A DISSERTATION
ON

EFFICIENT DATA GATHERING WITH ENERGY AWARE APPROACH IN CHAIN BASED WIRELESS SENSOR NETWORK

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DECLARATION

I hereby declare that the dissertation entitled "*Efficient Data Gathering with Energy Aware Approach in Chain Based Wireless Sensor Network*" which is being submitted to Delhi Technological University, in partial fulfillment of requirements for the award of degree of Master of Technology (Computer Science and Engineering) is a bonafide work carried out by me. The material contained in the report has not been submitted to any university or institution for the award of any degree.

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CERTIFICATE

This is to certify that the dissertation titled "*Efficient Data Gathering with Energy Aware Approach in Chain Based Wireless Sensor Network*" is submitted by Mr. Anurag Singh, 2K14/CSE/03 in partial fulfillment of the requirements for the award of degree of Master of Technology in Computer Science & Engineering at Delhi Technological University. It embodies the work carried out by him under my supervision.

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ABSTRACT

PEGASIS, a hierarchical chain based protocol, is an important protocol architecture for routing in WSNs. Till now many protocols based on PEGASIS have been proposed to improve the Lifetime of network and its load balancing capabilities. IEEPB was proposed to remove certain limitations of EEPB such as problem of Long Link, non-optimal selection of leader node and huge time delay involved in data transmission. Similar to EEPB, IEEPB allowed branching in chain which produces nodes with different degrees which imbalances the energy consumption due to data fusion at each node and leader selection still remains less optimal as it does not consider the difference in degree of nodes and leads to the early death of sensor nodes. This results in poor load balancing in the network. In our work, we propose a method to solve this load balancing problem in more efficient way by considering node degree threshold and distance between nodes while building chain and node degree, initial energy, residual energy and distance as key parameters in leader selection. Also, a new method is adopted for data transmission to reduce time delay.

Similarly, M-PEGASIS was also proposed as an improvement over PEGASIS. This uses a new method for formation of chain as well as leader selection but the mechanism of data transmission remains same as PEGASIS. It still suffers with the problem of Long Links, non-optimal chain formation, low load balancing among nodes and huge time delay. In our work, we also propose another method to solve the said problems in more efficient way by introducing a chain reconstruction phase and by adopting new mechanism to gather and transmit data.

Simulation performed using MATLAB R2010a shows that the Proposed1 and Proposed2 protocols have better energy efficiency and load balanced energy consumption with reduced time delay as compared with IEEPB, PEGASIS and M-PEGASIS respectively.

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LIST OF ABBREVIATIONS

PEGASIS	Power Efficient Gathering in Information Systems
WSN	Wireless Sensor Network
LEACH	Low Energy Adaptive Clustering Hierarchy
EEPB	Energy Efficient PEGASIS Based
IEEPB	Improved Energy Efficient PEGASIS Based
CREEC	Chain Routing with Even Energy Consumption
IBCA	Intersection Based Coverage Algorithm
PBCA	Phase Based Coverage Algorithm
RFND	Round of First Node Death
RMND	Round of Middle Node Death
RLND	Round of Last Node Death
PDCH	PEGASIS with Double Cluster Head
PEDAP	Power Efficient Data Gathering and Aggregation
PEDAP-PA	Power Efficient Data Gathering and Aggregation Power Aware
M-PEGASIS	Modified Power Efficient Gathering in Information System
DFS	Depth First Search

CHAPTER 1

INTRODUCTION

1.1 Wireless Sensor Networks

Recent advancements in technology made it possible to mass produce small sensor devices with sensing, computation/processing, and communication capabilities. Over the past few years, a substantial amount of research on wireless sensor networks has been done. As sensors are deployed randomly for ease of deployment, sensor nodes should be cheaper, smaller, and have a longer lifetime, which makes it very important to develop very efficient hardware and software solutions [29,30].

As sensors are equipped with very small battery and generally recharging battery is not possible due to deployment constraints, so routing protocols for sensor networks should be designed carefully to make the most efficient use of the limited resources such as battery, computation, and storage. These restrictions are likely to remain, since in many cases it is desirable to exploit technological improvements to develop smaller and more energy efficient devices rather than making them more powerful. Different applications make use of WSNs in different ways which leads to different communication patterns and in network requirements [14,15].

To make use of wireless sensor networks for a particular application involves deployment of sensors in the area to be monitored, sensing of required criteria (like temperature, pressure, humidity etc.), communication of sensed data to the sink using some routing protocol and processing data and send desired information to the user. In most of the applications sensors are deployed randomly where as some applications involve application of particular deployment algorithm. Routing of data is the most important step in the working of WSNs because most of the energy is dissipated in transmission of data. So a routing protocol should efficiently utilize the limited battery power to maximize network lifetime such that each node dissipate equal amount of energy after a given time.

Wireless Sensor networks are becoming more and more popular day by day. Applications such as Smart City, Driverless Cars, Internet of Vehicles, Smart Homes, Smart Parking, Smart Wastage Management, Automated Leakage detection in pipelines, Traffic monitoring, Fire Detection, Automated Air pollution monitoring, Monitoring Radiation levels and Monitoring Structural Health etc. [29-30] show the utility of sensor networks in modern intra-day life scenario.Figure1.1 depicts application of sensor networks in future smart cities.

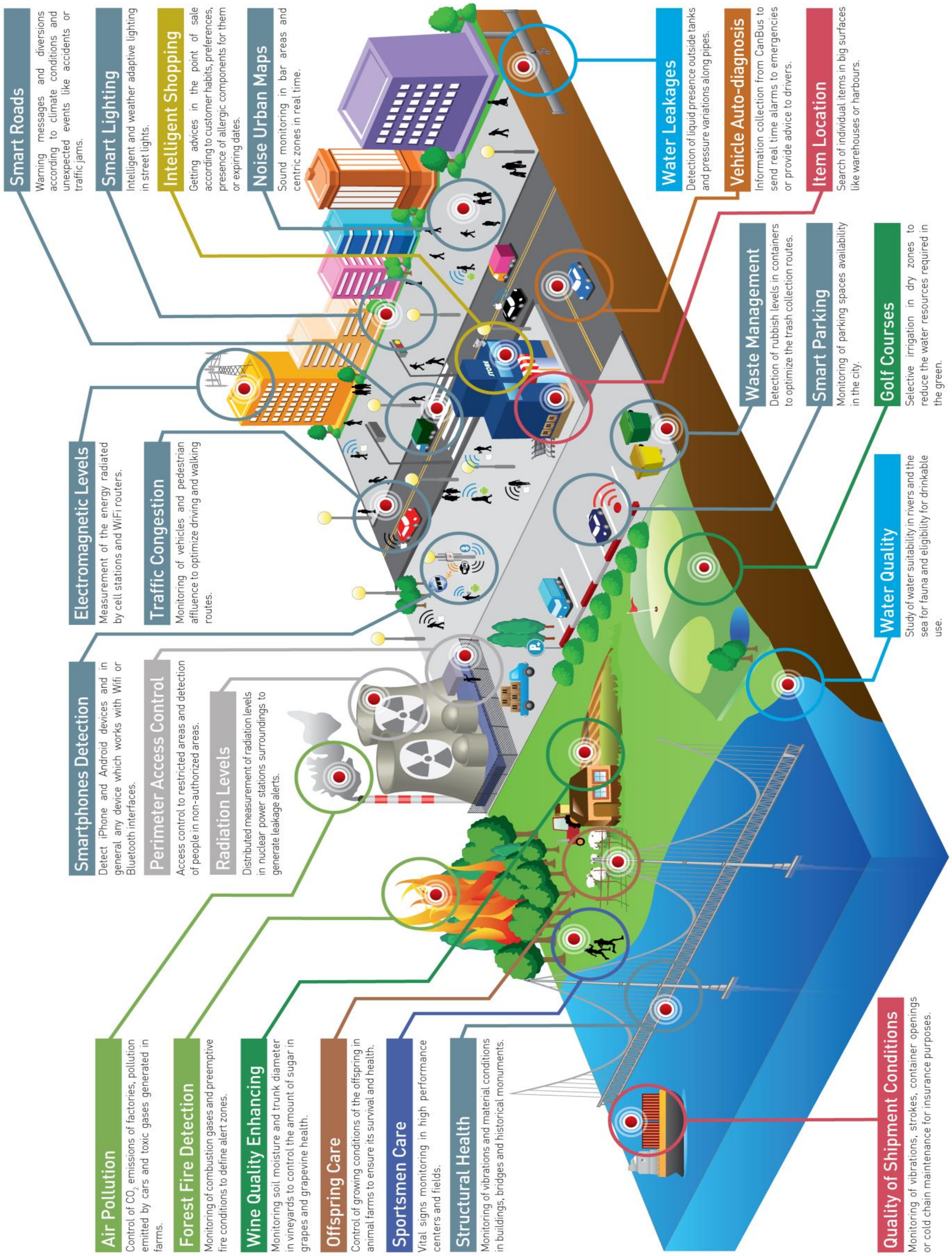

Figure 1.1: Applications of Wireless Sensor Network

1.1.1 Elements of Wireless Sensor Network

WSN comprises of following elements:

- **Sensor Node:** a small autonomous device equipped with a sensor, also known as mote, having capabilities of performing some processing, gathering sensory data and communicating with other nodes in the sensor network. A Sensor node needs to be equipped with following physical resources:
  - **Sensing subsystem** - senses data and converts them from analog to digital form.
  - **Processing subsystem** - stores gathered and configuration data in local memory, executes functions according to gathered data or received messages.
  - **Communication subsystem** - enables node to exchange messages with other nodes in range.
  - **Power unit** - supplies power from batteries to the other subsystems.

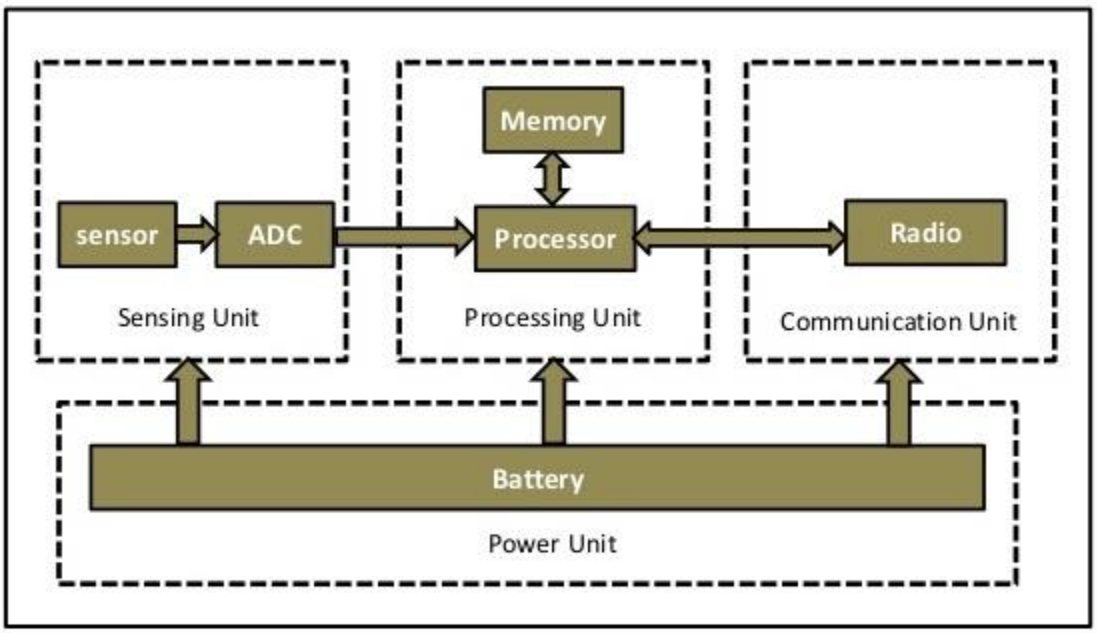

Figure1.2: Typical architecture of wireless sensor node

- **Sink:** processing center of the WSN; having a processor, antenna, radio board and USB interface board. It receives data from all sensors and also known as base station.
- **Gateway:** A gateway is an interface between the application platform and the wireless nodes on the wireless sensor network. All gateways can perform protocol conversion to

enable the wireless network to work with other industry or non-standard network protocols.

- **Cluster:** group of several sensor nodes based on some specific criteria.
- **Chain:** a cluster in which nodes connect to form a chain like hierarchy.
- **Leader Node:** a sensor node in the chain which is best fit (according to some criteria) to communicate with sink.

1.1.2 Concept of Smart sensor and IEEE 1451

Figure1.3 depicts basic architectural model of IEEE 1451. STIM (smart transducer interface module), TII (Transducer Independent Interface), TEDS (Transducer Electronic Data Sheet), and NCAP (Network Capable Application Processor) are the major components [25] as shown in figure1.3.

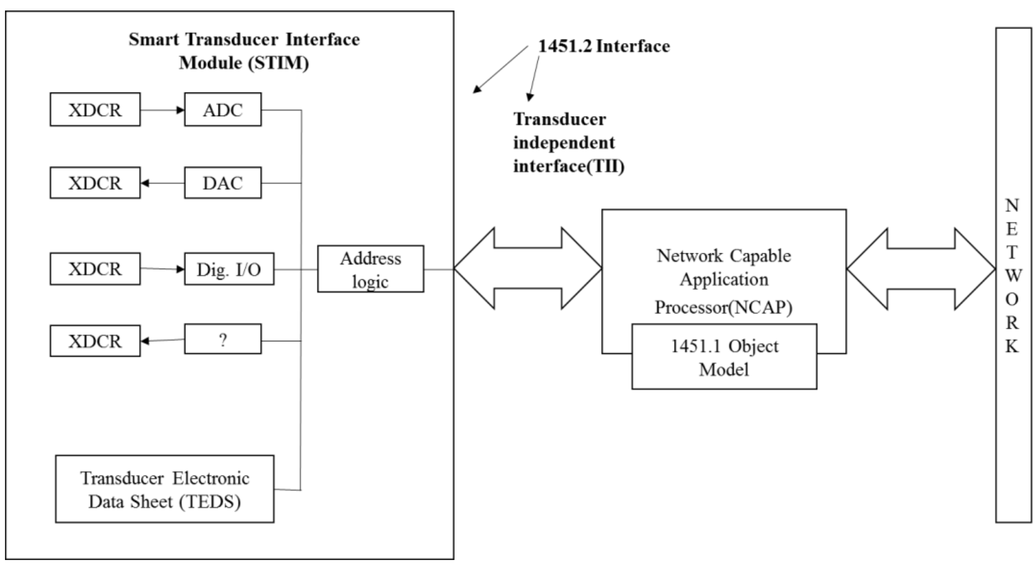

Figure 1.3: The IEEE 1451 Standard for Smart Sensor Networks

IEEE 1451 formalized the concept of Smart Sensor that is capable of performing some extra functions including necessary basic functions, for generating an accurate representation of the sensed attribute. These extra functions might include smart signal processing, signal conditioning and decision making /alarm functions [25]. Figure 1.4 depicts a general model for a smart sensor.

The main objectives of a smart sensor includes moving intelligence more closer to point of measurement; cost effectiveness in integrating and maintaining distributed sensor network systems; to create a confluence of , computation, transducers, control, and communications towards a common goal; and seamlessly interfacing numerous sensors of different types[25].

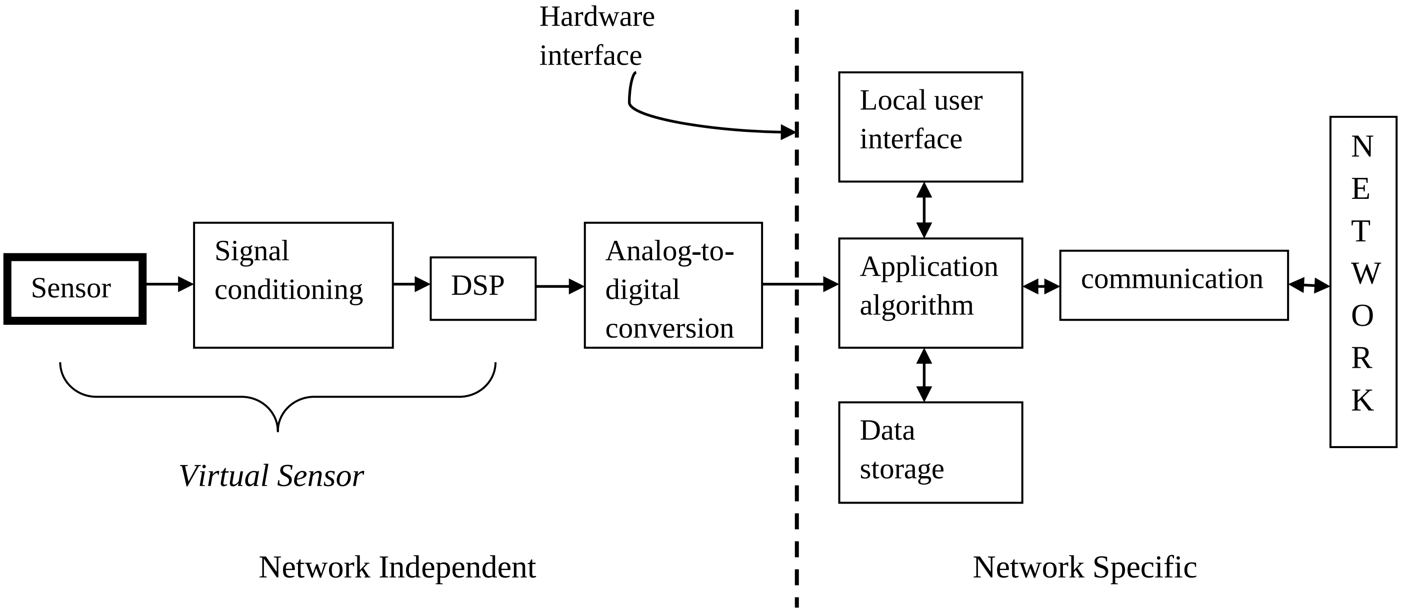

Figure 1.4: A general model of a smart sensor [IEEE 1451 Expo, Oct. 2001]

1.1.3 Working of Wireless Sensor Networks

A wireless sensor network consists of several sensor nodes. Generally sensor nodes are deployed randomly. These sensor nodes synchronize themselves according to a control signal from base station. Sensor nodes sense the desired attributes and communicate with each other depending upon the given application; applying some protocol sensors transmit the sensed data to the base station for further processing. Base station is supposed to be powerful in terms of capabilities and connected with Internet. It aggregates and processes data to fetch desired results and representation then it sends the processed information to the given destination (end user or end application).

