ENERGY AWARE AND LOAD BALANCING GEOGRAPHIC ROUTING IN WIRELESS SENSOR NETWORKS

by

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بسم الله الرحمن الرحيم

DEDICATIONS

Dedicated to my sweet son Ahmad Khalid
&
my loving husband Khalid Mahmood

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In the name of **Allah Almighty**, the most beneficent and the most merciful.

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ABSTRACT

Wireless Sensor Networks (WSNs) consist of thousands of tiny nodes having the capability of sensing, computation, and wireless communications. The major challenges faced by wireless sensor networks are energy-efficiency (as WSNs are battery powered and batteries are not chargeable and replaceable) and self-organization (as nodes may disappear).

A thorough literature study of routing protocols for WSNs presents a classification for the various approaches. Each of the routing algorithms has the common objective of trying to get better throughput and to extend the lifetime of the sensor network.

In this thesis work geographic routing in WSN is mainly focused for energy issues and a location based WSN routing protocol ELBGR (Energy aware & Load Balancing Geographic Routing) is presented that features the energy efficiency, load balancing and self organization of the wireless sensor networks. This protocol extends the lifetime of the network and balances the energy consumption of the nodes within the network.

This algorithm works on forwarding rule based on neighbor's energy levels, packet reception rate and the location. Each node knows geographic location, energy levels and PRR of its neighbors. The proposed algorithm consists of two phases; initially it selects the Forwarding Nodes Set (FNS) from all neighbors and then finally selects the Optimal Forwarding Node (OFN) from FNS for forwarding purpose.

The ELBGR is compared with Greedy algorithm, EAGR, EEAR and HHEAA for its performance and the simulations results depicted that the proposed algorithm (ELBGR) gives better performance in terms of higher success rate, throughput and less number of dead nodes and it effectively increases the lifetime of the sensor networks.

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LIST OF ABBREVIATIONS

ACK	Acknowledgement
AFR	Adaptive Face Routing
BPD	Backup Path Discovery
CU	Communication Unit
EAGR	Energy Aware Greedy Routing
EEAR	Efficient Energy Aware Routing
ELBGR	Energy & Load Balancing Geographic Routing
FR	Face Routing
FNS	Forwarding Nodes Set
GAF	Geographic Adaptive Fidelity
GEAR	Geographic and Energy Aware Routing
GOAFR	Greedy Other Adaptive Face Routing
GPER	Geographic Power Efficient Routing
GPS	Global Positioning Scheme
GPSR	Greedy Perimeter Stateless Routing
HHEAA	Hole Healing Energy Aware Algorithm
LQER	Link Quality Estimation based Routing
OFN	Optimal Forwarding Node
OFR	Other Face Routing
OMNET++	Objective Modular Network Testbed in C++
PRR	Packet Reception Rate
QoS	Quality of Service
REAR	Reliable Energy Aware Routing
SAR	Sequential Assignment Routing
SN	Sensor Network
SPD	Service Path Discovery
TH	Threshold
WSN	Wireless Sensor Network

Chapter 1

Introduction

1.1 Wireless Sensor Networks

The technology progress in the embedded system emerged a new network class called Wireless Sensor Networks (WSN) [1]. A WSN consists of many small autonomous systems, called sensor nodes or motes. Sensors are the devices that make sense to some physical change for which they are deployed for different applications, communicate wirelessly and cooperate with the neighbor nodes to route the sensed information towards the destination. This type of communication has different characteristics as compared to cellular networks or single hop wireless networks as they do not rely on a fixed infrastructure.

Many routing strategies have been introduced and developed for the WSNs. These strategies used in WSN are different from wired networks routing mechanisms as the schemes used for routing in WSN must not ignore the unique inherent features of the WSNs, the main critical issue in WSNs routing strategies development is to deal with the energy constraints and to cope with the changing nodes status changes (e.g. failure) that occur suddenly resulting unpredictable changes in the network topology. The communication protocols governing the network must be able to cope with all topological changes without human intervention. Most of the nodes are too far away from the sink node (node that finally collects the sensed information) to communicate directly. Intermediate nodes are hence used to relay the message, that's why this type of communication is also called ad hoc multi-hop communication [19]. The WSNs self-organizes to form a coherent communicating system.

An intensive research has been carried out in last decades in the area of WSN routing in order to develop efficient protocols which route data in the energy constrained, multi-hop environment. No standards have been developed for routing in WSNs yet and any protocol has not gained a dominant position among the research community. Routing puts a significant effect on WSN lifetime, the efficiency in energy savings achievement by the routing protocol is an open problem. The proposed algorithm addresses the energy efficiency issue common in WSNs.

The wireless sensor networks are used excessively with the passing time, these suits well for monitoring so many applications like industries, environmental forecast, transportation, health-care and safety/ security applications [19].

1.2 Motivation

Routing in Wireless Sensor Networks (WSNs) is bit difficult and a challenge for the researchers due to the different and unique features of WSNs which make them different from mobile ad hoc networks and any other type of wireless networks**.** These include types of flow of sensed data, limited energy resources (as nodes are battery powered), limited processing and storage capacities of nodes & a huge amount of the nodes that affects the time-efficient packet delivery. To sort out the above mentioned different features, many routing strategies have been proposed and introduced for the WSNs. These strategies are classified as the hierarchical approach, the data-centric approach, and the location-based routing approach (also known as geographic routing).

In geographic or location based routing, the nodes have information about their location and the source node has information about the destination. In the geographic routing the closest path is chosen for transmitting data packets from the transmitting node to the destination node. These protocols are efficient in many aspects like time efficient transmission of information to the destination or target node and reliable for the transmission of data, most of the geographic routing algorithms can not maintain the energy balance within the network, which ultimately causes the death of the frequently used nodes hence blocking the sensed information to be propagated to the destination node. The major purpose of this research is to develop an energy aware and energy efficient geographic routing algorithm for the WSNs that can play an important role in maintaining the energy balance within the network causing the prolonged life-time of the network.

1.3 Thesis Structure

The introduction of WSNs and the motivation for the research has been described above in this chapter. The remaining thesis is organized as under.

In **Chapter 2** WSN overview is described including the network structure, WSN applications classification, and the challenges of designing routing protocol. A survey of WSN routing algorithms is described in this chapter. The protocols are described which influenced the development of routing schemes for in WSNs.

In **Chapter 3** a literature review of prevailing WSN routing protocols is described and specifically location based and power aware routing protocols are focused and their potential limitations are explored. The Problem Statement and research contributions of this thesis are also described in this chapter.

In **Chapter 4** a new technique for optimizing the energy efficiency of the routing protocol is described. Its influences on the overall network lifetime are elaborated. This chapter also exploits the influence of the proposed algorithm on the load balancing and energy efficiency of the network. Later the proposed solution design and implementation is described in detail.

In **Chapter 5** a comparison is made between the proposed algorithm and pre-existing algorithms. The results detail of different experiments performed and their analysis is provided in this chapter.

In **Chapter 6** the thesis is concluded with a summary of this work along with some suggestions for future research.

Chapter 2

Overview of Wireless Sensor Networks

2.1 Structure of the Wireless Sensor Networks

WSNs mainly comprises of three main entities, [2] the **sensor nodes** whose main responsibility is to sense the information with some additional processing and relaying capabilities, the **base station (Sink node)** that collects the sensed information, and **the events** (used in different WSN Applications) that are monitored by sensor node and transmitted to the base station.

2.1.1 Sensor Node:

The basic parts of the sensor nodes are sensors, battery, processor, communicators and the memory unit. An introduction of each is given under

a. Sensing Unit (Sensors)

The sensing unit, sensor maintains a connection or link between the material world and the computing world. The sensors (hardware device) observe the physical changing conditions in the interest area; it generates response to the sensed/ measured changes. Sensors can sense the change in the environmental phenomenon, collect the data (information) and convert the sensed analogue data into the computer readable digital data and then send this for further processing to the microcontroller. Different types of the sensors are used for different sensing operations.

b. *Memory Unit*

The memory unit of the sensor stores data packets (data observed by the sensing unit of the sensor node) or received from the neighboring nodes as well as it stores the algorithm basis on which the sensor node decides to choose the next forwarding node for information transmission towards the destination.

c. Power Unit (Battery)

For sensing environmental change and converting it to digital data in sensing unit, storing it in the memory unit and data transmission towards the destination, the sensor node needs some energy. The sensor node consists of a battery (power unit) which provides the energy/ power to its all units. The major part of the node's power is used in its data transmissions. The computation also needs power but it is far less than the energy used for the transmission purpose.

d. Processing Unit (Processor)

A microcontroller exists in each sensor node, which comprises of further five parts i.e. a processor, memory unit, analogue to digital converters, the timer (calculates time for different processing) and the interfaces for receiving and transmission, to perform the processing within the sensor node. The processing unit is used for data collection from the environment, the collected information is then processed by it for incoming and outgoing purpose, it also implements the routing using the predefined routing algorithm.

e. The Communicator/ Communication Unit (CU)

Senor nodes utilize the radio frequencies for networking purpose. The CU in sensor nodes using the defined routing mechanism performs data transfer to the other forwarding nodes or sinks directly or using multi hop routing.

2.1.2 Base Station (Sink)

The sink node has unlimited computational capabilities and energy supply. The sink is an interface between the wired network or management center that utilizes the gathered information for any purpose and the wireless sensor network (that gather information).

There may exist a single sink node or multiple base stations in a network. Network delay is decreased and performance is increased in case of multiple base stations. Base station in a network can also be stationary or dynamic.

2.1.3 The Events (For different WSN Applications)

The events are the physical environmental conditions that are to be sensed and propagated towards the base station. Wireless sensor networks are used for different applications.

2.2 The Applications of Wireless Sensor Networks

The Wireless sensor networks are widely used to monitor and control different application areas [3] including industries, environmental forecast, transportation, health-care and safety/ security applications The wide range of WSN applications can be divided into three main categories space monitoring, things monitoring and the things interactions monitoring with each other.

Space monitoring incorporates the environmental monitoring, monitoring agricultural applications, indoor climate control, surveillance, and alarms (e.g. fire alarms). Monitoring things include the monitoring of different structures, maintenance of different equipments, medical diagnosis applications, and the mapping of the urban areas. And in the interactions of things monitoring the complex interactions of the things are monitored, including the management of disasters, monitoring process flow and monitoring of the ubiquitous computing environments

WSN applications [26, 27] can also be categorized based on the nature of the event (sensitivity, time crucial) to be sensed or observed. Immediate event detection and reporting is the major demand for some WSN applications like enemies detection in military surveillance, anomalies check at production level, fire detection in the forests. Time delay is very crucial for these applications, immediately after event detection the network the information transfer to the destination node in minimum possible time. Handling of the false reporting of such events is also a major challenge for these networks. Another main issue is the routing of event to the sink.

Some WSN applications require data gathering and periodic reporting of some physical/ environmental change on continuous basis. . Efficient energy utilization is very important for these applications e.g. monitoring of humidity, temperature and light in the environment and health applications etc.

2.3 Characteristics of Wireless Sensor Networks

The WSNs have few unique characteristics that differentiate them from traditional networks [4]. These include:

- Sensor nodes are small scale devices. Sensor nodes contain very less amount of energy.
- The total number of sensor nodes in the WSNs is multiple times greater than in ad hoc networks, which raises the scalability issues might be raised along with high level of redundancy.
- The topology of the WSN changes very frequently as the nodes deplete their energies with the passing time and due to the environmental effects. WSN should be adaptable to changing topology without human intervention. To extend network lifetime is of main consideration in WSNs. In case of path failure and no adaptability with the failures becomes problem for WSN working.
- Sensor nodes do not have global identification due to their large number and low resources. Location awareness of the nodes may solve this problem to some extent.

- Heterogeneity is another feature of WSNs. WSN may contain different types of nodes in respect of their sensors, communicators, batteries, and the memory
- The most important feature that must be incorporated in WSN is the least consumption of energy as nodes are battery powered and so many dispersed nodes can’t be recharged.

2.4 Routing Challenges in Wireless Sensor Networks

The sensor networks are multi-hop and it is impossible for the transmitting node to send the data directly to the destination/ target node. That's why intermediate nodes are utilizes for the data packets transmission and finally transmit it to the destination node. Routing is a process used to determine the path (route) between the transmitting node and the destination node for the purpose of data transmission. The path is determined using some predefined criteria or algorithm. In WSN it is impossible to follow the fixed paths for data transmission as this way the nodes on that specific path will deplete their energy very soon, resulting in the failure of the network, rather the routing protocol is responsible for choosing the next optimal forwarding node from its neighbors to prevent the same node be chosen every time. Due to the unique features of the WSN, different routing strategies are defined for WSN. The performance of WSN routing operation is affected by the following factors [20]:

Limited storage capacities: Since the sensor nodes are tiny devices which have to perform sensing, some processing and communication. For the routing purpose information storage activity is required, the stored information is then used to make decision to select the next relaying node for data transmission towards the sink node. The routing scheme must be efficient in sense to store minimum information in each node for optimal route selection.

Scalability: The scalability [22] is very important factor in WSN routing. As per requirement of the application, different numbers of nodes are deployed in a WSN, which may exceed to thousand. For efficient routing, all the nodes should adjust themselves with the changing network structure.

Latency: Another important factor that effect WSN performance is the time delay (in sensing, processing and communicating the information from source node to destination node). This time delay is called the Latency. For some applications of environmental monitoring (e.g. detection of fire in forest etc) latency becomes very important. The routing protocol must be efficient to reduce the latency at its level best.

Energy Constraints: As sensor nodes are small scale and battery powered devices means they have limited energy and the energy should be used in the optimal way for the computation and communication purpose. Each node utilizes the energy for its functions that include sensing, computation, data storage & communication. The maximum energy is used in the communication. Therefore, to use the energy optimally, the communication between the nodes must be minimized. Further all nodes of the network must know their current energy status so that the routing strategy may decide either to use a node for transmission purpose or not.

