HOLE HEALING ENERGY AWARE ALGORITHM FOR WIRELESS SENSOR NETWORKS

By

Ifrah Farrukh Khan
Regno. 2006-NUST-MS PhD-CSE(E)06

Submitted to the Department of Computer Engineering
in partial fulfillment of the requirements for the degree of
Master of Science
In
Computer Software Engineering

Advisor
Brig. Dr. Muhammad Younus Javed

College of Electrical and Mechanical Engineering, NUST.

2009

ABSTRACT

Extensive usage of wireless sensor networks is the reason of development of many routing protocols. Routing in sensor networks is a challenging issue due to limited energy, low processing capability and smaller storage area. Efficient usage of energy is a key concern in wireless sensor networks for better performance and longer network life, as sensor nodes work unattended and have limited battery power.

In this thesis, different routing algorithms have been discussed but the survey focus was on geographic routing. An energy efficient and routing hole healing, location based protocol HHEAA (Hole Healing Energy Aware Algorithm) has been presented for wireless sensor networks for better performance in data delivery and giving longer life time to the network by balancing the energy consumption of nodes. In HHEAA, each node takes decision for the selection of next hop locally. This algorithm works on location as well as energy level information. Each node knows about its own location and its available energy level as well as the location and energy level of its neighbors.

Then forwards packet based on average energy and distance of the neighbors. It also works well in case of formation of routing holes. Simulation was made using OMNET++. Simulation results show that the proposed algorithm is energy efficient and is better than Greedy Algorithm as it shows higher packet delivery rate and lesser number of dead nodes. The proposed algorithm can accommodate thousands of nodes in sensor networks and can give longer life to the network.

DEDICATION

In the name of Allah, the Most Merciful, the Most Beneficent.

To my family, without their understanding, moral support and prayers, it was not possible to achieve this goal.

ACKNOWLEDGEMENTS

All Praise for **Him**, **Who** raised the heavens high.

Lots of thanks to my thesis advisor **Brig. Dr. Muhammad Younas Javed** who provided me the ladder to climb up, as high as I could and whose guidance brought me to the doorsteps of success.

I would also like to thank my thesis committee members **Lt. Col. Dr. Rashid Ahmad**, **Lt. Col. Dr. Farooque Azam and Dr. Ghalib Asadullah Shah** for helping me in solving different technical and official issues during the thesis work.

My heartiest thanks for my family members, who always encouraged me and prayed for my success.

A bundle of thanks for my teachers for the inspiration, guidance and encouragement they provided me during my academic career at CEME.

Last but not the least, I would like to thank my friends who gave me confidence to face the difficulties of life. They all gave me good company and everlasting memories.

TABLE OF CONTENTS

LIST OF FIGURES

Figure No. **Caption** **Page**
No.

LIST OF TABLES

Table No. **Caption** **Page No.**

LIST OF ABBREVIATIONS

1.	CDMA	Code Division Multiple Access
2.	HHEAA	Hole Healing Energy Aware Algorithm
3.	EAGR	Energy Aware Greedy Routing
4.	GAF	Geographic Adaptive Fidelity
5.	GBR	Gradient-based routing
6.	GEAR	Geographic and Energy Aware Routing
7.	GPSR	Greedy Perimeter Stateless Routing
8.	GPS	Global Positioning Scheme
9.	LEACH	Low-Energy Adaptive Clustering Hierarchy
10.	MAC	Medium Access Control
11.	MANETS	Mobile Ad Hoc Networks
12.	MCU	Microcontroller unit
13.	MECN	Minimum Energy Communication Network
14.	PEGASIS	Power-Efficient Gathering in Sensor Information Systems
15.	QoS	Quality of Service
16.	SINA	Sensor Information Networking Architecture
17.	SPIN	Sensor Protocols for Information via Negotiation
18.	TDMA	Time Division Multiple Access
19.	WINS	Wired Integrated Network Sensors
20.	WSN	Wireless Sensor Network
21.	PGR	Probabilistic Geographic Routing

CHAPTER 1

INTRODUCTION

1.1 Introduction

Machines are involved in every aspect of our daily life. For getting information and controlling these machines, small sensor nodes are used (which are part of a network) to transfer data from one place to another. The network, composed of these tiny nodes is called Wireless Sensor Network. WSNs are used in military installations for getting information about the troops and different machines, in hospitals for keeping track of the doctors or patients by getting their location information and their present condition, in some disaster areas for monitoring the situation and to rescue people trapped there. They are also used for getting information about the atmospheric temperature and pressure etc. The sensor nodes have limited resources such as bandwidth, energy and memory, so transferring data from source node to destination is a challenging task for researchers.

Many routing strategies have been developed. The most commonly used is geographic routing in which the nodes have information about their location and source node has information about the destination. A shortest path is selected for transfer of data from source to destination. These protocols are efficient in many aspects but they lack energy awareness. Geographic routing also suffers from a problem that is routing hole, in which the nodes cannot communicate with each other due to dead nodes in their path.

1.2 Background

Sensor networks have no powerful hardware such as high capacity hard disk, screens, keyboards and mice etc. so they are not similar to mobile ad-hoc networks. Many routing protocols have been designed for ad-hoc networks but those protocols require large space for their processing and storage. Due to their complexity they also consume a large amount of power that is available to the network in form of electric connections. Sensor networks have limited space and power (in the form of battery) so they cannot use routing protocols developed for ad-hoc networks. Keeping in view the limitations and requirements of sensor networks new routing protocols were designed and this process is still going on to develop more efficient protocols for sensor network according to its topology and the application it is used for.

Different routing protocols are available working on data centric, location and hierarchical based architecture. These protocols can also be classified according to their routing strategy as multipath, query, negotiation, QoS and coherent based.

1.3 Motivation

Wireless sensor networks have unattended nodes with limited energy resource. The important issue for routing data in these networks is energy efficient routing protocol. Location based routing is very efficient in locating path to destination but as most of the protocols use the shortest path so the nodes in this path deplete their energy more quickly creating routing holes due to dead nodes.

The aim of this research is to utilize the advantages of geographic or location based routing and design an energy efficient protocol that also deals with the problem of routing holes and gives longer life to the network.

1.4 Statement of Problem

In Geographic routing, nodes only transfer data to the next nearest node without having information about the energy level of the next node. This repeated use of nodes, present in many shortest paths results in quick depletion of their energy, the nodes become dead and unable to transfer any more packets. These dead nodes create routing holes and because of these holes packets start dropping. Such routing algorithm should be developed which would take care of energy level i.e it should be energy efficient and also be able to handle the routing hole problem.

This research is about solving the above mentioned problem.

1.5 Objective

The main objective of this research thesis is to study different existing geographic and energy aware protocols and to analyze their performance and to propose an Energy Aware Algorithm that transfers data more efficiently than the greedy algorithm and also solves the problem of holes not addressed in greedy algorithm and then to perform a comparative analysis through simulation, of both algorithms to check the efficiency of the proposed algorithm. This research will explore the paradigm of routing in sensor networks in terms of energy efficiency and problem of routing holes. The proposed communication protocol can be used in various applications where the longer life of network is important, especially in the scenarios where change of sensor node or battery recharging is near to impossible. It can be used in hospitals to get the location of doctors or to monitor the condition of patient, it can also be used for rescue applications and also for any surveillance system.

1.6 Organization of Thesis

The thesis comprises of 6 chapters, description of each chapter is given as follow. Chapter 1 states the problem statement and objective of the research. Chapter 2 describes the introduction of sensor networks and different issues related to it. At the end of chapter some of the application areas of sensor networks have been discussed. Chapter 3 contains the detailed study of some routing protocols for sensor networks and explores their potential limitations. Chapter 4 presents the motivation of this research and defines the problem definition. Later it describes the proposed solution design and implementation in detail. Chapter 5 captures the detail of different test results and provides their analysis. Finally, conclusion and future work are discussed in Chapter 6.

CHAPTER 2

SENSOR NETWORKS AND THEIR APPLICATIONS

2.1 Introduction

Wireless Sensor Networks is a combination of simple wireless communication, fewer computation facilities and small size of hardware. These networks can be deployed using low cost and wireless communication facilities. These networks are composed of small devices called sensor nodes. Sensor nodes have radio front end, micro controller, power supply and a sensor. These sensor nodes are used to sense temperature, vibration, sound, light etc.

There is a concept that wireless sensor networks are similar to ad-hoc networks but actually they differ in following aspects.

WSNs are application specific means they can be used in different areas and for sensing different types of things. Their deployment may be dense at one point and not very much dense at any other depending on the application they are used for. Their protocols and topologies also depend on this. These networks are supposed to gather real time data so it is possible that there is no data traffic at one time and a very heavy load at other time. WSNs have a very large number of sensor nodes in their network as compared to ad-hoc networks.

Another important difference is availability of energy, differing from ad-hoc networks sensor nodes have a small battery and it cannot be recharged once the node is deployed.

2.2 Sensor Nodes

Sensor nodes are electronic devices that sense data from their surroundings and convert it into electrical signals. Sensor nodes can communicate either with each other or can send data directly to some external base station. Figure 2.1 shows diagram of components of a sensor node. Sensor node is composed of sensing unit, processing unit, transmission unit, mobilizer, power unit and position finding system.

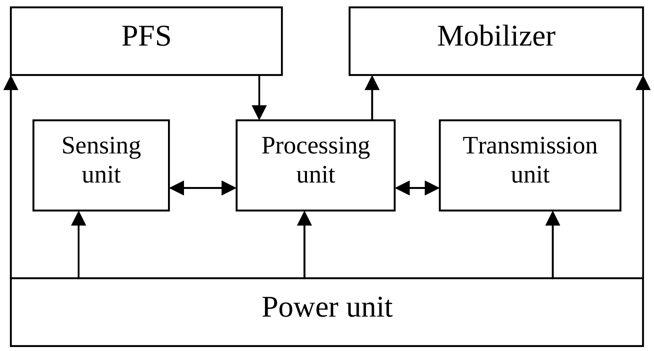

Figure 2.1 Components of Sensor Node

Sensor nodes take decision on the basis of application it is used for, its computing, communication and energy resources.

