by means of wired or wireless internet [9] directly to command centre or through some cluster head, known gateway.

### 1.1.1. System overview

To aid in my explanation of the infrastructure, I have included an overall system diagram, shown in Figure 2.

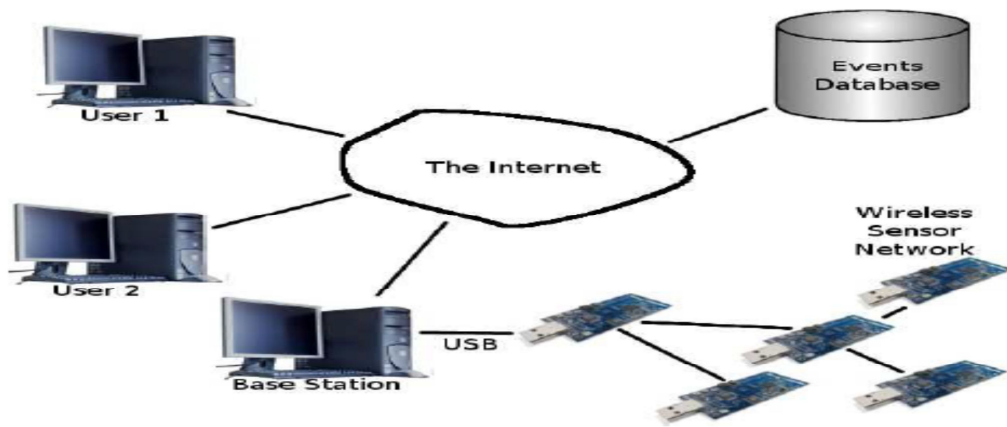


Figure 2. System overview

This diagram shows the interactions between each major component in the system. Beginning with the network of sensors, information travels to the base station through the sink node. Once the data has been parsed by the base station, it is sent to the database. Finally, users are able to view the status of the sensor network by using an application that queries event information from the data storage.

#### **1.1.1.1. Base Station**

By necessity, the base station will be a computer connected to the mesh network sink node, the node to which all other nodes will be programmed to send their packets. This base node will need to parse sensor data, and format the data for transmission into an appropriate storage medium.

#### **1.1.1.2. Data Storage**

For effective implementation of the sensor network, we require a centralized storage mechanism allowing for multiple concurrent clients reading and modifying the system at a given time. This storage mechanism must be able to hold the readings of an arbitrarily large number of sensor nodes, effectively organizing it for efficient read and write access.

#### **1.1.1.3. User Interface**

Given that at this point, all of our information will be housed in a central medium, we require an appropriate user interface to parse and display this data in a user-friendly manner. At the minimum, this interface needs to display the current status of each node, along with a description of past node readings. Additionally, users should be able to specify their own names for nodes, forgoing the default behavior of identifying via unique node numbers.

#### **1.1.1.4. Overall Requirements**

Our wireless sensor network must detect physical intrusion (the rail track failure detection having a mesh topology with an embedded camera which is established the communication between sensor nodes and sink). To this end, our nodes have to gather pertinent data from our available sensors, which include motion and acceleration, in order to not only ensure that physical intrusion will be detected, but also to intelligently maintain the trust of the individual sensors. This cohesive application will show that wireless sensor networks are not only a viable new technology, but also that they can form a good, cohesive solution for today's real-world problems.

The proposed system uses two entities to form a complete sensor network described as:

**1. IR Sensor Network:**

An infrared sensor is an electronic device that is used to sense certain characteristics of its surrounding by either emitting or detecting infrared radiation in electromagnetic spectrum; its wavelength is higher than the wavelength of visible light. The wavelength region is from (0.75-3) micrometer is termed as near infrared, the region from (3-6) micrometers is termed as mid infrared region after that it is far infrared region. One can use 5v IR for this arrangement which is powered by one of the digital pins.

**2. Photodiode:**

Photodiode is a semiconductor device whose resistance varies inversely with the intensity of light falling on it. The photodiode has a resistance of 45 kilo ohms and arranged in the form of a potential divider circuit the output of this potential divider arrangement is given to one of the analog pins on the board.

**1.2. Wireless Sensor Network design issues**

In this topic my project typically emphasize on routing protocol in terms of energy-efficiency and the system network lifetime. The basics for wireless sensor network design would be discussed as follows:

**1.2.1. MAC protocol**

MAC protocols affect the efficiency and reliability of hop-by-hop data transmission. Existing MAC protocols such as the IEEE 802 series standard may not be completely suitable for WSNs because of energy efficiency. General MAC protocols can result in a waste of energy in the following ways [2]: (a) since a wireless channel is shared in a distributed manner, packet collision cannot be avoided.

The collided packets require retransmission and result in energy waste. (b) Most distributed wireless MAC protocols require control messages for data transmission (e.g., request-to-send/clear-to-send in the IEEE 802.11 distributed coordination function). Control messages consume energy.

(c) Overhearing and idle listening can also result in energy waste. Overhearing means a node receives packets destined for other nodes. Idle listening refers to a situation where nodes there need to listen on the channel to get its status.

MAC protocols for wireless sensor networks emphasize energy efficiency through design of effective and practical approaches to deal with the foregoing problems. For example, S-MAC [3] designs an adaptive algorithm to let sensor nodes sleep at a certain time. The approach of Tay et al. [4] devises a non-uniform contention slot assignment algorithm to speed up collision resolution and reduce latency while in the idle state. Typical parameters used to measure performance of MAC protocols include collision probability, control overhead, delay, and throughput.

### **1.2.2. Routing protocols**

Routing protocols in WSNs are for setting up one or more path(s) from sensor nodes to the sink. Since sensor nodes have limited resources, routing protocols should have a small overhead, which may result from control message interchange and caching. Therefore, the traditional address-centric routing protocols for Internet (e.g., the routing information protocol, open shortest path first, border gateway protocol) do not meet the requirements of WSNs. Data-centric routing is more suitable for WSNs because it can be deployed easily, and due to data aggregation, it saves energy. Traffic models and system characteristics can be utilized to design efficient routing protocols.

To conserve energy, most routing protocols for WSNs employ certain technique to minimize energy consumption (e.g., data aggregation and in-network processing, clustering, node role assignment). For example, directed diffusion [5] is a data-centric routing scheme with three phases in its operation:

- A sink broadcasts its interest across the network in query messages with a special query semantic at a low rate.
- All the nodes cache the interest. When a node senses that an event matches the interest, it sends the data relevant to the event to all the interested nodes. Sink will also get the initial data and “reinforce” one of source nodes by resending the interest at a higher rate.
- After the reinforcement propagation, the source nodes send data directly on the reinforced path. The performance of a routing protocol can be expressed through such measures as computational overhead, communications overhead, path reliability, path length, convergence rate, and stability.

### **1.2.3. Transport protocols**

The following factors should be considered carefully in the design of transport protocols: a congestion control mechanism and especially, a reliability guarantee. Since most data streams are convergent toward the sink, congestion is likely to occur at nodes around the sink. Although a MAC protocol can recover packet loss because of bit error, it has no way to handle packet loss because of buffer overflow. Therefore, transport protocols should have mechanisms for loss recovery; to guarantee reliability, mechanisms such as ACK and selective ACK [1] used in the TCP would be helpful. At the same time, reliability in WSNs has a different meaning than that of traditional networks where correct transmission of every packet is guaranteed. WSNs need to receive packets correctly only from a certain area, not necessarily from every sensor in that area. For certain applications, only a certain ratio of successful transmissions from a sensor node is sufficient.

These observations can be utilized to design more efficient transport protocols. It is more efficient to have a hop-by-hop mechanism for congestion control, loss recovery since packet loss can be reduced, and energy may be conserved. The hop-by-hop mechanism can also lower the buffer requirement at the intermediate nodes. Transport control protocols for WSNs should also avoid packet loss as much as possible since packet loss translates to waste of energy. Furthermore, it should guarantee fairness so that individual nodes can achieve their fair throughput.

### **1.3. Performance modeling of Wireless Sensor Networks**

Two important performance metrics, system lifetime and energy efficiency, are used for the project and discussed in this section. Both of these metrics relate to energy consumption. The overall system performance measure can be explained based on [6].

#### **1.3.1. Performance metrics**

As discussed earlier, wireless sensor networks are different from the traditional communication networks, and therefore different performance measures may also be required to evaluate them. Among them are the following [6]:

- **System lifetime:** This term can be defined in several ways: (a) the duration of time until some node depletes all its energy; or (b) the duration of time until the quality-of-service of applications cannot be guaranteed; or (c) the duration of time until the network has been disjointed.
- **Energy efficiency:** Energy efficiency means the number of packets that can be transmitted successfully using a unit of energy. Packet collision at the MAC layer, routing overhead, packet loss, and packet retransmission reduce energy efficiency.
- **Reliability:** In WSNs, the event reliability is used as a measure to show how reliable the sensed event can be reported to the sink. For applications that can tolerate packet loss, reliability can be defined as the ratio of successfully received packets over the total number of packets transmitted.

- **Coverage:** Full coverage by a sensor network means the entire space that can be monitored by the sensor nodes. If a sensor node becomes dysfunctional due to energy depletion, there is a certain amount of that space that can no longer be monitored. The coverage is defined as the ratio of the monitored space to the entire space.
- **Connectivity:** For multi-hop WSNs, it is possible that the network becomes disjointed because some nodes become dysfunctional. The connectivity metric can be used to evaluate how well the network is connected and/or how many nodes have been isolated.
- **Quality-of-Service metrics:** Some applications in WSNs have real-time properties. These applications may have quality-of-service requirements such as delay, loss ratio, and bandwidth.