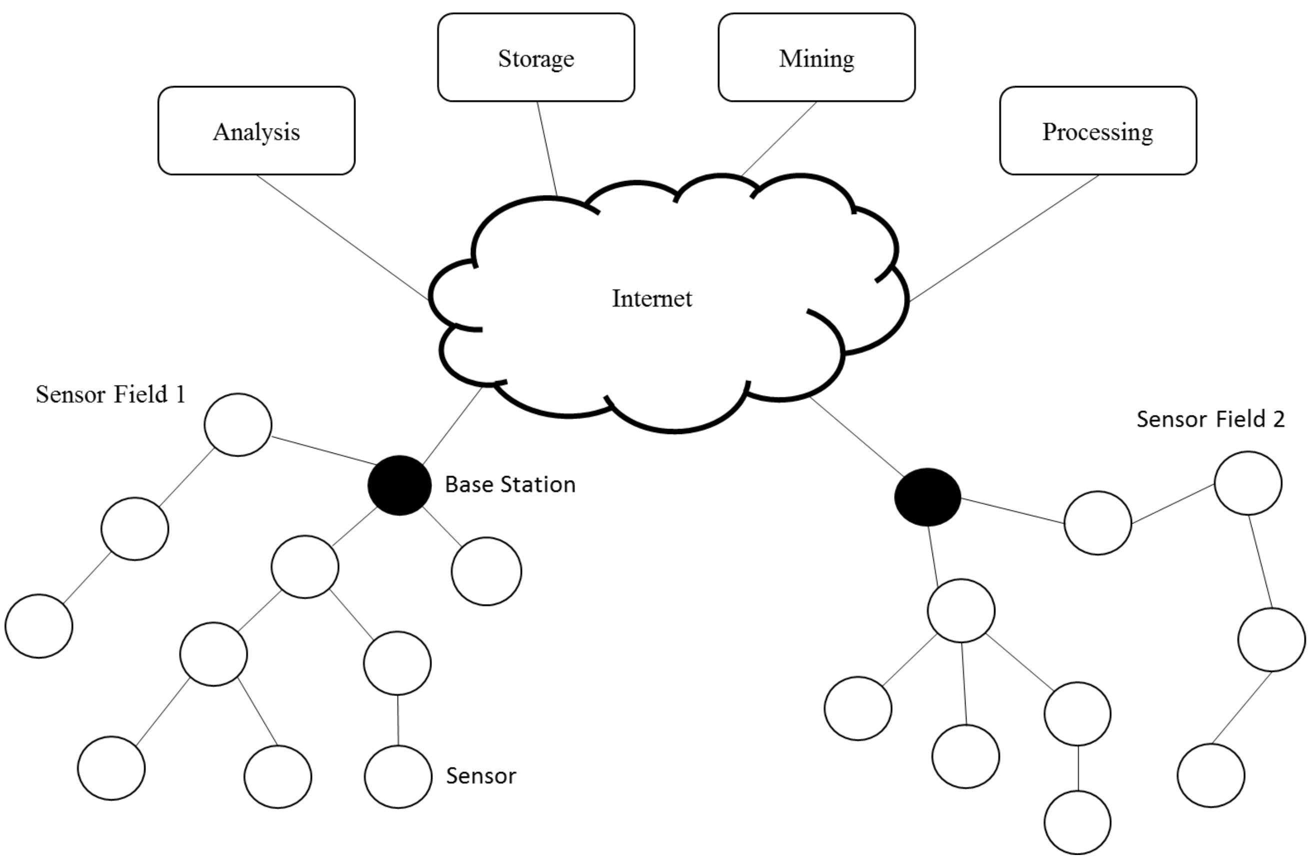

Figure 1.5: Working of wireless sensor networks

1.2 Data Models

The data model describes and characterizes the interaction between sensor nodes and application. It differs from topology in the fact that topology is a function of network protocol whereas data models are function of application. The suitability of a data model for an application is determined based on the requirements of the application. For different monitoring applications, there are different data models which are as follows:

- **Periodic Sampling:** For certain applications which needs constant monitoring of processes or conditions such as pressure, humidity or temperature; data is sensed by a number of sensors and transmitted to base station on a period basis. Determination of sampling period depend variability in the values of parameter to be measured.
- **Event Driven:** For some application which needs monitoring of crucial variables immediately on occurrence of some specific event or condition; data is sensed by sensors following that event and forwarded to the base station immediately. Sensors need special capabilities to support such applications. Sensors must be designed with minimal dissipation when sensor is idle and wake up time should be relatively short.
- **Store and Forward:** Many applications need that data could be sensed and stored and/or even processed by the sensor prior to transmitting it to the base station.

1.3 Motivation

The term ‘Smart’ became very much popular in recent years. Our daily life is full of words such as Smart phone, Smart City, Smart home, Smart TV, Smart vehicle, Smart manufacturing, Smart classes, Smart Healthcare etc. This is only due to the evolution of sensors and their networks. Much of research has been carried out in the field of wireless sensor networks in past few years. So strengths and limitations related to wireless sensor networks and their applications are well known now and recent researches are focusing on utilizing strengths and overcoming and/or minimizing impact of limitations.

As sensor has certain constraints like limited energy, limited computing/processing capability, limited memory etc. which poses several design challenges related to networking, routing and data aggregation etc. So, efficient designs are needed to maximize the life of sensors and the network to support various applications. Routing is one of the most important step in the working of wireless sensor networks. Various routing techniques are proposed by many researchers till now. These routing protocols are can be classified as Hierarchical routing, Data-centric routing, location-based routing etc. Cluster based routing and chain based routing are two types of hierarchical routings which focuses upon making efficient use of energy available to prolong network lifetime. Some of these protocols proposed techniques to balance load among the nodes in the WSNs.

Chain based routing protocols are simple and have objectives of efficient utilization of battery power and load balanced energy consumption among nodes of the network. The main problems with chain based routing protocols are lack of load balanced energy consumption and the huge time delay involved in the gathering and transmission of data to the base station. So much work is needed to improve energy efficiency, load balancing and to reduce time delay involved. We in our work emphasized on developing improved solution in terms of energy efficiency, balancing load among sensors and to reduce time delay.

1.4 Organization of Thesis

The dissertation starts with introduction of popular wireless sensor networks, their applications in real life, components that forms a sensor network, data models and other working details etc. all included in chapter 1. Chapter 2 covers study of various proposed works with detailed description of protocols which are used as base for this dissertation and a comparative study is presented at the end of chapter. The detailed description of work proposed in the dissertation is presented in the chapter 3 which contains problem statement with proposed improvements and detailed working. The performance of the proposed solutions is evaluated in Chapter 4 and comparison is performed with other previous works and a detailed analysis is presented. The dissertation is concluded with a brief summary of our findings and the future scope, all of this is covered in chapter 5.

CHAPTER 2

LITERATURE SURVEY

A wireless sensor network typically consists of a number of sensing devices (sensors) deployed randomly or using some particular techniques such as statistical distribution, optimization heuristics, complex geometric approach etc. over area to be sensed/monitored. Sensor is a tiny device having small battery as power source and hence the work efficiency is constrained. This limited power is the main hindrance in communication capabilities, signal processing abilities, and data processing capabilities of the sensing device as a result a sensor can monitor a small area only. This gives us idea to use multiple sensing devices to achieve the objective efficiently.

The efficiency of the application can be viewed in terms 'for how long the network remains functioning' i.e. Network Lifetime, the equality in energy consumption among sensor nodes i.e. death of the first sensor node. This depends upon network deployment, routing approach and data processing techniques used.

Routing is the most important phase in the whole activity of sensing. Cluster based and chain based routing are two important hierarchical topology architecture for data routing in sensor network. For chain based hierarchical routing, there two types of chains. Some protocol formed chains with nodes having maximum node degree as One i.e. Chain without Branches and Chains having nodes with degree of connectivity one or more i.e. Chain with Branches. Some protocols formed Single chain while others have formed multiple chains.

There are many factors such as energy consumption, scalability, connectivity, data aggregation, quality of service, fault tolerance, and mobility etc. should be considered while designing a routing protocol [22].

The main objectives of routing approach are given as follows:

- **Maximizing Network Lifetime:** The lifetime of the network is the time duration for which at least one sensor node is alive and successfully pursuing sensing activity. A round for a routing protocol is the time duration in which sensors complete the sensing activity and transmit data to the base station. So network lifetime is measured in terms of number rounds for which the network is up. So the main focus of any routing protocol is to maximize the network lifetime.

- **Balanced Energy Consumption:** Another objective of a routing protocol is to make sensors to consume equal energy in each round of sensing activity which involves sensing data, gathering data and transmitting it to sink. This is important when we need that all nodes should be up and sensing till the end. So for balanced energy consumption a routing protocol should focus on prolonging the death of the first node.
- **Time Delay:** transmission of data from one node to other requires time. So the time duration from the start of data gathering to transmission to the base station is called as time delay. In most of the application it is undesirable.

In proposed work, we have focused on prolonging network lifetime and balancing the energy consumption among sensor nodes in each round and over a period of time. Reducing time delay also remains our important objective to achieve.

There are many routing protocols are proposed till date having objectives of maximizing network lifetime and balanced energy consumption. These protocols can be classified based on nature of protocols, network structure, protocol operation, and data forwarding methods [22, 23, 24] which are as follows:

- Data Centric Protocols
- Hierarchical Protocols
- Location-Based Protocols
- QoS Aware Protocols

One of the class based on structure of protocol is Hierarchical protocols. LEACH, TEEN, APTEEN and PEGASIS are some important hierarchical protocols. Hierarchical protocols can be further classified as:

- Cluster based hierarchical protocols (like LEACH [3], TL-LEACH [26], EECA [27], EEUC [28], etc.)
- Chain based hierarchical protocols (like PEGASIS, EEPB, IEEPB, CREEC etc.)

In chain based hierarchical protocols, some allow branched chains while others don't. PEGASIS, ANT-PEGASIS and CREEC from simple chains while EEPB, IEEPB, PEDAP, PEDAP-PA and Modified-PEGASIS etc. forms branched chains.

The Remainder of this chapter includes essence of some important works carried out earlier by researchers which are important to the work proposed.

2.1 PEGASIS Protocol Architecture

Cauligi S. Raghavendra and Stephanie Lmdsey proposed a protocol titled Power-Efficient Gathering in Sensor Information System [1] in 2001. This protocol proposed a hierarchical chain based routing technique based on greedy approach in wireless sensor network. The protocol has following presumptions:

- The Base station is located at a far distance from the area to be sensed and is stationary.
- All sensors are of homogeneous nature i.e. they have equal capabilities such as Initial level of Energy, Communication and sensing abilities.
- Cost to transmit a packet is totally depends upon distance the packet travels to reach destination.
- All nodes possess no mobility i.e. they remains at the location where they are deployed.
- Sensors are deployed randomly in the area to be sensed.

The technique is round based and works in three phases such as Chain formation, Leader Selection and Data Transmission. In this all nodes have data to send in each round. In each round, first a chain is formed based on minimum distance criteria. Then a node is selected as Leader based on specific criteria and is responsible for gathering data from the chain and transmitting it to the Base station. These steps are discussed in detail as follows:

2.1.1 Chain Formation

This protocol employs a greedy approach for the construction of chain. The process of building chain begins with selection of the farthest node from Sink which is located far from the network area. This is the first node to be included in the chain and set it as the Start node. Now, the latest node who joined the chain, finds the nearest neighbor node based on distance from nodes which are not included in the chain till now. This nearest node connects with chain and the same process repeats till all the nodes get connected to the chain. So a node on chain can have node degree of connectivity at most 2.

For example in figure 2.1Nodes are deployed at random locations. The process of chain formation begins with finding farthest node from BS which is with node ID #3. Now Node with ID #3 finds node with ID #93 as its nearest node. Node with ID #93 connects with node with ID #3 which is already on the chain. Now, node with ID #93 is the latest node which is included in the chain. Node ID #93 finds its closest node based on distance similar to node with ID #3 and connects that node with it as Node with ID #11. This process repeats till all nodes will be on the chain. Similarly, the Node with ID #46 becomes the last node to connect with chain.

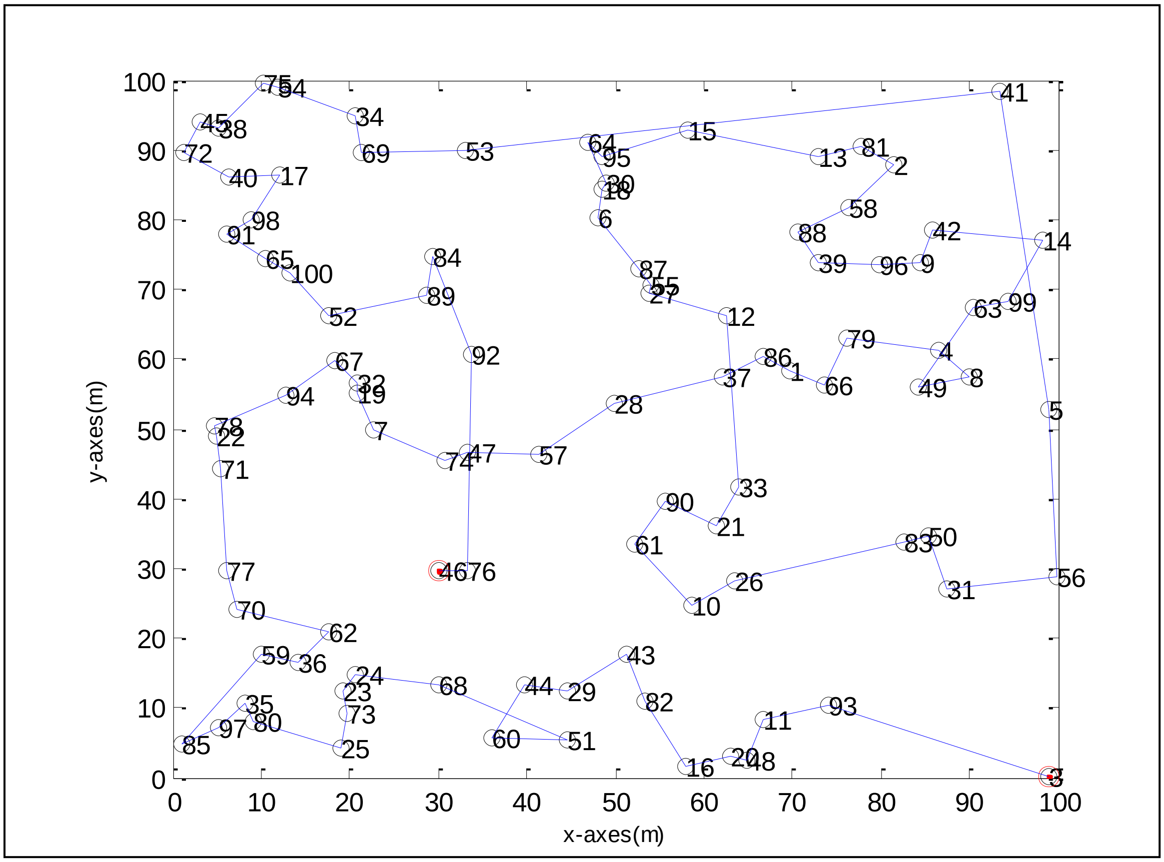

Figure 2.1: Depiction of chain construction in PEGASIS

2.1.2 Leader Selection

In this architecture only one node communicates to sink in any round that node is called as Leader. The optimal selection of leader node is also important factor in the performance of protocols. In this, selection of Leader is based on random number. So each node becomes Leader once in each 100 rounds. This approach leads to death of nodes at random locations in the network which makes network robust to failures. But this leads to imbalanced consumption of energy among the nodes in the network. As some nodes in the network may have their neighbors distant as compared to others so they will dissipate more energy to data forwarding to next node in the chain. So they are not supposed to become leader in every 100 rounds. So other criteria like threshold based on distant and remaining energy are applied to improve performance of the protocol.