Example

A sensor node named WSN430 [61] available in market is shown in the Figure 2.2

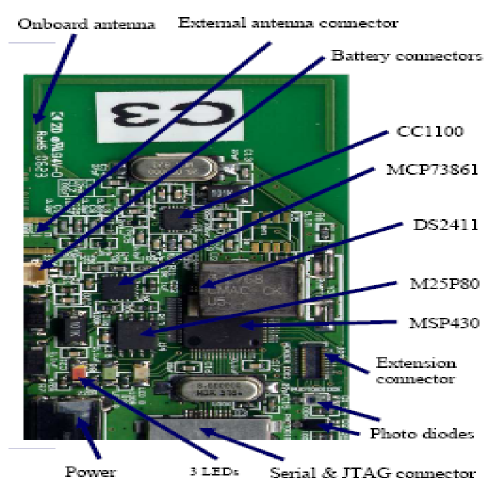

Figure 2.2 Sensor node WSN430

2.3 Wireless Sensor Networks

Wireless sensor networks are now part of many systems, such as distributed computing, inventory control, movement monitoring, survellience etc. These

Networks are composed of small sensor nodes which arrange themselves as multihop network. There are hundered and thousands of sensor nodes in a wireless sensor network, so it is impossible to give addresses to such a large number of nodes, as the nodes have small storage space therefore maintaining the traditional IP table is not possible. To overcome this problem communication is done using location information of the wireless nodes. Sensor nodes should be self configuring because they work unattended by human beings. These nodes have limited power, processing capability and storage capacity, so careful resource management is performed.

2.4 Routing Challenges

Sensor networks are used widely but these networks have several restrictions such as limited energy supply, processing capability and bandwidth of links. The main design goal is to implement such routing protocol that gives longer life to the network by transfering data energy efficiently and the routing protocol should not be very complex because it will become a load for limited resources of sensor node and will result in performance degradation.

Deployment of nodes in a sensor network is also a design issue. Node deployment depends upon application they are used for. They can be deployed randomly or manually. If they are deployed randomly then their density may vary at different places so routing protocol has to be designed in such a way that it uses the low density node more efficiently. If the nodes are deployed manually then there will be a uniformity in their arrangement and simpler protocol can work over it.

Importance of data is also a design issue because if the data is important then the routing protocol should be reliable so that data reaches its destination unchanged. The routing protocol has to be simple to cope with the limited resources. Routing protocol should be able to handle with the failure of nodes. It should also be able to deal with large number of sensor nodes.

Sensing data and reporting it in WSNs depends on the application used and the time, criticality of reporting the data. It can be categorized as either time-driven (continuous), event-driven, query-driven, and hybrid [60]. The time-driven model suits the applications in which periodic monitoring is required. Sensor nodes will periodically switch on their sensors and transmitters and after sensing the data from environment transmit it to the interested candidate at constant periodic time intervals. In event-driven and query-driven models reaction of sensor nodes depends on change in the data attribute being sensed by the node. Routing protocol is influenced by the model.

All sensor nodes are assumed to be homogeneous, means they have same communication, computation and power capabilities. While depending on the application sensor nodes can be different in a single sensor network. The existence of heterogeneous sensors raises many issues in to data routing. For example, an application gathers different kinds of data like sound, images, temperature etc so it has to use different types of sensors for getting all specified kinds of data.

Sensor nodes are mostly considered stationary while base stations and the sensing nodes may change their position, so node mobility is also a challenge in designing the routing protocol. Transmission media is also an important issue while designing Media Access Control protocols. Media used in WSN is very unpredictable as it has certain problems such as fading, data loss etc . Protocols designed for this medium should be reliable but also considers the power consumption incase of sensor nodes.

Sensor nodes can only gather data in limited area i.e they have limited coverage capabilities, proper coverage of area to be sensed is also important.

Data aggregation can be used for reducing the data redundancy over the network. Aggregation can be of different types, duplicate suppression, maxima and minima etc. Signal processing can also be used for this data aggregation.

Few applications require delivery of data within a certain period of time from the moment it is sensed. In many applications, conservation of energy is more important than the quality of data. As the energy gets depleted, the network reduces the quality of the results to reduce the energy consumption giving longer life to the network. Hence, energy-aware routing protocols are required to capture this requirement.

2.5 Survey Focus

Solution of few of the above-mentioned problems is a Location based energy efficient routing protocol that deals with the limited resources of sensor nodes and also supports the network in case of node failure. Location based protocol works on the location information of the sensor nodes. Nodes are addressed on basis of their location. Distance between the nodes can be estimated by the incoming signal strength. Nodes exchange their location information or it can be obtained directly by using a global positioning system. The designed protocol should be simple so that it does not take much processing time and the performance should not degrade.

2.6 Important Applications of Sensor Networks

Wireless sensor networks have played a significant role in efficient military and civil applications such as monitoring the environment , target surveillance, industrial process observation, etc. Due to their low cost and efficient data portability, these networks have potential applications in many areas. In military, sensors are widely used in monitoring the movement of machines and humans, communication from intractable areas to base-stations. In distributed surveillance highly mobile Sensor networks like the Underwater Autonomous Vehicle Odessey make it possible to transmit huge amounts of data at low powers. WINS Wireless Sensing Networks, contain large arrays of distributed sensors and the interpolation (by making use of multiple sensors on each node) of various sensed datum give high quality information. Sensors can be used for testing civil engineering structures. Smart sensor networks have a number of independent sensors. Each of the sensors makes a local decision and all the decisions are combined and weighed based on a specific algorithm and a global decision is taken. For rainfall and flood monitoring sensor networks have water level, wind and temperature sensors and the data is transmitted to a central database for analyzing and forecasting weather.

Now a days WSNs are playing important role in agriculture. By using sensor nodes fungal diseases in plants can be detected. In Green houses sensor nodes can be deployed to sense the temperature and humidity inside the green house that can improve the production rate in green houses.

2.7 Summary

In this chapter, Wireless sensor networks have been explained. Challenges faced by researchers during design of routing protocol have been discussed, differences between ad-hoc networks and wireless sensor networks have also been high lighted. Different application of sensor networks in daily life have also been mentioned.

CHAPTER 3

WSN Routing Algorithms and Holes

3.1 Introduction

The craving of getting more and more information about our surrounding has resulted in the creation of wireless sensor networks. These networks are composed of tiny sensor nodes, which can sense the surrounding data and after processing, it can forward the data to next node. In case of multi-hop networks several nodes forward the data until it reaches the sink [1, 2]. Communication between nodes is done using radio transmitters [2].

Sensor networks have proved themselves beneficial in almost every aspect of life. In industries, we can monitor the quality of work and progress easily. They can also prevent the major disasters by activating the smoke alarms. In military installations, land mines can be controlled remotely, can be used to help the disabled people and weather forecasts can be made with the help of data, collected about temperature and pressure by sensor nodes[1, 2, 3].

Different routing protocols are used for data communication in Wireless Sensor Networks (WSN) because of several factors (i.e Application for which the nodes are used, the number of nodes, topology of network and limitations of energy level available, energy required for transmission and capability of processing data)[2].

Research on WSN indicates that energy required for transmission is greater than the energy required for processing data. Due to this fact, many energy aware routing protocols have been introduced. The sensor networks work on a very small battery having very low energy. It is near to impossible to change the battery of a node, once it is deployed. In most of the cases, nodes survive on the energy recharged with the help of photovoltaic or thermal conversion [4].

Different problems arise during exchanging messages amongst the wireless nodes, these problems are known as holes in WSN. There are different types of holes that appear such as coverage holes, routing holes, black holes, worm holes and jamming holes.

3.2 Routing Protocols

There are three terms of networking that are used for routing.

Network layer

It is the third OSI layer that decides the path of in coming data over the network. It selects the next node to which the data should be transferred. This next node is also known as next hop.

Routing

Transferring the data from source to the destination, using the most optimal path is called routing.

Protocol

Set of rules and regulations used for communication of computers is called protocol.

In WSNs, data travels through a lot of intermediate nodes to reach the destination so network layer is used on each node for selecting the path for data packets. Routing tables are used to maintain the routing paths. These tables are maintained on each node with the help of routing protocols. So it is the task of a routing algorithm to maintain the most optimal path.

Some routing protocols of wireless sensor networks are discussed in this chapter.

3.2.1 Flooding

It is a very simple yet costly routing protocol for sensor networks. It works on broadcasting technique. Each sensor node creates multiple copies of the packet and forwards it to all its neighbors. This protocol is simple to implement but it has many drawbacks [1] as given below: -

a. Implosion is the problem of getting same packet multiple times. It happens because of getting the same packet from more than one neighbor.

b. Overlap problem arises when more than one sensors sense the same data and sends information about it to their common neighbor. The neighbor gets more than one copy of a packet.

c. Resource blindness is the most costly problem of flooding because the sensor nodes have limited energy level and bandwidth. Flooding uses these resources blindly. Thus, resulting in wastage of limited resources.

3.2.2 Gossiping

Gossiping is the enhanced version of flooding. In this protocol, all the neighbors do not get the copy of a packet.When a node gets packet it forwards it to some randomly selected neighbor. By selection of random node, gossiping overcomes the problem of implosion but introduces delay in the reception of data.

3.2.3 SPIN: Sensor Protocols for Information via Negotiation

In[46] a routing mechanism has been discussed in which high level data descriptors have been used for naming data. These data descriptors are exchanged by sensor nodes before starting transmission. When any node has new data it advertises it to its neighbors by using ADV message, any node which wants that data replies with a message REQ. Once the request is made data is transferred by using DATA message.

SPIN reduces the redundant data over the network. It only uses the single hop information so changes in the network topology do not matter. The drawback in this algorithm is that, if neighbors closer to the advertising node are not interested in retrieving data then they do not advertise it further, even if the farther neighbors are interested in getting that data.

3.2.4 LEACH: Low-Energy Adaptive Clustering Hierarchy

[59] It is a hierarchical algorithm that forms clusters of sensor nodes on basis of their signal strength. Each cluster has a cluster head that receives data from the cluster and forwards it to the sink. Cluster heads are changed overtime by using a mechanism in which node selects any number between 0 and 1.The node having number less than the threshold value i.e T(n) ={ p/1-p*(r mod 1/p), if n belong to G is considered as cluster head. Here p is the desired percentage of heads, r is the current round and G represents the nodes which have not been selected as heads in last 1/p rounds. LEACH reduces the energy dissipation but it introduces overheads for selecting cluster heads and changing them after some time.

3.2.5 EAGR: Energy Aware Greedy Routing in Wireless Sensor Networks

Razia et. al.[5] suggests a location, based protocol that works on geographical information of the node as well as the energy level available in the sensor node. In most of the greedy routing algorithms, only shortest path is calculated keeping aside the fact that in this case the node present in most of the shortest paths will loose its energy very quickly. Therefore, creates a hole in that area and results in dropping of packets.