#### **1.4. Statement of the problem**

Railway transportation needs safety and security for its operation and on-time maintenance. To meet the above requirement the deployed sensor network having a mesh topology with embedded camera enable to detect rail track flaws by establishing proper end-to-end data delivery between each sensor node and sink node along the gateway node. Since, Sensor nodes have resource constraints: limited energy, limited communication and computational capabilities, and limited memory; it needs suitable routing protocol having a consideration of heterogeneity in energy management of traffic within the sensor network field. The routing challenges for track failure monitoring are typically my interest to solve, using a suitable energy-efficient routing protocol (HABRP).

#### **1.5. Objectives of the study**

The ultimate goal of this project is to design and build the performance and energy management for multi-hop traffic in WSNs towards railway track failure monitoring application.

### **1.5.1. General objectives**

The project would be attained the following aims:

- Safe operation & maintenance of railway line
- Achieve cost-effective communication network
- Reduce the occurrence of derailment, collision between vehicle and susceptibility to threat
- To get my professional masters degree and to let open my project work for further study of others

### **1.5.2. Specific objectives**

The project would achieve the following specific goal:

- Obtain efficient transmission of packet delivery from each respective sensor nodes to the sink
- Obtain energy-efficient traffic management approach using a suitable routing protocol over WSNs for the railway track monitoring and crack detection purpose

### **1.6. Significance of the study**

The main significance of our project is on time crack detection of the railway track-line using an embedded camera incorporated within the deployed sensor network field and enables to find possible solution for the given problem at hand by using suitable energy-efficient routing protocol.

In this paper, an energy heterogeneity approach of routing protocol is designed for the reduction of energy consumption while being data delivery from the sensor nodes to the sink with minimum communication energy and as a result improves the lifetime of the network.

## 2. Related works

### 2.1. Introduction

In the transportation industry railway has a vital role for mass flow of passengers and freight. The safety issue for this transportation system is not an option, but it is crucial. One of the major problems is crack failure and it needs proper surveillance system in order to handle the traffic flaws using an energy-efficient routing protocol within the network field [22]. The devices that have the ability to sense compute and communicate using short-range transceivers known as **sensor nodes**. The interconnection of these nodes forming a network called **wireless sensor network (WSN)** [1]. The low cost, ease of deployment, ad hoc and multifunctional nature has exposed WSNs an attractive choice for numerous applications. The application domain of WSNs varies from environmental monitoring, to health care application, to military operation, to transportation, to security applications, to weather forecasting, to real time tracking, to fire detection [1] and so on. In addition, there can be a If there is the link or node failure, it leads to reconfiguration of the network and re-computation of the routing paths. Route selection in each communication pattern results in either network delay by choosing long routes or degrade network lifetime by choosing short routes resulting in depleted batteries [2]. To improve WSNs performance these challenges are subjected to be investigated. Therefore, the solutions for such environments should have an efficient routing mechanism to provide low latency, minimum consumption of energy, high network lifetime, reliable, fault tolerant communication, and quick reconfiguration. To maintain a reliable information delivery, data aggregation, and fusion is necessary for efficient and effective communication between these sensor nodes [4].

### 2.1.1. Classification of routing protocols for Wireless Sensor Networks

With respect to WSN’s application, single routing protocol cannot meet all the application requirements [2]. Thus, many routing protocols are proposed with the domestic and international research development of WSN. According to different classification standards, the various protocols can be classified as: Flat, Hierarchical, and Location-based as shown in table 1.

| Flat routing        | Hierarchical routing | Location based routing |
|---------------------|----------------------|------------------------|
| AODV                | LEACH                | GAF                    |
| DSDV                | LEACH-C              | GEAR                   |
| FLOODING            | TEEN                 |                        |
| DIRECT TRANSMISSION | APTEEN               |                        |
| MTE                 | PEGASIS              |                        |
| SPIN                | STAT-CLUS            |                        |
| DIRECTED DIFFUSION  |                      |                        |

Table 1. Classification of routing protocols in WSNs

In flat routing protocols, each node typically plays the same role and sensor nodes collaborate to perform the sensing task. Flooding is flat type of routing protocol in which each sensor node receives data and then sends them to the neighbors by broadcasting, unless a maximum number of hops for the packet are reached or the destination of packet is achieved. Disadvantage of this routing technique is data redundancy and energy consumption [3]. To reduce this redundancy proactive and reactive routing protocols were developed. In proactive routing, each node has one or more tables that contain the latest information of the routes to any node in the network. The proactive protocols are not suitable for larger networks, as they need to maintain node entries for each node in the routing table of every node. This causes more overhead in the routing table leading to increases energy consumption. Destination Sequenced Distance Vector routing (DSDV) is one of the table driven routing schemes for sensor networks based on the Bellman-Ford algorithm.

To reduce this regular update, Reactive Routing protocols were developed. Reactive routing protocols Dynamic Source Routing (DSR) and Ad hoc On-demand Distance Vector (AODV) discover route only when a source node wants to communicate with destination. The major drawback with Reactive routing technique is high routing overhead due to Route Request (RREQ), Route Reply (RREP) & Route Error (RERR) messages to maintain the network and produce higher energy consumption in network [5]. In Minimum Transmission Energy (MTE) routing, routes from each node to the Base station (BS) were chosen such that cache node's next hop neighbor is the closest node that is in the direction of the BS [5]. The drawback of this routing technique is energy consumption. All node pass own data to node closest to BS and that node will die sooner due to its higher energy consumption. Few amongst the serious disadvantages of the flat routing are identified as (a) absence of manage nodes in the network (b) lack of optimal management of the communication resources (c) complicated algorithms for self-organizing and cooperative work (d) slow response to the dynamic changes of the network etc.

Energy efficient routing is possible by means of Cluster based routing or Hierarchical schemes [6]. In static clustering protocol, the clusters are chosen a priori and fixed. Static clustering includes scheduled data transmissions from the cluster members to the cluster head and data aggregation at this cluster head [6]. However, the limitation of static clustering routing technique is energy consumption due to fixed cluster head node in every round. To overcome this issue, Low Energy Adaptive Clustering Hierarchy (LEACH) was proposed [7].

### 2.1.2. Low Energy Adaptive Clustering Hierarchy protocol (LEACH)

LEACH is an adaptive clustering routing protocol proposed by [1]. A primary design goal for wireless sensor networks is to use the energy efficiently [10]. The basic idea of clustering routing [10][14] is to use the information aggregation mechanism in the cluster head to reduce the amount of data transmission, thereby, reduce the energy dissipation in communication and in turn achieve the purpose of saving energy of the sensor nodes.

Cluster based routing algorithm has a better energy utilization rate compared with non-cluster routing algorithm [15]. The implementation process of LEACH includes many rounds. Each round consists of the set-up phase and the steady data transmission phase. In the set-up phase, the cluster head nodes are randomly selected from all the sensor nodes and several clusters are constructed dynamically. In the steady data transmission phase, member nodes in every cluster send data to their own cluster head, the cluster head compresses the data that received from member nodes and sends the compressed data to the sink node. LEACH protocol periodically elects the cluster head nodes, re-establishes the clusters according to a round time, which ensures energy dissipation of each in the network is relatively evenly.

The cluster head election algorithm in LEACH is as follows [11]. All the sensor nodes generate a random number between 0 and 1, and if it is less than a threshold  $T(S)$ , the sensor nodes will broadcast an announcement message to notify others that it is a cluster head. In each round, if a node has been elected as a cluster head, its  $T(S)$  is set to zero,

so that the node will not be elected as a cluster head again.  $T(S)$  can be expressed as:

$$T(S) = \begin{cases} \left( \frac{P}{1 - P * \left( r \bmod \left( \frac{1}{P} \right) \right)} \right) & \text{if } S \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Where  $p$  is the percentage of the number of clusters in the network (usually  $p$  is 0.05 in [8][12][13]),  $r$  is the number of the election rounds,  $r \bmod (1/p)$  is the number of nodes which have been elected as cluster heads in the round  $r$ , and  $G$  is the set of nodes that have not been elected as cluster heads in round  $r$ .

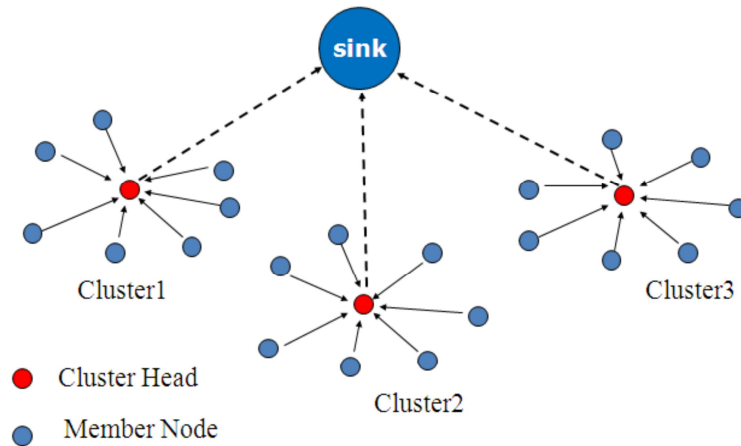


Figure 3. Network model with clustering

After cluster head election, the cluster head broadcasts its identity message to non-cluster head nodes. The non-cluster head nodes send a join-REQ message to the nearest cluster head to join in the corresponding cluster. After the cluster head receives all the join-REQ information, it will produce a TDMA schedule, and notify all the member nodes in the cluster. After a member node receives the schedule, it sends data in its own time slots, and remains in the sleep state in other slots. After a frame time of data transmission, the cluster head runs the data compression algorithm to process the data and sends the results directly to the sink node [12].

LEACH protocol lets the data transmission phase last for a fixed period of time [12], then enter into a new round of cluster head election.