Node deployment: Node deployment [23] is a WSN is a major issue, nodes can be deployed randomly or manually depending upon the applications. If nodes are deployed manually then routing is made using some predefined routes. Mostly the sensor nodes are distributed in the specific region in random style in the dense way to achieve maximum connectivity and network reliability. If nodes are deployed randomly they make a self organizing system rather than predefined routing system. The way of node deployment affects the performance of the routing efficiency.

Adaptability: Due to different harsh environmental conditions and energy depletion of some nodes in the WSN, the network must be fault tolerant, in case one route is out of work, then the routing strategy should adapt some secondary path and utilizes the remaining nodes for communication rather than failure of the network. Adaptability affects the performance of the routing protocol.

Node coverage range: Since the sensor nodes are small scale devices, their communication range is not very vast, if the nodes are densely deployed then the communication range problem can be solved and better connectivity can be achieved. In the designing of the sensor node, the coverage parameter is of much importance for efficient routing.

Mobility: For some application mobility of the sensor nodes can be an important issue for the efficient routing. Routing becomes complicated in that case. Mostly it is assumed for WSN that it consists of stationary nodes but for some applications where sensor nodes are mobile; their mobility must be considered while designing the routing strategy.

Quality of Service: Quality of service (QoS) may be considered differently for different WSN applications, in some cases it ensures the efficient communication within the given time delay. For some applications, to achieve quality of service, the protocols should make the network more stable for reliable data delivery to the sink node. It may include countering efficiently the resource limiting factors, like energy, storage and bandwidth. However QoS affects the routing efficiency a lot.

Network Life-time: The total life duration of the Wireless Sensor Network is of great consideration for better performance and it depends on the efficient use of energy by nodes through routing strategy. The routing protocol should be much efficient so that it may conserve the overall energy of the network and maintain a balance of energy in all nodes. This way the network will work for maximum time until almost all nodes utilize their energy. It will result in long life of the WSN.

2.5 Basic Routing Techniques in Wireless Sensor Networks

A large scope for designing the routing protocols for WSN exists because the functionality and design of these protocols depends upon multiple criteria. Many routing techniques are used for routing in WSN. Commonly the WSN routing protocols are categorized as is: Application specific (specifically designed for some application); Data centric (data is gathered after sink query); Capable of aggregating data (hierarchical mode used for data aggregation); Capable of optimizing energy consumption (energy conservation is the major task of this category). Additionally the WSN routing protocols are classified into four classes based upon different criteria: i.e. the routing operation mode, the network structure, the communication initiation mode in the network and the ways of path establishment. An introduction of each is given below

The routing operation mode, which is further subcategorized into five subcategories

Multi-path-based routing, [4] in multipath based routing when the primary path (the path that is used primarily for routing purpose) fails between source node and destination node an alternate path exists that is used for transmission, network is fault tolerant and more reliable but energy consumption increases.

Query-based routing, the sink node initiates the query in the network for some data transmission and the node having required data sends the information to the sink.

Negotiation-based routing, [4] in this type of routing the duplicate information is suppressed and the data redundancy in the network is reduced to save energy by conducting the negotiation before the data transmission begins.

QoS-based routing, [4] the routing is based on the fulfillment of any QoS (Quality of Service) metrics, i.e., data delivery delay, energy consumption, etc.

Coherent-based routing, [1] here data processing is of major concern, either maximum processing is done locally by node itself (low cost, coherent processing) or some aggregator does processing (high cost, non-coherent processing).

The network architecture, on the basis of the structure of the wireless network, the routing class in WSN is divided into three sub-classes i.e.

Flat-based routing, [5] it includes in generic type routing, the data-centric routing, where after sink node query, the data is sensed and transmitted by multiple nodes in a specific region. Redundancy occurs, all nodes play same role in flat routing.

Hierarchical-based routing, [4] scalability is of major concern in this type of routing, network clustering is used for data aggregation, these protocols are more scalable and energy efficient.

Location-based routing, [4] using GPS (global positioning system) or neighbor's coordinates, the location of a node is determined as no global addressing is defined for WSNs, location awareness is used for energy efficient routing to increase network lifetime.

The communication initiation mode, can be sub-divided into two classes

Source initiator routing, here the sensor nodes are deployed for some specific task, on periodic basis sensor nodes sense the environmental change for which they are deployed, do some processing and following the routing mechanism sends the information data towards the sink/ destination node.

Sink initiator routing, in this type of routing the communication is initiated by the sink node when it sends some query towards the nodes of some specific region, and after receiving the query the sensor nodes transmit the information towards the sink using pre defined routing algorithm.

Routing path establishment mode, *[6]* For routing path establishment, three modes are used which are

Proactive mode, in proactive routing, the routing paths are predefined and information about the path is stored in the routing tables. For any change in network structure (nodes failure) the new path is defined and routing tables are updated then. As WSNs may consist of thousands of nodes with limited energy and storage, proactive routing becomes very expensive and unrealistic for usage.

Reactive mode, in reactive routing, the routes are defined only when data transmission is required.

Hybrid mode is the combination of proactive routing and reactive routing.

The routing protocol from any of the four classes must fall in some type of the generic classification described earlier.

2.6 Research focus

The efficient consumption of energy in the wireless sensor networks is of significant importance for network lifetime. To cope with limited energy of sensor node remained a very hot research issue. Many routing algorithms have been defined to conserve node energy and to best utilize the small storage space of nodes. The location based routing protocols encompasses the limited energy issues efficiently. The main focus of this research is the location based or geographic routing that deal with the limited resources limited resources of sensor nodes and also supports the network in case of node failure (fault tolerant). In the geographic or location-based routing protocols, physical location information of the wireless sensor nodes is considered for the routing purpose. Evolution in location based routing is studied in this research. A new routing strategy based on the geographic location information of the node is proposed where neighbor nodes exchange some information along with their location with each other, on the basis of which routing decision is made.

Chapter 3

Literature Review

3.1 The WSN Routing Protocols

The routing process is the process used to evaluate the path between source & sink/ destination for the transfer of data. Routing is basically the function of layer-3, the network layer. In WSNs, the sink node can be far distant from the source (out of the range of sending node), due to which the data cannot be directly transmitted to the sink node and to cope with this multi-hop technique is used. Where multi-hops are used for routing the intermediate nodes are used to forward the data packets in order to achieve their final transmission to the sink. It is assumed by Location based routing protocols that the sensor nodes know their geographical position and use this information to find the path consisting of multiple hops to the destination node. The overview of routing techniques is already given in last chapter. In this chapter the routing protocols relating location awareness are discussed as these have gained widespread attention and attraction and this research is more concerned to the energy-aware geographic or location based routing [21, 24].

3.2 Location-Based/ Geographic Routing

In the location-based or geographic routing [7] in a specific area the sensor nodes are scattered randomly. The nodes are in large number, no global positioning is possible for so many sensor nodes in the WSN. Due to which the nodes are identified by their location. Global positioning system (GPS) is most commonly used for the position location identification; the sensor nodes exchange this information with the neighbors. After neighbors' evaluation, this is used to measure the distance between the neighbor nodes and their distance from the destination node. This geographic information is utilized to find the routes in the start of the transmission and maintain the route in case of any node failure as well as this information is used for data forwarding and transmission. The location information is basic requirement for the formation of routing tables which contains the list of the forwarding nodes used for data transmission. The routing tables are made according to the algorithm predefined for some protocol. Routing algorithm based on routing tables becomes very expensive in terms of storage due to extra large size routing tables (if WSN consists of thousands of nodes) and in terms of energy due to routing tables updation every time when topology changes (due to nodes addition or failure). To cope with these overheads many routing algorithm are defined which use only local information of neighbors for route determination, these are much energy efficient than the algorithms that use routing tables.

Greedy routing approach has been utilized by many researchers for making decisions in order to establish links for routing paths. Mostly the location-based or geographic algorithms use Greedy strategy to transmit the packets to the destination. If there is very large number of nodes and uniformly distributed in the networks, greedy strategy works very efficiently and effectively but its working fails when there appear the dead nodes and a node do not find any neighbor near to the destination or sink node.

3.2.1. Greedy Perimeter Stateless Routing (GPSR)

Greedy Perimeter Stateless Routing (GPSR) [8] is a very common location based routing scheme for the wireless sensor networks that follows Greedy forwarding algorithm. When a node starts transmitting the data, either the node senses this data itself or works as relaying node), first of all the nearest neighbor as the next-hop node is selected, and then the data packet is forwarded to that node. Using greedy strategy few nodes are selected repeatedly hence their energy level decreases and after a number of transmissions, the next-hop node may not be available due to its zero energy. This problem is called the local optimization problem where a satisfying next-hop node is not available. To cope with this problem, GPSR makes use of perimeter of the area to send the packet to the selected node called perimeter forwarding algorithm. This algorithm is used to make a planar graph on the initial network topology to solve the local optimization problem. It means when next-hop is failed, the route is recovered by routing the packet around the edge nodes of planar graph towards the destination/ sink node. The GPSR protocol combines the greedy forwarding strategy and the perimeter forwarding strategy to achieve successful routing to the destination node.

In short it can be said that the greedy strategy is the basic approach of routing in GPRS routing protocol, but in the case when optimal next-hop nodes are not available, the perimeter forwarding algorithm is used on the planar graph to choose the next-hop. This recovery path may incorporate so many nodes for some cases that it becomes very expensive for energy consumption and the time delay is significant for packet delivery. Yet packet delivery is absolute in GPRS.

3.2.2. Sequential Assignment Routing (SAR)

Sequential Assignment Routing (SAR) [9] is an energy efficient, table driven multi-path node centric algorithm. Each node has a local-table that contains the info of the multiple paths towards the destination including the least cost path, which is to be selected for data transmission. But in case of failure of least cost path some alternate path is available there as there is for sure one path existing to the destination. It also incorporates the QoS metric into the routing decision. SAR functioning can be split into three tasks: path construction, packet forwarding over existing paths (stored in routing table) and path maintenance. If there is a single routing path, its failure will badly affect the routing protocol performance, to prevent this, SAR creates trees outward from each neighbor of the sink node such that most nodes are part of several such trees. The created trees evaluate the multiple paths from the destination node to the sensor nodes. The single path reuse is avoided specially closer to the destination node as these nodes may die early due to early consumption of batteries due to their double duty, first the relaying of data packets coming from distant nodes, second transmission of their own packets. Very important feature of SAR is that the process of path construction avoids the low energy nodes and the nodes which do not guarantee QoS. To deliver the data towards the destination, the transmitting node chooses the path having minimum value of weighted QoS based metric. This weighted QoS (Quality of Service) based metric is the product of the additive QoS metric (corresponding to delay over a path) and the weight coefficient (that is associated to the priority the packet). After a regular time period the sink node reconstructs the routing paths for better performance of the protocol as due to failures of nodes, the topology changes and new paths may be required for successful routing. A hand-shake process among neighbor nodes is used that is based on the local path-restoration scheme.

The power usage in SAR is very low, it ensures QoS, it has very low latency due to its tree structure and it features the fault tolerance and easy recovery. Yet it is scalable for limited nodes in a network as it has to reconstruct the routing tables for any change in the topology.

3.2.3. Geographic Adaptive Fidelity (GAF)

Geographic Adaptive Fidelity (GAF) [10] is a geographic and energy-aware routing protocol, in the start it was designed and used for ad-hoc networks but later it was also used for WSNs. It decreases the redundancy in the network and turns off all unused nodes of the network and does not affect the effectiveness of routing that results in the savings of node energy of the network. The total network region/ area is divided into the small rectangles by GAF protocol in such a way that few nodes (or any node) of a rectangle are in the range (radio range) of the adjacent rectangle's nodes and can communicate with each other. Nodes belonging to the same rectangle or grid area are considered equivalent and only some of them are in awaking state for communication and the rest of nodes can be in sleeping state for a certain time period to save the energy. The rectangles size is a dependent factor which depends on the transmission range. The equivalent nodes of two adjacent rectangles are the nodes which are on the diametrically opposed corners of two rectangles and communicate to one other at their maximum radio range R. The distance between two such nodes must be smaller than R. As the nodes know about their physical locations, they make the equivalency rectangles easily, and the nodes in their own rectangle are found to make a sleeping pattern collaboratively. GAF consists of three states: *discovery state* for determination of the neighbors in the grid, *active state* (when the node is awaking and ready for sending data) and sleep-state (where the radios of node is shut down to conserve energy). GAF-basic mode is implemented for the non-mobile nodes and for the mobile nodes GAF-mobility adaptation mode is used for the routing purpose. For mobile nodes in the network, all node of the rectangle calculates its time of leaving the rectangle and exchange the information with its neighbors. When the sleeping neighbors get this info they wakeup & one becomes the active node to continue the routing process. GAF can be difficult to implement in WSNs because of the required location awareness of every node. Hence it can be assumed that the nodes get their coordinates information using GPS receivers.

In comparison with other ad hoc networks routing protocols the GAF proves that it is better energy efficient resulting longer lifetime. GAF is highly scalable even so many nodes when join the network, divide themselves into the rectangles. The latency of GAF is moderate because when a source node sends data to the nearby rectangle only one node among them which is active forwards the data and all the rest of nodes stay sleep. GAF quality of service (QoS) is low factor as its data traffic pattern is unpredictable and no end to end transmission prevails.