2.1.3 Data Transmission

After the selection of leader node, data gathering and fusion starts. A token based approach is used to gather data. Leader node passes a token along the chain to the end node. After receiving the token end node sends its data and token to its next node along the chain. This process continues till data reaches to the leader. Each intermediate node performs data fusion by fusing its neighbor's data with its own and creates a single packet of same length. At last leader node transmits the resultant data packet to the BS.

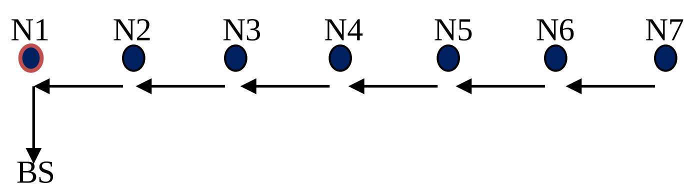

Figure.2.2 Illustration of Data Transmission (TOKEN passing) with leader at the start of the chain

In case of chains with leader node at the start of the chain, data transmission happens as in figure.2. In this leader node N1 is at start of the chain. N1 passes TOKEN (small sized control packet) to the end node N7 along the chain. After receiving TOKEN, node N7 transmits its sensed data and TOKEN to its next node in the chain i.e. N6. Node N6 on receiving data packet and TOKEN from node N7, perform data fusion with received packet and its own sensed data and transmits it to the next node i.e. N5.

Similarly N5 sends packet to N4, N4 to N3, N3 to N2, and N2 to N1. Finally, Leader node N1 on receiving packet from N2 fuses its own sensed data with received packet and then sends it to the Base Station.

In case leader node is any intermediate node of the chain then data transmission happens as represented in figure.3. Here leader node is N4. As author in [1] not mentioned any priority criteria to decide to which end node the Leader will transmit TOKEN first, this may be because Leader will transmit data packet to BS only when it will receive packets from both neighbors N3 and N5. So, N4 passes TOKEN to any one of the two end nodes .i.e. N1 or N7.

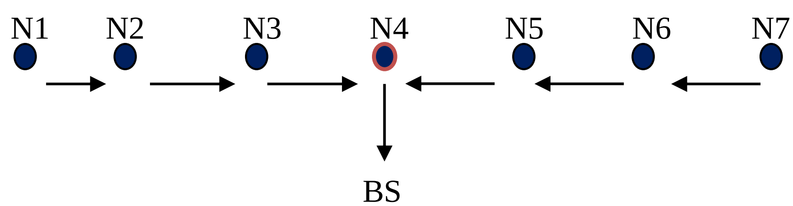

Figure.2.3 Illustration of Data Transmission (TOKEN passing) with leader is any intermediate node

Let N4 passes TOKEN to N1 first. After receiving TOKEN, N1 transmits it sensed data and TOKEN to node N2 which is next to it in the chain. N2 fuses its own sensed data with received data packet and transmit it along with TOKEN to N3 and then N3 to N4. Similarly, N4 passes TOKEN to the other end node in the chain i.e. N7. Now, N7 sends data and TOKEN to N6, N6 fuses it with its own sensed data and transmit it along with TOKEN to N5, and N5 to N4. After receiving data from N3 and N5, N4 fuses received data with its own sensed data and then transmit it to the BS. In this way we can see that in each round a node transmits only one data packet irrespective of the position of Leader node, length of the chain or any other factor.

This protocol is advantageous in terms it outperforms LEACH [3] by 100 to 300 % better performance for networks of different sizes and topologies but suffers with certain limitations such as formation of Long Links, non-optimal total length of the chain, lower load balancing capabilities occurs due to non-optimal selection of Leader node and huge time delay in data transmission due to single TOKEN based transmission approach.

2.2 PEDAP and PDAP-PA

Tan, HüseyinÖzgür, and Ibrahim Körpeoğlu[2] in 2003 proposed two approaches for hierarchical chain based networks based on PEGASIS[1] using concept of Minimum Spanning Tree[4]. This works in two phases namely chain formation and data transmission. There is no leader selection phase as data is transmitted along the edges of spanning tree. As BS is root of this near optimal spanning tree, immediate children transmit to it.

This also works in rounds and its focus is on optimal chain construction. For this purpose it uses MST concept by applying PRIM'S algorithm to construct chain with link cost to be calculated as:

$$C_{ij}\ (k) = 2 * E_{elec} * k + \varepsilon_{amp} * k * d_{ij}^2 \quad (2.1)$$

$$OrC_i^{'}\ (k) = E_{elec} * k + \varepsilon_{amp} * k * d_{ib}^2 \quad (2.2)$$

Where C_{ij}: transmission cost between node *i* and *j*.

C'_i: transmission cost between sensor *i* and *B.*

d_{ij}: distance between sensor *i* and *j*

d_{ib}: distance between sensor *i* and *BS*

PEDAP improves lifetime of network but lacks in Load Balanced energy dissipation among nodes i.e. fails to prolong the death of first node while prolonging death of last node. This is done in PEDAP-PA which is power aware version of PEDAP [2]. In PEDAP-PA, the criteria for calculation of Link Cost take into account remaining energy and is given as:

$$C_{ij}(k) = \frac{2*E_{elec}*k+\varepsilon_{amp}*k*d_{ij}2}{e_i} \quad (2.3)$$

$$C_i'(k) = \frac{E_{elec}*k+\varepsilon_{amp}*k*d_{ib}2}{e_i} \quad (2.4)$$

Where e_i is remaining energy normalized with respect to initial energy level of battery. The value of e_i lies between 0 and 1.

As a node with lesser energy intended to dissipate least energy in upcoming rounds so this change in link cost calculation delays the inclusion of sensor node with less remaining energy in the spanning chain. As late as a node is included into chain, less degree of connectivity it will have. So a node receives less number of messages and dissipates less energy in data reception and data fusion.

PEDAP and PEDAP-PA [2] outperforms both LEACH [3] and PEGASIS [1] in terms of network Lifetime and Death of first node which is due to load balanced energy consumption. As this work applies minimum spanning tree approach for chain construction and Data transmission is done on the sides of this tree so nodes near to the BS are subject to more dissipation of energy as they have to transmit to BS which is at far distance from them. So an approach is needed to avoid these nodes from transmitting data to BS when they have lower energy, this will further improve its performance.

2.3 EEPB

WEI Gang, YU Yong-chang [5] proposed an improved protocol based on PEGASIS. The protocol follows similar approach as PEGASIS and is round based. Each round involves three phases, namely, Chain construction, Selection of Leader and transmission of data [5]. It modifies Chain formation and Leader selection and adopts same data transmission phase as in PEGASIS [1]. It adopts Threshold approach while building chain to avoid Long Links in the chain. It considers remaining energy and distance to the BS as key parameters in selection of Leader sensor. The frequency of Leader reselection is adjusted according to number of alive nodes in network. EEPB removes some problems of PEGASIS but still has certain limitations which are as follows:

- Threshold adopted for chain construction is complex and uncertain to determine, if value is inappropriate then it's inevitable to avoid formation of Long Links.
- Leader selection is non-optimal as it is unable to optimally utilize node energy and distance.

2.4 IEEPB

IEEPB [6], in chain formation, allows a node to get connected to a node which is already included into the chain based on distance between neighbor nodes. This avoids formation of long links and reduces chain length up to some extent as compared to length of the chain formed in EEPB [5] and produces a chain in which nodes have different degree of connectivity. This selects Leader node by calculating weight for each node considering distance to the base station and node energy as follows:

$$\text{Weight}(i) = a * E_{portion}(i) + b * D_{toBS}(i) \quad (2.5)$$

Where a and b are weight factor coefficients and given as

$$a + b = 1 \quad (2.6)$$

$$E_{portion}(i) = \text{Initial Energy}(i) / \text{Residual Energy}(i) \quad (2.7)$$

$$D_{toBS}(i) = (\text{DisToBS}(i))^4 / (\text{AvgDis})^4 \quad (2.8)$$

The node with minimum weight is selected as Leader for that round of data transmission. Leader transmits data to the Base Station. The data transmission phase is same as used in PEGASIS.

IEEPB overcome several deficiencies of EEPB [5] and hence of PEGASIS but still suffers with the following limitations:

- While building chain, IEEPB allows a node to connect with another node which is already connected with the chain which produces nodes having different degrees [5]. This will lead to the nodes with more degree of connectivity dissipating more energy in data fusion than the nodes with less node degree.

- As in PEGASIS architecture, Base Station is situated far away from the nodes [1]. So distance to base station is much more as compared to average distance between nodes which makes the leader selection formula biased to the Distance of node to the Base station. Also, optimal determination of weight factor coefficients is also a difficult problem.
- It ignores the data fusion energy which is proportional to node degree while selecting Leader.
- This leads to lower energy efficiency and poor load balancing in the sensor network.

2.5 PDCH

Linping, Wang, et al [7] proposed a new approach based on PEGASIS [1] and EEPB [5] which use different layered hierarchical chain topology [8] to reduce time delay. At each layer a chain is constructed based chain construction method in EEPB [5] which allows branching. Nodes of different layer cannot join same chain, only nodes of same level can join the same chain. So, sensor nodes can have degree of connectivity more than one. Each chain has two Leaders, one is primary leader head and other is secondary leader head.

Nodes belonging to the primary chain can become Primary leader while nodes joining secondary chains can take part in becoming secondary leader head. The nodes which are on the primary chain and having more number of secondary chains, have more chance to be selected as Primary Leader head. Secondary leader are selected from branches connected to the primary leader. In this chain construction and leader selection is not performed in every round. Chain construction and leader selection is repeated when a node death is detected. Also, when node energy of primary leaders is reduced to 50% of the previous level then Primary Leader heads will be selected again to ensure that all primary leaders are working [7].

Primary gathers data from chain and send it to secondary leader node which transmits it to the secondary leader head of the next level chain. This is repeated till the data reached to the super level which is nearest to BS. Then secondary leader node of this level transmits data to BS.

This approach outperforms PEGASIS [1] and EEPB [5] in terms of prolonging network lifetime as well as load balancing. It also reduces time delay by applying Layered hierarchical topology [8]. But the problem of optimal load balancing among nodes still remains as it selects primary leader to nodes which has high degree of connectivity and hence high load, so for optimal load balancing the node with high degree of connectivity should be discouraged to be elected as Leader. As EEPB [5] has the problem of Long Links, there is also possibility of Long Link and hence non optimal chain length.

2.6 PEG-Ant

GUO Wen-yu, ZHANG Wei, and LU Gang [9] applied Ant colony optimization technique to build the chain. Other phases remain same as in PEGASIS [1]. Using Ant colony approach authors are able to eliminate the problem of Long Links and produce chain of length much less as compared to PEGASIS[1] which results in Better performance in terms of network lifetime and load balanced energy consumption. As PEG-Ant makes no change in Leader selection and data transmission phases, so similar to PEGASIS it suffers problem of non-optimal leader selection and huge time delay involved in data transmission.

2.7 PEGASIS-PBCA

Neng-Chung Wang, Young-Long Chen, Yu-Cheng Lin and Chin-Ling Chen [10] proposed a coverage based modification to PEGASIS. Phased-Based Coverage (PBCA) [10] technique is used to find redundant sensors which can be allowed to sleep mode. Authors applied this technique on PEGASIS to find redundant sensors. A node is redundant if it is covered by other sensors. After running PBCA on network all nodes can be categorized into two modes, namely, Active mode and Sleep mode. Now, as some nodes enter to sleep mode so there are fewer nodes which are active and will take part in chain construction. So as smaller number of active nodes lesser the energy consumption in the network. Authors claim that this approach also has better coverage area than PEGASIS and LEACH [10]. Also outperforms base protocols in terms of Lifetime of the network.

This technique is only about finding Active mode nodes and applying PEGASIS over them. So the limitations of the PEGASIS remain same here as well. It lacks in optimizing chain length and load balancing energy consumption.

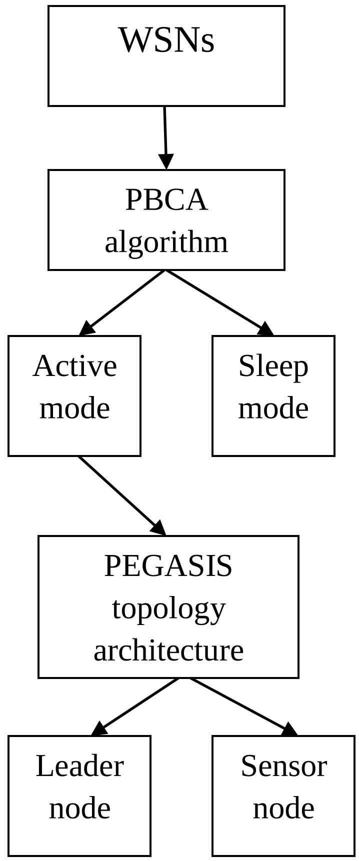

Figure 2.4: Flow Chart diagram of PEGASIS topology architecture with PBCA

2.8 PEGASIS-IBCA

Neng-Chung Wang, Young-Long Chen, Yu-Cheng Lin and Chin-Ling Chen [11] combined Intersection Based Coverage Algorithm (IBCA) [12, 13] with PEGASIS architecture [1]. Similar to PEGASIS-PBCA [10], in this work authors find redundant nodes using IBCA which can be made to enter into sleep mode and then applied PEGASIS over Active mode nodes.

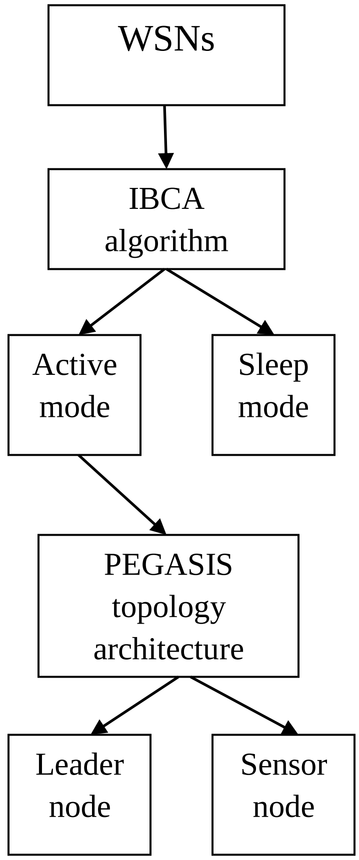

Figure 2.5: Flow Chart diagram of PEGASIS topology architecture with IBCA

In this a node is considered redundant if it is covered by at least one sensor. After running IBCA on network all nodes can be categorized into two modes, namely, Active mode and Sleep mode. Now, as some nodes enter to sleep mode so there are fewer nodes which are active and will take part in chain construction. So as smaller number of active nodes lesser the energy consumption in the network, similar to PEGASIS-PBCA [10]. Authors claim that this approach also has better coverage area than PEGASIS and LEACH [10]. Also outperforms PEGASIS, LEACH, and LEACH-PBCA in terms of Lifetime of the network.

Similar to PEGASIS-PBCA [10], this technique is also only about finding Active mode nodes and applying PEGASIS over them. So the limitations of the PEGASIS remain same here as well. It lacks in optimizing chain length, optimal selection of Leader and load balancing energy consumption.

2.9 MH-PEGASIS

Aliouat Makhlouf and Aliouat Zibouda [14] in their work proposed a multi-hop approach with PEGASIS topology architecture. In this authors combined Clusters and Chain approaches together for routing. PEGASIS [1] is used to form chain and data transmission inside the clusters. Leader of the chain or clusters is selected as in PEGASIS. Leaders transmit their data to BS using multi-hops. The whole network is divided into Levels based on distance from BS. Now, Leader of the lower level chains sends data to Leader of the upper level chain which is nearest to it. This approach is used by all the leaders to transmit data to the sink.

This protocol outperforms LEACH and PEGASIS in prolonging life time of the network. But the problems related to optimal chain length, optimal leader selection and balanced energy consumption among the sensors remains unresolved.

2.10 MIEEPB

Jafri Raza Mohsin, Javaid Akmal, Javaid Nadeem, and Khan Ali Zahoor [15] proposed improvement over IEEPB [6] using Sink Mobility. In this, authors constructed multiple chain rather than single chain as in original PEGASIS [1]. Multiple chains are constructed by dividing Network area into multiple regions. In each region, PEGASIS approach is applied to form chains. So the number of chains will be equal to the number regions the network is divided into.

The multiple chains avoid formation of Long Links. Now, each chain selects its own Leader sensor which is responsible to transmit data to mobile Sink. Leaders are selected based on the Distance to sink and Residual energy. Here, Sink is mobile but it moves in a fixed path/trajectory which is based on sojourn location and time [16, 17, 19]. For data transmission MIEEPB uses same TOKEN based technique as used in PEGASIS whereas aggregation of data is performed using DCT [18]. In this Leader of the chain collects data from their respective chain and waits for Sink. When Sink comes to the sojourn location of respective region it receives data from Leader and moves to other region. This it collects data from all the leaders and repeat the process for next round.