EAGR combines the location information and energy level of nodes so beautifully that the workload is evenly distributed amongst the alive nodes.

In EAGR, all the nodes have same energy level and a threshold energy level is set. Node having less than that energy level is considered dead. Then, it finds out the location of each node. All the nodes having energy level greater than their threshold value get information about their neighbor and create a table of their locations. On the basis of this table, average distance to its neighbor is calculated. For forwarding data, it selects the node having distance equal to or less than this average distance value and having maximum energy level amongst the neighbors. By considering energy level in selection, every time a new node is selected and no single node gets depleted and its energy is not lost more quickly. Resultantly, giving longer life to the network.

In EAGR, packet only gets dropped when the destination is dead or there is no further neighbor alive to forward data. Authors have compared the results of EAGR with shortest path greedy algorithm using OMNET++ simulator and simulation results show the great difference between these two protocols. EAGR is much better than simple greedy algorithm.

3.2.6 GEAR: Geographical and Energy Aware Routing

Yu et. al. [6] has suggested a protocol that uses geographical information of the nodes to propagate data to some specific rectangular region with energy efficiency. It also has a mechanism for dealing with holes.

This algorithm works in two phases.

a. Forwarding the Packet Towards the Target Region: When there is a node available whose distance from destination is less than the forwarding node, then the forwarding node selects that neighbor for its next hop. If all the nodes have greater distance than the forwarding node, it means there is a hole. This hole problem is solved by selecting the next hop on the basis of learning cost mechanism.

b. Disseminating the Packet within the Region: When the packet reaches the region, recursive geographic forwarding algorithm is implemented on it. When the density of nodes is high, recursive geographic algorithm creates four copies of the packet and divides the region into four sub-regions and gives one copy to each sub-region. It divides the sub-regions further until the sub-region contains only one node. By doing this, all the nodes in a particular region will get the copy of the packet. In case the density of nodes is low in a region, restrictive flooding method is used instead of recursive geographic forwarding.

In GEAR each node knows two types of costs: (1) estimated cost that is used for simple forwarding, consisting of the remaining energy level and the distance and (2) is learning cost that is used to tackle the problem of holes.

The authors have compared GEAR with GPSR. The simulation results for non-uniform traffic are: GEAR delivered 70% to 80% more packets than GPSR and in case of uniform traffic GEAR delivered 25% to 35% more packets than GPSR. It shows that GEAR works better than GPSR under different traffic scenarios.

3.2.7 REAR: Reliable Energy Aware Routing

Hassanein et. al. [8] have proposed a routing algorithm in which reliability of packet delivery is high and it is also energy aware. REAR uses three types of nodes in a network Sink, Intermediate Nodes (IN) and Target Source (TS).

This algorithm works on two layers. Network layer over which it provides the energy aware path using energy-reservation mechanism and on transport layer, which provides reliability.

Parts of REAR are as under

a. Service Path Discovery (SPD): In SPD, the node known as sink sends the request over network for path discovery. It uses flooding for this path request. On the way the broadcasting speed is combined with available energy to select the energy efficient path. Once the node is selected it contains two logical energy levels (one is available energy and the other is reserved energy occupied by the path). When this candidate path reaches the source, it generates a path reservation request in which it reserves the required energy of nodes for the path. Any other path cannot use this energy until it is released.

b. Backup Path Discovery (BPD): It is also initiated by sink and has same procedure as SPD. The only difference is that it does not contain the nodes already selected for service path. Backup path is used in case of failure of service path.

c. Reliable Transmission: For reliable transmission, each sending node stores the data until it gets acknowledgment from the receiver. Due to low memory, all the packets are not stored in case of SP link failure. The source node will transmit all the packets again.

d. Reserved Energy Release: When the link fails, an error message is transmitted to all the intermediate nodes, which release the reserved energy for that path.

Authors of the REAR claim that it can transmit 10%-20% more packets to the destination node.

3.2.8 LQER: Link Quality Estimation Based Routing for Wireless Sensor Networks

This protocol is proposed by Chen et. al. [9]. LQER takes decision about data forwarding on the basis of a dynamic window (m,k) that stores the history of transmission success over the link. This dynamic window is represented as (m,k) where m represents the total successful transmission bits and k is the length of window. Minimum hop-count is also considered to make this protocol reliable as well as energy efficient.

In the bit sequence of the window, left-most bit represents the oldest and right-most bit represents the newest data. When the transmission is unsuccessful 0 is inserted while 1 represents successful transmission. LQER estimates the link quality by m/k . Largest value of m/k value is considered the best one.

This protocol also considers the minimum hop-count value for selection on next hop. Using flooding mechanism in which sink starts advertising, the hop-count sets minimum hop count field. Initially, all the nodes have maximum hop-count set when the nodes receive any hop-count lesser than it has already recorded, it replaces the stored hop count with the new one. By doing this, it gets the shortest path.

LQER first selects the neighbors having minimum hop-count and from that set, it chooses the node having the largest m/k value to forward the data. In this way it selects the most optimal path for data transmission.

3.3 Holes: A Challenge for Wireless Sensor Networks

When the data transfer amongst sensor nodes is stopped by some problem then it is said that there is a hole in communication. There are different types of holes in WSN. Coverage holes, Routing holes, Jamming holes, Sink/Black holes and Worm holes which will be discussed later.

3.3.1 Coverage holes

When the nodes sensing an area are less than the number required by the application then the coverage hole is created. Dead nodes can cause coverage holes because no node will be present to sense the data. Coverage requirements are different for different scenarios e.g. military installations need to cover more area and even a single dead node can result in disaster. Any security system also requires dense deployment of the sensor nodes.

Coverage area of sensor nodes also depends upon the type and capacity of the sensor node. One way to avoid coverage holes is to deploy redundant nodes in important installations and backup nodes should sleep until they are needed in case of any dead node [10].

3.3.2 Routing holes

Routing holes are created by energy depletion of nodes resulting in failure of paths, movement of nodes to some other location in case of mobile nodes, any other disorder or destruction of node. A routing protocol has only two options in this scenario, either to drop the packet or to solve the routing hole problem, by using a certain mechanism. There are different methods of dealing with this problem, some of them are as under [10].

Introducing multiple paths (such as Service Path and Backup Path) for data transmission to avoid the failed path and for reliability of data delivery, one such protocol (REAR) has been discussed in section 2.5.

Another method is creating graph and traversing it by using right-hand rule as done in GPSR (Greedy Perimeter Stateless Routing) [7]. GEAR [6] uses learning cost mechanism to solve this problem.

A lot of work has been done to overcome this problem but discussion of all the methods is beyond the scope of this work.

3.3.3 Sink/ Black holes

These kinds of holes are created, when a malicious sensor node introduces best path to the destination. These best paths include the malicious node itself. As a result the misbehaving node attracts the traffic of the network. On receiving the packets it can either drop them or can even forward those packets after changing them [10]. All the traffic starts moving in one direction, so due to low capacity of the network overflow occurs and more packets are dropped. The nodes in that path are also extensively used, so they deplete their energy very quickly.

Zdravko[11] has suggested in his paper a routing algorithm named REWARD (Receive, Watch, Redirect) .REWARD uses two messages, (1) MISS (Material for Intersection of Suspicious Sets). It indicates the misbehaving node or team of nodes.
(2) SAMBA (Suspicious Area, Mark a Black-hole Attack). This message gives the location of misbehaving nodes.REWARD consumes energy but provides security against black-holes.

3.3.4 Worm Holes

Worm holes are created when some sensor nodes present in different parts of WSN start exchanging messages with each other [13]. When a node sends the packet fro one part of the network to a node in another part of that network using some different radio frequency, then the new part nodes will falsely consider themselves the neighbors of the first part nodes. This results in incorrect routing paths and degradation in performance of the network.

3.3.5 Jamming Holes

Jamming holes are created when the communication becomes impossible amongst the sensor nodes. It happens because of intrusion in the radio frequency allocated to WSN, or because of continuous usage of wireless channel. These holes appear either because of the out of order sensor nodes, which are sending garbage packets over the network and occupying the wireless channel, or because of the malicious nodes which are being compromised by some attacker and are sending some useless packets to exhaust the network. Jamming holes can be detected by the neighbors sensing the high background noise in that region and alternate path can be provided to the nodes around the jammed region [12].

Jamming holes can also appear in the region where the objects being sensed behave differently, like if a sensor is deployed to sense a light of specific wavelength, then it cannot detect the light having wavelength greater than or less than the assigned wavelength. In this scenario the sensors are said to be jammed [10].

3.4 Summary

In this chapter different routing protocols have been discussed on the basis of their pros and cons. EAGR is an energy efficient protocol but has no criteria to solve the problem of holes when the packet reaches a node having all the neighbors dead. At this stage the packets are dropped which give poor performance. There must be some mechanism that can use alternative path to reach the destination. GEAR is energy efficient and also provides a mechanism to deal with the problem of holes. REAR in addition to energy efficiency provides reliability in data transmission. LQER provides reliability in data transmission by using link history and is also energy efficient. There are many factors effecting the performance of routing protocols. Holes are discussed in which coverage holes effect the coverage area, jamming holes block the communication by sending packets, black/ sink holes create false destinations, in routing holes paths to destination break and in worm holes links are created between different parts of a network.

CHAPTER 4

DESIGN AND IMPLEMENTATION OF HHEA ALGORITHM

4.1 Introduction

Geographic routing is widely used in wireless sensor networks due to its efficiency and scalability. But due to energy inefficiency it suffers the problem of void areas called holes[30]. As sensor nodes are very small and have smaller battery so geographic routing has to be tamed in such a way that it consumes lesser energy and provides its full benefits in WSN, as they are now used in many applications.

4.2 Geographic Routing and Routing Holes

Geographic routing is also known as location based routing. Wireless Sensor Networks do not use any addressing scheme, so this routing helps in sending packets to the geographic position of the node instead of their network address. In geographic routing each node knows about its location. In this routing method, source has information about destination node so it sends packet over the network. Node decides the next hop for this packet. What will be its next hop? It is done in such a way that each hop takes the packet closer to the destination node. By using this method prior setting of the shortest path is avoided.