3.2.4. Greedy Other Adaptive Face Routing (GOAFR)

Greedy Other Adaptive Face Routing (GOAFR) [11] is a geographic routing scheme that uses the greedy routing along with the face routing. In the greedy routing of GOAFR, the source node picks the closest neighbor from all one-hop neighbors for routing. But there may exist the situation of local minimum all neighbors are farther to the next node than the current node itself. When GOAFR reaches the local minimum point it adopts the face routing (FR) mode. The Face Routing (FR) mode ensures the successful packet delivery if the network is not partitioned and the source node and the sink node are connected. Sometimes the face routing can be the worst for energy savings as the face routing is proportional to the network size and if the path towards the destination uses so many nodes for packet relay it consumes high energy effecting network lifetime. Other Face Routing (OFR) and Adaptive Face Routing (AFR) are the variants of the face routing. The Adaptive Face Routing (AFR) algorithm selects the best routing path for the worst case scenario, but for the average case it is inefficient. For average-case efficient routing the Other face Routing (OFR) is used which uses the face boundaries determined by the planar graphs for the routing purpose, face boundaries are traversed therefore. The OFR finds the closest node (best node) to the destination. Using this method the local minimum problem within the network is resolved. Two counters are used in the GOAFR algorithm to make the record of the visited nodes in FR which are closer to the destination node and the nodes that are far from the destination node in comparison with starting node. These two counters values tell the algorithm either to go for face routing or revert to the greedy routing.

The simple greedy algorithm gives very good performance in very dense networks but it fails in low dense networks very early while the network is partitioned and no way is available towards the destination node. Rather the GOAFR protocol combines the greedy forwarding with other adaptive face routing to get routing efficiency for both worst case & average case. GOAFR protocol is much better in energy efficiency. It's time delay in data delivery and network lifetime is also much better.

3.2.5. Geographic and Energy Aware Routing (GEAR)

Geographic and Energy Aware Routing (GEAR) protocol [12] is an improved type of the directed diffusion protocol. It uses basic strategy of greedy algorithm for forwarding purpose. It also uses the nodes' location information and the remaining energy level to select the neighbor node with the least overall overhead. Queries are used to initiate the routing. GEAR forwards queries to the specific regions according to the geographic information that can be included in the interest packets. This way the flooding of interests in the whole network (as in Directed Diffusion) is avoided and only a certain region may be considered for limited flooding. GEAR keeps record of two types of costs, the learned cost & the estimated cost, the estimated cost is based on nodes' remaining energy levels and its distance to the destination node & the learned cost is achieved by refining the estimated cost and in the network it is used for routing around the holes. GEAR comprises of two steps: In the first step the data packets are flooded towards the direction of target region: Upon reception of the interest packet by some node, the node selects a next hop having lowest estimated cost. There may exist some cases where no such neighbors are available it means a hole is on the way, in such case one neighbor is selected to send the data using the function of the learned cost In the second stage the interest packets are forwarded within the specific area (region): in the specific region when the data packet reaches, GEAR uses two ways for packet forwarding, one is the recursive geographic forwarding and the other way is the Restricted blind flooding to disseminate the packet within that region. In highly dense networks, the recursive data forwarding is effective in energy conservation than the restricted flooding. In recursive forwarding approach, the node that first receives the query request inside the target area divides the target area into several sub-regions and forwards the query request to the centers of all sub-regions. Similarly, the node nearest to the center of a sub-region, upon receiving the query request, further splits the sub-region into several smaller ones and forwards the query request to sub-regions. This recursive splitting and forwarding procedure is repeated until a node finds itself the only one inside the sub-region. After the forwarding procedures in all sub-regions finish, the entire recursive procedure terminates. This approach is better suitable for the applications where the nodes are densely deployed but if nodes are not dense in the network then limited flooding can also be used.

GEAR is not highly energy efficient rather it behaves moderately as the nodes can only use the lowest-cost paths which have already been estimated, and those paths are used until a new least cost path is estimated even it exists means low energy conservation. GEAR has low latency and low QoS because due to link or power failure that results in topology change the network is instable The most important limitation of GEAR is that for immobile networks its performance is better and is inefficient for mobile networks.

3.2.6. Geographic Power Efficient Routing (GPER)

Geographical Power Efficient Routing (GPER) [13] is energy aware location based protocol for sensor networks. The distance to which the transmission is to be carried out is calculated by local decisions made by each node the fact which is emphasized in this protocol is that the node’s transmission range puts viable effect on the energy utilization of transmitting node and the listener nodes. In GPER, the final destination node is pre-defined and each sensor node in the start determines a sub-destination node within its radio range. It is decided by the node to send the data to this sub-destination via an intermediate node or the node can change the sub- destination for more conservation of the energy. The geographic routing protocols usually choose the shortest weighted path to achieve the transmission but normally they selects the same path again and if the sender and the destination are same. As a result the power of nodes on such paths is consumed early which effect badly the lifetime of the network because communication distribution is uneven. To counter this type of problems GPER generates paths using the local information. The communication (transmission of data) is lesser here therefore nodes failure is less. GPER consumes very low network power in comparison with the other geographic routing algorithms.

It can be concluded that the GPER algorithm is energy-efficient, highly scalable and distributed.

3.2.7. Link Quality Estimation based Routing (LQER)

Link Quality Estimation based Routing LQER [14] is location aware routing protocol which basically utilizes the greedy forwarding strategy that selects next hop using minimum hop counts for data forwarding for making LEQR power-efficient & reliable. It also takes into consideration the successful transmission history over the link. LQER measures the link quality also. It uses flooding mechanism. In the start the counter of each node that counts the number of hops has an infinite value which is updated after receiving less hop count information than its own value. LEQR select the neighbor node with minimum number of hop from the set of nodes that have higher link quality. This selection results in selecting the best path for transmission purpose.

3.2.8. Energy Aware Greedy Routing (EAGR)

Energy Aware Greedy Routing (EAGR) [15] uses the location information of nodes and their powers available. In traditional Greedy techniques, where the shortest-path is measured and considered, the nodes present on the shortest path deplete their energy very soon, resulting in the formation of the hole in place of energy depleted node and packets start dropping on the holes. EAGR uses both the info of the nodes location and their power level to distribute the network workload (data packets) equally among all nodes (live ones). EAGR assumes that all nodes in advance know about their location and the same power-level and power-threshold (TH) is set. Neighbors whose power-level is $\geq$ than the TH value exchange info with their neighbors and each node creates local small-size table (that’s why no small storage space issues) of their locations. This table is used to calculate the average distance of all of its one-hop neighbors. To transmit the data, the neighbor whose distance is = or $<$ than the average distance value with the highest power-level is chosen. The power-level is used to select the forwarding node, always previously selected node is avoided as that's power-level decreases to some extent that's why no single node depletes its power very quickly. As a result the life to the network prolongs. In EAGR, packets are dropped when no neighbor is alive to forward the data. EAGR protocol is much more energy efficient and balances the network loads very well and in optimized way resulting the higher throughput and longer life network. It can also be used for the immobile nodes of the WSN. EAGR results are better than the simple greedy-algorithm**.**

3.2.9. Hole Healing Energy Aware Algorithm (HHEAA)

Holes Healing Energy Aware Algorithm (HEEAA) [16] is location based and energy aware routing protocol that works on average energy and distance of nodes to overcome weak node problem in WSN. If only shortest distant neighbor node is considered for forwarding purpose, the nodes having shortest distance from the destination are selected repeatedly that's why those node are deplete their all energy very soon resulting hole formation on that path. In other case if only higher energy nodes are selected then it may result in longer paths due to which the packet delivery delay increases. The above mentioned both problems are taken into account in HHEAA, as in this algorithm first of all the average energy of all the neighbor nodes is calculated then the node having energy > or = to the average energy is chosen. If number of nodes satisfying this condition is greater than one node then the node having shortest distance is selected from that set of nodes. If a packet reaches some node whose all neighbor nodes are dead (power-level lower than TH power-level) the packet is sent back to the previous node. Then again average energy is used to select another alive node. By doing this the rate of packet dropping decreases in case of dead nodes.

HHEAA selects the next node in energy efficient manner. It has high throughput with reliable packet delivery and long lived network. The dropped packets ratio is very small as it takes care of the dead nodes.

3.2.10. Efficient Energy Aware Routing (EEAR)

Efficient Energy Aware Routing (EEAR) [17] algorithm is a location based & a power-aware routing technique for the WSN. Its routes creation decision making is based on the remaining power-level of the node and its distance from the sink/ destination node. This algorithm exploits the neighbor's information (geographical location & nodes' power-levels) of each node efficiently and saves this info in the mapping table. The geographical location & node's power-level is exchanged between all one-hop neighbors, using this info the current node makes decision that which neighbor node it can select as the forwarding node. EEAR algorithm selects the neighbor node (having energy level greater than the threshold) whose distance is < or = to average distance & the energy is > or = to the average energy. If more than one neighboring node satisfies this condition, then randomly any node can be selected as forwarding node. The sending node transmits the data packet to the selected one and subtracts the transmitting energy from it. The selected neighbor node receives the data and continues the procedure until finally the data reaches to the target. If the data reaches to a node whose all neighbors are dead (having energy less than the threshold energy), the packet is simply dropped.

EEAR uses efficient energy aware routing mechanism to choose the neighbor node that has sufficient power-level and meets the distance criteria to determine the receiving node for forwarding the packet EEAR gives higher packet delivery rate, less energy consumption with the maximum network life time as compared to traditional routing mechanisms for the wireless sensor networks.

3.2.11. Reliable Energy Aware Routing (REAR)

Reliable Energy Aware Routing (REAR) [18] is a re-active and distributive routing protocol that works as per routing demand; it gives the reliable data transmission. It is an energy aware routing scheme which instead of using the minimum energy cost path, uses energy sufficient path. REAR provides energy conservation at network layer and reliable paths are requested for the reliable data transmission & to reduce the number of retransmissions which are due to unstable and unreliable paths. REAR uses the limited power and memory resources of the network in a very efficient way. REAR algorithm initially discovers the paths including the Service Path Discovery (SPD) and Backup Path Discovery (BPD), & the nodes power is saved at its maximum possible level on the service and backup paths. In Service Path Discovery (SPD), the destination/target node uses flooding mechanism to sends the path finding request throughout the network. The energy of the nodes is also taken into account in this flooding mechanism to choose a power-efficient path. When the path is found, the chosen nodes on that path maintain two logical energy-levels, the energy available in the node & the reserved energy that is occupied by the selected path. This reserved or bounded energy for one path cannot be used for any other path until the selected path is destructed and the energy is released from that path. Sink node also sends request for the finding of the backup path using same process used for finding service path called Backup Path Discovery (BPD). BPD is different in the only sense that it avoids the nodes in creating BPD that are already utilized in SPD. BPD is used when the SPD is failed due to any reason. After selection of both paths the next phase is of data transmission called the reliable transmission. In the phase of reliable transmission, the acknowledgement (ACK) technique is used and the sensor nodes do not delete the data that they have sent to the next node until it receives the ACK from that node. As the sensor nodes have very less memory so it is impossible to store all the data packets in case when service path fails. In such case the transmitting/ source node will retransmit all the data packets again. In case of link failure, an error message consist of the information about the link failure is transmitted to all the nodes that lie on service path as a result of this error message all nodes release their logically reserved energy for that specific service path so that energy can be used for some other path then.

REAR transmits more packets successfully; retransmissions are very low. It is energy efficient and much reliable routing protocol which takes less time in packet delivery. It has high throughput and it distributes the traffic load more evenly through the network.

3.3 Problem Statement

The scope of this research is limited to the geographic routing mechanisms; It is required to develop some energy efficient routing mechanism which maintains a balance to the overall network power and holes appearance be prevented consequently. This research work consists of followings,

- Carryout literature review in the area of the geographical routing in Wireless Sensor Networks (WSNs).
- Design and implementation of an energy aware geographical routing mechanism, ELBGR (Energy & Load Balancing Geographic Routing)
- Obtain comprehensive simulation for the evaluation of the proposed algorithm

- Compare simulation results of the proposed algorithm with the pre existing relevant protocols and discuss on the behaviors of different routing protocols.

In this chapter, a literature review of the sensor network protocols has been discussed and different prevailing proposed routing strategies developed for the sensor networks (SN) have been explained with their basic concepts, functionality, effectiveness and limitations of each protocol. This research contribution is also explained then.

Chapter 4

Design and Implementation of ELBGR

4.1 The Greedy Routing

Geographic routing protocols utilize only local information for routing decision; no extra infrastructure is required for them. Geographic routing works very for WSN cause of its different (unique) features. The *greedy routing mechanism* is the basic concept used for almost all geographic routing techniques that are just based on the nodes' location-awareness; the location of the nodes can be learnt by different methods, using GPS is one of them. In the greedy routing mechanism, the forwarding node always selects the 1-hop neighbor node for relaying purpose (among all 1- hop neighbors) which is closest to the destination node than itself. The forwarding node is selected by comparing all neighbors' distance to the target node

4.2 Drawbacks of Greedy Routing

Greedy Routing has a major drawback that as the construction of the routes using greedy routing protocol is based only on a single metric i.e. the minimum distance of the neighbor from destination regardless of considering the energy level or any other parameter of the nodes to be selected. It badly affects the energy-balance among all nodes. Greedy routing chooses the same group of nodes repetitively for sending data from the source to the destination if source & destination are constant. It is not taken into account that a node contains how much energy and how frequently energy is consumed from the node when it is frequently selected for routing being on shortest path. That's why even the node having very low energy, the packet can be forwarded to that node in greedy routing resulting in the breakdown of that optimal path. In the greedy routing only a small number of nodes participate in routing the packets.

Greedy Routing has another main drawback, it puts bad effect on network connectivity because some of the nodes become dead much faster than others as they lie on some optimal paths and are selected repeatedly for routing. There may exist some of the nodes in networks which depend on only these dead nodes for routing the packet. This effect results in the partitioning of the network and is more visible in limited energy static networks.