Authors says that it results in improved network lifetime as compared with PEGASIS and IEEPB [6] However, construction of multiple chain prevents formation of long links in the chain but the overall length of chains is not optimal as it uses same technique as in PEGASIS [1]. Also multiple Leader avoid load on single leader but selection of leader is not load balanced among the nodes of a particular chain. A better leader selection technique can result in the improved load balancing energy consumption among the nodes of the chain and hence better network lifetime.

2.11 Modified-PEGASIS

Madhuri Gupta and Laxmi Saraswat [20] proposed a new approach which modifies chain construction and Leader selection phases to improve performance of PEGASIS [1]. This technique allows branched chains construction. It uses distance and Node ID as key parameter while building chains. A node which is nearest to the recently added node in chain and having Node ID greater than it can join the chain by connecting to that recent node. In this the problem of long links is inevitable as last nodes have least options to get connected to the chain. The Leader sensor is selected using remaining energy, distance to BS and node degree. A node having more remaining energy, lower node degree and less distance to BS will be preferred to be selected as Leader node. This work outperforms PEGASIS [1] in terms of death of last node but Load balancing capabilities are limited and need more attention. The data transmission step remains same as in PEGASIS. So this work also suffers with the problems involved in PEGASIS as Formation of Long Link, non-optimal chain length and huge time delay.

2.12 CREEC

Changjin Sun and Shin, Jisoo [21] in their work proposed new routing method for hierarchical chain based networks based on Krushkal's Minimum Spanning Tree and Link Exchange techniques. It focuses on maximizing fairness of energy distribution and to reduce total consumption of energy. It use mechanism of feedback for energy distribution.

Authors define transmission as throwing and forwarding. '*Throwing*' transmissions are those which transmit directly to the Sink while '*Forwarding*' is the transmission of data to the neighbor node. CREEC emphasize that all nodes should spent equal amount of throwing energy as well as forwarding energy which leads to the balanced energy consumption among the nodes. The chain formed is single and with maximum possible node degree as two. For chain construction, all nodes are sorted based on their remaining energy and categorized in three different levels as level-1, level-2 and level-3. Level-1 nodes are made two leaf nodes of the chain. Level-1 and/or level-2 nodes have a chance to occupy short adjacent links which leads to less energy dissipation by these nodes in the next round.

This applies concept of Krushkal's MST algorithm with some constraints that lead to the formation of chain without branches which is similar to finding Hamiltonian path using Cheapest Link Algorithm. After building chain, Link Exchange technique is applied replace long links with other smaller links which are not part of the chain due to loop avoidance criteria. This results in reduced chain length. CREEC outperforms LEACH [3], PEGASIS [1], PEDAP and PEDAP-PA [2] in terms of chain length, network lifetime and load balancing capabilities.

Table below presents comparison of different protocols based on PEGASIS architecture using different key parameters.

Parameter	PEGASIS	PEDAP	PEDAP-PA	EEPB	IEEPB	PDHC	PEG-ANT
Sensor Deployment	Random	Random	Random	Random	Random	Random	Random
Classification	Chain Based	Branched chain	Branched chain	Chain Based	Chain Based	Chain Based	Chain Based
Number of Chains	Single	Single	Single	Single	Single	Single chain at every level	Single
Number of CH per Chain	1	0	0	1	1	2	1
Data Transmition to BS	Round Leader Node	Immediate child of BS in chain	Immediate child of BS in chain	Round Leader Node	Round Leader Node	Secondary CH	Round Leader Node
Mobility of BS	No Mobility	No Mobility	No Mobility	No Mobility	No Mobility	No Mobility	No Mobility
Desired Number of Groups / Clusters	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Selection of next node of chain (Chain Formation)	Nearest neighbour based on Signal Strength	Node with minimum Link Cost in the form of Energy	Node with minimum Link Cost in the form of Energy	Distance Threshold with user defined Constant alpha	Nearest neighbour based on Distance	Based on EEPB	Neighbor Node's Remained Energy, Consumed Energy, quantity of Pheromone
Selection of CH	Based on Distance from BS	None	None	Residual Energy of Node and Distance from BS	Based on weight calculated using Residual energy and Distance from BS	Node Degree and Energy	Node Energy

Delay	Very Large	Very Large	Very Large	Very Large	Very Large	Medium	Very large
Energy Efficiency	Low	High	High	Medium	Medium	Medium	Medium
Load Balancing	Low	Low	Medium	Low	Medium	Medium	High
Quality of Service	No	No	No	No	No	No	No
Query Based	No	No	No	No	No	No	No
Type of Sensors	Homogeneous	Homogeneous	Homogeneous	Homogeneous	Homogeneous	Homogeneous	Homogeneous
Type of Protocol (Sensing)	Proactive	Proactive	Proactive	Proactive	Proactive	Proactive	Proactive
Algorithmic Approach	Greedy	Greedy-MST	Greedy-MST	Greedy	Greedy	Greedy	ACO
Branched Chains	No	Yes	Yes	Yes	Yes	Yes	No
Node Connectivity (Degree)	1 or 2	1,2, or more	1,2, or more	1, 2, or more	1, 2, or more	1, 2, or more	1
Data Transmission in Chain	Token Based	Token Based	Token Based	Token Based	Token Based	Token Based	Token Based
Number of Messages Transmitted per Node	1	1	1	1	1	1	1
Number of Packets Received per Node (intermediate)	1	1 or more	1 or more	1 or more	1 or more	1 or more	1
Long Links Avoidance	No	Yes	Yes	No	Yes	No	Yes

Parameter	PEGASIS-PBCA	PEGASIS-IBCA	MH-PEGASIS	Multi-Chain PEGASIS	Modified-PEGASIS	CREEC
Sensor Deployment	Random	Random	Random	Random	Random	Random
Classification	Chain Based	Chain Based	Chain + Cluster	Chain Based	Chain Based	Chain Based
Number of Chains	Single	Sinlge	Single chain per Cluster	4	Single	Single
Number of CH per Chain	1	1	1	2	1	1
Data Transmition to BS	Round Leader Node	Round Leader Node	CHs with Multi-Hop Routing	Primary and Secondary CHs depending on the condition	Round Leader Node	Round Leader
Mobility of BS	No Mobility	No Mobility	No Mobility	Yes, Fixed Trajectory	No Mobility	No Mobility
Desired No. of Clusters	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Selection of next node of chain (Chain Formation)	Based on PEGASIS with Active Nodes only	Based on PEGASIS with Active Nodes only	PEGASIS within Cluster	Based on PEGASIS over individual chains	Nearest neighbour based on Distance, connecting with already visited node is allowed	Node with minimum Link Cost in the form of Energy
Selection of CH	Based on PEGASIS with Active Nodes only	Based on PEGASIS with Active Nodes only	Based on PEGASIS	Based on weight calculated using Residual Energy and Distance from BS	Based on weight calculated using Residual Energy, Node Degree and Distance from BS	PEGASIS
Delay	Large	Large	Large	Medium	Large	Very Large

Energy Efficiency	High	High	Medium	High	High	High
Load Balancing	Low	Low	Low	Low	Medium	Medium
Quality of Service	No	No	No	No	No	No
Query Based	No	No	No	No	No	No
Type of Sensors	Homogeneous	Homogeneous	Homogeneous	Homogeneous	Homogeneous	Homogeneous
Type of Protocol	Proactive	Proactive	Proactive	Proactive	Proactive	Proactive
Algorithmic Approach	Greedy	Greedy	Greedy	Greedy	Greedy	Greedy-Krushkal's MST
Branched Chains	No	No	No	Yes	Yes	No
Node Connectivity (Degree)	1	1	1	1, 2, or more	1, 2, or more	1
Data Trans-mission in Chain	Token Based	Token Based	Token Based	Token Based	Token Based	Token Based
Messages Transmitted per Node	1	1	1	1	1	1
Packets Received per Node	1	1	1	1 or more	1 or more	1
Long Links Avoidance	No	No	No	No	Yes	Yes

Table I: Comparison of Different Protocols based on PEGASIS

CHAPTER 3

PROPOSED WORK

As we have gathered from previous chapter that energy efficient, load balanced and optimal time delay routing in wireless sensor networks still have doors widely open to researchers. The previous chapter gives us insight into some of the protocols proposed by researchers for tackling the challenge. We have noted that transmitting data with least energy consumption and in minimum time is the main concern while using WSNs as they have very limited power. LEACH and PEGASIS are the two important hierarchical nature routing architectures used for routing in WSNs. While LEACH forms clusters, PEGASIS is chain based. In PEGASIS, each node transmits one packet and receives one packet in each round making it much energy efficient as well as Load balanced than LEACH in which nodes send and receive different number of packets in each round.

Power Efficient Gathering in Sensor Information Systems (PEGASIS) [1] architecture consists of three phases involving Chain formation, Leader Selection and transmission of data [1]. PEGASIS suffers from the problem of Long Link as the nodes which are going to become part of chain at last have least choices to get connected to the chain. The chain formed in PEGASIS is not of optimal length due to its greedy approach. Low Load balancing due to non-optimal selection of leader node and large time delay in data transmission are some other major problems with it.

After the proposal of PEGASIS[1] many other protocol based on it such as PEDAP and PEDAP-PA[2], L-PEDAP[14], EEPB[3], IEEPB[4], PEGASIS-IBCA[9], PEGASIS-PBCA[10], CREEC[5], COSEN[16], PEG-ANT[7], MH-PEGASIS[11], PDCH[6], MODIFIED-PEGASIS[13], and MULTI-CHAIN PEGASIS[10] etc. are proposed which try to improve the network life and load balancing capabilities by applying different approaches in chain building and leader selection while data transmission phase remains almost untouched by these protocols and is same as applied in PEGASIS.

Considering the above discussed problems and available solutions, in this chapter we propose two new improved techniques. Proposed1considers IEEPB [6] as base and applies modified algorithm to improve the performance of the sensor network. This approach considers Node Degree Threshold and degree of connectivity as the key parameters including initial energy, residual energy, and distance to base station and distance between sensors. The approach works in three phases similar to PEGASIS [1]. Construction of the chain of sensors is first phase while selecting leader is second phase. Data transmission occurs in third phase. This enhances the load balancing capabilities of the routing technique while prolonging the network lifetime. Proposed2 considers Modified-PEGASIS [20] as base protocol. As Modified-PEGASIS suffers with the problem of long link which results in poor performance; Proposed2removes the long links using connected component approach. It also reduces the huge time delay involved in data transmission. Similar to Proposed1 it also works phases. First phase involves formation of chain while second phase involves removal of long links (enhanced chain). Leader is selected in third phase considering some important parameters and data transmission occurs in fourth phase applying new reduced time delay approach.

First, we explain the system model used and assumptions made for the proposed work. Later, we analyze the performance of our proposed work with other previously proposed protocols.

3.1 System Model

We described here about the system model consisting of network model and energy model used for our proposed work. The network environment and sensor node capabilities are described in Network model. While energy model describes how the sensor node utilize its energy during communication with other nodes.

3.1.1 Network Model

In our proposed work, the network model consists of the operating environment which consists of N number of nodes and one base station. Nodes are randomly deployed in a square area $A \times A$ with the base station assumed to be located at (X, Y) which may be inside the network area or outside. The sensor nodes periodically sense the environment and send the sensed data to the base station. And on the other hand, the base station is responsible for getting data from the sensor nodes and then presented the user a condition of the environment where the nodes are sensing. Some of the characteristics of the network model are as follows:

- The network deployment is random i.e. sensors are deployed at random locations in the square area to be monitored.
- Sensor nodes don't possess mobility i.e. sensor remains at the same location where they are deployed.
- All sensors are aware of their location and ID, energy levels, and location of base station.
- All sensors possess same capabilities i.e. same level of initial energy, processing, power control and communication capabilities [17].
- Base station is stationary and situated far away from the area to be sensed.
- All nodes have the ability to communicate directly to the Base Station.

3.1.2 Energy Model

The First Order Radio Energy model is opted in [2, 3, 5, 6, 7, 18, 20] is also opted for our proposed work.

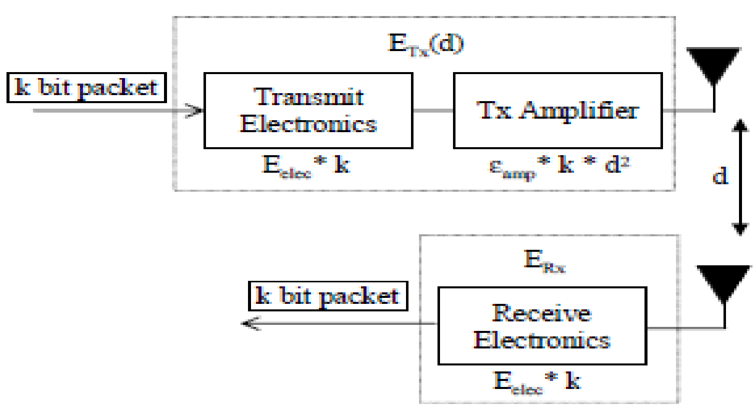

Figure 3.1 First Order Radio Energy Model

As shown in figure 3.1transmitter, power amplifier, and receiver are three modules present in this radio model. The energy dissipation occurs due to functioning of transmitter circuitry, receiver circuitry and transmission of data. Two basic propagation models are as follows:

- **Free space model of propagation**
- **Two-ray ground model of propagation**

The free space propagation model has direct line of sight path between transmitter and receiver whereas in two ray ground propagation model, propagation between transmitter and receiver is not direct and electromagnetic wave will bounce off the ground and reach to receiver from different paths at different instant of time.

In free space propagation model, the propagation loss of power (energy dissipation) is inversely proportional to d^2, where d is distance between transmitter and receiver. In two-ray ground propagation model, propagation loss of transmitting power is inversely proportional to d^4.The power amplifier is used to amplify transmitting power to compensate propagation loss during the transmission.

Thus, for transmitting a K bit message from transmitter to receiver which is at a distance *d;* the energy dissipation is given as:

$$E_{Trans}(k,d) = \begin{cases} k * E_{elect} + \quad k * \epsilon_{fs} * d^2 & , d < do \\ k * E_{elect} + \quad k * \epsilon_{amp} * d^4 & , d \geq do \end{cases} \tag{3.1}$$

If the transmission distance is less than d_o then free space model of propagation is applied otherwise two-ray model of propagation is used.

To receive k-bits the energy dissipated is given as:

$$E_{rx}(\, k\,) = k \times \, E_{elect} \tag{3.2}$$

And the energy dissipated in data fusion of k-bits is given as:

$$E_{df}(\, k\,) = k \times \, E_{da} \tag{3.3}$$

Where, E_{elect}: energy consumption for transmitter to transmit 1-bit.

$\in_{fs}$: amplifier energy in free space model and

$\in_{amp}$: amplifier energy in multipath model.

E_{da} : the unit energy required to aggregate data, d_o is distance threshold [12] and is given as:

$$d_o = \sqrt{\frac{\in_{fs}}{\in_{amp}}} \tag{3.4}$$

3.2 Proposed Work

The focus of our work is energy efficient and load balanced protocol with reduced time delay for chain based routing in homogeneous wireless sensor networks. This also involves delaying death of first sensor node and improving overall lifetime of the network. We are proposing two different solutions for two different problem statements.

IEEPB [6] an improvement over EEPB [5] based on PEGASIS [1] overcomes overcome several deficiencies of EEPB and hence of PEGASIS as discussed in previous chapter but still suffers with the some limitations; the problem statement 1 is based on this. Similarly Modified-PEGASIS is an enhanced form of PEGASIS which suffer with the problems like formation of long links, non-optimal leader selection, and huge time delay in data transmission which are considered while formulation of Problem statement 2 and the solutions are developed with objective of overcoming the present shortcomings and enhanced performance based on various performance metrics.

3.2.1 Problem Statement 1

Development of an energy aware load balanced protocol with reduced time delay for chain based homogeneous wireless sensor network which provide an efficient chain formation and Leader selection technique with reduced time delay data transmission approach, to improve network lifetime, load balancing and to decrease overall time delay.