### 2.1.3. A Stable Election Protocol (SEP)

A Stable Election Protocol (SEP) [16] is improved version of LEACH protocol. Main aim of it was used heterogeneous sensor in wireless sensor networks. This protocol have operation like LEACH but with this difference that, in SEP protocol sensors have two different level of energy. SEP based on weighted election probabilities of each node to become cluster head according to their respective energy. This approach ensures that the cluster head election is randomly selected and distributed based on the fraction of energy of each node assuring a uniform use of the nodes energy.

In SEP, two types of nodes (normal and advanced) are considered. It is based on weighted election probabilities of each node to become cluster head according to the remaining energy in each node. This prolongs the stability period i.e. the time interval before the death of the first node.

#### **2.1.4. Routing challenges in Wireless Sensor Networks**

Factors that influence the design of routing protocol in WSN are summarized below:

- **Node deployment:** Sensor nodes are densely deployed in the area of interest depending upon the application, which affects the performance of routing protocol. Nodes can be deployed either manually or randomly. When nodes are manually placed, data is routed through pre-determined paths. In self-organizing systems, sensor nodes are scattered randomly creating a topology in an ad hoc manner.
- **Network topology:** It must be maintained even with high node density.
- **Data aggregation:** It is a combination of data from different sources. Similar packets from multiple nodes can be aggregated to reduce transmission.
- **Transmission media:** Generally, communication takes place through wireless media, which is affected by fading and as a result, it will affect the operation of WSN.
- **Node capability:** Depending on the application, a sensor node can have a different role or capabilities such as relaying, sensing and aggregation. If the same node performs all these functions, the energy of that node would be drained more quickly. Different capabilities of sensor nodes raise multiple issues related to data routing and makes routing more challenging [17].
- **Scalability:** The deployment of sensor nodes is dependent on the nature of the application. Sensor node deployment varies with respect to the demand of the application, therefore the number of sensor nodes can be hundreds, thousand or even more. To handle network scalability, routing algorithm should have the capability to cope with scalable network.

## 2.2. Heterogeneous Wireless Sensor Networks

Wireless sensor networks (WSNs) are composed of many homogeneous or heterogeneous sensor nodes with limited resources. Routing techniques are the most important issue for networks where resources are limited. This section presents a paradigm of heterogeneous wireless sensor network and discusses the impact of heterogeneous resources [18][19].

### 2.2.1. Types of heterogeneous resources

There are three common types of resource heterogeneity in sensor nodes: computational heterogeneity, link heterogeneity and energy heterogeneity.

- **Computational heterogeneity:** means that the heterogeneous node has a more powerful microprocessor and more memory than the normal node. With the powerful computational resources, the heterogeneous nodes can provide complex data processing and long-term storage.
- **Link heterogeneity:** means that the heterogeneous node has high bandwidth and long distance network transceiver than the normal node. Link heterogeneity can provide a more reliable data transmission.
- **Energy heterogeneity:** means that the heterogeneous node is line powered or its battery is replaceable.

Among above three types of resource heterogeneity, the most important resource heterogeneity is the energy heterogeneity because both computational heterogeneity and link heterogeneity will consume more energy resource.

If there is no energy heterogeneity, computational heterogeneity and link heterogeneity will bring negative impact to the whole sensor network, i.e., decreasing the network lifetime.

### 2.2.2. Impact of heterogeneity on wireless sensor networks

Placing few heterogeneous nodes in the sensor network can bring following benefits:

- **Decreasing latency of data transportation:** computational heterogeneity can decrease the processing latency in immediate nodes and link heterogeneity can decrease the waiting time in the transmitting queue. Fewer hops between sensor nodes and sink node also mean fewer forwarding latency.
- **Prolonging network lifetime:** The average energy consumption for forwarding a packet from the normal nodes to the sink in heterogeneous sensor networks will be much less than the energy consumed in homogeneous sensor networks.
- **Improving reliability of data transmission:** It is well known that sensor network links tend to have low reliability and each hop significantly lowers the end-to-end delivery rate.

With heterogeneous nodes, there will be fewer hops between normal sensor nodes and the sink. Therefore, the heterogeneous sensor network can get much higher end-to-end delivery rate than the homogeneous sensor network.

### 2.2.3. Performance measures

The project design would typically focus on the evaluation of the performance metrics for clustering protocols are listed below [20].

- **Network lifetime (stability period):** It is the time interval from the start of operation (of the sensor network) until the death of the first alive node.
- **Number of cluster heads per round:** Instantaneous measure reflects the number of nodes that would send directly to the base station, information aggregated from their cluster members.
- **Number of alive nodes per round:** This instantaneous measure reflect the total number of nodes and that of each type that has not yet expended all of their energy.
- **Throughput:** This includes the total rate of data sent over the network, the rate of data sent from cluster heads to the base station as well as the rate of data from the nodes to their cluster heads.

Figure 4 shows the heterogeneous model for wireless sensor network.

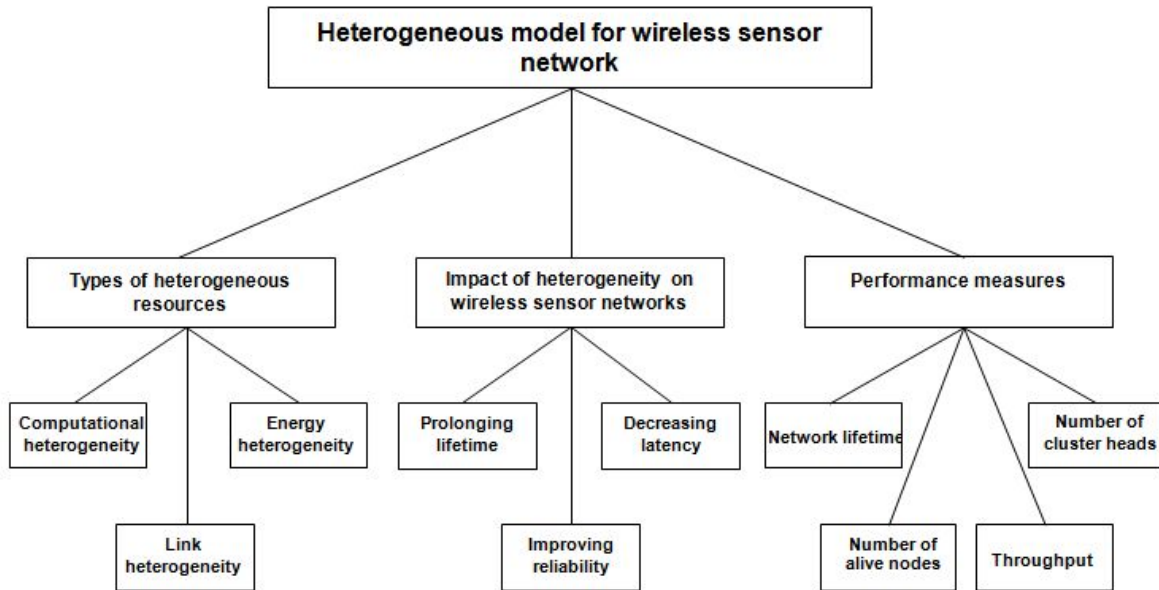


Figure 4. Heterogeneous model for wireless sensor network

## 2.3. Wireless sensor network models

### 2.3.1. Network model

In this chapter, we assume a sensor network model with following properties:

- The sink locates at the center of sensor nodes and has enough memory and computing capability.
- The WSNs consist of the heterogeneous sensor nodes. Percentage of sensor nodes are equipped with more energy resources than the rest of the nodes. Let  $m$  be the fraction of the total number of nodes  $N$ , which are equipped with  $a$  times more energy than the others.
- The distance can be measured based on the wireless radio signal power.
- All sensor nodes are immobile and have a limited energy.
- All nodes are equipped with power control capabilities to vary their transmitting power.

### 2.3.2. Radio energy dissipation model

For this project, three routing protocols, namely LEACH and SEP and our protocol Hierarchical Adaptive Balanced energy efficient Routing Protocol (HABRP), we use the same radio model shown in fig.5 for the radio hardware energy dissipation in order to achieve an acceptable Signal to Noise Ratio (SNR) in transmitting a L-bit message over a distance  $d$ .

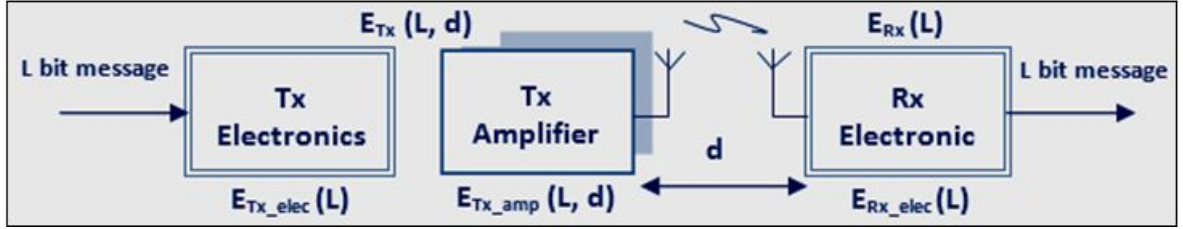


Figure 5. Radio Energy Dissipation Model

In fig.5  $L$  is the number of bits per packet transmission and  $d$  is distance between the sender and receiver. Electronics energy consumption is same for transmitting and receiving the data, is given by,

$$E_{TX}(L) = E_{RX}(L) = E_{elec} * L \quad (2)$$

$E_{elec}$  is the energy dissipated per bit to run the transmitter or the receiver circuit.