4.3 ELBGR (Energy & load balancing Geographic Routing)

To address the above mentioned problems of greedy routing i.e. the uneven energy consumption within the network and un-avoidance of the dead nodes, energy aware and load balancing greedy routing scheme ELBGR (Energy & load balancing Geographic Routing) is proposed. The main emphasis of the proposed protocol is to discover a path using only 1-hop neighbors information (local information), which forwards the packet with more reliability, less and balanced energy consumption, balanced overhead, and increased throughput. The proposed algorithm ELBGR uses the nodes resources such optimally that the nodes' powers are utilized in a balanced way and the load is distributed among all neighbors rather than selecting single optimal node. Though the forwarding node is selected optimally but the optimality does not depend only on the basis of the shortest distance, rather some additional QoS parameters i.e. remaining energy of the nodes and packet reception rate (PRR) are also used to make decision in choosing optimal forwarding node (OFN).

4.3.1 Assumptions of ELBGR

For the designing of the ELBGR routing algorithm some assumptions are taken to simplify the functioning of the protocol.

a. Sensor nodes are considered to be static or immobile having fixed coordinates.

b. The location of the nodes is determined by the GPS system (some central-location database is used for the nodes to extract their location/ position and the sink position)

c. The energy levels and the PRR values of the nodes are known by each node itself by some central database. Initially both values are set 01 for each node.

d. The topology used is irregular random topology as in real the sensors are deployed in random style in some interest area.

e. Single destination node is considered with already known location by each node.

f. The limited-size buffers/ queues are used at each node for containing incoming and outgoing message packets.

4.3.2 Out of Scope

a. The fixed-size packets are used for transmission of data. That's why the sizes of packets are not discussed in the analysis of simulation results.

4.3.3 Description and Methodology of ELBGR

The major role of the proposed algorithm is the avoidance of holes formation in the network by equally distributing the load among the nodes, no single node depletes its energy very soon as relatively optimal node is selected for forwarding purpose. Initially this algorithm selects a set of nodes FNS (forwarding nodes set) from all 1-hop neighbors. After FNS selection, the node closest to the destination among FNS is finally selected for forwarding purpose. The FNS selection is based on energy-levels of nodes & nodes' packet reception rate. No absolute values of energy and PRR are used. As per assumptions, each node has knowledge about its location (used to measure its distance from the sink node in terms of number of hops); its current energy level and its current packet reception rate (PRR = total packets sent by node A/ total packets received by node A) and each node exchanges this information with each of its all neighbors. This way each node know about its own distance and its all neighbors' distance from sink node, energy level and PRR value. Based on this all information each node contains, the ELBGR extracts the relatively optimal node among all neighbors, first of all finds the average distance of all nodes' distances from the sink/destination node, & then it calculates the average energy and average PRR of all neighbor nodes. After taking these measures, this algorithm selects the neighbor nodes for FNS which have average or greater remaining energy as well as average or greater PRR value. It is obvious that greater energy nodes selection for forwarding purpose prevents the high rate of nodes death in the network. Nodes PRR values are important in respect of the holes avoidance, if a node forwards all the packets its PRR value doesn’t change (remains 1, initially set value) and the routing decision is almost energy dependent. But when a node drops the packet due to any reason i.e. lower energy level or queue fill, the packet reception rate lowers down and for next packet transmission that node is avoided due to low PRR value (lower than average PRR value of all neighbors), resulting the avoidance of the hole. Neighbors having energy and PRR below average value are ignored so that the balance of energy can be maintained among all neighbors and this way of selection prevent some nodes to be selected frequently resulting in energy depletion. Therefore FNS contains only nodes having greater energy and PRR values. In next phase ELBGR considers only FNS for decision making and selects the node nearest to the target/ destination node from the set of nodes that lie in FNS. After choosing the optimal forwarding node (OFN), the packet is sent to it, this current node then makes further decision for next forwarding node among its neighbors using ELBGR mechanism. This process continues until the destination node is reached. When packet is sent to a neighbor, the energy used suppose 0.0001joule is deducted from its current energy level, this way the remaining energy value and current PRR value of each node is updated after each time when it forwards the packet. The new values are stored in the node's memory. For next transmission if any neighbor node considers it for forwarding, it will check its energy and PRR values, which are if less than average values then that node will not be considered for selection in FNS and the nodes which are not selected previously or having greater energy and PRR values are selected in FNS. Using ELBGR routing scheme the network work load is taken as the data packets which are needed to be sent to the destination or target node, is equally distributed (all nodes are considered equally for forwarding purpose) among all nodes and almost an energy balance is also maintained among nodes. So the path selected may not be the similar every time & the traffic is spread over many nodes rather than to the specific nodes only. As a result the sensor network is utilized for maximum time with greater throughput in energy efficient and load balancing way. ELBGR algorithm tries its best to prevent the formation of holes, but as it is unavoidable due to energy constraints but this algorithm avoids the routing of packet towards holes considering PRR values, using ELBGR a very little number of holes can be seen in the network even after a long time span of network utilization when almost all nodes of the network have consumed almost their whole resources.

4.4 Greedy Routing Algorithm

4.4.1 *Network Initialization*

a. N number of nodes defined

b. Links between nodes defined

4.4.2 ***Node Level Processing***

a. Find Nodes Location

b. Find all 1-hop neighbors

c. Determine sink node location

4.4.3 ***Greedy Routing***

If Node is alive

a. Determine the node with minimum distance from sink from neighbors

b. Send packet

Else If node is dead

Drop Packet

4.5 ELBGR Algorithm

4.5.1 ***Network Initialization***

a. N number of nodes defined

b. Links between nodes defined

4.5.2 ***Node Level Processing***

a. Data Maintenance at node level

    (1) Node location

    (2) Node Energy

    (3) Node PRR value

b. Find all 1-hop neighbors and maintain a Local 1-hop neighbors table

c. Exchange local information with all neighbors; add the values in Local table against each neighbor

d. Determination sink node location by each node

4.5.3 *Routing Decision Making*

Phase-1: FNS Selection

a. For each node a Forwarding Nodes Set (FNS) among all neighbors is selected

If the node is alive // Energy greater than threshold

(1) Calculate average energy of all neighbors

(2) Calculate average PRR value of all neighbors

(3) Find forwarding neighboring nodes set (FNS)

Having energy >= average energy && PRR value >= average PRR

Phase-2: Optimal Forwarding Node (OFN) Selection

b. Using FNS neighbors, the optimal forwarding node is selected

(1) Determine the node with minimum distance from sink from FNS neighbors

(2) Send packet to the node at minimum distance from sink node (OFN)

Else If node is dead

Drop Packet

c. Deduct energy used for processing

d. Update the neighbors with new energy level and PRR value.

4.6 Flowchart of Greedy Algorithm

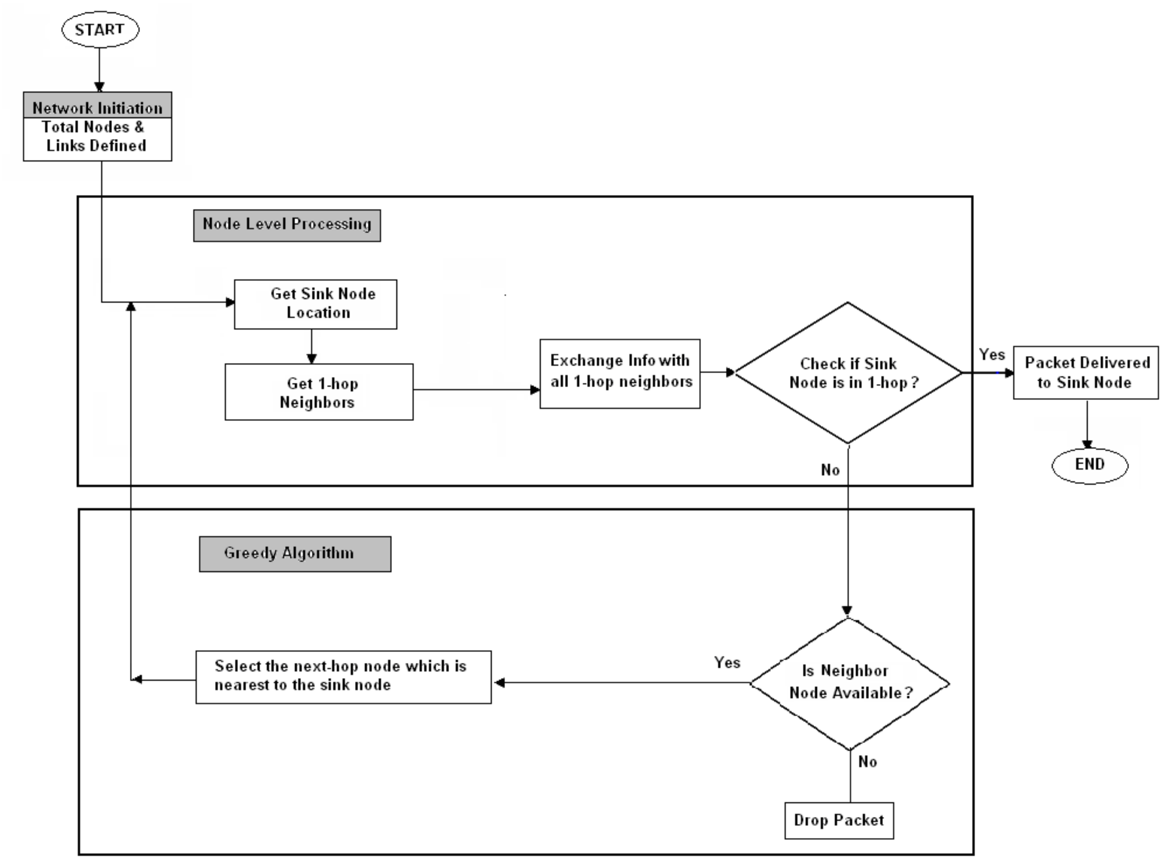

Figure 4.1 Flow chart of Greedy Routing

4.7 Flowchart of ELBGR

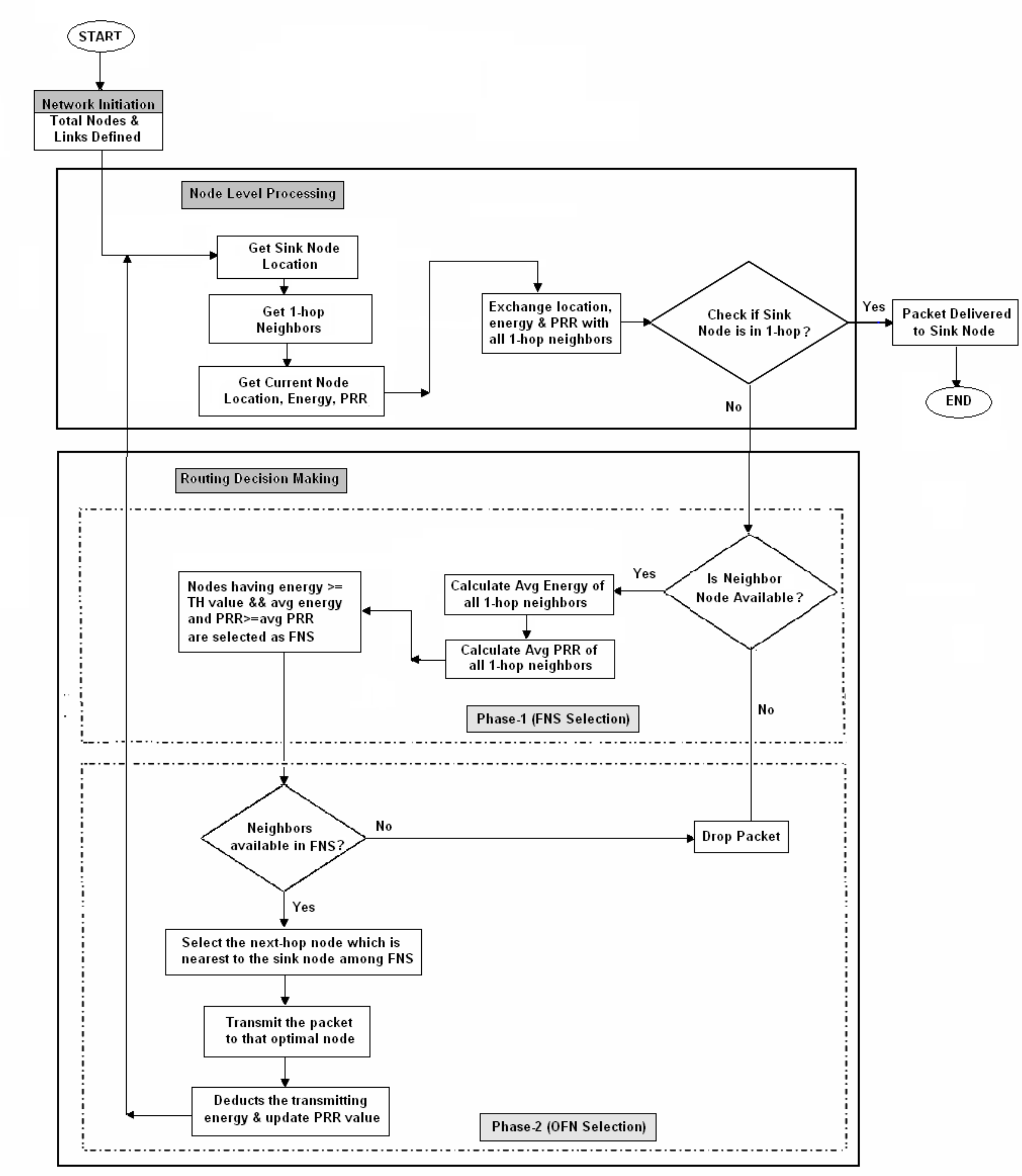

Figure 4.2 Flow chart of ELBGR

4.8 The Proposed System implementation

The proposed system is implemented on OMNET++ Simulator. OMNET++ works on the modules system; four different modules defined in the proposed system are network generator, Route generator, proposed ELBGR algorithm and the router module.