The solution for the above problem is proposed as follows:

3.2.2 Proposed Solution: Proposed1

This section discusses in detail the proposed solution to address the above problem. The proposed solution works in three phases, namely, Construction of Chain, Selection of Leader and Data Transmission which are described in detail as below:

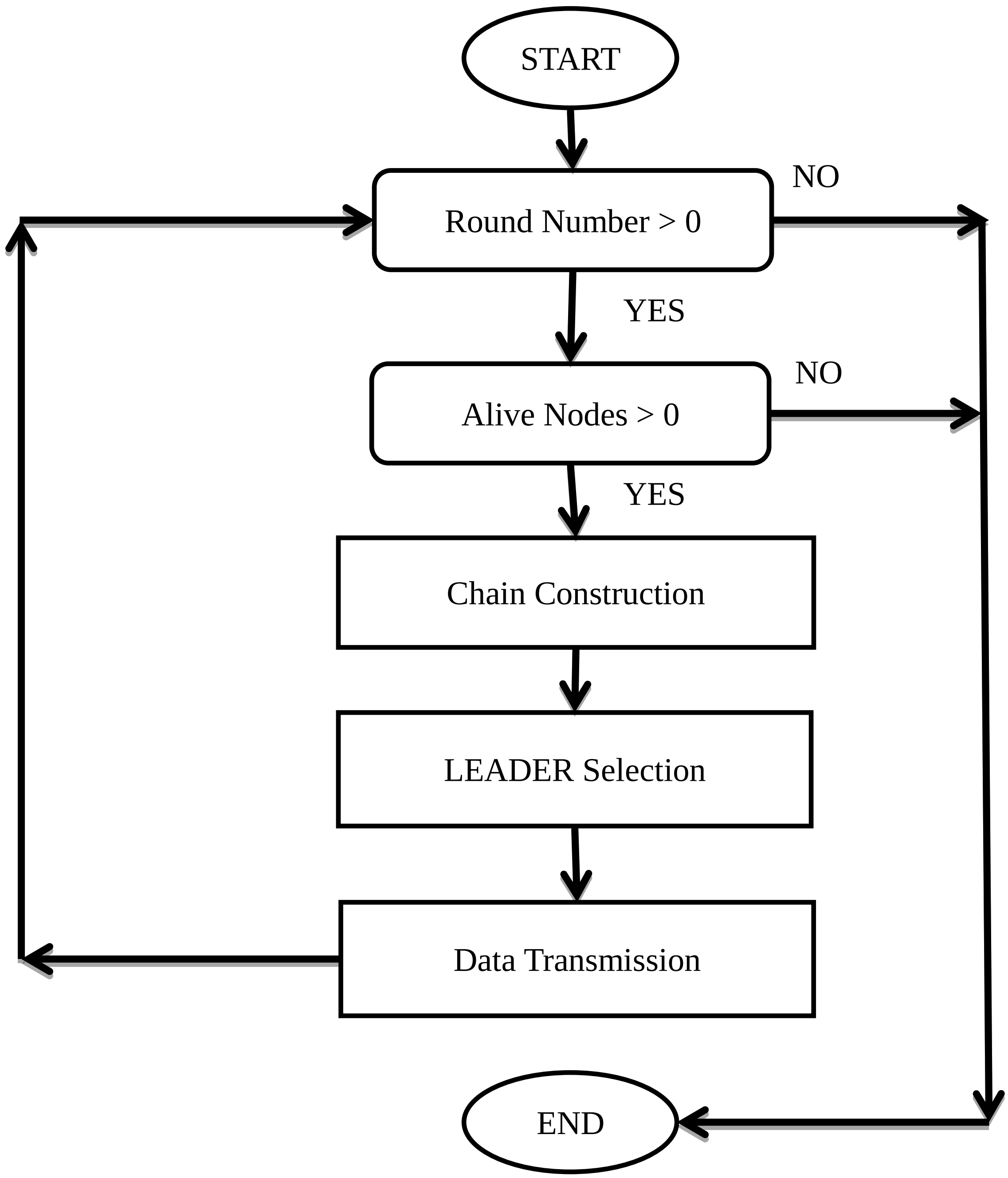

Figure 3.2 Different phases in a round and working of protocol

3.2.2.1 Construction of Chain

The formation of chain is similar to the chain construction in IEEPB with added Node Degree Threshold as one of the parameter to be considered with distance between nodes while connecting one node to the other in the chain. This threshold restricts the maximum degree of connectivity a node could have. It involves following steps:

a) Find the Alive Nodes and store their IDs. Set the degree of connectivity of each node to zero. Further processing is done only considering alive nodes.

b) From Alive nodes, find the node which is farthest from the BS and set it as First Node to join the chain.

c) The most recently connected node of the chain finds the nearest neighbor node based on the distance between itself and neighbor nodes which are not included in the chain till now. Set this node as *i*, the next node to be included in the chain.

d) Find the nodes having degree of connectivity less than T_{nd}, from *i-1* nodes which are part of the chain. Say, the number of such nodes is *m* ($m <= i - 1$).

e) Now, this *i* node finds node *j* from m nodes which is nearest to it and joins the chain by connecting directly to *j*. Increment degree of nodes *i* and *j* by *1*.

$$j = min(\ distance\ (i, k))\ where\ 1 <= k <= m. \quad (3.5)$$

$$node\_degree(i) = node\_degree(i) + 1 \quad (3.6)$$

$$node\_degree(j) = node\_degree(j) + 1 \quad (3.7)$$

f) Repeat steps from (c) to (e) till all nodes get connected to chain.

This results in the formation of chain having branches and nodes with node degrees as:

$$Node\_degree(i) < T_{nd}\ \ where\ 1 <= i <= number\ of\ nodes\ in\ the\ chain.$$

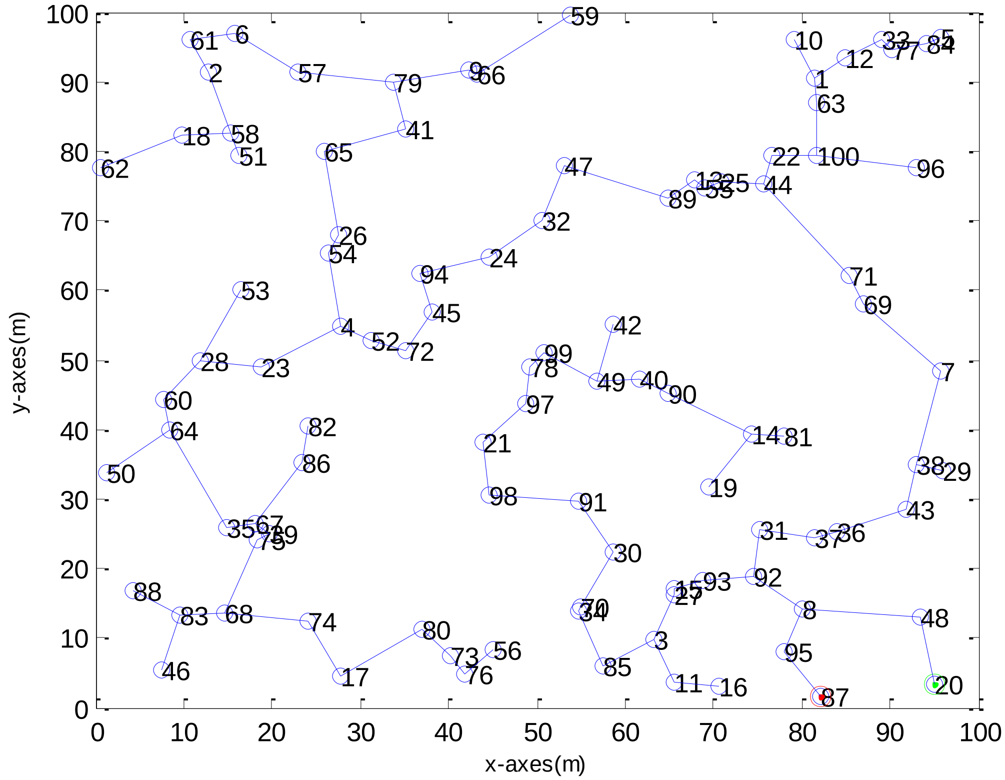

Figure 3.3: Construction of Chain

Figure 3.3 shows the chain formation using above approach. Numbers represent corresponding ID of the node. The node with RED color and with ID #87 is the starting node of the chain while the one with GREEN color and ID #20 is the last node to join the chain. There is no node having degree more than Node Degree Threshold T_{nd} which leads to the balanced energy consumption due to data fusion and reception of packets.

3.2.2.2 Selection of Leader

Leader selection in this paper is based on Node degree, Initial Energy, Residual energy, and distance of the node to Base station. The basis for the formula is the facts:

- Node with high remaining energy can withstand the cost of communication to BS and will not die quickly as the case with low remaining energy nodes.

- The rate of decrement of energy level is better parameter than remaining energy only as it helps to know how fast or slow a nodes energy is draining.

Leader is selected based on the following function:

$$LEADER = max\ (\ W(i)) \tag{3.8}$$

$$W(i) = \frac{RE}{E_o} \times \frac{1}{Node\_\mathrm{deg}(i)} \times \frac{1}{D_{toBS}(i)} \tag{3.9}$$

Where for i^{th} node in a particular round:

RE is the remaining energy

E_o is the initial energy

Node_deg is the degree of connectivity

D_{toBS} is the distance of node to BS.

W is calculated for each sensor node. The node with maximum value of W will be selected as LEADER which is responsible for coordinating the data forwarding inside the chain and transmission of data directly to the BS.

3.2.2.3 Data Transmission

IEEPB follows same data transmission approach as EEPB and PEAGSIS which is single TOKEN based transmission. This paper proposes different approach for data transmission. This approach is based on different TOKEN used for transmission and receiving of data. LEADER uses two types of control packets, FTOKEN for data forwarding and CTOKEN for collecting data from sub-chains. LEADER simultaneously transmits CTOKEN to all nodes which are directly connected to it and FTOKEN to the node which has aggregated data from all nodes of sub-chain originating from this neighbor node of LEADER. The same approach is applied by all sub nodes for data transmission and reception from sub-chain originating on them.

For example in Figure 3.3, assume Node with ID #92 is LEADER, now LEADER sends CTOKEN to Node with IDs #31, #93 and #8 simultaneously. Node with ID #8 sends CTOKEN to #5 and #48 and so on. To receive data node #8 sends FTOKEN to node #5 and after receiving data it sends FTOKEN to node #48. After receiving data from node #5 and #48 it fuses its sensed data with received packets. Now node #8 waits for FTOKEN from LEADER node #92 which transmits FTOKEN using TDMA. On receiving FTOKEN from LEADER, node #8 sends data to it. Similarly, nodes #93 and #31transmit data to LEADER node #92. On receiving data from all its neighbor nodes it fuses data packets with its own sensed data and transmit it to the BS. So a node can have multiple CTOKEN to transmit to nodes connected to it to start gathering of data in sub-chains but a single FTOKEN to receive the data which prevents collision of packets.

So the time delay from starting of the gathering process to transmission to the BS is

$$TimeDelay_{new} \propto max\ (length\ of\ sub\text{-}chain\ originating\ at\ LEADER) \quad (3.10)$$

While in IEEPB which uses single TOKEN for data transmission [4] purpose, the time delay is given as:

$$TimeDelay_{ieepb} \propto Total\ length\ of\ the\ chain \quad (3.11)$$

This shows that proposed work significantly reduces time delay involved in data transmission.

3.2.3 Problem Statement 2

To develop a chain based load balanced routing technique to avoid formation of long links in chain; with reduce data transmission delay in homogeneous wireless sensor networks.

The solution for the above problem is given as follows:

3.2.4 Proposed Solution: Proposed2

This section discusses in detail the proposed solution to address the above problem. The proposed solution works in three phases, namely, Formation of Chain, Selection of Leader and Data Transmission. The chain is formed in similar manner as in Modified-PEGASIS [20] with a new approach to remove long links formed in the chain. So chain formation involves to sub-phases as:

1. Chain formation: using Modified-PEGASIS approach
2. Chain Reconstruction: Removal of Long Links using Concept of Connected Component with DFS

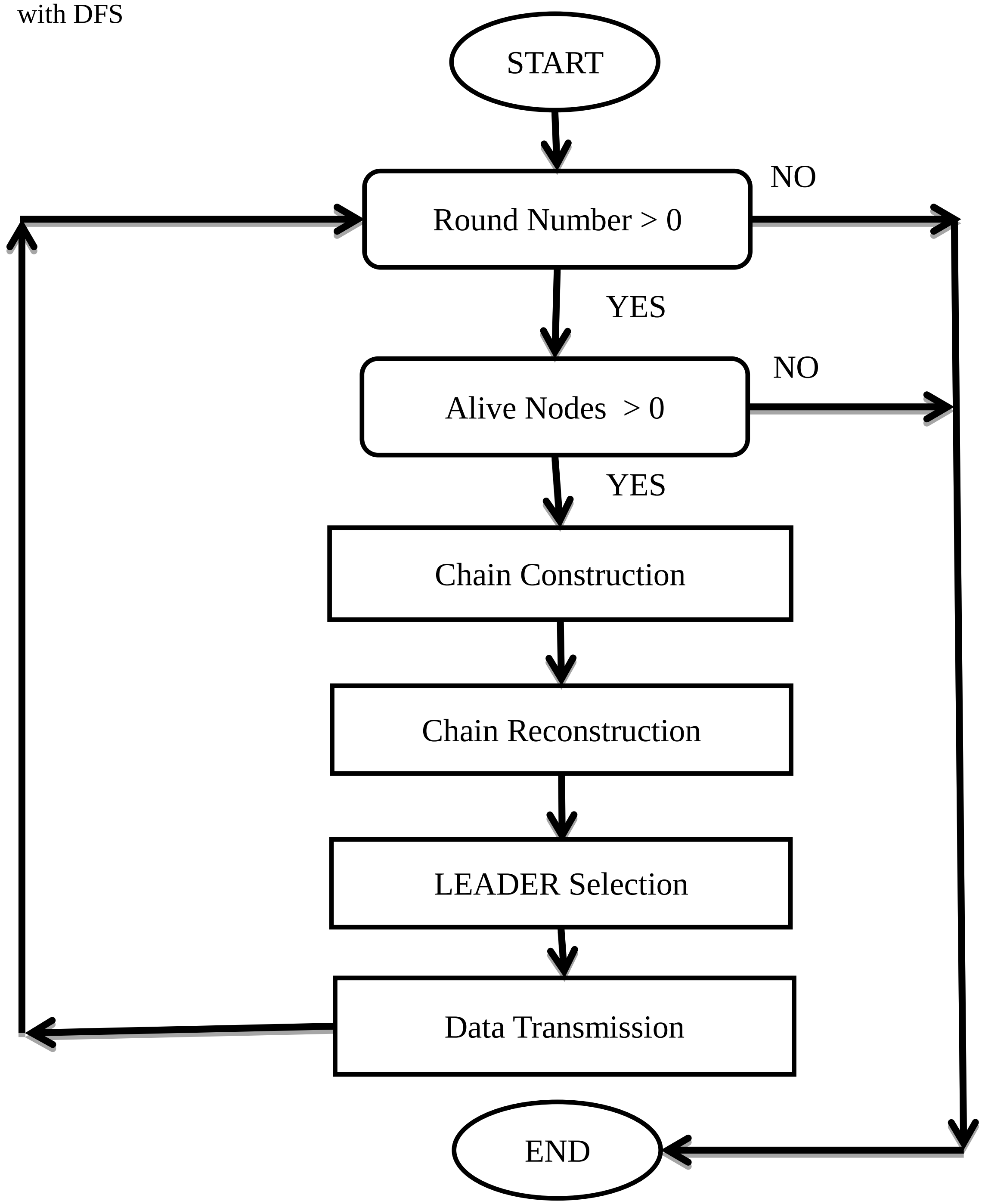

Figure 3.4: Different phases and working of Proposed2

3.2.4.1 Chain formation: using Modified-PEGASIS Approach

This method of chain formation allows branched chains similar to IEEPB [6] and EEPB [5]. Chain formation considers Node ID and distance between them as key parameters. A sensor node can connect to the previously visited sensor node if it is nearest to the sensor which is going to join the chain. This method of chain formation involves following steps:

a) Formation of chain starts with the first node i.e. sensor with node ID #1. It is given chance to join the chain first by getting connected to closest sensor node in its neighborhood.
b) Take next sensor in order of their node ID connects with other sensor node which is nearest to it and having node ID greater than it.
c) Repeat b) till all nodes join the chain. The loop formation is avoided by parameter node ID as a node can connect to only those nodes which has higher node ID.
d) As chain grows search space for nearest node reduces (cause of Long Links) and last node has no node to connect. But it has the probability that at least one of the N-1 sensor nodes must connect to it.

Figure 3.5 shows the chain formed by above method and long links are clearly visible.