Transmission cost to transmit L-bit message between any nodes over distance  $d$  is given by the following equation:

$$E_{TX}(L, d) = E_{elec} * L + E_{amp}(L, d) \quad (3)$$

$E_{amp}(L, d)$  is the amplifier energy consumption and it can be further expressed in terms of  $\epsilon_{fs}$  or  $\epsilon_{mp}$ , depending on the transmitter amplifier mode that applied. They are power loss factors for free space ( $d^2$  loss) when  $d < d_o$ ; and multipath fading ( $d^4$  loss) when  $d \geq d_o$ , respectively.

To transmit L-bit message within  $d$  distance, a node expends:

$$E_{TX}(L, d) = \begin{cases} E_{elec} * L + \epsilon_{fs} * L * d^2 & \text{if } d \leq d_o \\ E_{elec} * L + \epsilon_{mp} * L * d^4 & \text{if } d > d_o \end{cases} \quad (4)$$

By equating the two expressions at  $d = d_o$ , we have:

$$d_o = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (5)$$

To receive a  $L$ -bit message, a node expends:

$$E_{TX}(L) = L * E_{elec} \quad (6)$$

Where:  $E_{elec}$  is the energy used by the receiver electronics

### 2.3.3. The verification of optimal number of clusters

We assume there are  $N$  nodes distributed uniformly in  $M * M$  region. If there are  $C$  clusters, there are on average  $N/C$  nodes per cluster. Each cluster head dissipates energy receiving signals from the nodes, beam forming the signals, and transmitting the aggregate signal to the base station. Therefore, the energy dissipated in the cluster head node during a single frame is:

$$E_{CH} = \left[ L * E_{elec} * \frac{N}{C} \right] + \left[ L * E_{DA} * \frac{N}{C} \right] + \left[ L * E_{elec} + L * \varepsilon_{mp} * d_{BS}^4 \right] \quad (7)$$

Where  $L * E_{elec} * \left( \frac{N}{C} - 1 \right)$  is the energy consumed by the cluster head to receive  $L$ -bits information from  $\left( \frac{N}{C} - 1 \right)$  non-cluster heads and  $E_{DA}$  represents the processing of data aggregation cost of a bit per signal. The expression for the energy spends by a non-cluster head is given by:

$$E_{non-CH} = L * E_{elec} + L * \varepsilon_{fs} * d_{toCH}^2 \quad (8)$$

Where:  $d_{toCH}$  is the distance from the member node to the cluster head (CH)

The area occupied by each cluster is approximately  $(M^2/C)$ . In general, this is an arbitrary-shaped region with a node distribution  $\rho(x,y)$ .

The expected squared distance from the nodes to the cluster head (assumed to be at the center of mass of the cluster) is given by:

$$d_{toCH}^2 = \iint (x^2 + y^2) * \rho(x, y) dx dy = \iint r^2 \rho(r, \theta) r dr d\theta \quad (9)$$

If we assume this area is a circle with radius  $R = \frac{M}{\sqrt{\pi C}}$  and  $\rho(r, \theta)$  is constant for  $r$  and  $\theta$ , simplifies to:

$$d_{toCH}^2 = \rho \int_{\theta=0}^{2\pi} \int_{r=0}^{M/\sqrt{\pi C}} r^3 dr d\theta = \left(\frac{\rho}{2\pi}\right) \left(\frac{M^4}{C^2}\right) \quad (10)$$

If the density of nodes is uniform throughout the cluster area, then  $\rho = \left(\frac{1}{\left(\frac{M^2}{C}\right)}\right)$

and

$$d_{toCH}^2 = \left(\frac{1}{2\pi}\right) \left(\frac{M^2}{C}\right) \quad (11)$$

Therefore, in this case the expression for the energy spends by a non-cluster head is:

$$E_{non-CH} = L * E_{elec} + L * \epsilon_{fs} * \left(\frac{1}{2\pi}\right) \left(\frac{M^2}{C}\right) \quad (12)$$

The energy dissipated in a cluster per round,  $E_{cluster}$  is expressed by:

$$E_{cluster} = E_{CH} + \left(\frac{N}{C} - 1\right) * E_{non-CH} \approx E_{CH} + \frac{N}{C} * E_{non-CH} \quad (13)$$

Therefore, the total energy dissipated in the network per round,  $E_{total}$ , is expressed by:

$$E_{total} = C * E_{cluster} \quad (14)$$

We can find the optimum number of clusters by setting the derivative of  $E_{total}$  with respect to  $C$  to zero [1].

$$\frac{\partial E_{total}}{\partial C} = 0 \quad (15)$$

$$C_{opt} = \sqrt{\frac{N}{2\pi}} \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \left( \frac{M}{d_{toBS}^2} \right) \quad (16)$$

The optimal probability of a node to become a cluster head  $P_{opt}$  can be computed as follows:

$$P_{opt} = \left( \frac{C_{opt}}{N} \right) \quad (17)$$

The optimal probability for a node to become a cluster head is very important. The authors [21] showed that if the clusters are not constructed in an optimal way, the total consumed energy of the sensor network per round is increased exponentially either when the number of clusters that are created is greater or especially when the number of the constructed clusters is less than the optimal number of clusters.

### **3. Methodology**

The design and simulation would be conducted in this chapter. Also, the comparative solution for an energy-efficient routing protocol on WSNs rail track failure monitoring with an embedded camera is presented here. MATLAB is used to implement the simulation.

#### **3.1. Design of the project**

The system uses the concept of sensor network with GSM and GPS module to determine the cracks on the rail road. The system inherits IR sensor on one side of the track and a photodiode on the other side of the track. When the robot starts its motion IR sensors gets activated, the resistance of the photodiode remains high until no cracks are there on the railway track. Whenever a crack gets detected, IR rays directly fall on the photodiode and decreases its resistance value. The resistance of the photodiode is inversely proportional to the intensity of incident light falling on it. Hence the soul concept lies on the fact that a change in resistance determines whether a crack is there or not.

After a crack gets detected in the first step, robot stops its motion and starts extracting data such as position coordinates by GPS module and image of the crack by camera module simultaneously. The second step is to send extracted data via GSM modem. On the completion of the task robot resumes its motion after a certain delay. A huge rail path can be surveyed with a single automated robot in a lucid way.

The specialty of this project is in order to find better solution for the railway track flaws by using the suitable routing protocol which meets the requirement of the rail monitoring with automated embedded robotic system.

### 3.1.1. Hierarchical Adaptive Balanced energy efficient Routing Protocol (HABRP)

In order to meet the requirements of rail monitoring the suitable routing protocol HABRP is depicted below. In this section, we describe HABRP that is an extension of the LEACH, which improves the stability period of the clustering hierarchy and decrease probability of failure nodes using the characteristic parameters of heterogeneity.

Routing in HABRP works in rounds and each round is divided into two phases, the setup phase, and the steady state phase; each sensor knows when each round starts using a synchronized clock. Let us assume the case where a percentage of sensor nodes are equipped with more energy resources (advanced nodes) than the rest of the nodes (normal nodes). We refer to these powerful nodes as NCG nodes (nodes selected as normal nodes or cluster heads or gateways). Let  $m$  be the fraction of the total number of nodes  $N$  which are equipped with  $a$  times more energy than the others and the rest  $(1 - m) * N$  as normal nodes and  $E_o$  the initial energy. We assume that all nodes are distributed uniformly over the sensor field. The total number of nodes and total energy in network is expressed by:

$$N = N * m [NCG \text{ nodes}] + N * (1 - m)[normal \text{ nodes}] \quad (18)$$

$$E[total] = N * m * E_o * (1 + a) + N * (1 - m) * E_o \quad (19)$$

### 3.1.2. HABRP network model

The basic system model of the protocol HABRP is depicted in fig.6. Each sensor node sends the sensed data to its cluster head. The cluster head aggregates the collected data and transmits the aggregated information to closest gateway that will send data to the base station.

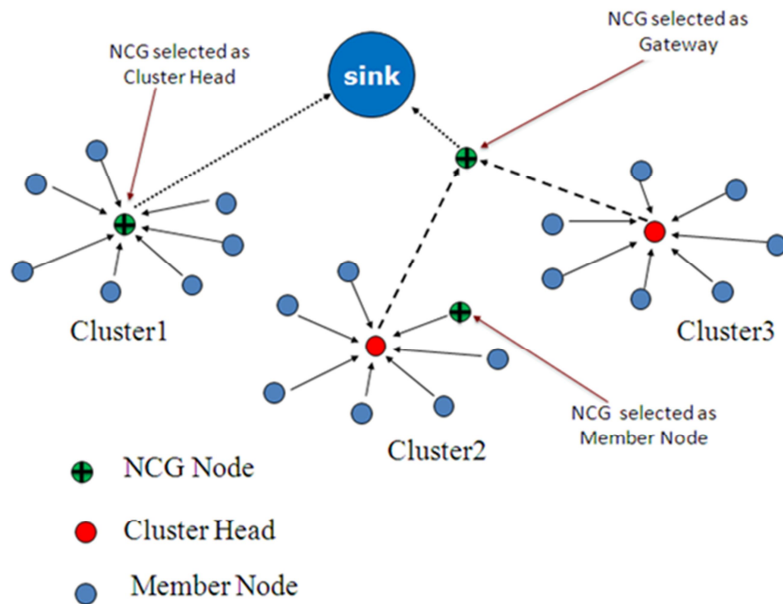


Figure 6. The HABRP network model

The operation of HABRP is divided into rounds. Each round begins with a set-up phase followed by a steady-state phase, as shown in fig.7.