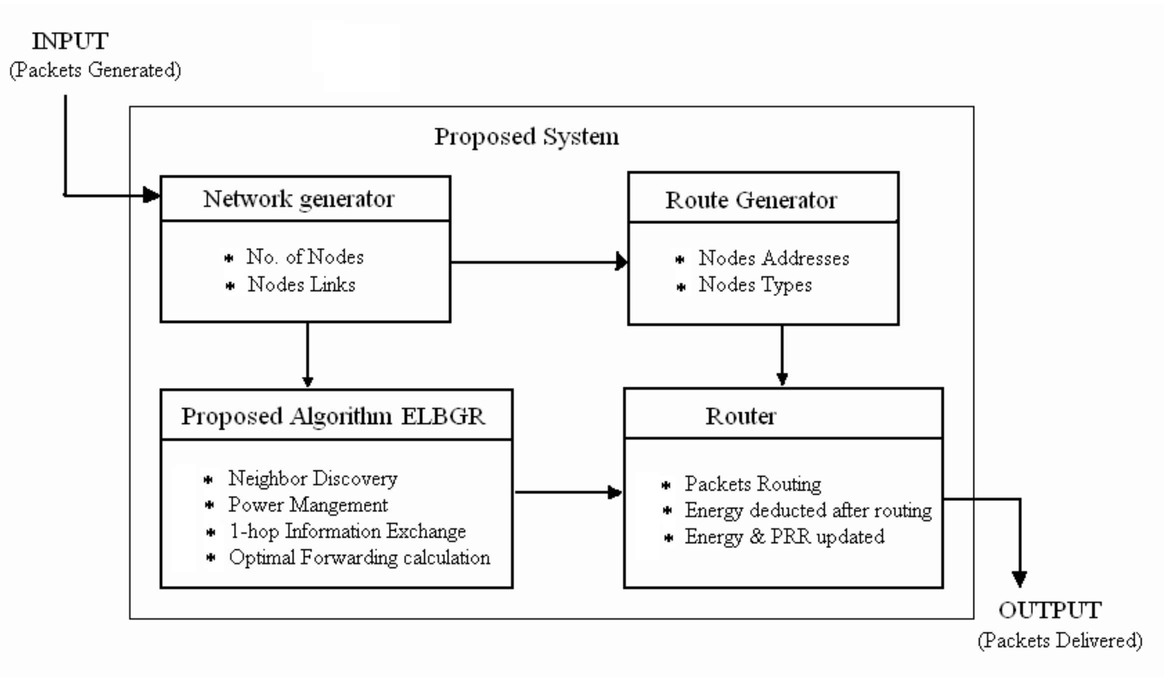

Figure 4.3 Proposed System Block Diagram

The *Network generator* module generates the network, the total number of nodes is defined in this module and the packet sending rate is also defined as a parameter of this module. While defining the total number of nodes, a sub module, named as Node module is also defined, this describes the basic structure of a node and its functioning regarding the receiving and sending of the data packet through different gates, i.e. input gate and output gate. After defining the nodes, the links between the nodes are also defined in this module, it can be said that the neighbors are defined in this module as the connections between all the nodes creates the topology of the network automatically that determines the neighbor nodes; hence on this stage a node is unaware of its neighbors. The time delay between packets transmission is also defined in this module. Main tasks of this module are the network generation (node and links creation).

The *Route Generator* uses the addresses of the nodes for determination of the sending/ source node & sink/ destination node for data packet sending and receiving respectively. Every node utilizes the neighbor nodes for data forwarding and ultimately delivers the data packets to the sink/ target node. The target node is considered constant for the proposed algorithm, and each node have knowledge about the sink/ destination node address. As the target/destination is fixed it makes the routing decision easier than that of changing destination.

The *Proposed Algorithm ELBGR* is very important module that chooses the next forwarding node. The proposed algorithm assumes that all nodes in the network know their own geographic-locations, their energy-levels and current PRR values & they exchange this info with their all one-hop neighbors. In the First phase of the ELBGR algorithm it selects some neighbor nodes, one of which is selected finally for forwarding purpose and ignore some neighbors having lower energy and PRR value in comparison to all neighbors. The selected node set is called forwarding nodes set (FNS). In the next phase the FNS is taken into consideration for further scrutinizing and for making final decision to select the optimal forwarding node (OFN). The node is chosen on the basis of the closest distance from the destination node in terms of number of hops. It is clear that this module works for the next forwarding node selection.

The *Router* module is also very important in its functionality. First of all this module receives the optimal next-hop information from the proposed algorithm ELBGR module and routes the packet to that node. As this algorithm works on local information, the whole path information is not required to be stored. The local information about neighbors' energy, PRR value and location information is hence required, that's why this module creates a map about neighbors at each node level. It consumes very short memory rather than to store information about whole network. When the packet is sent towards the neighbor node, this module subtracts the energy from the node's current energy and re-evaluates the PRR value. The information about new energy level after deduction and PRR value is then updated to all neighbors as they contain the old values. This information is updated in the neighbor nodes only if the current node is utilized for the forwarding purpose. In the last, the router module shows output of simulations as the successfully delivered-packets, dropped-packet, node's current power-level, node's current PRR value and the status of the node.

4.9 A Comparison between Greedy Routing & ELBGR

As already described in section 4.3 the ELBGR (Energy & load balancing Geographic Routing) is proposed to let the WSN work in energy efficient way, to prolong the network life time and to utilize the network energy at its maximum possible level. The ELBGR is evaluated on the basis of different metrics (described in chapter 5) in comparison to the Greedy algorithm used for routing purpose in WSNs.

In the Greedy Algorithm, the destination is available in data packet to be sent so that the current node having that packet may decide locally to transmit the data packet to the destination node. In the greedy mechanism the next hop node that is selected for forwarding purpose is the node closest to the target node among all neighbors. This way at each step the packet gets closer to the sink node and finally reaches the sink/destination node. A minimum number of nodes are used in greedy forwarding mechanism; hence very low energy is utilized and resulting in the saving of overall network energy. But in case the nodes are fixed, same path is followed for same source-destination pair and that path depletes its energy very soon, network can be partitioned or can be failed even so many nodes are available with sufficient energy. Greedy algorithm utilizes the network resources very poorly and network lifetime decreases due to early death of some nodes that may be the backbone for different paths between other source-destination pairs of the network. In greedy forwarding mechanism even if the node is dead but as it exists on the shortest path, the packet is forwarded to it regardless of considering the energy-level of the nodes. On the other hand, ELBGR utilizes all nodes rather than specific shortest path nodes (in greedy algorithm) and distributes the workload among all whole the network equally. It utilizes the energy-levels of the nodes (to avoid the nodes to die early) and their PRR values (to avoid the data packets to be dropped due to dead node or queue overflow) as well as the sink/ destination node's distance of the node. It is an energy-aware algorithm; each node determines its neighbor nodes in the start and each node exchanges 1-hop information with all its neighbors as a result each node knows its neighbor positions, neighbors distance from the destination, neighbors packet reception rate value and their energy levels. The sink/ destination node is identified by the transmitting node, the transmitting node add location information about destination to the packet header & then send the packet to OFN using the proposed algorithm. A local table is maintained at the node level which contains all local information about the 1-hop neighbors that is used for making decision of routing the data. First of all proposed algorithm selects the Forwarding Nodes Set (FNS) which consists of the 1-hop neighbors having greater energy levels and greater PRR values among all neighbors, in the next phase the optimal forwarding node is selected from the FNS neighbors which is nearest to the sink/destination node (local-routing table is used for this purpose). The packet is then forwarded to that optimal forwarding node (OFN). While forwarding the packet to optimal forwarding node the node consumes some energy, after forwarding packet that consumed energy is subtracted from the initial energy level and the PRR value is updated for that node. This updation of values is required as for next packet forwarding that node may lie on the way to the destination, the updated values are then considered for making decision that the node can either be selected as relaying node or not. The procedure repeats until the data finally reaches to the sink/ target node. All packets follow the similar method to reach the destination. As ELBGR uses relative optimal selection method, the node which is selected initially as forwarding node is avoided next time as its energy level and PRR value will be less than other neighbors.

Chapter 5

Simulation and Analysis of Results

5.1 The Simulation

Sometimes it is not easy to check the event's sequence and the final outcome in real situations, simulations provide *the estimation that how the events might occur in real situation and what might be their outcomes*, almost same results are generated by simulations which can be gathered after real time experiments but real time experiments may cost very high. Simulations are the economical way of collecting experimental results on the computer system under realistic conditions. Simulation is a 3-steps process; a) The design of the model for the theoretical system, b) execution of the designed model on computer system, and c) the gathering of output from the execution and its analysis.

For WSN protocols, many experiments have been performed to find their efficiency, hence the performance of many routing protocols is evaluated by their simulation results only. Different simulators have been used for simulation purpose. OMNET++ simulator is used to check the performance of the proposed algorithm ELBGR in comparison with Greedy routing algorithm.

5.2 Simulation Platform (OMNET++ Simulator)

The simulation platforms must cope with the difficulties that occur by using large and object-oriented programs as well as they must fulfill the requirements for meeting the challenges of the sensor network programs. Sensor network program face common challenges of very low resources, robustness and the hardware evolution, the simulator affects the design & development process significantly.

To check the functioning of the proposed algorithm and to evaluate its efficiency in terms of energy savings, rate of packets delivery & the network overall lifetime, the OMNET++ simulator has been chosen which is developed for the event- driven and resource constrained embedded system. OMNET++ simulator is written in C++, it was designed by Dr. György Pongor. at the Technical University of Budapest. OMNET++ is the abbreviation of the Objective Modular Network Testbed in C++. A network simulation model in OMNET++ and different steps of simulation process in OMNET++ are described below in this section.

5.2.1 Simulation Model in OMNET++

In Omnet++, a WSN consisting many sensor nodes that are distributed at random over a square area for routing, are simulated. As clear from its name, OMNET++ (Objective Modular Network Testbed in C++), a very important feature of this simulator is the introduction of modules in it. Using the concept of modularization a single layer functioning is broken into smaller modules which can interact with each other. Hierarchically nested modules can be used in the OMNET++ There may exist any number of modules, no limit for the modules depth is defined. Modules are of two types, compound modules and simple modules. The compound modules in OMNET++ are programmed using graphic editor (GNED) provided by OMNET++ or using its NED programming, usually the compound modules are used to define the structures i.e. network structure, node structure etc. The lowest level modules of the hierarchy are responsible for the behaviors of the compound modules. These modules are called the simple modules, and they are programmed in C++ using the simulation library. Modules can have their self-parameters that show the behavior of the module. When structure of network is designed, the main module known as the network module contains so many nodes as sub-modules, which further contain sub-modules to handle the incoming and outgoing data. The nesting modules show the actual picture of the system using the modules structure. Modules communication is made by messages containing any type of data structures. The gates and the connections are the entities using which the modules send messages. OMNET++ provides many types of the user platforms called user interfaces for different purposes that can be for the purpose of demonstration of model working and debugging. Along with the user interfaces OMNET++ also contains some advanced user interfaces which are used to make the internal of the model structure that can be viewed by the user; these advanced interfaces control the execution of the simulation. This process is very beneficial in the designing, development and debugging of the project. All tools and interfaces either user interfaces or simulator interfaces are portable. They can perform well on the Windows systems and on many UNIX systems, with the help of many C++ compilers. The parallel distributed simulation can be carried on the OMNET++ using many types of mechanisms (using configuration only, no special instruments) between the simulation partitions. These parallel simulation algorithms are plug & play and can be extended easily.

5.2.2 OMNET++ Simulation steps

An OMNET++ simulation-model has different modules of different types. These modules use the messages to contact/ communicate with one another. Depending upon the logical structure of the system which is to be considered for simulation, there may exist the nested modules, it means that many modules can be combined in a single module called compound module. The whole system is in the form of hierarchy of the communication modules.

a. In the start, the structure of the network model is designed using the NED language. NED file is editable using a text editor or using the graphical editor of the OMNET++ called GNED. Compound modules are used for this purpose.
b. Next the active components of the model are defined called the simple modules show the behavior of the system components. They are programmed and written in C++ language by the help of class library and the simulation kernel.
c. A configuration file named as omnetpp.ini is defined by the user which contains the OMNET++ configuration parameters as well as the proposed system's parameters.
d. A main program called the simulation program is programmed which incorporates the overall functioning of the proposed system, in other words the algorithm is implemented in the simulation program file.
e. The simulation program is run to evaluate the proposed system.
f. The code is linked to the simulation kernel and an interface (user interfaces) is available in the OMNET++ to show the processing of the simulation program i.e. command line (batch) and interactive, graphical user interfaces.
g. Output vector and output scalar files are used to write the simulation results on them.
h. Plove and Scalars can be used to visualize the simulation results in graphical form.

5.3 ELBGR Simulation Model

ELBGR Simulation model is designed in OMNET++. Different numbers of nodes exist in the network so that the simulation results may be evaluated for variable-sized network having variable number of nodes. All evaluation metrics are checked for different models with different number of nodes (different network size). In this simulation, the nodes' locations of network are taken randomly without any predefined criteria and irregular random topology is used as in real conditions the WSN sensor nodes are also deployed randomly. As per assumptions already described in 5th chapter, it is clear that the nodes are static and do not ever change their position. The position of each node is determined by the node itself using a central location database, this central database also inform each node with sink/ destination node location. In ELBGR system, the sink node is fixed and pre-defined. One node is declared as target node, as each node have knowledge about its location, each node itself measures its distance from the target/ sink node (as for number of hops). In start each node has allocated same energy level i.e. 01 Joule and same PRR value i.e. 1. Before the simulation starts, each node has the following information:

a. Node's location
b. Sink node location
c. Node's distance from sink node
d. Node's energy level
e. Node's PRR value

This all information is to be exchanged among all 1-hop neighbors for maintaining a local-table of neighbor's info, which will be used for routing decision making later. In the start a threshold (TH) energy-level is defined & the nodes whose energy-levels are lower than threshold value are considered as dead nodes. Each node has a limited size buffer, a fixed size queue is defined which is used to store incoming / outgoing packets temporarily. In this simulation model, the packets used are of fixed size 562 bytes, different number of packets are generated by some source node at some pre-defined time delay, this time delay can be changed to analyze its effect on the proposed algorithm's performance. Total simulation time is also pre-defined. The simulation process is repeated with different number of packets generated and with different numbers of nodes to evaluate the proposed algorithm.