There are many approaches for geographic routing but here only the single-path greedy routing is studied. In greedy routing, source node after acquiring knowledge about destination location creates a packet and sends it over to the network. The next node may be an intermediate node that will forward packet to next hop or it may be the destination node. If it is the intermediate node then it calculates its distance from its neighbors and sends packet to the closest one. This procedure is repeated until the packet reaches its destination.

Greedy routing can lead to a dead end where no more nodes are near destination. At this point the packet is dropped. This dead end is called a routing hole. Routing hole is the area in wireless sensor network where nodes are not present to forward data to next node. It happens because of malfunctioning node or energy depletion of any node.

4.3 Routing Algorithm for the Inter-Sensor Nodes Communication

Nodes can forward data as long as they have energy. So energy consumption is the main factor that gives longer life to the network. This can only be achieved by using such routing algorithm which is energy efficient.

4.3.1 Weak Node Problem

In geographic greedy forwarding, nodes closer to destination are used heavily resulting in loss of energy. These nodes do not have sufficient energy to forward packets after some time. Such nodes having low energy due to continuous usage are called weak nodes.

4.3.2 Principle of Holes Healing Energy Aware Routing

Holes Healing Energy Aware routing works on average energy and distance of nodes to overcome weak node problem in WSN. When only distance of neighbor node is considered, the nodes having shortest distance from the destination are selected repeatedly which results in more energy consumption of those nodes and they become weak. If only strong nodes are selected then it may result in long paths , that also increase the time of arrival of packets to the destination. Therefore, the strategy used in holes healing energy aware routing is that, first the average energy of all the neighbor nodes is calculated then the node having energy greater than or equal to average energy is selected. If more than one nodes have energy level greater than or equal to average energy then the node having shorter distance is selected amongst those nodes. If a packet reaches some node whose all the neighbors are dead (having energy less than the preset threshold energy) 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. So, the proposed algorithm selects the next node in energy efficient manner and also takes care of the dead nodes.

4.3.3 Assumptions for HHEAA

Assumptions taken for this research are: Sensor nodes do not change position once they are deployed. Random topology for the network is considered. A central entity manages the location information, all the nodes contact that central entity for getting information about the location of other nodes, just like GPS system in real time scenario. Packets used are of fixed length and all the nodes can send packets to only one destination node. Buffers are of unlimited size on each node so overflows or queuing problems are not considered in this research.

4.4 Block Diagram

Using the platform of Visual C++ 6.0 with service pack 6 and OMNET++ network simulator makes the proposed system. There are four basic modules in the proposed system i.e. network generator, route, HHEAA and packet router.

4.4.1 Network Generator

Network generator creates the topology of the network. It defines the position of the nodes and establishes the connection between them. Data rate for the connection is also declared in this module and the total number of nodes in the network is also set in network generator.

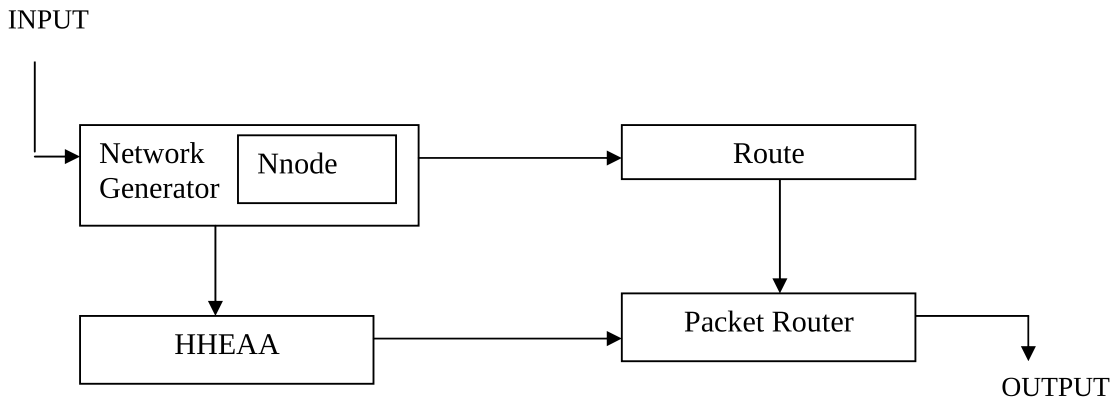

Figure 4.1: Block Diagram of proposed system

Structure of single node is mentioned in sub module Nnode that gives address to a node and also declares gates for a node.

There are two types of gates for each node In gate and Out gate. In gate receives the packets and out gate sends the packet to the node connected to it. Links between nodes and also time delay on each link is declared in this module.

4.4.2 Route

This module plays its role of generating packets. It assigns the source address to the source address of the packet and as the destination node is considered constant so it always assigns the same destination address to the destination address field of the packet. It sets the “haspayload” field to “true” and assigns some dummy data to the data field of the packet. After assigning the values to all the fields of sample packet it hands it over to the network, where HHEAA is applied to forward this packet.

4.4.3 HHEAA

It selects the neighbors of the current node. It checks the position of the neighbors of current node and stores them in a link list. After creating the link list of neighbors it counts the total number of neighbors of current node. This total number of nodes is used to calculate the average energy of neighbors. It then calculates the sum of energy levels of the neighbors and divides it with total number of neighbors to get the average energy of the nodes. This average energy is compared with all the neighbors and the ones having energy level greater than or equal to this average energy are stored in an array. Distances of all these neighbors are compared with each other and the one having minimum distance is selected and stored in a variable. This variable is sent to the packet router module.

4.4.4 Packet Router

Packet router receives packet and stores it in a sending queue. Then it checks that whether that node is destination node or not, if it is the destination node then it delivers the packet to the node, else it sends the packet to the next node selected by HHEAA and decrements the remaining energy of the current node. It also checks the remaining energy of the nodes and if all next hop neighbors are dead then it sends the packet one level back and again applies HHEAA for selection of another neighbor. It also changes the color of dead node i.e the node having energy level less than or equal to 0.25. If all the nodes are dead it drops the packet.

Supporting Modules

4.4.5 Statistics

It keeps track of total packets generated, number of packets delivered successfully and number of packets dropped. These statistics are shown at the end of simulation.

4.4.6 Packet

Structure of packet is defined in this file. It contains the following fields.

- source address
- destination address

- data field
- and a flag that shows the packet contains data or not.

4.5 Greedy Algorithm

Greedy algorithm is represented in Figure 4.2 in which node selection is purely on the basis of their distances. Greedy algorithm selects the node having smallest distance to destination.

Figure 4.2: Greedy Algorithm for the Sensor Networks

```
Initialize the network(with specified number of nodes);
        1.  Get Location; // Location of each node in the network.
        2.  Get neighbors; // detect the neighbors of each node and create a table
        3.  Calculate Shortest distance to destination and store it in routing table
        4.  For each node
            If the node is alive      //energy level greater than threshold
                a.  Send packet to the closest node to destination // selecting next hop
                                                             from routing table
                b.  Deduct energy required for processing
            Else (if node is dead i.e energy level <= Threshold)
                Drop packet
```

4.6 HHEA Algorithm

In Figure 4.3 HHEA algorithm is presented which takes care of all the issues such as energy efficiency and routing holes. Simulation results have been presented in chapter 4 which shows that HHEAA works very efficiently, as compared to Greedy Algorithm.

Initialize the network; //With specified number of nodes

1. Get Location; //Location of each node in the network.
2. Get Neighbors; // Check the neighbors of each node and create a table
3. Find neighbor distance; // Get the distance of each neighbor

   //Transmission

4. For each node

   If the node is alive // Energy greater than threshold

   a) Calculate average energy of neighbors
      - ❖ Find neighboring nodes having energy >= average energy
      - ❖ Determine node with minimum distance
      - ❖ Send packet to the node at minimum distance

   b) Deduct energy used for processing

      // Hole Healing

   Else If node is dead

   Reverse link; // Send packet to previous node

   Go to step 4;

5. If all nodes dead

   Drop Packet ;

Figure 4.3: HHEAA for sensor Networks

4.7 Flow Chart of Greedy and HHEA Algorithm

Figure 4.4 shows the flowchart of Greedy routing algorithm. The first step is to initialize the topology of network with specified number of nodes. Then location of each node is stored in a table. A packet is generated that has the address of source node and the destination node. Distance is considered for selection of the next hop and packet is sent to the node at minimum distance from the destination. By checking the source node field of packet neighbors of sending node are identified. Path is stored in a routing table by comparing the distance of all the neighbors from the destination and shortest path is stored. Then if the node is alive next hop is selected on the basis of shortest path routing table, and then the energy consumed for processing is deducted from the remaining energy of the node. If the packet has reached the destination node then time is checked. If it is time to end the simulation then it is stopped else if packet has not reached its destination then process of next hop selection is repeated for the next node. If the closest node is dead then the packet is dropped. Packets are generated and forwarded until the end of simulation time.

Figure 4.5 shows flow chart of HHEAA in which after initialization of network, location of each node is stored and then distance of each neighbor is checked and stored. A packet is generated. Then for alive node, average energy of all its neighbors is calculated and packet is sent to the node having energy greater than or equal to the average energy. If more than one such node exists then distance is considered and the packet is sent to the node at minimum distance. Energy required for processing and sending is deducted from the energy of the node. Then it is checked that whether the packet has reached its destination or not, if yes, then the simulation is stopped else the process is repeated. If the packet reaches at dead node then it is sent back to the previous node from where again energy comparison is performed and packet is transmitted. If all the nodes in the path are dead then the packet is dropped.

This process continues until the packet reaches its destination.

4.8 Comparison between Greedy Algorithm and HHEAA

Packets in greedy algorithm have their destination address. Intermediate nodes take decision about the next hop of packet. By using this address the node checks its distance from all the neighbors and selects the one having shortest distance when going towards the destination. Shortest path from source to destination is selected and whenever that source node has to send packet to the same destination it always take the previously selected shortest path. On the other hand HHEAA first checks the energy level and then the distance that is as the 2^{nd} priority. A selection criterion of the node on basis of available energy is specified in HHEAA principle.

In greedy algorithm the nodes consume their energy more quickly, so when the packet reaches a node having dead neighbors the packet is dropped. While, in case of HHEAA the packet is redirected towards the destination by using the mechanism specified in the principle.

4.9 Energy Model

When the simulation starts all the nodes have energy equal to 1 joule. Node consumes one unit that is equal to 0.0001 joule, while processing and transmitting the packet. Threshold value is set equal to 0.25 joule.