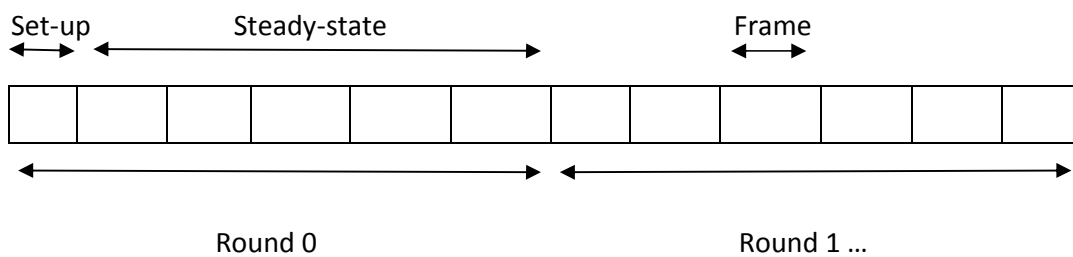


Figure 7. Time line showing HABRP operation

We suppose that the time of set-up phase is  $\alpha$ , and the steady data transmission time is  $\beta$ , then the time length of every round is:  $\tau = \alpha + \beta$ . For simpleness, we define the time when the first sensor node dies as the lifetime of the network, which is denoted as  $t$ . The relationship of the lifetime  $t$  and  $\beta$  is shown in Fig. 8. From Fig. 8, we can obtain that:

$$t = n * (\alpha + \beta) \tag{20}$$

Where  $n$  is the number of rounds after which the first sensor node dies.

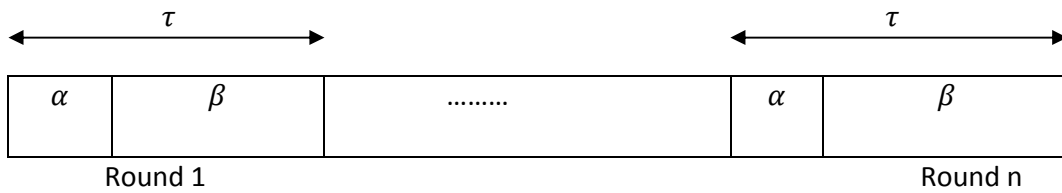


Figure 8. The lifetime  $t$  of the network

According to LEACH protocol, there are  $z$  frames in the time  $\beta$ , so  $\beta = z * T$ , here  $T$  is the time length of each frame. Therefore,

$$t = n * \tau = n * (\alpha + z * T) \tag{21}$$

During the set-up phase, the gateways are elected and the clusters are organized. It is constituted by gateway selection algorithm, cluster head selection algorithm and cluster formation algorithm.

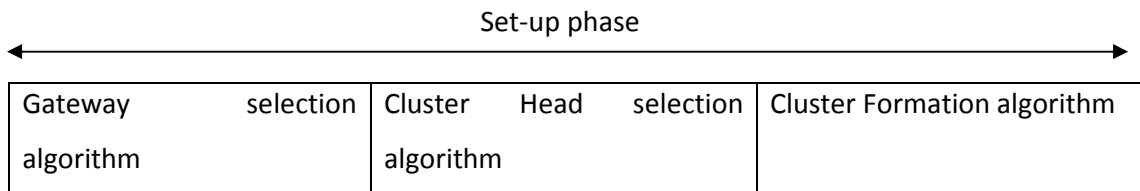


Figure 9. Time line showing set-up phase

After the set-up phase is the steady-state phase when data are transmitted from the nodes to the cluster head to aggregate data and transmit it to the base station through the gateway that requires the minimum communication energy. The duration of the steady phase is longer than the duration of the setup phase in order to minimize overhead.

### 3.1.3. Gateway selection algorithm

Each sensor  $S$  elects itself to be a gateway at the beginning of each round. This decision is based on the suggested percentage of gateways for the network (determined a priori) and the number of rounds the node has been a gateway so far. The desired percentage of gateways is chosen such that the expected number of gateway nodes for each round is  $N_g$ .

Thus, if there are  $N * m$  NCG nodes (advanced nodes) in the network, the desired percentage of gateways is:

$$P_g = \left( \frac{N_g}{N * m} \right) \quad (22)$$

Decision to become gateway is made by the node  $S$  choosing a random number  $X$  between 0 and 1. The node becomes a gateway for the current round if the number  $X$  is less than the following threshold:

$$T(S_{gat}) = \begin{cases} \left( \frac{P_g}{1 - P_g * \left( r \bmod \left( \frac{1}{P_g} \right) \right)} \right) * \left( \frac{E_{s \text{ current}}}{E_{s \text{ initial}}} \right) & \text{if } S \in G_{gat} \\ 0 & \text{otherwise} \end{cases} \quad (23)$$

We define as  $T(S_{gat})$  the threshold for gateway node  $S$ ,  $r$  is the current round,  $G_{gat}$  is set of nodes which have not been gateways in  $(1/P_g)$  rounds,  $E_{s \text{ current}}$  is the current energy of the node and  $E_{s \text{ initial}}$  is the initial energy of the node.

### 3.1.4. Cluster head selection algorithm

The main idea is for the sensor nodes to elect themselves with respect to their energy levels autonomously. The goal is to minimize communication cost and maximizing network resources in other to ensure concise information is sent to the sink. Each node transmits data to the closest cluster head and the cluster head performs data aggregation. Assume an optimal number of clusters  $C_{opt}$  in each round. It is expected that as a cluster head, more energy will be expended than being a cluster member. Each node can become cluster head with a probability  $P_{opt}$  and every node must become cluster head once every  $(1/P_{opt})$  rounds.

The optimal probability of a node to become a cluster head,  $P_{opt}$ , can be computed as follows:

$$P_{opt} = \left( \frac{C_{opt}}{N - N_g} \right) \quad (24)$$

$N_g$  is a number of gateway nodes;  $C_{opt}$  is the optimum number of clusters that is expressed by:

$$C_{opt} = \sqrt{\left( \frac{N - N_g}{2\pi} \right)} \sqrt{\left( \frac{\epsilon_{fs}}{\epsilon_{mp}} \right)} \left( \frac{M}{d_{toBS}^2} \right) \quad (25)$$

Our approach is to assign a weight to the optimal probability  $P_{opt}$ . This weight must be equal to the initial energy of each node divided by the initial energy of the normal node. Let us define as  $P_{nrm}$  the weighted election probability for normal nodes, and  $P_{adv}$  the weighted election probability for the advanced nodes. Virtually there are  $N * (1 + a * m)$  nodes with energy equal to the initial energy of a normal node. In order to maintain the minimum energy consumption in each round within an epoch, the average number of cluster heads per round per epoch must be constant and equal to  $C_{opt}$ . The weighted probabilities for normal and advanced nodes are, respectively:

$$P_{nrm} = \left( \frac{P_{opt}}{1 + a * m} \right) \quad (26)$$

$$P_{adv} = \left( \frac{P_{opt}}{1 + a * m} \right) * (1 + a) \quad (27)$$

In Equation (1), we replace  $P_{opt}$  by the weighted probabilities to obtain the threshold that is used to elect the cluster head in each round.

We define as  $T(S_{nrm})$  the threshold for normal nodes, and  $T(S_{adv})$  the threshold for advanced nodes. Thus, for normal nodes, we have:

$$T(S_{nrm}) = \begin{cases} \left( \frac{P_{nrm}}{1 - P_{nrm} * \left( r \bmod \left( \frac{1}{P_{nrm}} \right) \right)} \right) * \left( \frac{E_{s \text{ current}}}{E_{s \text{ initial}}} \right) & \text{if } S \in G_{nrm} \\ 0 & \text{otherwise} \end{cases} \quad (28)$$

Where  $r$  is the current round,  $G_{nrm}$  is the set of normal nodes that have not become cluster heads within the last  $(1/P_{nrm})$  rounds of the epoch and  $T(S_{nrm})$  is the threshold applied to normal nodes.

Similarly, for advanced nodes, we have:

$$T(S_{adv}) = \begin{cases} \left( \frac{P_{adv}}{1 - P_{adv} * \left( r \bmod \left( \frac{1}{P_{adv}} \right) \right)} \right) * \left( \frac{E_{s \text{ current}}}{E_{s \text{ initial}}} \right) & \text{if } S \in G_{adv} \\ 0 & \text{otherwise} \end{cases} \quad (29)$$

Where  $r$  is the current round,  $G_{adv}$  is the set of advanced nodes that have not become cluster heads within the last  $(1/P_{adv})$  rounds of the epoch, and  $T(S_{adv})$  is the threshold applied to advanced nodes.

### 3.1.5. Summary of Hierarchical Adaptive Balanced energy efficient Routing Protocol (HABRP)

HABRP is a self-organizing, adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensors in the network. Each sensor elects itself to be a gateway at the beginning of each round with a certain probability.

These gateway nodes broadcast their status to the other sensors in the network using advertisement message (ADV). The non-gateway nodes elect themselves to be cluster heads with a certain probability.

These cluster head nodes broadcast their status to the other sensors in the network using advertisement message (ADV). The non-cluster head nodes wait the cluster head announcement from other nodes. Each sensor node determines to which cluster it wants to belong by choosing the cluster head that requires the minimum communication energy, and send the join-request (Join-REQ) message to the chosen cluster head, and the cluster head nodes wait for join-request message from other nodes.

Once all the nodes are organized into clusters, each cluster head creates a schedule for the nodes in its cluster. This allows the radio components of each non-cluster head node to be turned off at all times except for its transmit time, thus minimizing the energy dissipated in the individual sensors. Once the cluster head has all the data from the nodes in its cluster, the cluster head node aggregates the data and then transmits the compressed data:

- To the chosen gateway that requires the minimum communication energy to reduce the energy consumption of cluster head and decrease probability of failure nodes if:

$$E_{CH-to-BS} > E_{CH-to-Gat} + E_{Gat-to-BS} \quad (30)$$

These collected data are transmitted to the base station using cluster head-gateway-base station routing.