A sample network designed in OMNET++ with 90 numbers of nodes is shown below

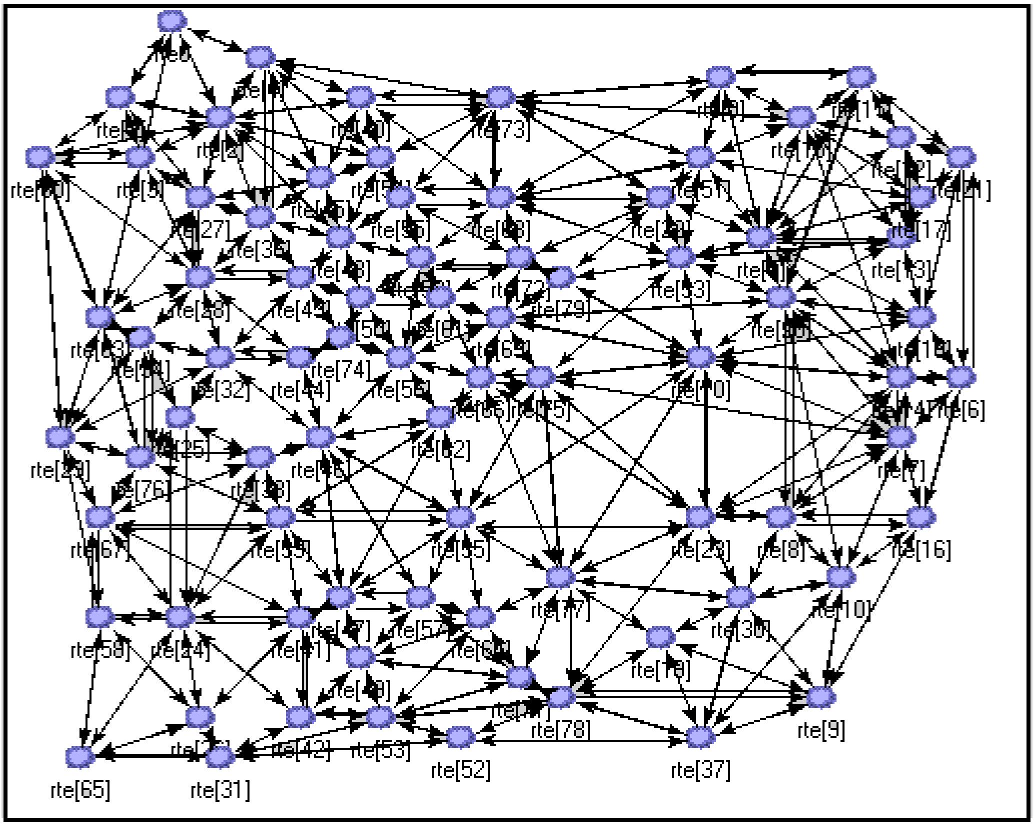

Figure 5.1 Sample Network with 90 Nodes

5.4 Network Input Parameters

For this simulation various input parameters are defined which are considered same for both routing strategies (Greedy Routing and ELBGR routing) that are compared for evaluation of the proposed one's performance.

Parameters	Value
Network Size (Number of nodes)	Variable for each scenario
Traffic type	Constant (1pkt/microsecond)
Nodes type	Static/ Fixed
Topology	Irregular random topology
Data packet size	562 byte
Buffer/ Queue size	10
Initial Energy level of each node	1 Joule
Energy Threshold value	0.1 Joule
Transmission energy	0.001 Joule
Initial PRR value	1
Number of receiver	1 (Predefined)

Table 5.1 Input Parameters

The network size is variable for each scenario as this research focuses that the proposed algorithm ELBGR scales very well and performs better with different sized network having different number of nodes. Yet for each scenario both the Greedy and ELBGR routing algorithms are evaluated for comparison purpose.

5.5 Evaluation Metrics

To make evaluation for the performance of the proposed routing scheme, the following performance or evaluation metrics are analyzed for both greedy routing and the proposed ELBGR routing mechanism:

a. *Packets delivered:* Total data packets that are successfully delivered/ sent to destination.

b. *Packets Dropped:* Total data packets dropped due to the overflow queue or low energy nodes.

c. *Success rate:* The rate at which the data packets are received by the target node successfully. It can be expressed mathematically as;

Success Rate = Total number of packets received at the target / Total number of data packets sent from the source node

d. *Alive Nodes:* Total number of nodes having sufficient energy or energy level greater than the energy threshold level at the end of simulation.

e. *Dead Nodes:* Total number of nodes having energy level lower than predefined energy threshold value.

f. *Throughput:* The ratio of total data packets received by the target node to the total time span of the simulation, its units are pkts/s & bytes/s. mathematically it is expressed as

Throughput (packets/sec) = Total packets delivered / Total simulation duration

5.6 Simulation of Routing Protocols

As defined in input parameters before simulation starts each node has total energy equal to 1Joule. Initially each node creates a local-table of its neighbors containing all 1-hop neighbors along with their current energy levels (initially 1J), PRR values and their distance to the destination. When a node is used for transmission purpose and its energy level or PRR value changes then it informs its 1-hop neighbors to update their local tables. Nodes initiate the sending of the data to the destination by selecting a neighbor nodes set (FNS, Forwarding Nodes Set) on the basis of ELBGR algorithm. Using ELBGR, the current node first of all calculates the average remaining energy and average PRR of its all neighbors. Initially when all nodes have same energy levels and PRR values (equal to the average energy level and average PRR value respectively), ELBGR works like Greedy scheme, the data packets are sent to the node closest to the sink node (minimum hops to the target node is considered the nearest or closest node), the process carries on until the arrival of the packet to the destination. After utilizing a node for forwarding purpose, its energy & PRR values are updated and exchanged with neighbors. For the next packet from the same source which is to be forwarded towards the same destination, the sending node will have same neighbor nodes but it will not use the previously selected neighbor for forwarding purpose as the nodes that have been used in previous packet forwarding have updated their local values, energy and PRR values are now less than the average energy and PRR, due to this those nodes are not selected in next transmission, some other node will be selected now. This is the beauty of ELBGR that it distributes the load among all neighbors by screening out previously used nodes; this procedure has great impact on the overall energy consumption of WSN and on the network lifetime. Secondly ELBGR does not use any specific values, rather it uses relatively optimal node among all neighbors, this way it utilizes almost all resources of the nodes hence the network remain alive until almost complete consumption of all network resources.

Along with the Greedy algorithm, the ELBGR is also compared with some other proposed algorithms that proved themselves better in performance than simple greedy routing i.e. EAGR, HHEAA and EEAR.

A comparison among above mentioned algorithms is shown below for constant values of number of nodes, number of packets generated and time duration i.e. 90 nodes, 45000 number of packets generated and 500 seconds.

Parameters Evaluated	ELBGR	GREEDY	EEAR	EAGR	HHEAA
Packets Delivered	44730	26008	43499	42666	36615
Packets Dropped	270	18992	1501	2334	8385
Throughput (pkts/sec)	89.46	52.016	86.998	85.332	73.23
Alive Nodes	89	85	89	89	86
Percentage Alive	98.89%	94.44%	98.89%	98.89%	95.56%
Dead Nodes	1	5	1	1	4
Success Rate	99.4	57.8	96.66	94.81	81.37

Table 5.2 Evaluation of different routing algorithms for network size 90 Nodes

The above table shows a comparison between different algorithms the constant number of nodes and packets generated. Each node consumes equal energy for the transmission purpose, viewing the results of the simulations; it is vivid that ELBGR algorithm performs much better than greedy algorithm as for the success rate, throughput, & number of alive nodes. The network lifetime using ELBGR is longer than the Greedy algorithm. ELBGR also outperforms EEAR, EAGR and HHEAA in terms of throughput and success rate yet the number of alive nodes after the simulation is similar to that of EEAR and EAGR. So many simulations are performed to attain the complete picture of the results of different algorithms. The main objective is to evaluate different algorithms with changing network size and the traffic load; all other parameters remain constant in the simulations. The main aim of the simulation is to evaluate the performance of the proposed algorithm that what type of behavior it shows with increased number of the nodes and how it scales and performs better for different sizes of the networks. Viewing the detailed picture of simulation result, it is clearly seen that the delivered number of packets increases with increasing number of nodes of the network. It is also observed that the number of alive nodes is far greater using ELGBR routing algorithm than in number of alive nodes using Greedy routing. This increases the life-time of the network.

5.7 Results & Performance Comparison

This Section describes the experimental results of the simulations & briefs the observations of the strengths and the limitations of the proposed algorithm ELBGR in comparison with the Greedy Routing algorithm. Some already existing relevant routing protocols including EEAR, EAGR and HHEAA are also compared later on with ELBGR to check the proposed scheme efficiency.

The results that are collected from the experiments include the comparison of the total number of packets delivered, the total number of packets dropped, the success rate, remaining live and dead nodes after simulation and throughput by different routing protocols. It is observed that the proposed algorithm utilizes maximum network resources and results far better than above mentioned existing routing protocols.

It has been observed that in Greedy routing algorithm due to excessive use of few nodes those nodes deplete their energy very soon and results in the formation of holes, greedy algorithm do not consider the remaining energy of the nodes when data is transmitted towards the nodes for the forwarding purpose, and even the node is dead, the data is forwarded to it and the dead node simply drops the data packet. Hence using Greedy algorithm, the data delivery rate (shown in Figure 5.2) is quite lower than the proposed algorithm ELBGR due to the dead nodes in the network. These dead nodes simply drop the data which they receive.

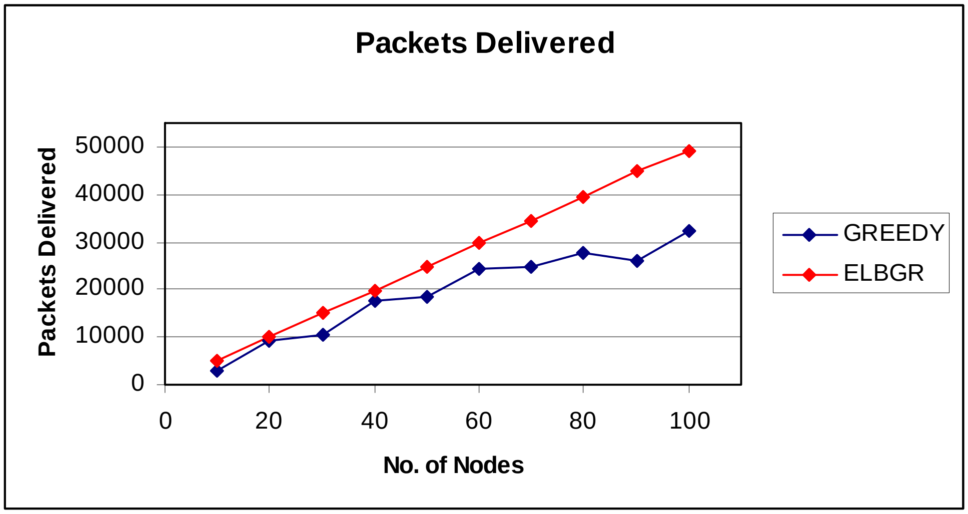

Figure 5.2 Comparison of No. of packets successfully delivered

It is clear from Figure 5 .3 that so many packets are dropped during data transmission, and this number of packets drop increases with the increased number of data packets to be transmitted.

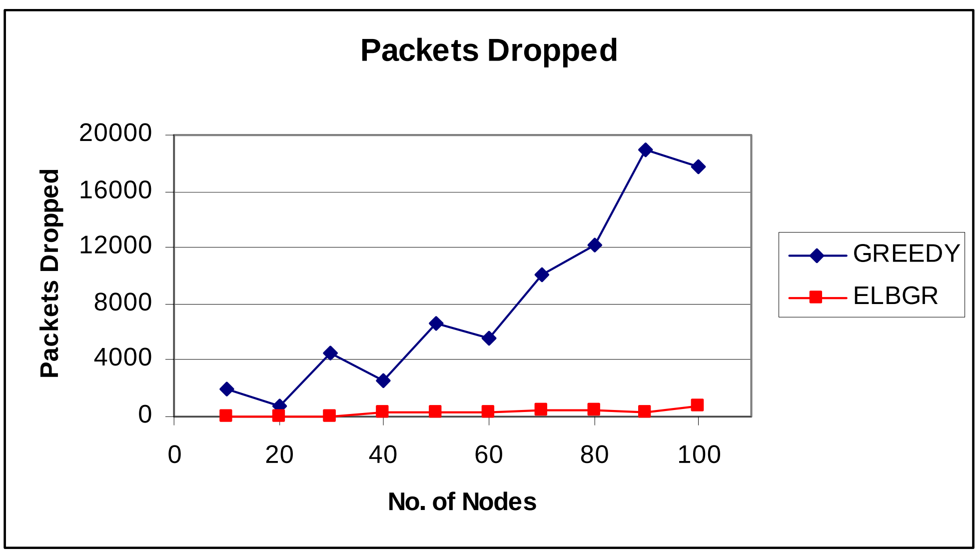

Figure 5.3 Comparison of No. of packets dropped

The proposed algorithm ELBGR considers the current energy levels of nodes & does not send the data towards the lower energy nodes that result in increased number of packets delivery and very low number of packets are dropped using ELBGR. Hence it can be seen from Figure 5.4 that the throughput of the proposed algorithm is consistent throughout all simulations and is far better than Greedy algorithm.