3.2.4.2 Chain Reconstruction: Removal of Long Links using Concept of Connected Component with DFS

The above method of chain formation results in formation of Long Links in the chain which results in increased overall length of chain. Increased length of chain directly increases energy dissipation of sensors and the network as a whole which is undesirable. So this sub-phase removes long links and hence reduces chain length which ultimately results in improved network performance. The complete process is described below:

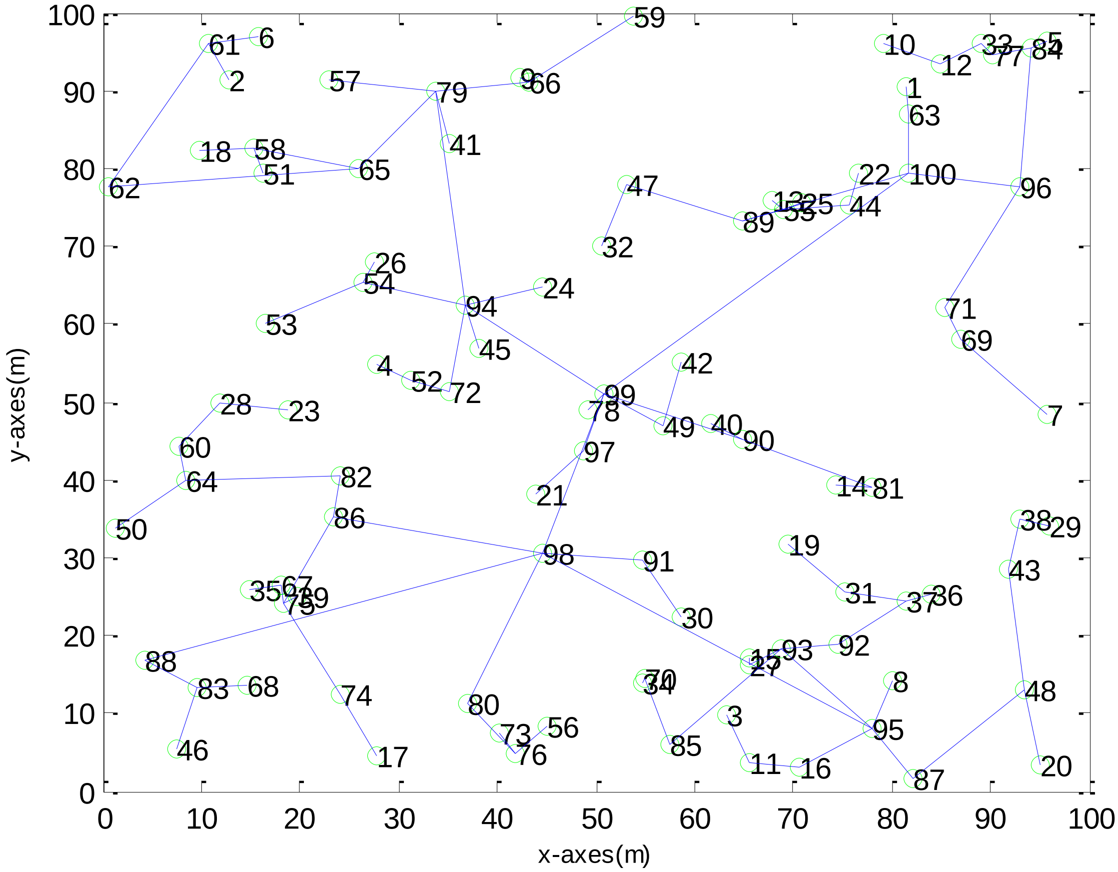

Figure 3.5 Chain formation using Modified PEGASIS having Long Links

a) Calculate the total length of the chain formed in above sub-phase and obtain the threshold distance to determine long links as:

$$T_d = \frac{Total\ length\ of\ all\ links}{number\ of\ alive\ nodes} \tag{3.12}$$

b) Long Links are those links in the chain which have link length greater than T_d. Delete these long links. This results in network with disconnected components as shown in figure 3.6.

c) Now connect these components by finding the minimum distance sensor pair between two components with one sensor from both components. This step works as follows:

1) Take a component from all disconnected components.

2) *For each node of the selected component find a nearest node which is not part of the selected component.*
3) *Now find the minimum distance sensor pair from the pairs generated in the above step.*
4) *Now connect these sensors which results in bigger connected component.*
5) *For this resulted component repeat step 2) to 5) till all sensors form a single connected chain as shown in figure 3.7.*

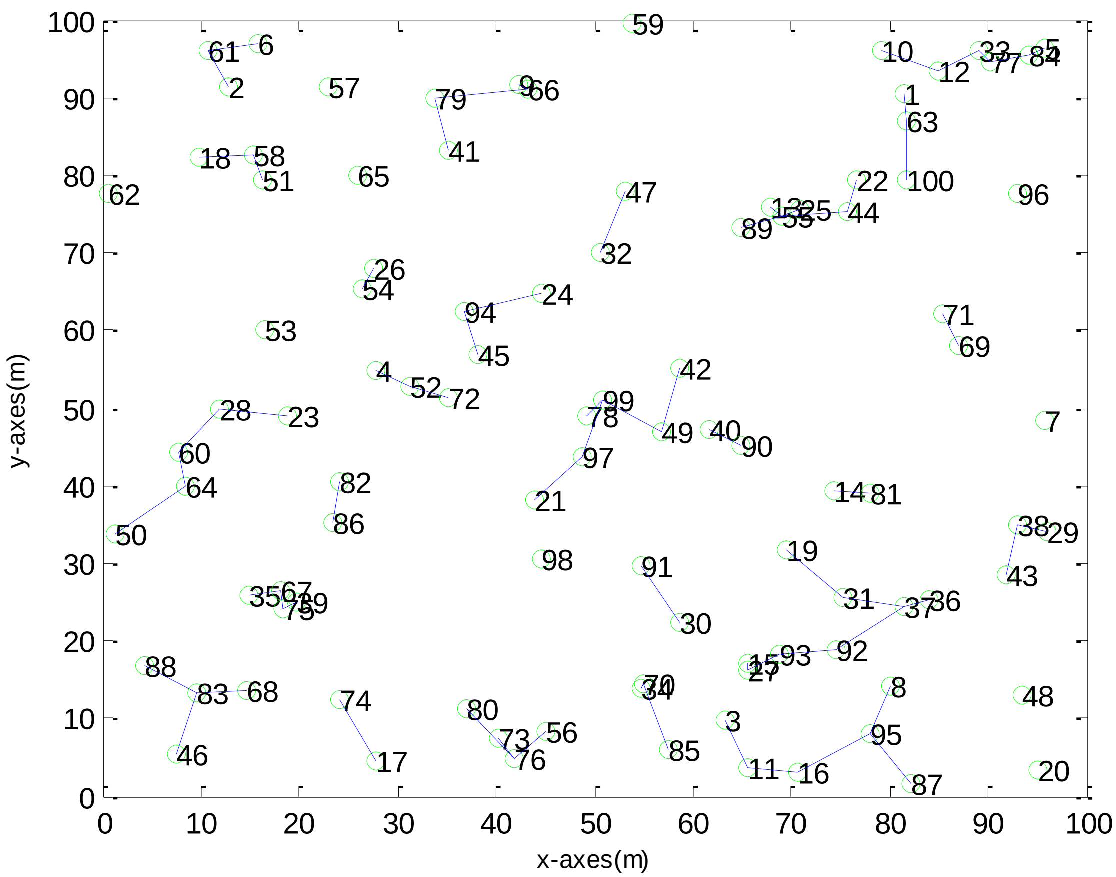

Figure 3.6: Disconnected Chain after removal of Long Links

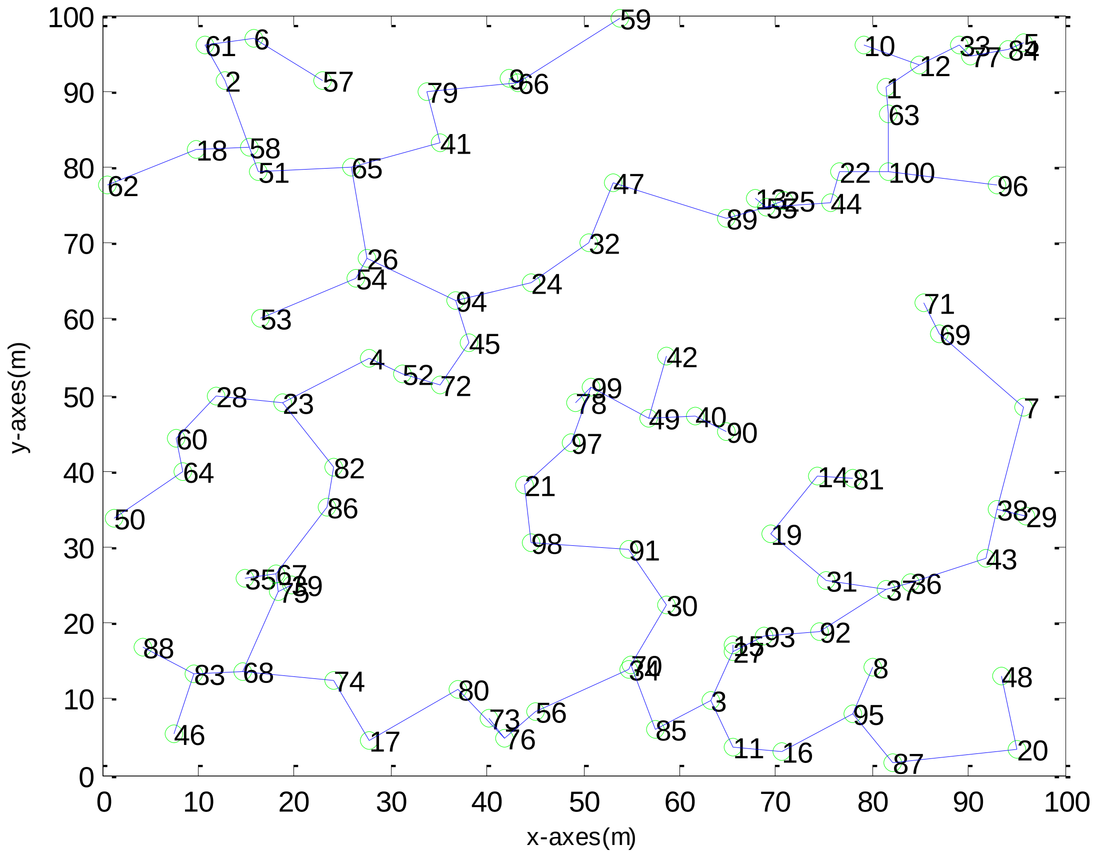

Figure 3.7: Chain formed after reconstruction phase

The resultant chain formed after chain reconstruction is free form long links and has shorter overall chain length which reduces energy consumption of the network in communication. As finally data has to be transmitted to base station, a sensor node is elected as LEADER in following phase.

3.2.4.3 Selection of Leader

A sensor node is elected as LEADER using initial energy, remaining energy, node degree, and distance to base station using equations (3.8) and (3.9).

W is calculated for each sensor node. The node with maximum value of W will be selected as LEADER which is responsible for coordinating the data forwarding inside the chain and transmission of data directly to the BS.

3.2.4.4 Data Transmission

As Modified-PEGASIS [20] uses same approach for data transmission as in PEGASIS; in our work we adopted the approach introduced in Proposed1. In this we used two TOKENs instead of one in PEAGSIS, namely, CTOKEN which is used to tell child node to gather data from its children and keep ready to transmit to it and FTOKEN which is used tell the child node to send data to its parent, as shown below:

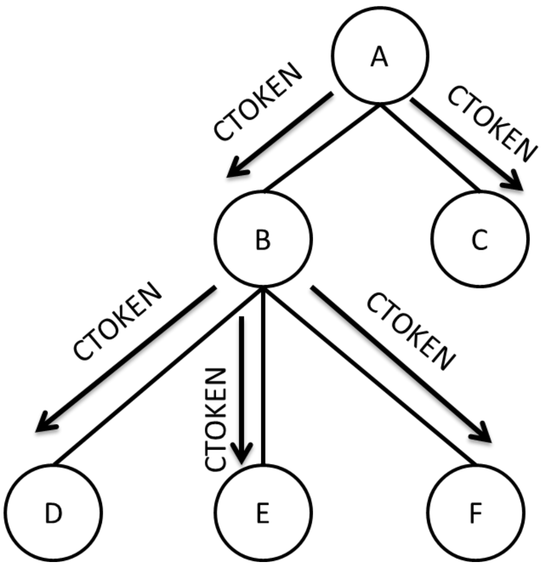

Figure 3.8: Transmission of CTOKEN

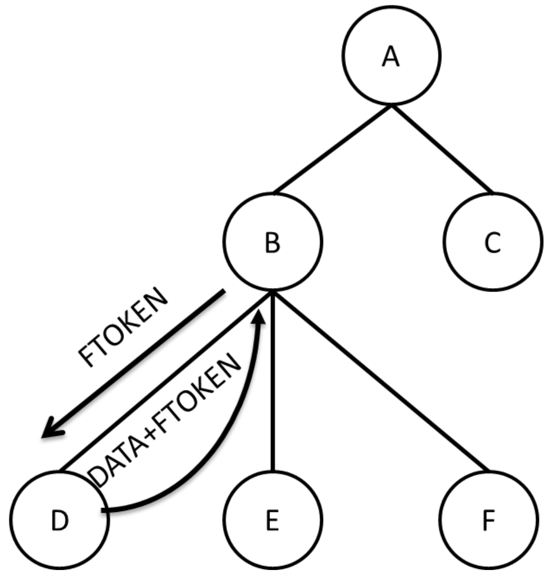

Figure 3.9: B transmits FTOKEN to D which on receiving control packet, forwards the DATA along with FTOKEN

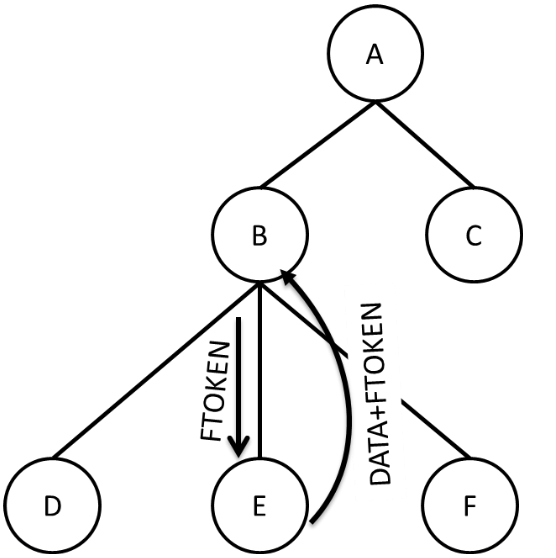

Figure 3.10: B transmits FTOKEN to E which on receiving control packet, forwards the DATA along with FTOKEN

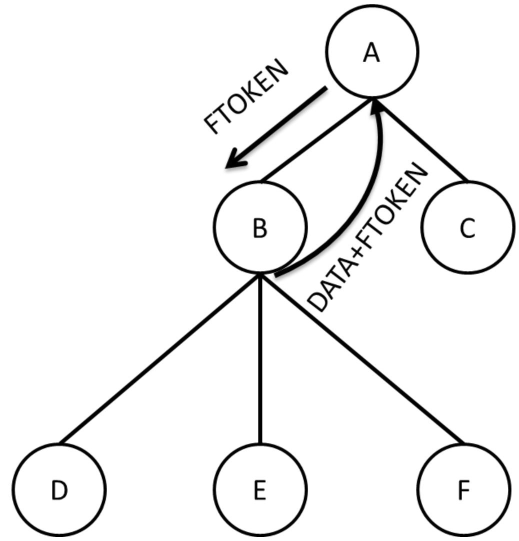

Figure 3.12: A transmits FTOKEN to B which on receiving control packet, forwards the DATA along with FTOKEN

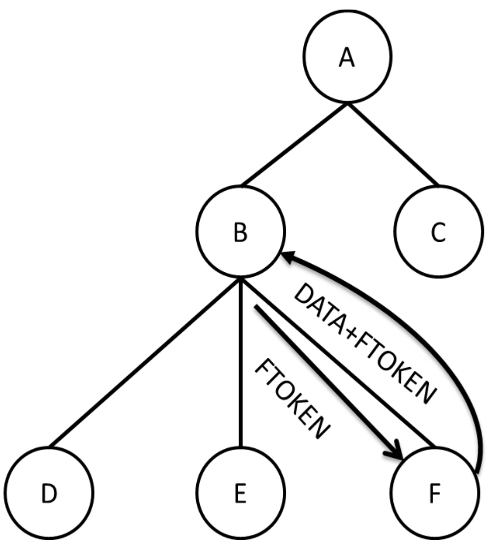

Figure 3.11: B transmits FTOKEN to F which on receiving control packet, forwards the DATA along with FTOKEN

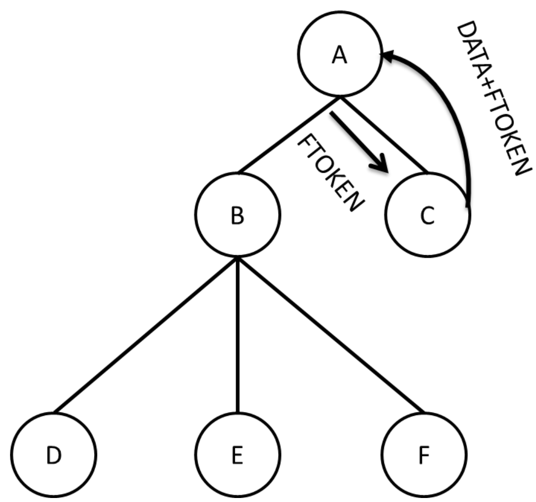

Figure 3.13: A transmits FTOKEN to C which on receiving control packet, forwards the DATA along with FTOKEN

CHAPTER 4

SIMULATION SETUP and RESULT ANALYSIS

A comprehensive evaluation of results and their detailed analysis is covered in this chapter. Results of the proposed protocols are obtained by simulation and their performance is compared with base protocols proposed earlier. Generally there are two ways of analyzing performance of protocols. First, the theoretical analysis, this method of analysis uses mathematical tools and assertions with the help of theorems with valid proof and corollaries. Theoretical analysis considers key operations of the protocol and number of times these key operations are executed. Second method for analyzing performance of a protocol is by performing experiments and making observations of the performance of concerned protocol using simulated test environment. In this various key parameters related to protocol are varied and the results are maintained in the tabulated form for later analysis and comparison.