- To the base station directly if:

$$E_{CH-to-BS} \leq E_{CH-to-Gat} + E_{Gat-to-BS} \quad (31)$$

Where  $E_{CH-to-BS}$  is total energy dissipated for send data from cluster head to the base station and  $E_{CH-to-Gat}$  is total energy dissipated for send data from cluster head to the gateway and  $E_{Gat-to-BS}$  is total energy dissipated for send data from gateway to the base station as shown in fig.10.

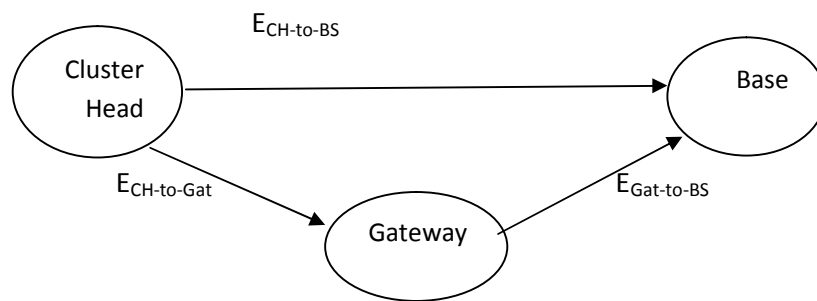


Figure 10. Cluster head would transmit to base station through gateway if

$$E_{CH-to-Gat} + E_{Gat-to-BS} < E_{CH-to-BS}$$

## 3.2. Simulation

### 3.2.1. Parameter settings

We use a 100\*100 region of 100 sensor nodes scattered randomly. MATLAB is used to implement the simulation. To make a fair comparison, we introduced advanced energy levels to LEACH and SEP nodes with same settings as in our HABRP protocol, so as to assess the performance of these protocols in the presence of heterogeneity.

Specifically, we have the parameter settings:

| Notation         | Description                                    | Value                          |
|------------------|--|--------------------------------|
| M*M              | Area   | 100*100, 300*300               |
| N                | Number of the sensors                          | 100, 900                       |
| (Sink x, Sink y) | Sink node location                             | 50*50, 50*200, 50*300, 300*300 |
| $E_o$            | Initial energy                                 | 0.5J                           |
| $E_{elec}$       | Electronics energy                             | 50nJ/bit                       |
| $E_{DA}$         | Energy of data aggregation                     | 5nJ/bit                        |
| $d_o$            | The threshold distance                         | 87m                            |
| $\epsilon_{fs}$  | Amplified transmitting energy using free space | 10pJ/bit/m <sup>2</sup>        |
| $\epsilon_{mp}$  | Amplified transmitting energy using multipath  | 0.0013pJ/bit/m <sup>4</sup>    |
| L                | Data packet size                               | 500 bytes                      |
| $L_{broad}$      | Broadcast packet size                          | 25 bytes                       |
| $P_{opt}$        | Probability                                    | 0.05                           |
| $C_{opt}$        | Optimum number of clusters                     | 5                              |
| $N_g$            | Number if gateway nodes                        | 4                              |

Table 2. Simulation parameter

### 3.2.2. Simulation metrics

Performance metrics used in the simulation study are:

- Energy consumption analysis
- Length of stable region for different values of heterogeneity. Stability period is the period from the start of the network operation and the first dead node. We also refer to this period as “stable region”
- Number of alive nodes per round
- Percentage of node death
- Variation of the base station location
- Sensitivity to degree of heterogeneity in large scale networks
- Improvement of stability period:

$$Improvement = \frac{\text{stable period of HABRP} - \text{stable period of LEACH}}{\text{stable period of LEACH}} \quad (32)$$

### 3.2.3. Simulation results

#### 3.2.3.1. Energy consumption analysis

The performance of HABRP is compared with that of the original LEACH and SEP in terms of energy and is shown in fig.11 and fig.12.

With the use of gateway nodes for data transmission from cluster heads to the sink, the energy consumption of the network is decreased. This is due to the gain of the energy dissipated by cluster heads to the base station. From the graph it is clear that HABRP can achieve twice the energy savings than LEACH and SEP protocol.

Fig.11 illustrates the energy performance of HABRP in homogeneous WSNs.

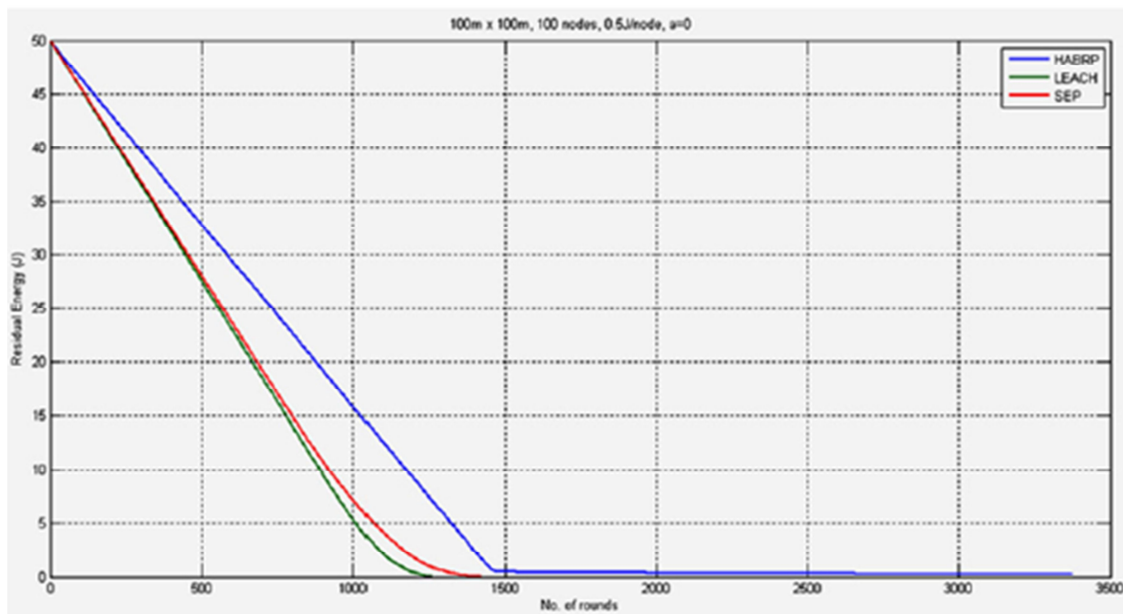


Figure 11. Energy analysis comparison of HABRP, LEACH and SEP in Homogeneous WSN (100m\*100m, 100 nodes, 0.5J/node, a=0(Homogeneous WSNs))

Fig.12 illustrates the energy performance of HABRP in heterogeneous WSNs

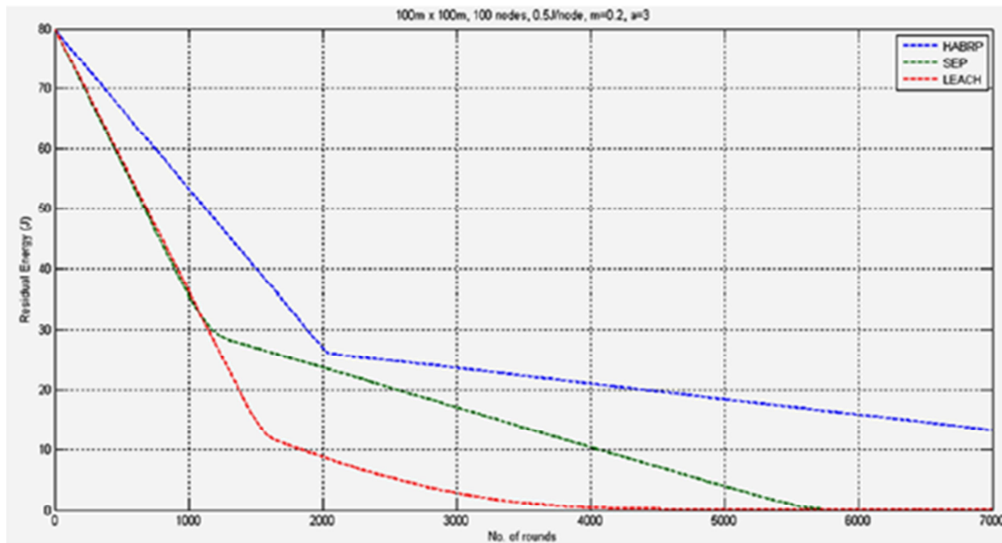


Figure 12. Energy analysis comparison of HABRP, LEACH and SEP (100m\*100m, 100nodes, 0.5J/node, m=0.2, a=3 (Heterogeneous WSNs))

### 3.2.3.2. Network lifetime

The number of nodes alive for each round of data transmission is observed for the HABRP protocol to evaluate the lifetime of the network. Fig.13 shows the performance of HABRP compared to LEACH and SEP. It is observed that the HABRP outperforms LEACH and SEP due to balanced energy dissipation of individual node throughout the network.