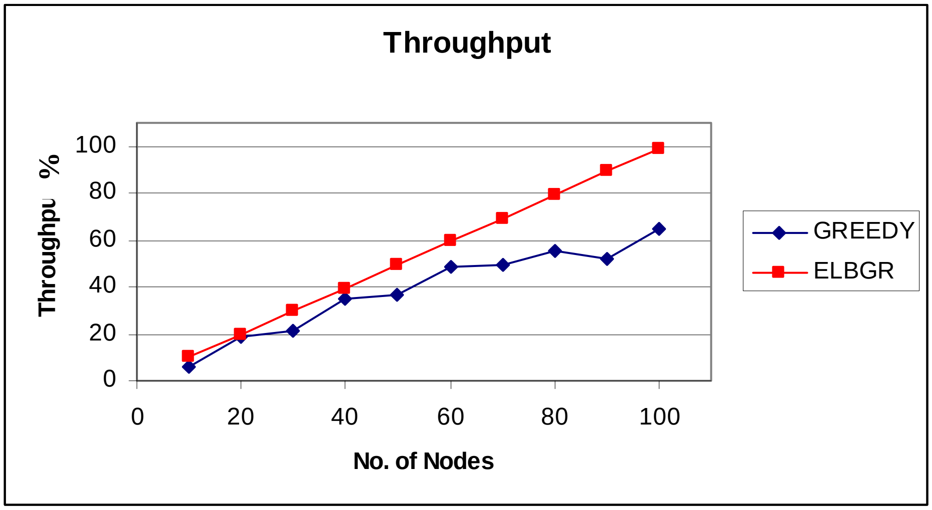

Figure 5.4 Comparison of Protocols Throughput

Figure 5.5 provides the comparison of the success rate of the Greedy algorithm and ELBGR; it is opaque that ELBGR performs very well and steadily while the Greedy algorithm's success rate fluctuates a lot, it can be seen that the success rate of Greedy algorithm is better for 20, 40 and 60 number of nodes than other network sizes.

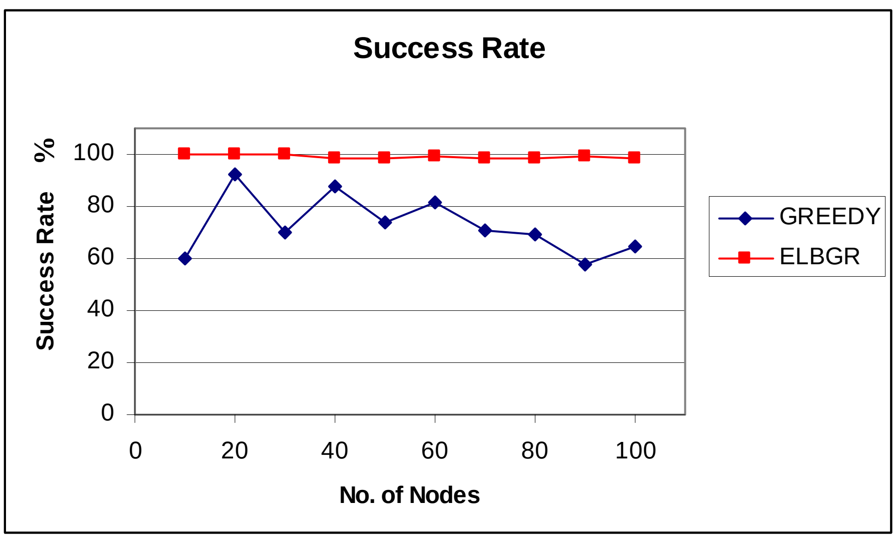

Figure 5.5 Comparison of Protocols Success Rate

Figure 5.6 shows that the number of alive nodes after the simulation duration using the proposed algorithm ELBGR is greater than the number of alive nodes using Greedy algorithm.

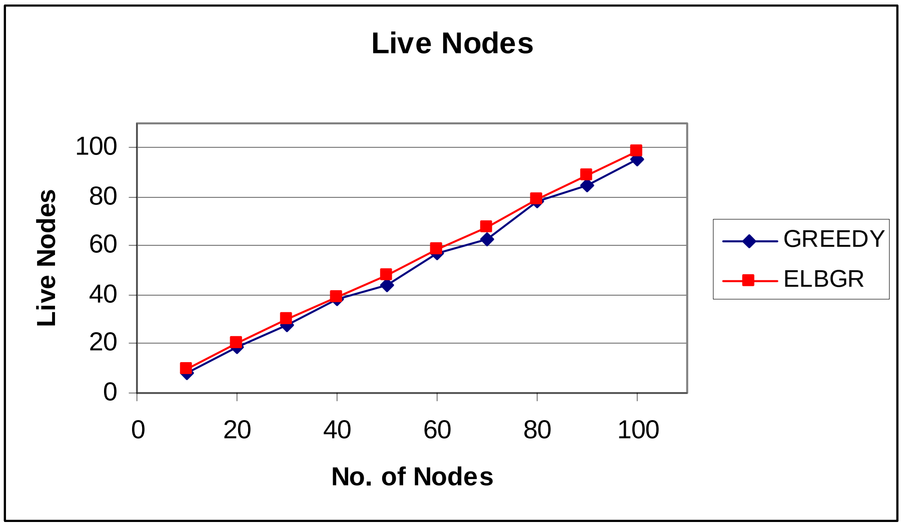

Figure 5.6 No. of Live Nodes Comparison

Figure 5.7 shows a comparison of dead nodes using both Greedy and ELBGR routing schemes. Greedy routing results in a larger number of dead nodes than ELBGR.

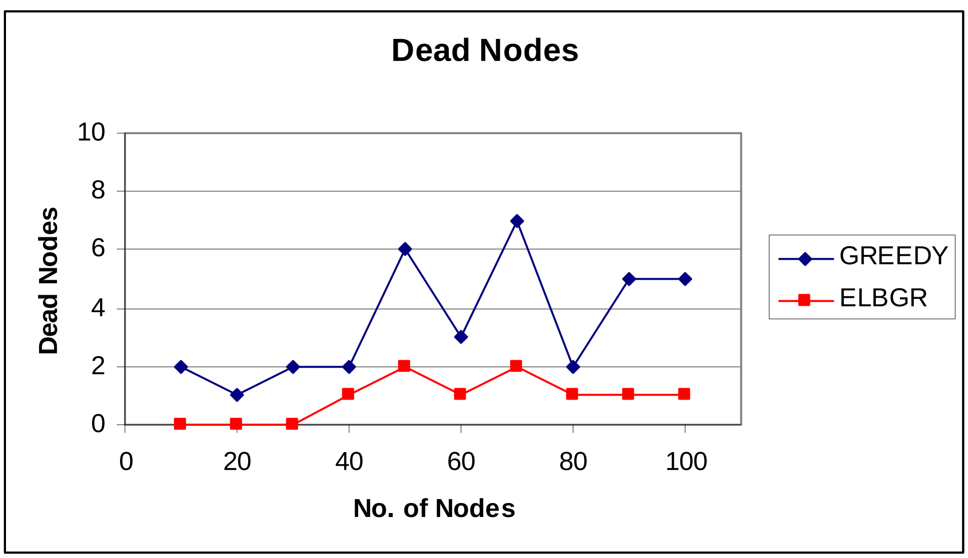

Figure 5.7 No. of Dead Nodes Comparison

Figure 5.8 shows a comparison of time delay in data delivery using both Greedy and ELBGR routing schemes, ELBGR take more time as it has to compute multiple parameters before forwarding the data.

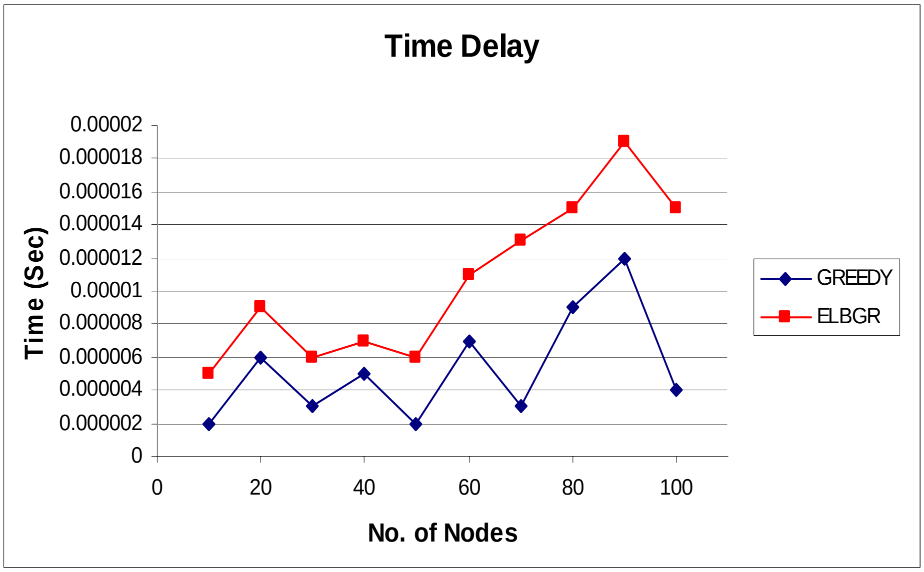

Figure 5.8 Time Delay Comparison

The performance of the proposed algorithm ELBGR is also compared with the relevant routing protocols EEAR, EAGR and HHEAA. It can be very clearly seen from the following figures that show the comparison of different evaluation parameters using different algorithms that the proposed algorithm ELBGR performs better than EEAR, EAGR and HHEAA in terms of number of packets delivered (Figure 5.9) and dropped (Figure 5.10), success rate (Figure 5.11) and throughput (Figure 5.12).

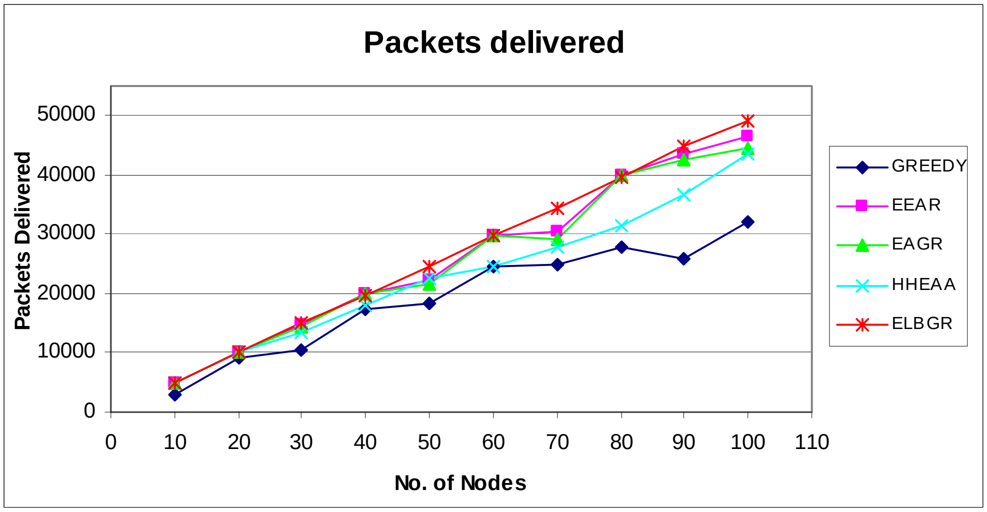

Figure 5.9 No. of packets delivered Comparison

Figure 5.9 shows the packet delivery comparison of the proposed algorithm ELBGR with Greedy, EAGR, EEAR and HHEAA, ELBGR packets delivery is somehow equivalent for all network sizes to packets delivery of EEAR and EAGR except for the networks sizes 50,70 and 100 nodes, where the ELBGR performs better than EEAR and EAGR.

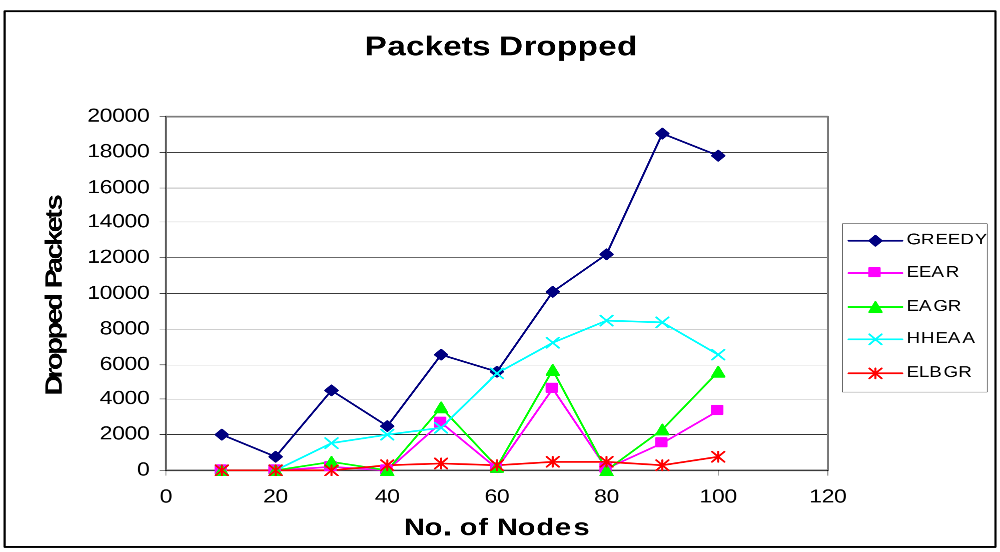

Figure 5.10 No. of packets Dropped Comparison

Figure 5.10 shows the packet dropped comparison, it is clearly seen that the minimum number of packets are dropped using proposed algorithm ELBGR, EEAR and EAGR results are somehow competitive, however HHEAA and Greedy algorithms performance is very poor regarding this case.