For evaluation of our proposed protocols, we have applied second method of analyzing performance of the protocol which uses simulation as the tool. Organization of the remaining chapter is as follows. Details of experimental setup and presumptions are covered in section 4.1. Section 4.2 covers performance metrics used to evaluate the performance of protocols and their comparative analysis. Results and analysis of Proposed1 are described in section 4.3. Section 4.4 covers results and analysis of Proposed2.

4.1 Experimental Setup and Presumptions

MATLAB is used as simulation tool for our proposed works. A network of 100 sensors is used to simulate working environment for the protocols. The deployment method used to deploy sensors in the area to be monitored is random i.e. the coordinates for location of a sensor are generated randomly. The nodes are deployed over a square area of 100 × 100. The experiments are performed over a PC with Intel® Core™2 Duo Processor T6670 (2M Cache, 2.20 GHz, 800 MHz FSB) and 2 GB RAM.

The different parameters used are listed with their values in the following tables:

A × A	100 m X 100 m
Number of Sensors	100
Location of BS	(50, 300)
Initial Energy (E_o)	1 Joule
E_{elect}	50 nj/bit
$\mathcal{E}_{fs}$	100 pj/bit/m^2
$\mathcal{E}_{amp}$	0.0013 pj/bit/m^4
E_{df}	5 nj/bit/ message
Size of Data Packet	3000 bits
Size of CTOEKN	10 bits
Size of FTOKEN	10 bits
T_{nd}	4

Table II: System Parameters

4.2 Performance Metrics

Network Lifetime, Total Remaining Energy per Round, Round of First Node Death (RFND), Round of Middle Node Death (RMND), Round of Last Node Death (RLND), and Average Consumed Energy etc. are the key performance metrics used to evaluate our proposed work. Network lifetime is calculated as number of nodes alive per round. Average consumed energy is calculated as total consumed energy divided by number of alive nodes in that round. The next section describes the results of experiments performed for evaluation and comparison of the proposed work with previous protocols.

Same deployment sequence and system parameters are applied over the proposed work and the protocols with which the performance is compared. Figure 4.1 presents deployment of nodes used for performance evaluation.

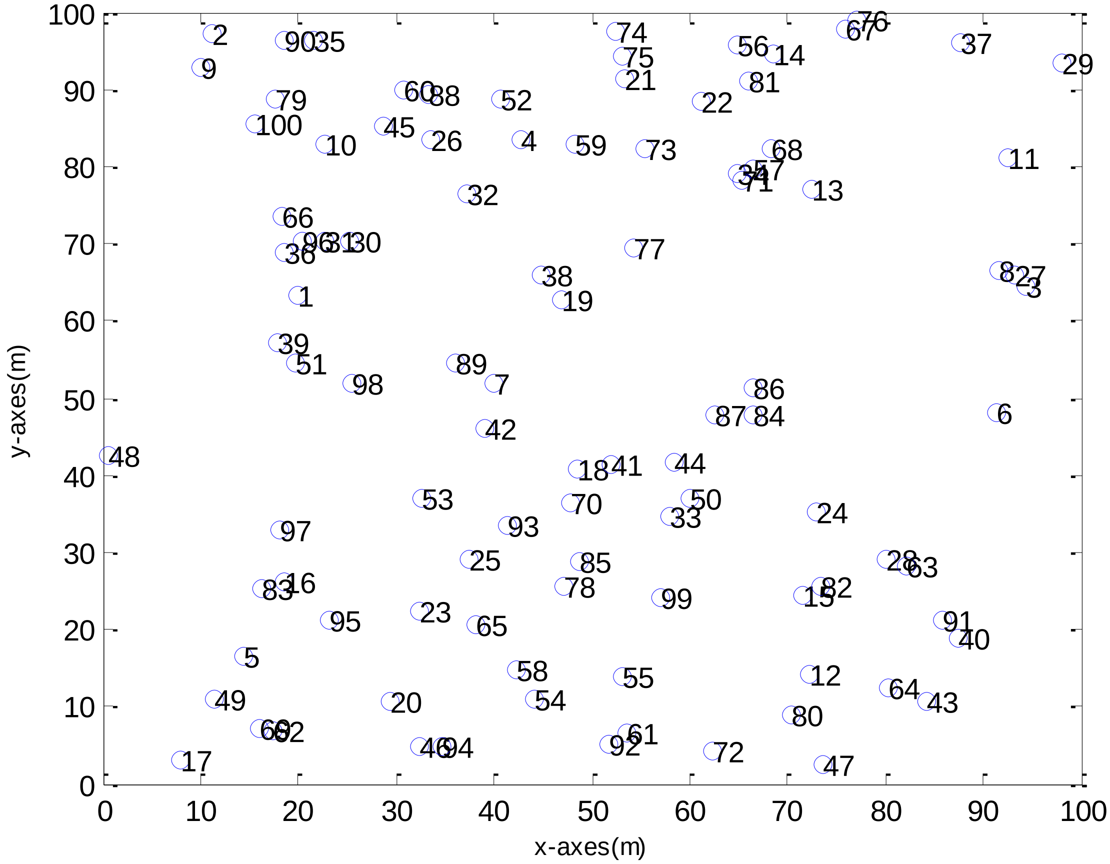

Figure 4.1: Network Deployment

4.3 Performance Evaluation: Proposed1

The performance evaluation of the Proposed1 is presented in this section. Results of the Proposed1 are compared with PEGASIS [1] and IEEPB [6] protocols. Same simulation environment as described in section 4.1 are used to implement the protocols. The network model and energy models adopted are as described in the sections 3.1.1 and 3.1.2 respectively. Performance metrics used are same as explained in section 4.2. Experiments are carried out for 2500 rounds and results and their analysis is presented in the next section.

4.3.1 Results and Analysis

This section describes results and their analysis to evaluate performance of the proposed work. The results are compared with existing protocols PEGASIS [1] and IEEPB [6]. Figure 4.2 depicts the improved chain formed in Proposed1 which makes it clear that there is no sensor node which has degree of connectivity more than threshold T_{nd} which is helpful for load balanced energy consumption.