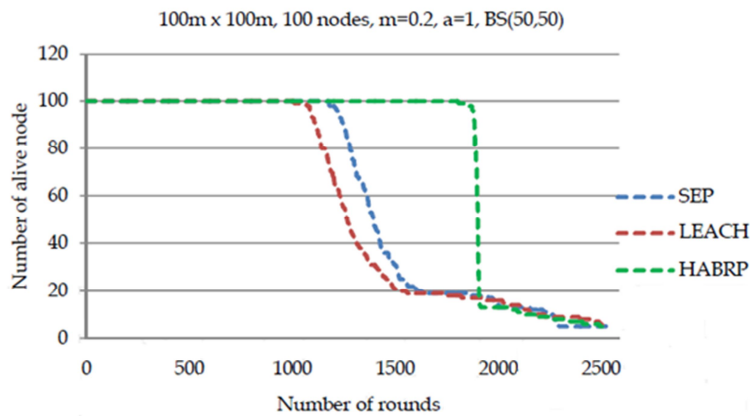


Figure 13. Number of alive nodes per round with (100m\*100m, 100nodes, 0.5J/Normal node, 1J/Advanced node, m=0.2, a=1, BS (50,50))

### 3.2.3.3. Variation of the Base Station Location

The results presented in the previous section show that HABRP is more energy efficient than LEACH and SEP routing. Is this just a function of the simulation parameters? What happens if the base station is actually located within the network or very far away from the network? To answer these questions, we ran simulations where we varied the location of the base station from (x=50,y=50) to (x=50,y=300).

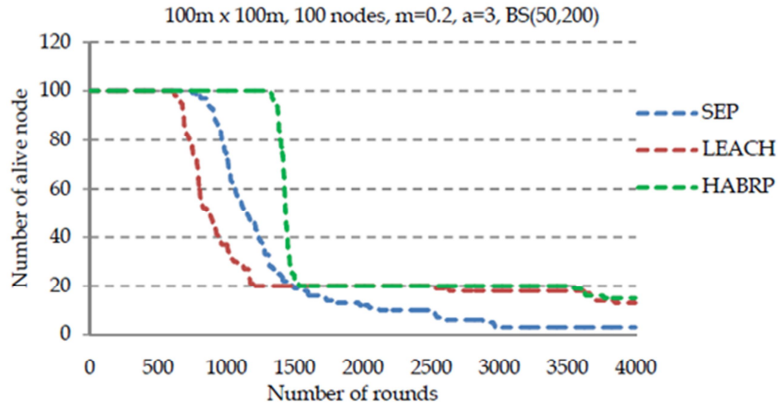


Figure 14. Number of alive nodes per round with (100m\*100m, 100nodes, 0.5J/Normal node, 2J/Advanced node, m=0.2, a=3, BS (50,200))

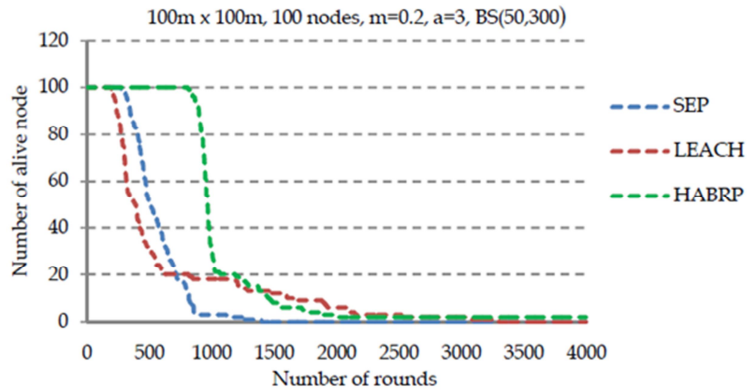


Figure 15. Number of alive node per round with (100m\*100m, 100nodes, 0.5J/Normal node, 2J/Advanced node, m=0.2, a=3, BS (50,300))

For all base station locations we simulated, as the base station moves further away from the network, the performance of HABRP improves compared to LEACH and SEP.

### 3.2.3.4. Percentage of node death

The number of rounds for 1%, 20%, 50%, 80% of node death is observed for HABRP and LEACH in fig.14 and fig.15. From the results of fig.14 the stability period of LEACH is limited to 892 rounds and the HABRP protocol extents up to 1335 rounds in homogeneous WSNs. In heterogeneous WSNs HABRP provides an extended lifetime of approximately twice LEACH protocol. HABRP has longer lifetime than LEACH and SEP.

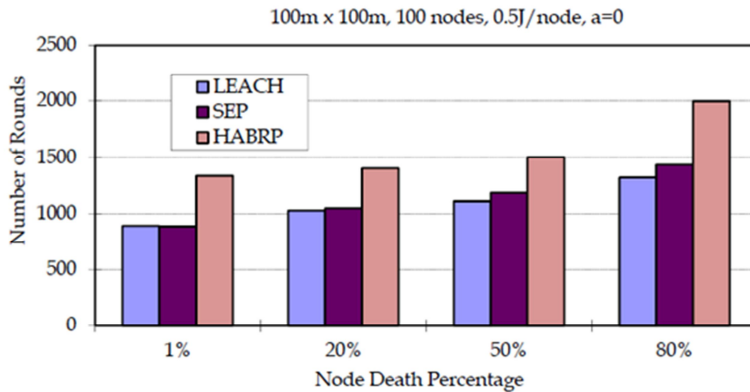


Figure 16. Node death percentage per number of rounds with (100m\*100m, 100nodes, 0.5J/node, a=0)

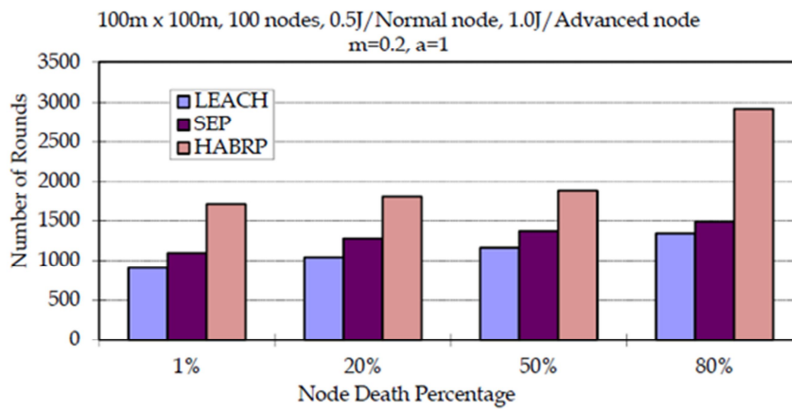


Figure 17. Node death percentage per number of rounds with (100m\*100m, 100nodes, 0.5J/Normal node, 1.0J/Advanced node, m=0.2, a=1)

### 3.2.3.5. Stable region in heterogeneous Wireless Sensor Networks

In fig.16 the length of stable region for different values of energy heterogeneity is simulated, we observed that if we increase the number of NCG nodes with  $a=1$ , the stability period is extended of approximately twice as LEACH protocol. In heterogeneous WSNs, HABRP has longer stable region than LEACH and SEP for different values of energy heterogeneity.

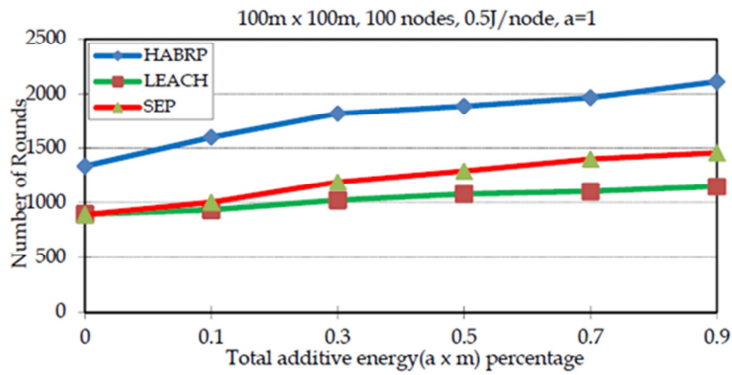


Figure 18. Length of stable region for different values of energy heterogeneity with (100m\*100m, 100nodes, 0.5J/node, a=1)

### 3.2.3.6. Heterogeneity in large-scale networks

We simulated the performance changes in large network with 900 nodes in area 300m\*300m.

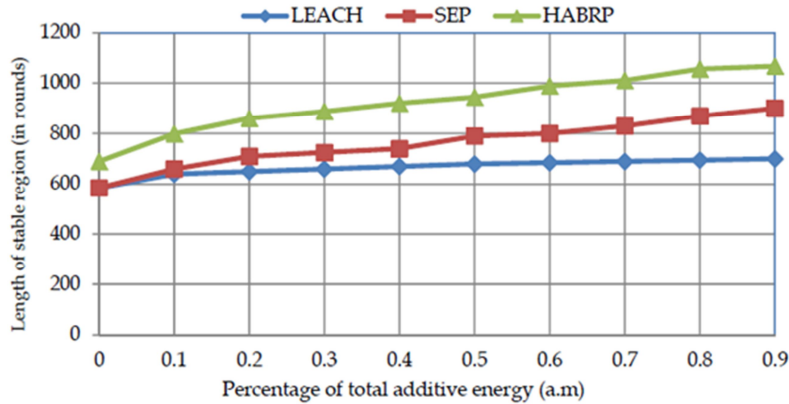


Figure 19. Sensitivity of HABRP and LEACH to degree of heterogeneity in large scale networks with 900 nodes in an 300m\*300m field.

In fig.17.the simulation result shows, that the network lifetime decrease in large area network and the period that the first dead node appears is earlier than those of previous cases. The phenomenon is caused by the fact that the cluster heads waste the considerable amount of energy for transmitting their data to the far away base station. In HABRP cluster head would transmit data to base station through gateway to eliminate that the cluster head far away from the base station dissipate their energy much faster than those close to the BS. HABRP outperforms LEACH and SEP for different values of total additive energy a\*m. Because in LEACH and SEP, all cluster heads transmits aggregated data to the BS directly.