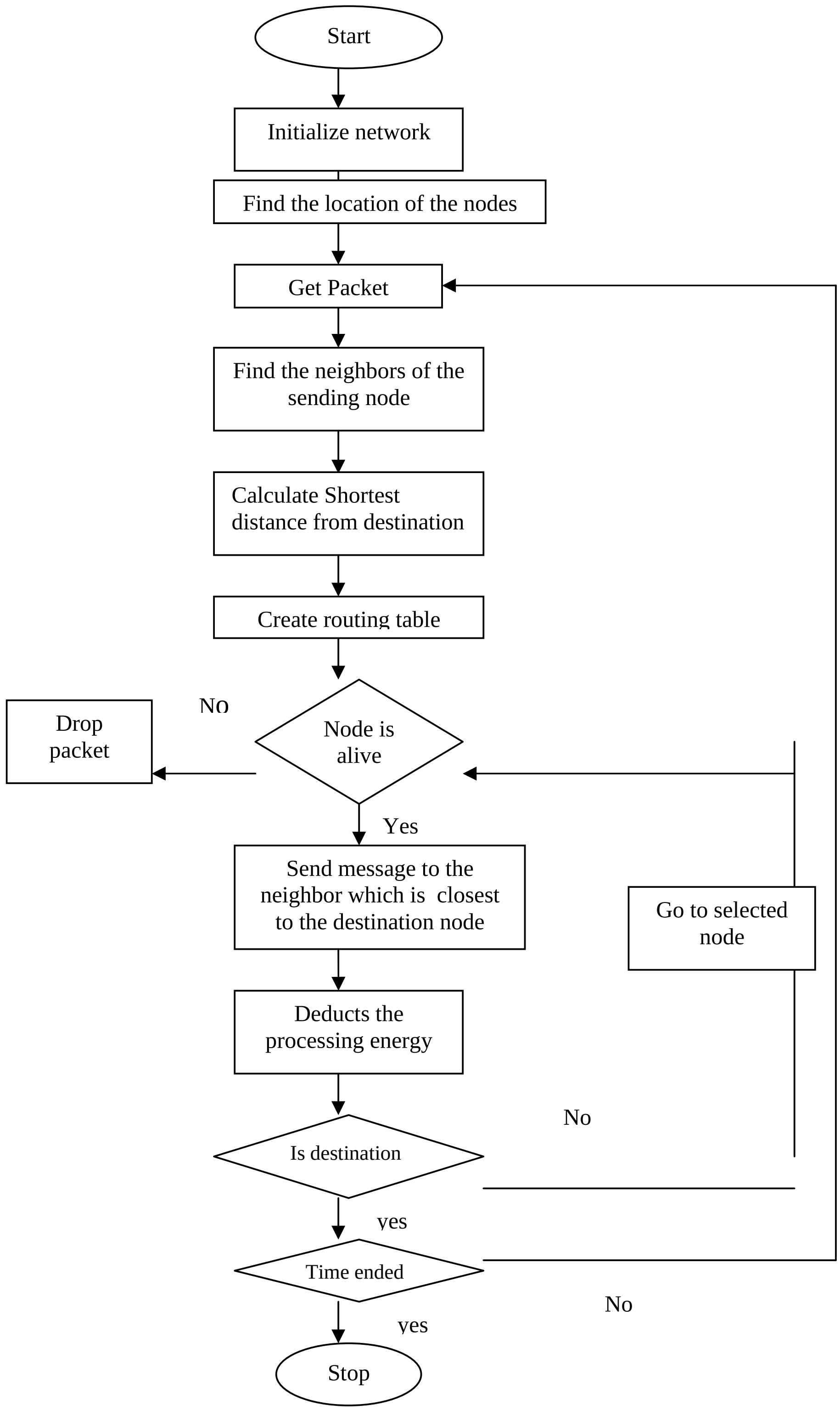

Figure 4.4: Flow chart for Greedy Algorithm

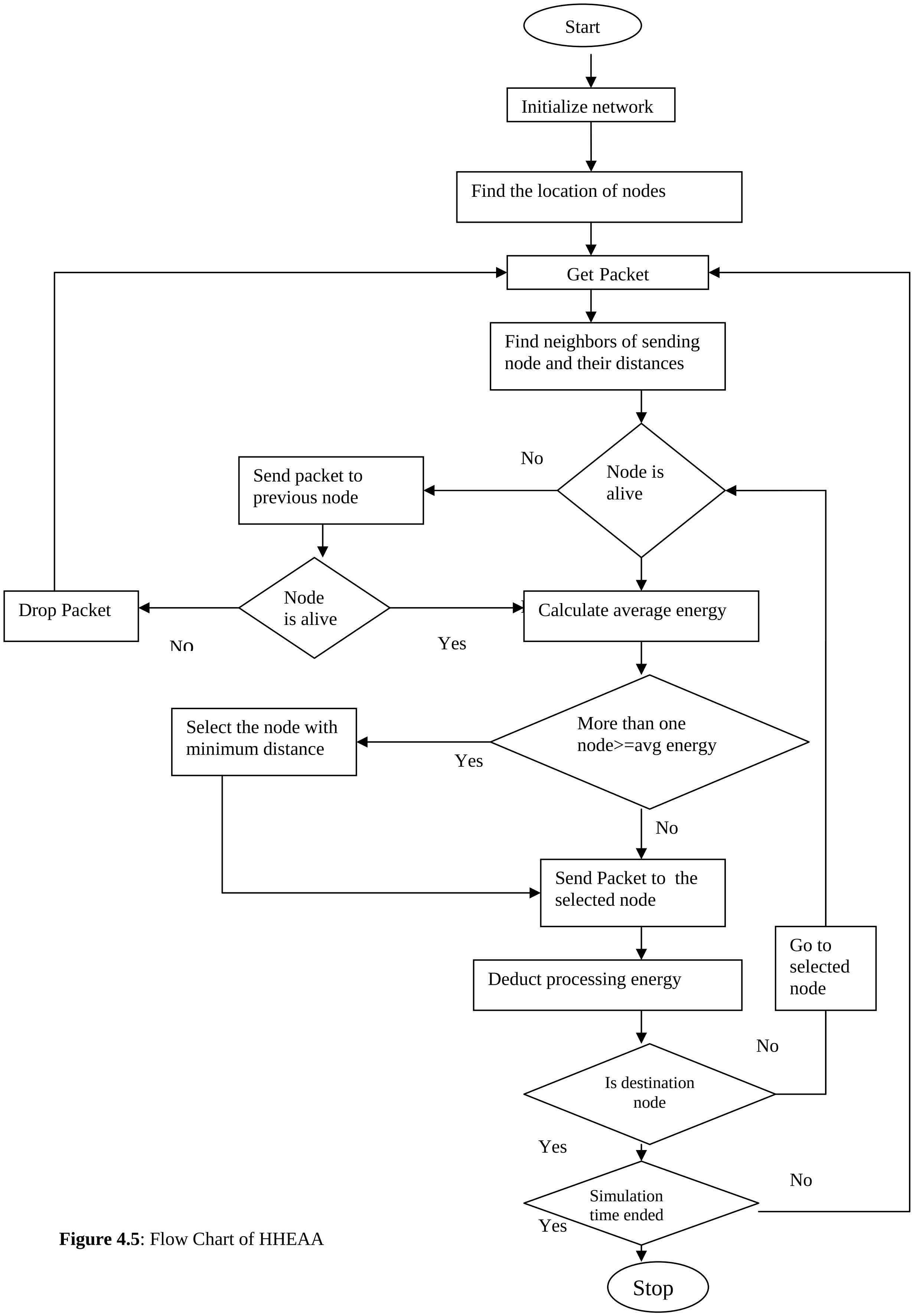

Figure 4.5: Flow Chart of HHEAA

4.10 Summary

This chapter gives an idea about geographic routing, Greedy routing has been explained along with its problems. Then Hole Healing Energy Aware Algorithm is proposed and its design and implementation is discussed in detail.

CHAPTER 5

SIMULATION AND RESULTS

5.1 Introduction

Simulation is developed using Omnet++ and is executed with different numbers of nodes. For noting the performance of proposed algorithm, nodes are randomly placed in each network. Two algorithms are compared here HHEAA and greedy for checking the success of the proposed algorithm.

5.2 History of OMNET++

OMNET++ is an object-oriented modular discrete event simulator. It is being used in development since 1992. Primary use of OMNET++ is to simulate communication networks, distributed systems and parallel systems. Students at Technical University of Budapest, Hungry, started OMNET. András Varga, one of the pioneer students maintains this open source simulation package. Several people contributed to this package. The first public release was in 1997 and animation was added in 1998, which made the package even more usable for education.

OMNET++ is only free for academic and non-profit use – for commercial purposes one needs to obtain OMNEST licenses from Omnest Global, Inc.

5.7Simulation Model

5.7.1 Model for 10 nodes WSN and its operation.

OMNET++ is used for developing simulation for 10 nodes. Nodes are randomly placed and are immobile. They do not change their position during the simulation. Initially, each node is assigned same energy that is equal to 1 Joule. It decreases during the processing and transfer of packets. If a node reaches to energy level that is equal to a pre set energy threshold it is considered dead and its color is changed. For simplicity only one node is considered as destination node to which all other nodes send their data i.e. source nodes can be different but destination will be the same. A packet of fixed length i.e. 563 Bytes is generated by the source nodes and simulation runs for 500 seconds in different scenarios.

Figure 5.1 shows WSN of 10 nodes. Each node has a specific identification, different energy levels and distances are assigned for clarification of working of HHEAA.

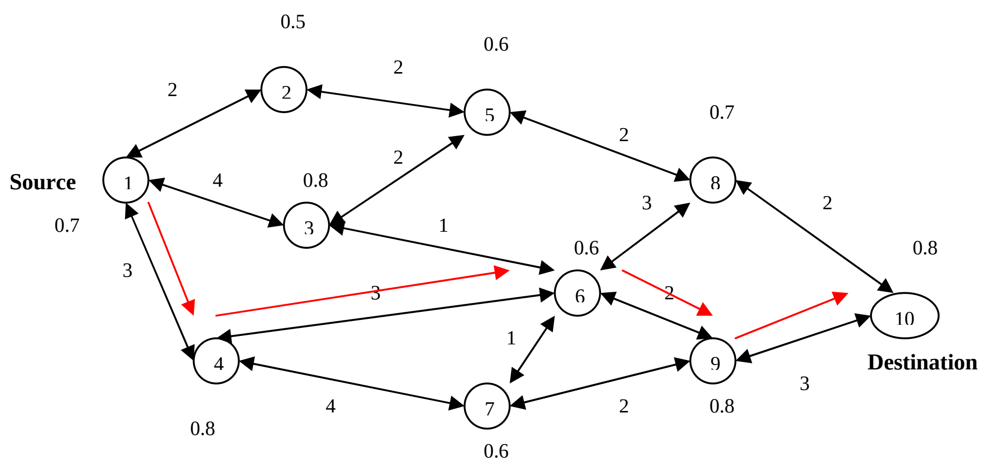

Figure 5.1: WSN with 10 nodes

In the above mentioned figure circles represent nodes and the number with in the circle represents its identification. Real numbers written outside the circles represent energy level of the node and numbers along the edges represent the distance between those nodes. Red line represents the path taken by a packet.