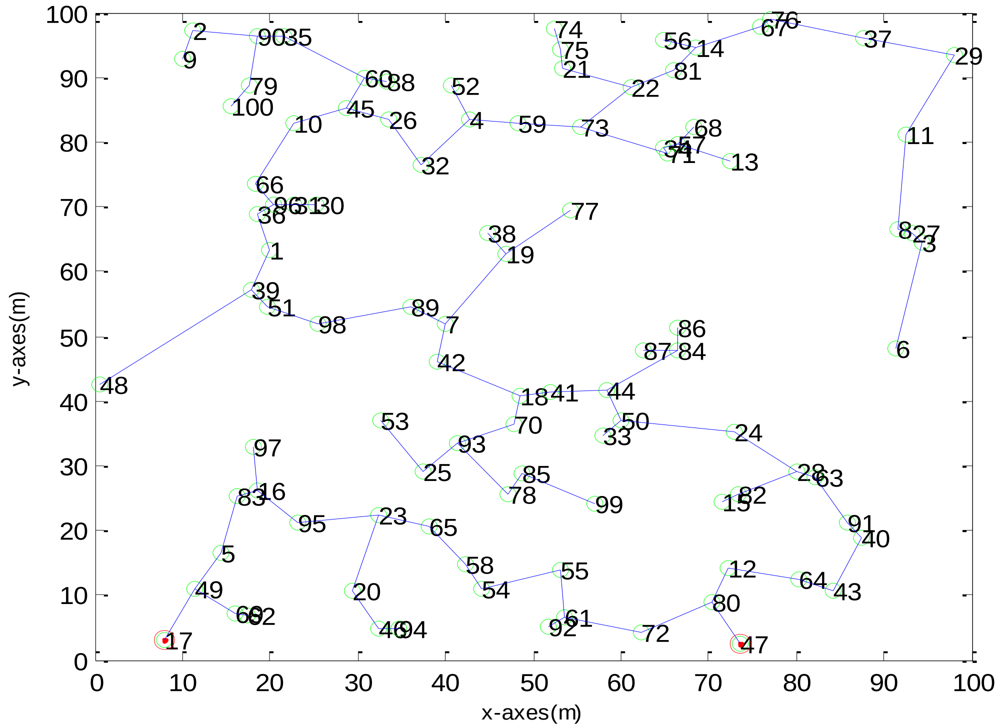

Figure 4.2: Chain formed in Proposed1

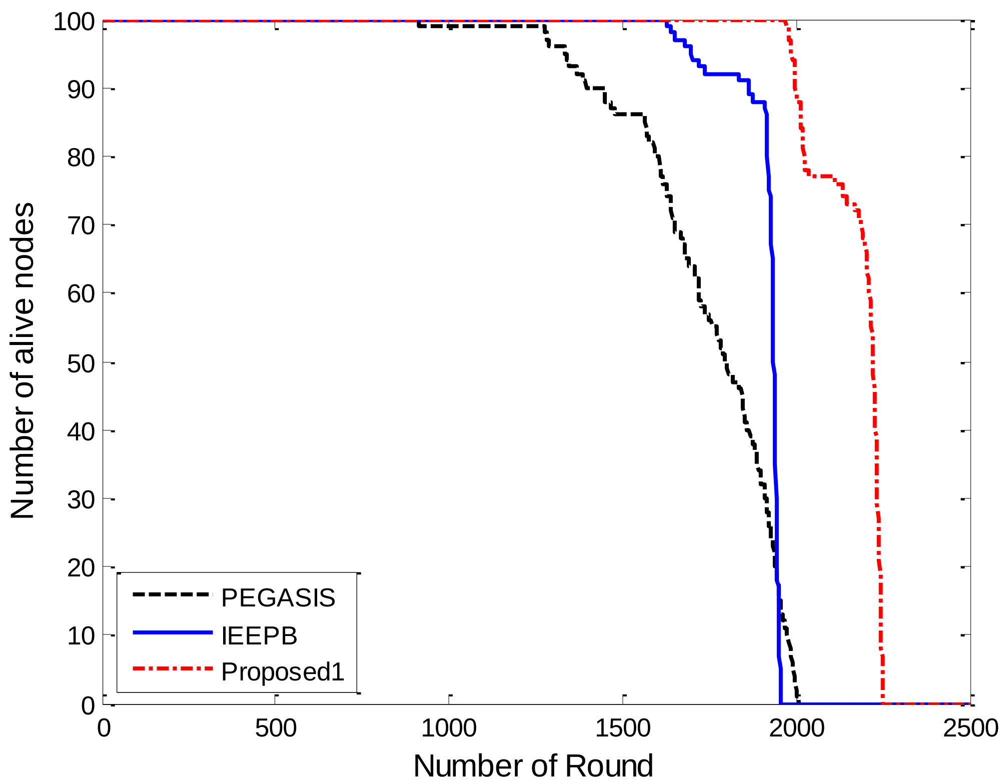

Figure 4.3: Network Lifetime

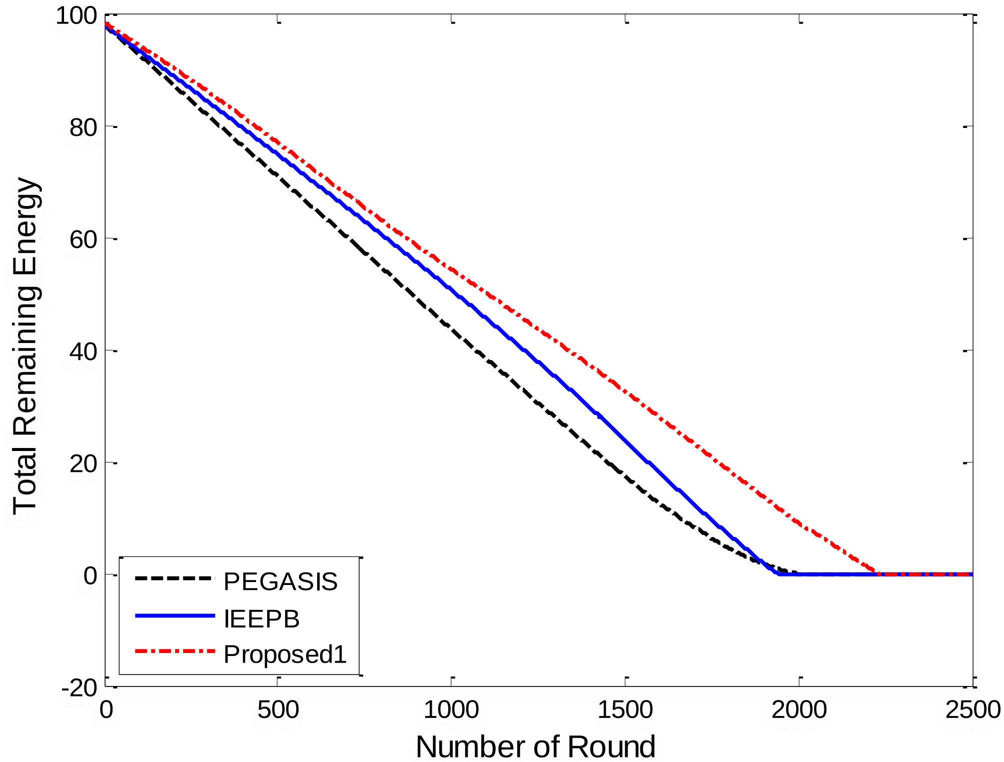

Figure 4.4: Total remaining energy per round

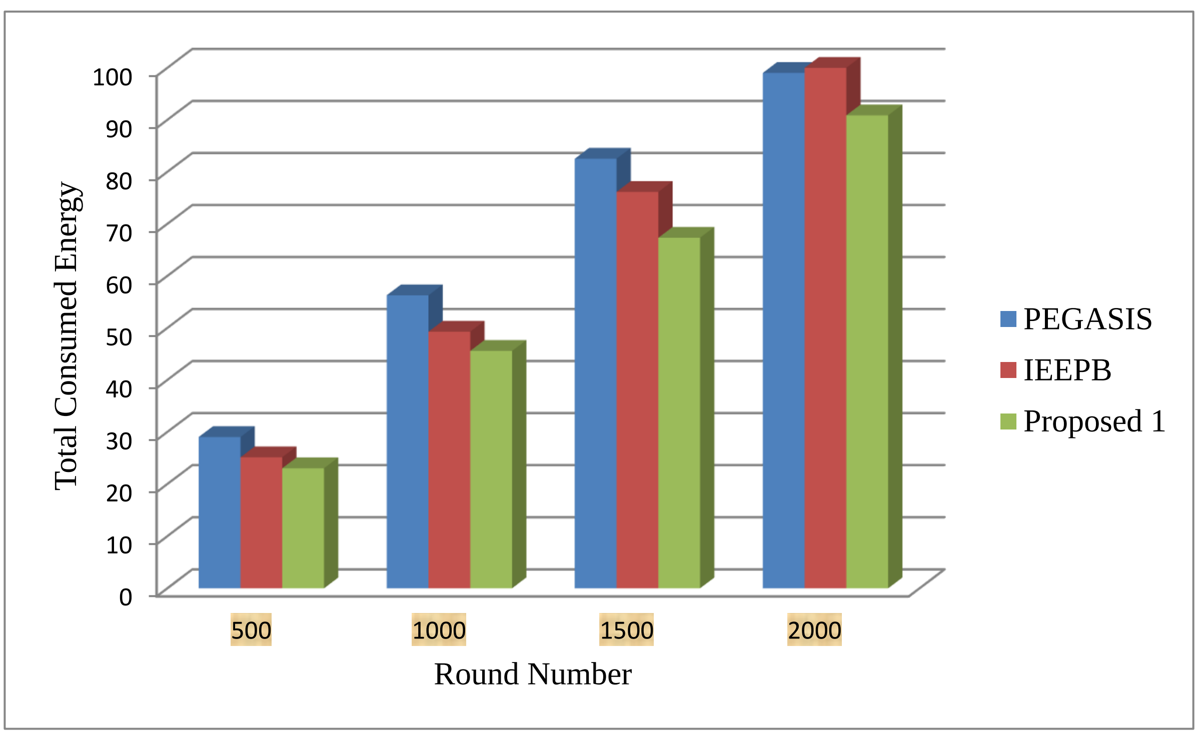

Figure 4.5: Total Consumed Energy of the network over interval of 500 rounds

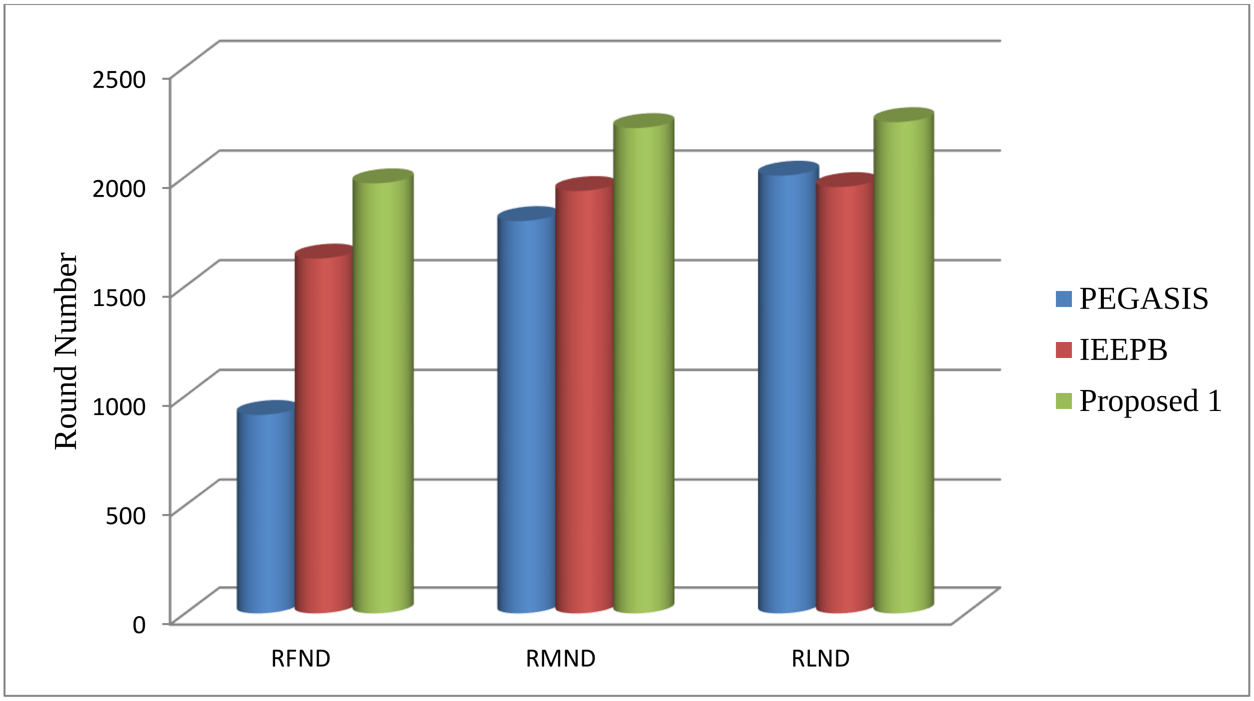

Figure 4.6: Round Number of death of First, Middle and Last node

Figure 4.3 shows the comparison among protocols using performance metric network lifetime. It is clear that Proposed1 outperforms PEGASIS [1] as well as IEEPB [6] and hence EEPB [5] in terms of prolonging lifetime of the network. This improvement in the network lifetime is due to better chain formation and near optimal LEADER selection.

Figure 4.4 depicts total remaining energy of the network after each round. One can easily note that the Proposed1 has more remaining energy in every round in comparison with IEEPB which has better remaining energy than PEGASIS. This is mainly due to application of node degree threshold for better chain formation and improved LEADER selection which balances energy consumption among the nodes in the network.

Figure 4.5 gives detailed view of total consumed energy over intervals of 500 rounds. It is easy to take note of the fact that Proposed1 has consumed less energy over intervals as well in comparison with PEGASIS and IEEPB. Figure 4.6 show that Proposed1 has significantly delayed death of first node, middle node as well as of last node in comparison with PEGASIS and IEEPB.

The above analysis clearly shows that Propsed1 has significant improvement over PEGASIS and IEEPB and outperforms them in all performance metrics considered for performance evaluation. The performance of Proposed2 is evaluated next section of the chapter.

4.4 Performance Evaluation: Proposed2

The performance evaluation of the Proposed2 is presented in this section. Results of the Proposed2 are compared with PEGASIS [1] and M-PEGASIS [20] protocols. Same simulation environment as described in section 4.1 are used to implement the protocols. The network model and energy models adopted are as described in the sections 3.1.1 and 3.1.2 respectively. Performance metrics used are same as explained in section 4.2. Experiments are carried out for 2500 rounds and results and their analysis is presented in the next section.

4.4.1 Results and Analysis

The current section describes results and their analysis to evaluate performance of the Proposed2. The results are compared with existing protocols PEGASIS and M-PEGASIS. Figure 3.7 depicts the improved chain formed in Proposed2.

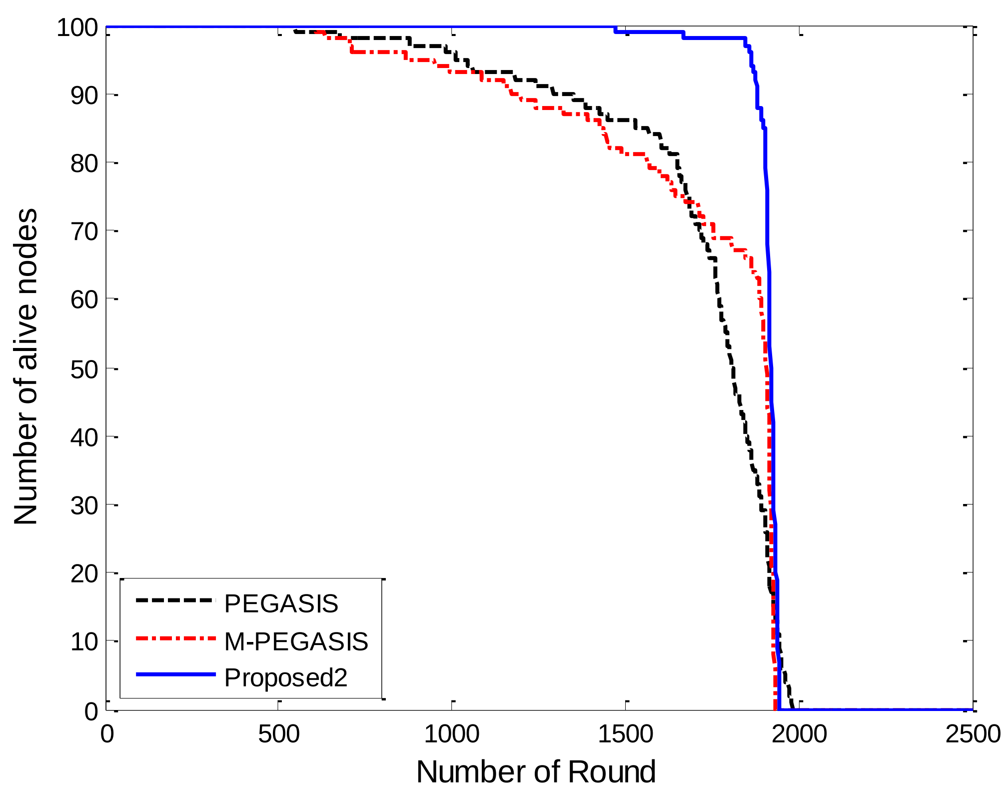

Figure 4.7 Network Lifetime

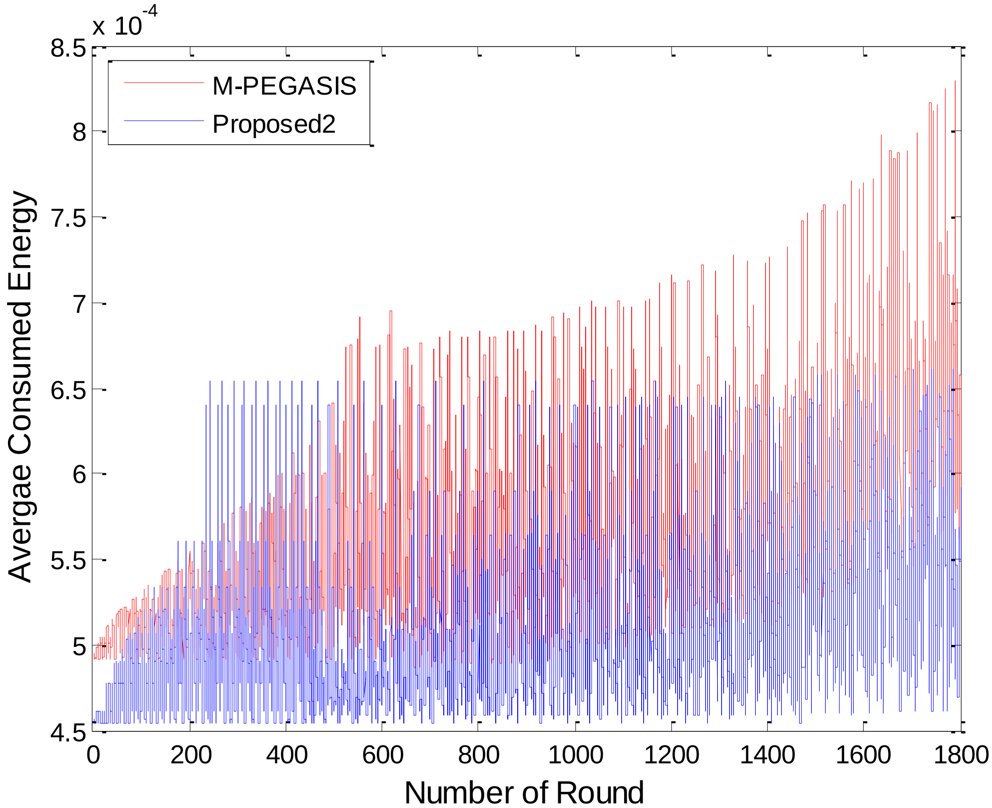

Figure 4.8 Average consumed energy per round

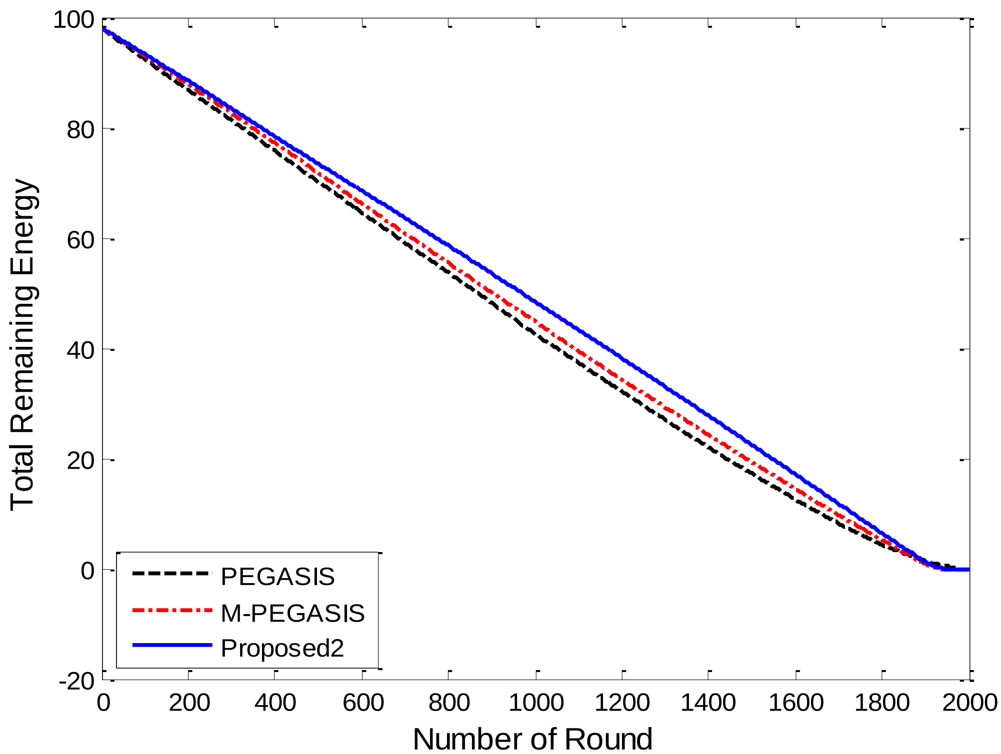

Figure 4.9: Total remaining energy per round

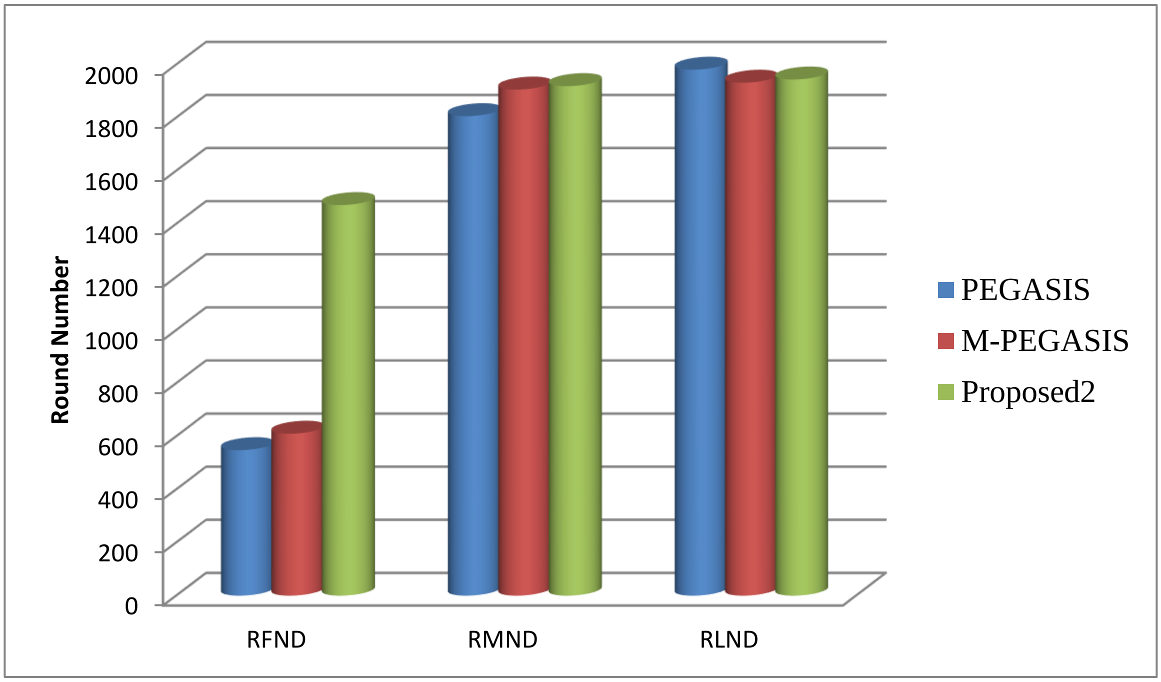

Figure 4.10: Round Number of death of First, Middle and Last node

Figure 4.7 shows the comparison among protocols using performance metric network lifetime. It is clear that Proposed2 outperforms PEGASIS [1] as well as M-PEGASIS [20] in terms of prolonging quality lifetime of the network. This improvement in the network lifetime is due to removal of long links in chain and near optimal LEADER selection. One can easily take a note that Proposed2 significantly delays death of first node, resulting into better load balanced energy consumption among sensors of the network.

The comparative analysis of average energy consumed per round in Proposed2 and M-PEGASIS [20] is represented in figure 9.8. It is clear from the figures that the Proposed2 protocol has more even consumption of energy in each round in comparison with M-PEGASIS.

Figure 4.9 depicts total remaining energy of the network after each round. One can easily note that the Proposed2 has more remaining energy in every round in comparison with M-PEGASIS which has better remaining energy than PEGASIS [1]. This is mainly due removal of long links in the chain resulting in reduced length of chain and improved LEADER selection which balances energy consumption among the nodes in the network. The round of death of the first, middle and last node is compared in Figure 4.10. The Proposed2 protocol delays death of first and middle node significantly while keeping the round of death of last node near about to round in PEGASIS and M-PEGASIS.

The above analysis clearly shows that Propsed2 has significant improvements over PEGASIS and M-PEGASIS and outperforms them in all performance metrics considered for performance evaluation.

CHAPTER 5

CONCLUSION and FUTURE SCOPE

We devoted our work to the problem of optimal chain formation and leader selection in chain based wireless sensor networks with objective to maximize the network lifetime and improving load balancing capabilities to produce even energy consumption among the sensors. In the event of finding better solution, we have drawn inspiration from previous researches carried out by researchers.

In our work, we proposed two different protocols built on the outlines of the conventional PEGASIS for solving the problem of efficient routing in chain based wireless sensor networks. The results of both the proposed protocols are compared with base algorithms under similar simulation environment on same simulation tool. Results and their analysis shows that both the proposed protocols effectively solves the problem and they outperform base protocols in terms of various performance metrics considered for evaluation, details of which are covered in chapter 4. We are able to enhance the overall network lifetime with improved load balanced energy consumption among the sensors and significantly reduced the time delay involved.

Even though our proposed protocols solve the problem of near optimal chain formation and leader selection with reduced time delay and shows significant improvement in performance described in chapter 4, the room for improvements still remains open. The possible modification could be the introduction of quality of service mechanism, secure data gathering and transmission, reducing time delay involved, support for critical information transmission and time critical applications etc.

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