### 3.2.3.7. Improvement of stability period

The comparison results are shown in Table 3, Show that HABRP is more energy-efficient, and the stability period is extended than LEACH in both homogeneous and heterogeneous WSNs.

| First Node Dies | a*m | LEACH | HABRP | Improvement % |
|-----------------|-----|-------|-------|---------------|
|                 | 0   | 892   | 1335  | 50%           |
|                 | 0.1 | 908   | 1704  | 88%           |
|                 | 0.3 | 1020  | 1820  | 78%           |
|                 | 0.5 | 1076  | 1888  | 75%           |
|                 | 0.7 | 1100  | 1966  | 79%           |
|                 | 0.9 | 1145  | 2111  | 84%           |

Table 3. Improvement of HABRP compared to LEACH with a=1

#### 4. Result analysis

From our simulations, we observed the followings:

- HABRP can achieve twice the energy savings than LEACH and SEP protocol.
- HABRP outperforms LEACH and SEP due to balanced energy dissipation of individual node throughout the network and extends network lifetime.
- For all base station locations we simulated, as the base station moves further away from the network, the energy efficient performance of HABRP improves compared to LEACH and SEP.
- In heterogeneous WSNs, HABRP provides an extended lifetime of approximately twice than LEACH protocol and the stability period of the HABRP was prolonged than LEACH and SEP in heterogeneous settings.
- Energy dissipation is balanced between normal nodes and advanced nodes in the HABRP compared to LEACH and SEP.
- Balancing the energy consumption, reducing the phenomenon of rapid death of the cluster head caused by excessive energy consumption, also preventing the situation of instability period caused by one cluster head failure to work, ensure that the network work normally.
- Using gateway and cluster head, it saves excessive energy consumption for long distance transmission, increased energy utilization of the entire network. The simulation results show that HABRP protocol could suitably form clusters and effectively prolonging the survival time of the entire networks.

## 5. Conclusion and future work

### 5.1. Conclusion

Generally, I observed that an achievement of cost-effective communication network where being the low cost motion and acceleration sensors deployed along the track (100m\*100m coverage area per-cluster) for the sake of track failure monitoring purpose.

Specifically, I observed that the rail crack detection having a mesh topology using a WSN embedded with incorporated camera has been able to achieve an energy-efficient traffic management within network field.

Energy efficient routing is paramount to extend the stability and lifetime of the wireless sensor networks. Routing in sensor networks is very challenging due to several characteristics that distinguish them from traditional communications and wireless ad hoc networks since several restrictions, e.g., limited energy supply, computing power, and bandwidth of the wireless links connecting sensor nodes. The major difference between the WSN and the traditional wireless network is that sensors are very sensitive to energy consumption. Introducing clustering into the networks topology has the goal of reducing the number of message that need to be delivered to the sink in large-scale WSNs.

In this chapter, we have proposed an Hierarchical Adaptive Balanced energy efficient Routing Protocol (HABRP) for wireless sensor networks. The energy efficiency and ease of deployment make HABRP a desirable and robust protocol for wireless sensor networks. In order to improve the lifetime and performance of the network, routing in HABRP works in rounds and each round is divided into two phases, the set-up phase and the steady state phase. During the set-up phase some high-energy nodes called NCG nodes are elected gateways, other choice cluster heads and the clusters are organized. During the steady-state phase, data are transmitted from the cluster member's nodes to the cluster head to aggregate data and transmit it to the base station through chosen gateways that requires the minimum communication energy to reduce the energy consumption of cluster head and decrease probability of failure nodes.

Simulation results shows that the HABRP improves the stable region of the clustering hierarchy and decrease probability of failure nodes, increase the lifetime of the network due to balanced energy dissipation of individual node throughout the network, and extends network lifetime. Balancing the energy consumption, reducing the phenomenon of rapid death of the cluster head caused by excessive energy consumption, also preventing the situation of instability period caused by one cluster head failure to work, ensure that the network work normally.

Finally, HABRP is scalable and achieves better performance compared to SEP and LEACH in both heterogeneous and homogeneous environments.

On the design process of railway track failure monitoring our desired routing protocol HABRP satisfies an improvement compared with LEACH by 76%.This system furnishes a cheap, reliable, flexible, and intellectual alternative for the existing system.

## **5.2. Future work**

The work can be done in order to provide a better speed to the to the automated vehicle robot. Also enhancement can be done to get better accuracy about the location of the place where the fault had occurred. Also the robot can be made large so that by using its weight track shiftiness i.e. stress and strain parameters of the track can be determined so as to make this system more effective. A Zigbee module can also be incorporated for low cost short distance scrutinizing mechanism in order to provide good connectivity at low input cost.

In the railway industry track monitoring and detection of flaws is a vital role for the existing railway operation and on-time maintenance before any damage happening. I have been discussing the suitable and energy efficient routing protocol which is enable the crack detection of rails within the wireless sensor network based on energy heterogeneity. For future, different experiment on wireless sensor network might be conducted and tested in order to reduce any kinds of railway incident (accident) in related with derailment, collision and so on.

## 6. References

- [1] W. B. Heinzelman, A. Chandrakasan, H. Balakrishnan, "An Application-Specific Protocol Architecture for Wireless Micro-sensor Networks," *IEEE Transactions on Wireless Communications*, Vol. 1, No. 4, Oct. 2002, pp. 660–670.
- [2] I. Demirkol, C. Ersoy, F. Alagoz, "MAC Protocols for Wireless Sensor Networks: A Survey," accepted by *IEEE Communications*, 2005.
- [3] W. Ye, J. Heidemann, D. Estrin, "Medium Access Control with Coordinated Adaptive Sleeping for Wireless Sensor Networks," *IEEE/ACM Transactions on Networking*, Vol. 12, No. 3, June 2004, pp. 493–506.
- [4] Y. C. Tay, L. Jamieson, H. Balakrishnan, "Collision-Minimizing CSMA and Its Applications to Wireless Sensor Networks," *IEEE Journal on Selected Area in Communications*, Vol. 22, No. 6, Aug. 2004, pp. 1048–1057.
- [5] C. Intanagonwiwat, R. Govindan, D. Estrin, "Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks," *Proceedings of the 6th ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom'00)*, Aug. 2000.
- [6] C. F. Chiasserini, M. Garetto, "Modeling the Performance of Wireless Sensor Networks," *Proceedings of the 23rd Annual Joint Conference of the IEEE Computer and Communications Societies (InfoCom'04)*, Mar. 2004.
- [7] Shiokumarsingh 1, M p singh 2, and D k singh," Routing protocols in wireless sensor networks –a survey", *International Journal of Computer Science & Engineering Survey (IJCSSES)*, vol.1, November 2010.
- [8] k. Akkaya and M. Younis," A survey of routing protocols in wireless sensor networks," in the *Elsevier Ad hoc Network Journal*, vol.3/3 pp.325-349, 2005.
- [9] ZiboundraAliouat, saudharous," An efficient clustering protocol increasing wireless sensor networks lifetime", *Innovations in Information Technology (IIT)*, *IEEE International conference on communication, Networking & Broadcasting*, pp. 194-199, 2012.

- [10] Junuo Zhang, Wenbin Li, Xueliang Zhao, Chen chen," Simulation and research on data fusion algorithm of the wireless sensor network based on ns2" Computer Science and InformationEngineering, WRI world congress on computing & processing, vol.7, pp 66-70, IEEE, 2009.
- [11] S.k. singh, M.p. singh, and D.k. singh," A survey of energy efficient hierarchical cluster based routing in wireless sensor networks", International Journal of Advanced Networking and Application (IJANA), sept.-oct. 2010, vol.02, issue 02, pp.570-580.
- [12] Kumarawadu, D.J. Dechene, M. luccini, A. Sauer," Algorithms for node clustering in wireless sensor networks: a survey", Information and Automation for sustainability, ICIAFS 2008, 4<sup>th</sup> international conference on communication, pp.295-300, IEEE, 2008.
- [13] Fan Xiangning, song yulin," Improvement on LEACH protocol of wireless sensor network", Sensor Technology and Application, sensor comm. 2007, IEEE Trans. Wireless communication, vol.1, No.6, pp.670-70,
- [14] J.Hu, Y.Jin, and L. Dou, "A Time based cluster head selection algorithm for LEACH," IEEE symposium on computers and communications, 2008, 1172-1176.
- [15] J.D. Yu, K. T. Kim, B. Y. Jung, and H. Y. Youn," An Energy Efficient Chain Based Clustering Routing protocol for wireless sensor networks," Advanced Information Networking and Applications Workshops, 2009, 383-384.
- [16] G. Smaragdakis, I. Matta, A. Bestavros, 2004." SEP: A Stable Election Protocol for clustered heterogeneous wireless sensor networks", Second International Workshop on Sensor Actuator Network Protocols and its Applications,
- [17] N.M.A. Latiff, c.c. Tsimenidis, and B.S. Sharif," Performance comparison of optimization algorithm for clustering in wireless sensor networks," IEEE International conference on Mobile Adhoc and sensor systems, 2007, 1-4,
- [18] M. Yarvis, N. Kushalnagar and H. Singh," Exploiting heterogeneity in sensor networks," IEEE INFOCOM, 2005,

- [19] V. Katiyar, N. Chand, S. Soni, (2011), "A Survey on clustering algorithms for Heterogeneous Wireless Sensor Networks," International journal Advanced Networking and Applications Vol. 02, Issue: 04, pp. 745-754.
- [20] R. Sheikhpour, S. Jabbehdari, A. Khadem-Zadeh (2011), "Comparison of Energy Efficient Clustering Protocols in Heterogeneous Wireless Sensor Networks," International Journal of Advanced Science and Technology Vol. 36.
- [21] W.B. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy efficient communication protocol for wireless micro-sensor networks," proceedings of the 33<sup>rd</sup> Hawaii International conference on system sciences, 2000, 1-10.
- [22] D. Punetha, D. Mani Trpathi, A. Kumar, "A wireless approach for real-time railway track surveillance system," International Journal of Engineering Trends and Technology (IJETI), vol. 9, No. 9, March 2014.