When node 1 sends a packet to node 10 by using HHEAA it follows the following

Steps

At Node 1

Step 1:

Average energy of neighbors = (0.5+0.8+0.8)/3=0.7

Two nodes, node 3 and node 4 in the network have energy greater than 0.7

Step 2:

Compare distances of node 3 and node 4

Distance of node 4 < Distance of node 3

Step 3:

Send packet to node 4

Step 4:

Deduct energy of node 1

0.7-0.0001

At Node 4

Step 1:

Average energy = (0.5+0.6)/2 = 0.55

Two nodes node 6 and node 7 have energy equal to or greater than 0.5

Step 2:

Distance of node 6 is less than node 7

Step 3:

Send packet to node 6

Step 4:

Deduct energy from node 4

0.8-0.0001

At Node 6

Step 1:

Average energy = (0.6+0.8+0.7)/3 = 0.7

Two nodes, node 8 and node 9 have energy equal to or greater than 0.7

Step 2:

Distance of node 9 is less than node 8

Step 3:

Send packet to node 9

Step 4:

Deduct energy from node 6

0.5-0.0001

There is no other neighbor node at node 9 other than the destination itself, so the packet will be transferred to node 10, that is the destination node.

5.3.2 Model for 40 nodes WSN and its operation

Figure 5.2 shows the simulation model of 40 nodes. Selection of nodes and dealing with holes on the basis of HHEAA is shown in this model.

In Figure, circles are the sensor nodes. Numbers written in the circles represent their identification. Red circle shows the dead node i.e the node having energy less than threshold energy. Real number, adjacent to the node is the energy level of that node. Numbers written with edges are the distances between two nodes. Working of HHEAA in this scenario is as under.

At Node 1

Step 1

Average energy of the neighbors = (0.7+0.7+0.8)/3 = 0.73

Step 2

Node 2, Node 3 and Node 4 have energy greater than or equal to the average energy.

Step 3

Packet is sent to Node 4 because it is at the minimum distance.

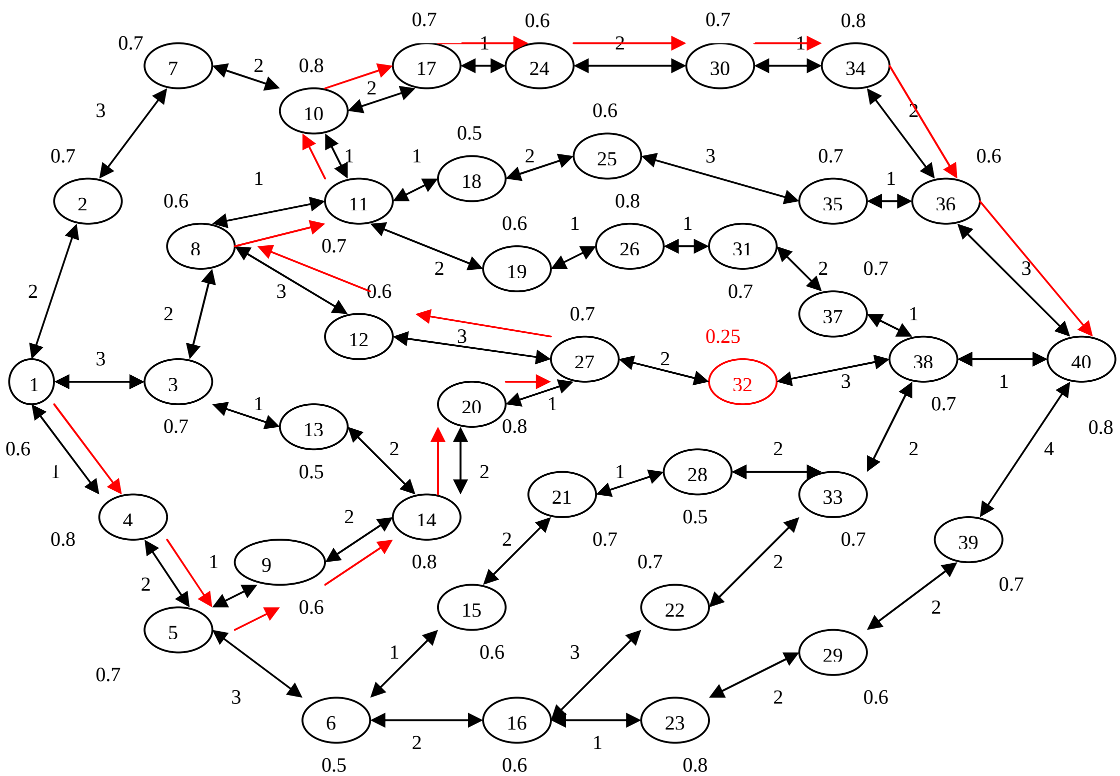

Figure 5.2: 40 nodes WSN

Step 4

Energy of node 1 – 0.0001

There is only one neighbor that is node 5 so packet is sent to node 5.

Energy of node 4 -0.0001.

At Node 5

Step 1

Average energy of the neighbors = (0.5+0.6)/2 = 0.55

Step 2

Node 6 and Node 9 are candidates.

Step 3

Packet is sent to Node 9 because it is at the minimum distance.

Step 4

Energy of node 5 – 0.0001

Node 9 has only one neighbor that is node 14 so send packet to node 14. Energy of node 9 -0.0001.

At Node 14

Step 1

Average energy of the neighbors = (0.5+0.8)/2 = 0.65

Step 2

Node 20 has energy greater than 0.65.

Step 3

Packet is sent to Node 20.

Step 4

Energy of node 14 – 0.0001

Node 20 has only one neighbor that is node 27 so send packet to node 27. Energy of node 20 -0.0001.

At node 27, one neighbor node 32 is dead so packet is sent to node 12, energy of node 27 -0.0001.

Node 12 has only one neighbor that is node 8 so packet is sent to node 8. Energy of node 12 -0.0001.

At Node 8

Step 1

Average energy of the neighbors = (0.7+0.7)/2 = 0.7

Step 2

Node 3 and Node 11 have energy equal to 0.7.

Step 3

Packet is sent to Node 11 because it is at the minimum distance.

Step 4

Energy of node 8 – 0.0001

At Node 11

Step 1

Average energy of the neighbors = (0.6+0.5+0.8)/3 = 0.63

Step 2

Node 19 and node 10 are candidates.

Step 3

Packet is sent to Node 10 because it is at minimum distance.

Step 4

Energy of node 11 – 0.0001

Node 10 has only one neighbor that is node 17 so packet is sent to node 17. Energy of node 10 -0.0001.

Node 17 has only one neighbor that is node 24 so packet is sent to node 24. Energy of node 17 -0.0001.

Node 24 has only one neighbor that is node 30 so packet is sent to node 30. Energy of node 24 -0.0001.

Node 30 has only one neighbor that is node 34 so packet is sent to node 34. Energy of node 30 -0.0001.

Node 34 has only one neighbor that is node 36 so packet is sent to node 36. Energy of node 34 -0.0001.

Sent to Destination node.

5.3.3 Hole Healing

Using HHEAA packet is forwarded by comparing average energy and minimum distance of the nodes. As the processing energy is deducted from a node when it forwards a packet so after sometime the mostly used nodes start loosing their energy and become dead. When the packet reaches such a node that has all dead neighbors this point is called a routing hole. At this point the packet is sent back to the node which forwarded it. It is shown in Figure 5.3.

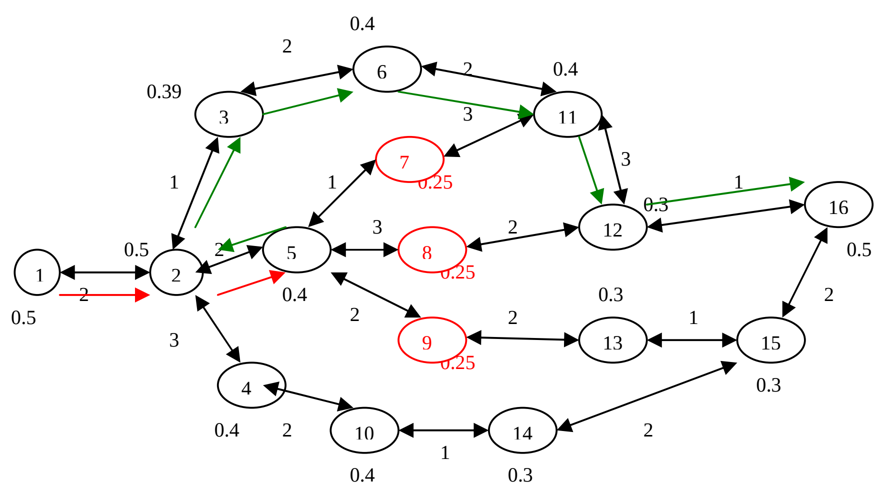

Figure 5.3: Hole Healing Case 1

Case 1

Source generated a packet and sent to node 2. At node 2 average energy was calculated for its neighbors i.e (0.39+0.4+0.4)/3 = 0.4 (rounding off). When energy and distance were compared node 5 was selected. It is supposed that 0.01 energy is used for processing. Energy of node 2 reduced to 0.49.

At node 5 all the neighbors, node 7, node 8 and node 9 were checked and all were dead so node 5 sent the packet back to node 2 and energy of node 5 reduced to 0.39. Again at node 2 average energy was calculated i.e (0.39+0.39+0.4)/3 = 0.39. When average energy and distance were compared node 3 was selected and the packet reached the destination via node 6 , node 11 and node 12.