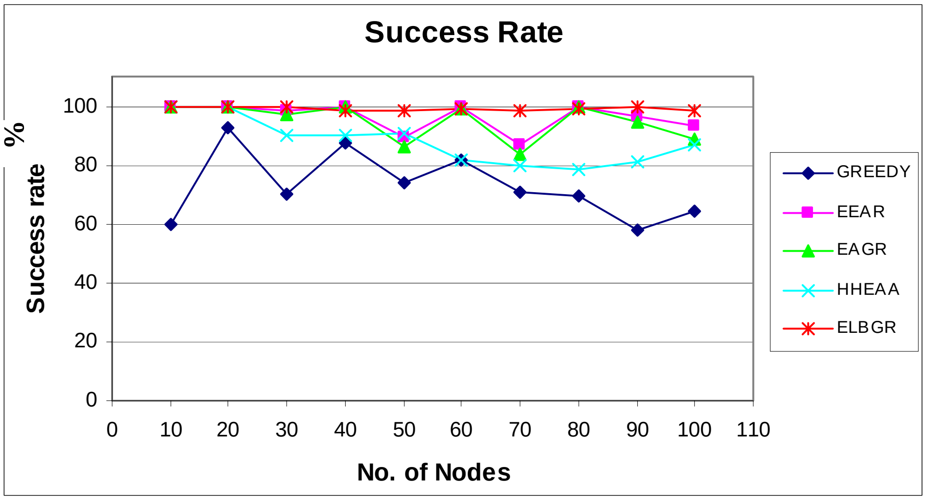

Figure 5.11 Success Rate Comparison

Figure 5.11 shows the success rate of the proposed algorithm along with other relevant algorithms, it is clearly depicted that the proposed algorithm has a very smooth and consistent success rate, EEAR and EAGR have also better success rate but it is compromised for some network sizes. HHEAA and Greedy algorithms' success rate is remarkably lower than the ELBGR.

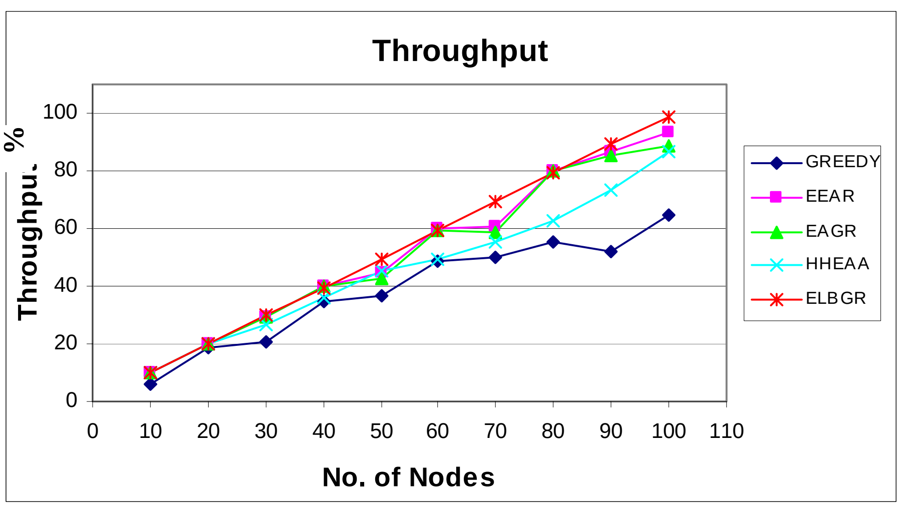

Figure 5.12 Throughput Comparison

Figure 5.12 shows the comparison of the throughputs of the algorithms, ELBGR throughput is almost constant for all set of networks, Greedy and HHEAA throughputs are lower than others especially for the greater network sizes. EEAR and EAGR throughput is almost competitive to the proposed ELBGR.

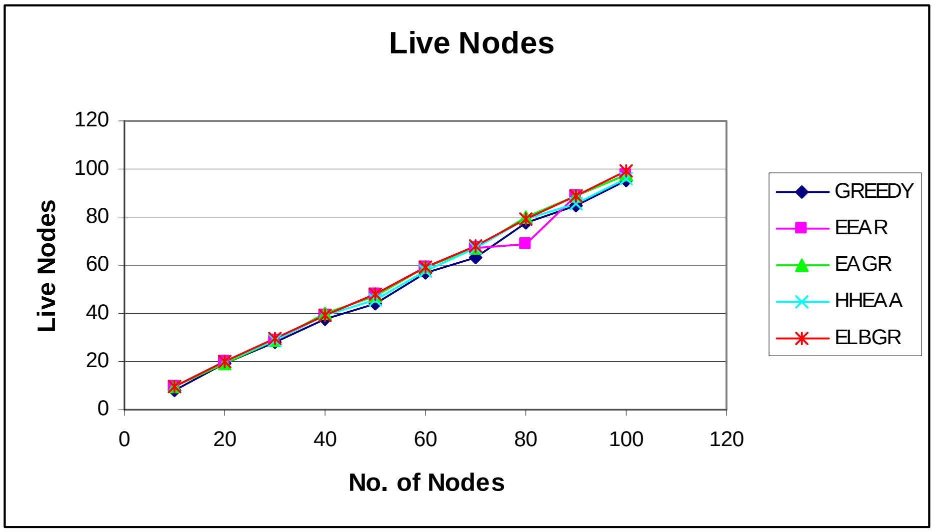

Figure 5.13 No. of Live Nodes Comparison

Figure 5.13 & 5.14 shows that using ELBGR the number of alive nodes & dead nodes after the simulation completion is almost similar to the number of remaining alive nodes & dead nodes using EEAR, EAGR and HHEAA. The number of dead nodes is far greater using Greedy algorithm than the number of dead nodes using EEAR, EAGR, HHEAA and ELBGR.

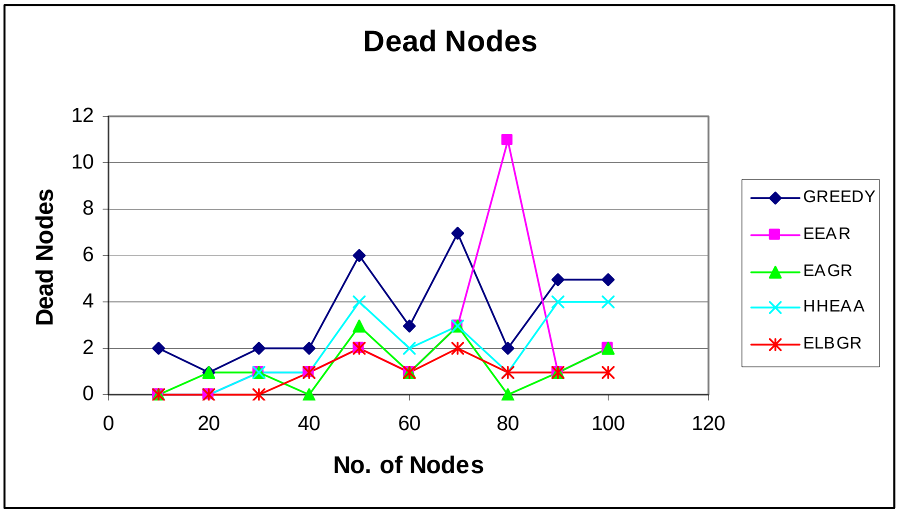

Figure 5.14 No. of Dead Nodes Comparison

In the last the above mentioned algorithms are evaluated on the basis of their overall performance, which is measured by taking percentage of their average throughputs for different sizes of networks and different amount of traffic generated. It is clearly seen from Figure 5.15 that the performance/ efficiency of the proposed algorithm ELBGR (98.92%) is far better than that of Greedy algorithm (70.56%). It can also be seen that ELBGR also outperforms EEAR, EAGR and HHEAA having average throughput percentage 95.4%, 93.52 and 84.76% respectively.

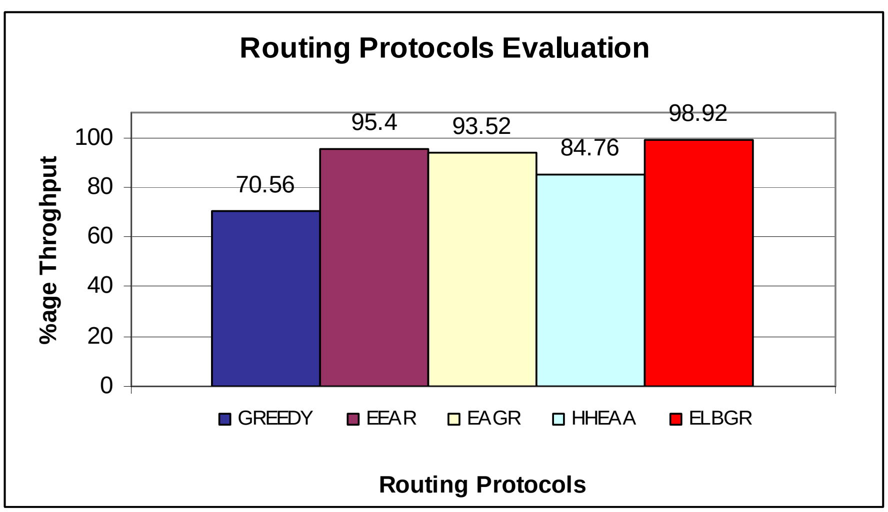

Figure 5.15 Throughput Percentage Comparison

5.8 Discussion

Using the same input parameters, different experiments have been performed for different sized-network (having different amount of nodes). Same energy is consumed for each transmission by each node. It is observed that the proposed algorithm ELBGR outperforms Greedy routing algorithm in all aspects including successful packets delivery, throughput and remaining number of alive nodes except the data delivery time-delay component, for greedy routing computation time is lesser than ELBGR as ELBGR has to compute multiple parameters. It is also seen that the ELBGR also outperform some pre-existing routing protocols (EEAR, EAGR and HHEAA) in the success rate and throughput.

A thorough picture of the detailed simulation results is presented using the graphs. Initially the Greedy routing algorithm is compared for different parameters with the ELBGR as the main focus is to make a comparison of the proposed algorithm's (ELBGR) performance with the Greedy routing strategy to evaluate the proposed algorithm's performance. Later on a comparison of ELBGR is also made for EEAR, EAGR, and HHEAA for the above parameters to check ELBGR efficiency.

It can be concluded after vivid observation of the results extracted from the simulations that ELBGR is better, more efficient and reliable as compared to Greedy algorithm, EEAR, EAGR & HHEAA routing schemes and it increases the network life-time with maximum utilization of the resources for maximum possible duration.

Chapter 6

Conclusions and Future Work

6.1 Conclusions

In this research report first of all an introduction and overview of the wireless sensor network is presented, that includes structure of the WSNs and its applications. WSNs have some unique characteristics different from the wired networks, their overview is also described in second chapter, and due to these unique characteristics the routing challenges which are faced by the researchers while designing the routing protocols are discussed later. In the end of second chapter the basic techniques used for designing different routing schemes for WSNs are briefly overviewed.

In chapter 3, the literature review incorporates the already existing routing protocols description and their working along with their benefits and drawbacks relating to the research area i.e. Location based routing or Geographic routing, the problem statement is also defined in this chapter along with the description of this research objectives.

The main theme of this research to handle the wireless medium's broadcast nature along with energy constraints associated with the wireless sensor networks that put the great effect on the network life time, scalability and reliability. In chapter 4 the design and implementation of the proposed algorithm is described. The main idea used to propose the routing scheme is to distribute the workload of the whole network among all nodes evenly so that the network resources may be utilized at their maximum capacity. The proposed routing scheme is compared mainly with the Greedy routing, the main limitation of Greedy routing is that it heavily utilizes few nodes for data transfer that are at optimal distance from the destination and an uneven workload distribution among the nodes of the network has been observed. Therefore Greedy routing algorithm results in the formation of many holes (over-utilized nodes), that blocks the further packets transmission and the network lifetime becomes very short even there are sufficient resources available in the network. These limitations of Greedy routing are mainly focused in this research and the proposed algorithm very smartly removes these shortcomings. Initially the proposed algorithm tries its level best to avoid the creation of holes, but when all the neighbors utilizes almost their all resources and they reach at the lower threshold levels then the holes formation can not be avoided. So therefore when the holes are created, the proposed algorithm selects the remaining live nodes for data transmission rather than sending data to the dead end that may result in the decreased throughput. The proposed algorithm ELBGR works on the raw information that is just locally collected i.e. location of the nodes, nodes' energy levels and PRR values. This locally collected information is then exchanged among one-hop neighbors, every node maintains a local-table of its all one-hop neighbors, this local-table helps the node in making decision to either select any neighbor as forwarding candidate or not. The proposed scheme chooses multiple forwarding candidates initially based on remaining energy levels and the reception rates of the nodes, using this strategy the successful transmission rate is significantly improved. The ELBGR algorithm decides that which set of neighbor nodes is good (having sufficient resources) to form the forwarding candidate set and in the next phase they are prioritized based on their distance from the destination/target. In this research work, the principles of the local behavior of ELBGR is presented, further more the efficiency of ELBGR has been concluded that the proposed routing strategy (ELBGR) is more efficient than Greedy routing strategy in all aspects (parameters that are evaluated) as well as the proposed algorithm ELBGR also out-performs some other routing protocols

(HHEAA, EAGR, and EEAR) in most of the aspects. The detailed analysis using graphs is described in chapter 5.

6.2 Future Work

The WSN field is in the evolutionary stage since last few decades, therefore having a great research potential for the researchers. Routing is the main area of interest in this field. For proving the proposed algorithm ELBGR more reliable and efficient, this algorithm may be extended in some directions in future.

a. For this research work, the static or immobile sensor nodes are considered. The mobile sensor nodes may be considered for the future work.

b. A single destination is considered in this research work, for the future work multiple destination nodes may be considered.

c. The fixed-size packets are used for transmission of data in this research, variable size packets can be used for future research work.

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