Case 2

It was supposed that node 6 was dead as shown in Figure 5.4. Source generated a packet and sent it to node 2 represented by red line. At node 2 average energy was calculated i.e (0.39+0.39+0.4)/3=0.39. After comparing the average energy and distance, node 3 was selected and energy of node 2 reduced to 0.49.

At node 3 the neighbor node 6 was dead so node 3 returned the packet to node 2, represented by green line and energy of node 3 became 0.38.

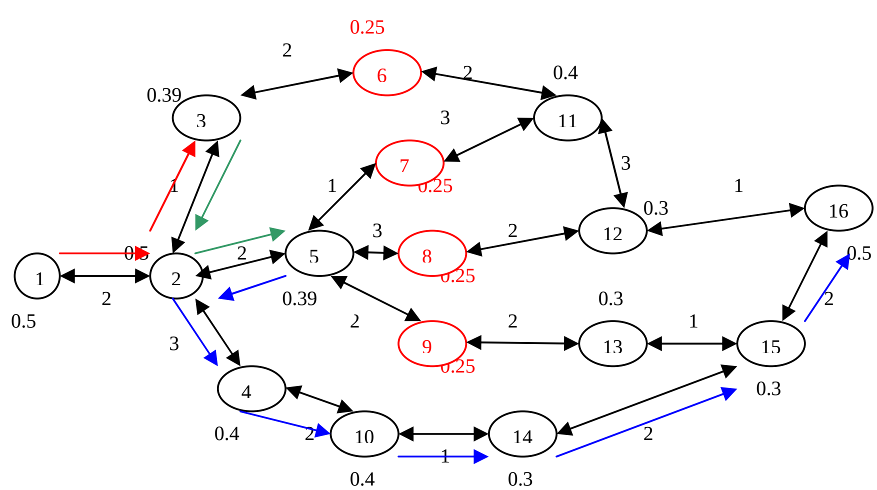

Figure 5.4: Hole Healing Case 2

Again at node 2 average energy was calculated i.e (0.38+0.39+0.4)/3=0.39. Node 5 was selected after comparing energy and distance. Energy of node 2 reduced to 0.48.

At node 5 it neighbors, node 7, node 8 and node 9 were dead so packet was sent back to node 2 represented by blue line and energy of node 5 reduced to 0.38.

At node 2 average energy was calculated i.e (0.38+0.38+0.4)/3=0.39(rounding off). By comparing the energy of neighbors, node 4 was selected and the packet reached its destination via node 10, node 14 and node 15.

5.4 Performance Criteria

Greedy Algorithm and HHEAA are compared on the basis of Packets delivered, packets dropped, percentage of packets delivered, nodes alive, nodes dead and percentage of alive nodes. The two algorithms are hereby compared using 10, 40 and 80 nodes.

5.4.1 Performance of Greedy Algorithm for 10 nodes WSN

All nodes were assigned equal energy, at the start of simulation. The nodes were placed randomly. Shortest distance from destination node was calculated at each hop and shortest path was selected from source to the destination. It was noted that Greedy algorithms work efficiently for smaller number of nodes as shown in Table 5.1. The results for 10 nodes show that all packets were delivered successfully. Only one node was dead at the end of simulation. Packet success rate was 100% while 90% nodes were alive.

5.4.2 Performance of HHEA Algorithm for 10 nodes WSN

Initially all the nodes were assigned equal energy that is equal to 1 joule. Source node generated a packet and intermediate nodes forwarded it to the destination node by using HHEAA. This algorithm calculates average energy of neighbor nodes and forwards the packet to the node at minimum distance. It is shown in Table 5.1 that this algorithm works efficiently for 10 nodes as the packet successful delivery rate is

100% and also 100% nodes are alive. Energy is consumed equivalently by all the nodes so all the nodes are alive giving longer life to the network.

Table 5.1: Results of Network having 10 Nodes

	HHEA Algorithm	**Greedy Algorithm**
Delivered Successfully	5000	5000
Packets Dropped	0	0
Percentage Delivered	100%	100%
Alive Nodes	10	9
Percentage alive	100%	90%

5.4.3 Performance of Greedy Algorithm for 40 nodes WSN

It was noted that when greedy algorithm was implemented on 40 nodes, few packets were dropped. It was because when the number of nodes increased demand of shortest path also increased which resulted in early depletion of energy of few nodes in that path. Packet success rate was 87.5% while 38 nodes were alive at the end of simulation and 2 were dead. It means 95% of nodes were alive. It is an acceptable performance as packet delivery rate is not very poor for 40 node network.

5.4.4 Performance of Greedy Algorithm for 40 nodes WSN

When HHEAA was implemented for a 40 node WSN it displayed the results slightly better than greedy algorithm as the packet delivery rate was 87.8 % and 39 nodes were alive at the end of simulation. Results of both the algorithms were same for 10 nodes which became better for HHEAA when 40 nodes were used. This is an indication that as the number of nodes increases performance of HHEAA and becomes better than the performance of greedy algorithm. The results are shown in Table 5.2.

Table 5.2: Results of Network having 40 Nodes

	HHEA Algorithm	Greedy Algorithm
Delivered Successfully	17554	17500
Packets Dropped	2446	2500
Percentage Delivered	87.8%	87.5%
Alive Nodes	39	38
Percentage alive	97.5%	95%

5.4.5 Performance of Greedy Algorithm for 80 nodes WSN

When greedy algorithm was implemented for 80 nodes the packet delivery success rate dropped down to 69.4%. That shows degradation in performance of greedy algorithm, as the number of nodes increases. At the end of simulation 78 nodes were alive while 2 were dead.

5.4.6 Performance of Greedy Algorithm for 80 nodes WSN

It is obvious from the results shown in Table 5.3 that performance of greedy algorithm is far better than greedy algorithm, as the packet success rate is 78.7% that is much better than 69.4%. Only one node was dead at the end of simulation.

Table 5.3: Results of Network having 80 Nodes

	HHEA Algorithm	Greedy Algorithm
Delivered Successfully	31498	27773
Packets Dropped	8502	12227
Percentage Delivered	78.7%	69.41%
Alive Nodes	79	78
Percentage alive	98.7%	97.5%

5.4.7 Average Results of 50 nodes WSN

When HHEAA was executed for three different topologies of 50 nodes wireless sensor network results mentioned in Table 5.4 were noted.

Table 5.4 Average Results of 50 Nodes

Topology	Packets Delivered	%age Delivered	Packets Dropped	Nodes Alive	Nodes Dead
1	23542	94	1458	46	4
2	24025	96.1	975	46	4
3	20286	81.14	4714	46	4
Average	22618	90.47	2382	46	4

5.5 Summary of Results

HHEAA was tested for 10, 20, 30, 40, 50, 60, 80, 90 and 100 nodes. The summary of results shown in Table 5.5 provides a clear picture of efficiency of the proposed algorithm. It is evident from the results that performance of HHEAA gets better and better when the number of nodes increases. It is an energy aware algorithm so number of dead nodes are also lesser than the greedy algorithm.

Table 5.5: Complete Simulation Results

	Packets Delivered				Packets Dropped	
# of Nodes	**HHEAA**	**HHEAA %age**	**Greedy**	**Greedy %age**	**HHEAA**	**Greedy**
10	5000	100	5000	100	0	0
20	10000	100	9251	92.5	0	749
30	13500	90	10500	70	1500	4500
40	18000	90	17500	87.5	2000	2500
50	22618	90.47	18452	73.8	2382	6548
60	24524	81.7	24436	81.4	5476	5564
80	31500	78.7	27773	69.41	8500	12227
90	36615	81.4	26008	57.8	8385	18992
100	41499	83	32237	64.5	8501	17763

Table 5.6: Simulation Results of Nodes

No. of Nodes	HHEAA Nodes Alive	Percentage of Alive nodes	Greedy Nodes Alive	Percentage of Alive nodes
10	10	100	9	90
20	20	100	19	95
30	29	96.7	28	93.3
40	39	97.5	38	95
50	46	92	44	88
60	58	96.7	57	95
80	79	98.7	78	97.5
90	86	95.5	85	94.4
100	96	96	95	95

5.5 Comparison of HHEA and Other Routing Algorithms using charts.

Greedy Algorithm is a simple shortest path routing algorithm. It is not energy aware so it does not consider energy level while selecting the next hop. The proposed algorithm HHEAA checks the energy available in the nodes and also the geographic location of the node. Graphic representation of the results presented earlier in the Table 5.4 clearly shows the better performance of HHEAA as compared to the Greedy Algorithm.

Figure 5.5 shows the packets that are successfully delivered in both the algorithms. It is clear from the graph that in HHEAA number of packets delivered is higher than the Greedy Algorithm . This shows that HHEAA is more efficient as compared to Greedy Algorithm. In Figure 5.5 Results of GPSR[62], Flooding[62] and PGR[62] are also compared with HHEAA. Packets delivered by HHEAA are better than GPSR, Flooding and Greedy Algorithm. But PGR shows better performance in this case. PGR works on the geographical information of the nodes and also the remaining energy of the node and reliability of the link. It assigns probabilities to the nodes on the basis of energy and reliability cost. Roulette wheel algorithm is used to select the next hop from the neighbors.

Figure 5.6 shows the number of alive nodes and number of dead nodes after the execution of the simulation for HHEAA and Greedy Algorithm. It is clear from the results that the proposed algorithm consumes energy very efficiently so the number of alive nodes is higher as compared to Greedy Algorithm. This gives longer life to the network and avoids creation of routing holes.

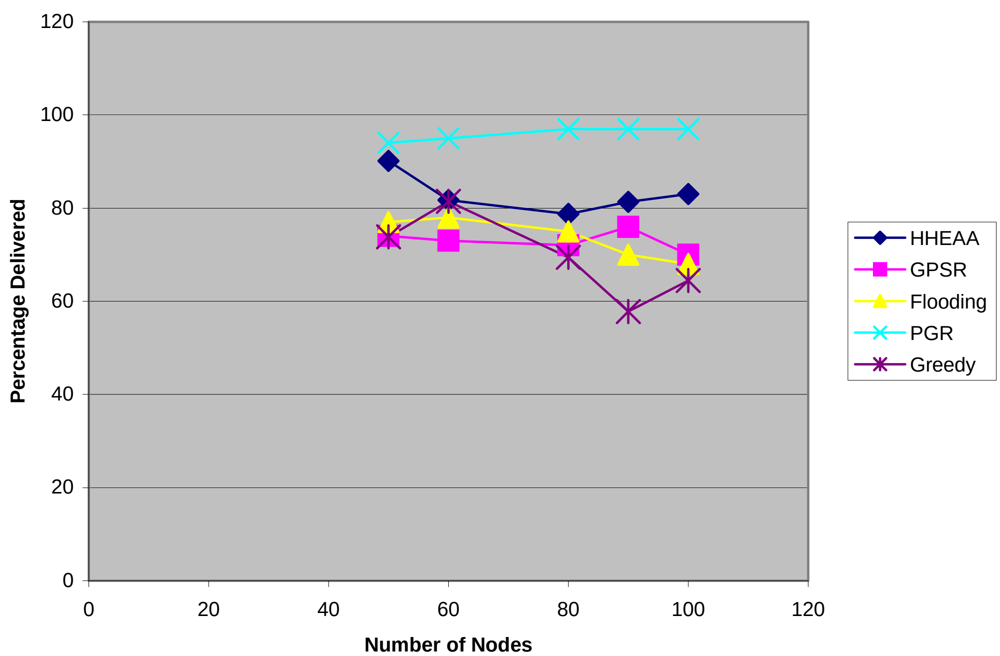

Figure 5.5: Packets Delivered in HHEA, GPSR, Flooding, PGR and Greedy Algorithm.

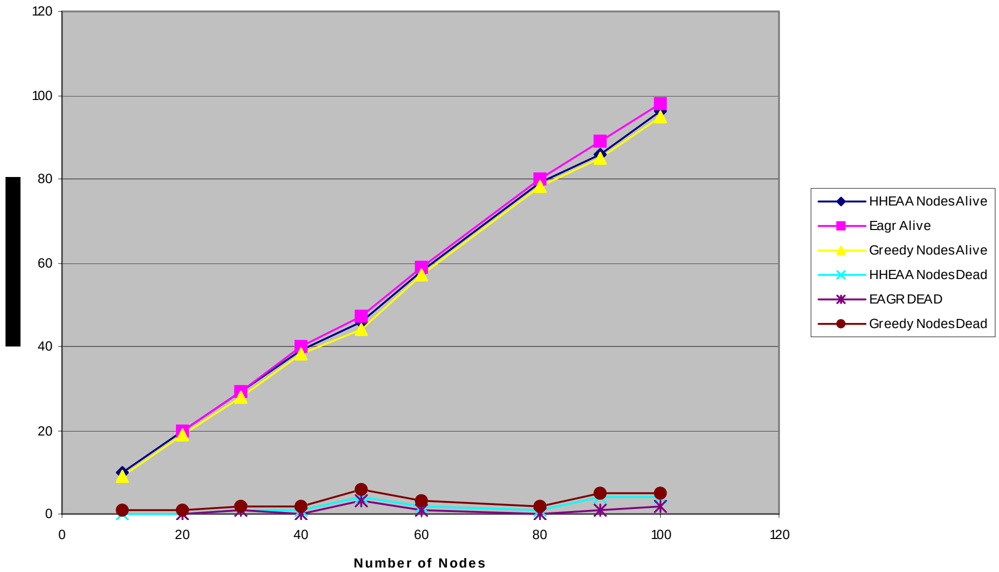

Figure 5.6: Nodes Alive and Dead in HHEA and Greedy Algorithm.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

Vast use of sensor networks has resulted in routing issues for these networks. It has introduced new challenges as compared to wired networks, because of lesser number of resources available, incase of wireless networks. Sensor networks are used in different applications, ranging from defense purposes to every day weather forecast. Different routing strategies are used according to the application area. Routing protocols can be classified in three major categories. Those are data-centric, hierarchical and location based.

Data-centric protocols assign names to data and retrieves information from the nodes according to the naming scheme. In hierarchical protocols node clusters are made. Each cluster has a cluster head that aggregates data and transfers it to destination nodes. Location based protocols work on location information and topological deployment of the sensor nodes. The main problem in intelligent utilization of location information is that it should also use available energy efficiently.

Geographic routing has many positive aspects but due to energy inefficiency it is a big challenge for researchers. Researchers are developing new strategies to get the best out of geographic routing. In sensor networks there are two types of nodes, data sensing nodes and forwarding nodes. Sensing nodes sense the data from surroundings but the forwarding nodes have to forward packets of many nodes. This continuous usage of these nodes results in early depletion of their energy and formation of routing holes. Routing hole is an area where the nodes cannot further transfer the data due to dead nodes in path.

In this research work location of nodes and energy level of a node is considered for forwarding data so that the load of forwarding packets should be equally distributed among the nodes. In greedy algorithm the packets are forwarded to nodes having shortest distance from the destination and due to heavy utilization these nodes lose their energy more quickly resulting in formation of routing holes. When packets reach these routing holes they are dropped because of unavailability of further alive nodes.

In HHEAA all the nodes equally utilize their energy by selection of node on basis of average energy of all the neighbors and shortest distance. Even then if a routing hole is created HHEAA comes out of it by reversing the link and using some alternate path decided by HHEAA.

By comparing the results obtained by execution of greedy algorithm and HHEAA on basis of packets delivered, dropped, nodes alive and nodes dead, it was noted that HHEAA is more efficient than simple greedy algorithm. Its packet delivery success rate is higher and also gives longer life to the network.

6.2 Future work

Rapid increase in use of sensor networks has opened many doors for research in this field. Routing, data security, data reliability etc are the main areas for research. To further improve the performance of HHEAA in terms of efficiency, network life and awareness of energy, the following methodologies are suggested for implementation.

- In this research work static sensor nodes are considered, it should also work for mobile sensor nodes that change their location resulting in change of topology.

- Buffer size of sensor nodes is considered infinite, so overflow situation is not taken care of. Routing protocol can be redesigned for fixed buffer size and handle the problems associated with queuing and overflow in that situation.
- Fixed size of packets is taken in this work so energy consumption is same for all packets. Variable size packets use different energy levels for their transmission, this routing algorithm can be extended to be used for taking care of variation in packet size and usage of energy respectively.

REFERENCES

[1] lan F. Akyildiz, Weilian Su, Yogesh Sankarasubramaniam, adna Erdal Cayirci,,“ A Survey on Sensor Networks”, IEEE Comm. Mag, Aug. 2002, pp. 102.

[2] K. Akkaya and M. Younis, “A Survey on Routing Protocols for Wireless Sensor Networks”, Elsevier Journal of Ad Hoc Networks. v3 i3. 325-349. .

[3] K. Akkaya and M. Younis, “Energy and QOS aware Routing in Wireless Sensor Networks”, Source Cluster Computing archive, Volume 8, Issue 2-3 (2005) , 179 – 188.

[4] V. Rahunathan, C. Schurgers, S. Park and Mani B. Srivastava, “Energy Aware Wireless Sensor Networks”, pp. 1-17; Dept of Elec Eng, Uni of California, L. A, 2004.

[5] Razia Haider and Dr. M. Younas Javed, “EAGR: Energy Aware Greedy Routing in Sensor Networks”, (fgcn 2007), Dec. 2007,Volume: 2, 344349-344349

[6] Y. Yu, D. Estrin, and R. Govindan, “Geographical and energy aware routing: A recursive data dissemination algorithm for wireless sensor networks,” UCLA-CSD, Technical Report TR- 01-0023, may 2001.

[7] B. Karp and H. Kung, “Gpsr: Greedy perimeter stateless routing for wireless networks,” in ACM MOBICOM, Boston, August 2000.

[8] H. Hassanein, J. Luo, “ Reliable Energy Aware Routing in Wireless Sensor Networks”,dssns,pp.54-64, Second IEEE Workshop on Dependability and Security in Sensor Networks and Systems, 2006.

[9] J. Chen, R. Lin, Y. Li , Y. Sun, “LQER: A Link Quality Based Routing for Wireless Sensor Networks”, Sensors 2008, 8, 1025-1038.

[10] N. Ahmed, Salil S. Kanhere, S Jha, “The Holes Problem in Wireless Sensor Networks A Survey”, “SIGMOBILE Mob. Comp. Comm. Rev., vol. 9, no. 2, 4-18, 2005.

[11] Z. Karakehayov, “Using REWARD to detect team black-hole attacks in wireless sensor networks”, **http://www.sics.se/realwsn05/proceedings.html,2005**..

[12] Anthony D. Wood, Jhon A. Stankovic, " Denial of Service in Sensor Networks", vol. 35, no. 10, 2002, 54–62.

[13] Yih-Chun Hu, A. Perrig, David B. Johnson, " Wormhole detection in wireless adhoc networks". Technical Report TR01-384, Dept of Compr Sci, Rice Uni, June 2002.

[14] B. Deb, S. Bhatnagar, B. Nath, "ReInForM: Reliable Information Forwarding using Multiple Paths in Sensor Networks", Proc. 28th IEEE Int'l Conf (2003), 406-415.

[15] Ghalib A. Shah, Demet Aksoy, "RAT: Routing by Adaptive Targeting in Wireless Sensor/ Actor Networks", COMSWARE 2007, pp. 1-9.

[16] E. Le Merrer, V. Gramoli, M. Bertier, "Energy Aware Self-organizing Density Management in Wireless sensor networks", Proc. 1st int'l workshop on Decentralized resource sharing in mob comp and networking , 24 – 29.

[17] S. Singh, M. Woo, C. S. Raghavendra, "Power-Aware Routing in Mobile Ad Hoc Networks", MOBICOM 1998: 181-190.

[18] Rahul c. Shah, Jan M. Rabaey, "Energy Aware Routing for Low Energy Ad Hoc Sensor Networks", Proc. IEEE (WCNC), Orlando, FL, March 2002..

[19] Danie A Sadi ek, "Energy-aware Compilation for Wireless Sensor Networks", MidSens 2007: 25-30.

[20] C. Huang ,Y.Tseng, "The Coverage Problem in a Wireless Sensor Network", Proc.2nd ACM Int'l Conf., 115 - 121.

[21] Q. Fang, J. Gao, L. J. Guibas, "Locating and Bypassing Routing Holes in Sensor Networks", IEEE INFOCOM 2004.

[22] Andreas A. Strikos, "A full approach for Intrusion Detection in Wireless Sensor Networks".

[23] Peter Corke, Ron Peterson and Daniela Rus, "Finding Holes in Sensor Networks".

[24] F. L. Lewis, “Wireless Sensor Networks”, in the Proceedings of Smart Environment Technologies, Protocols, and Applications, New York, 2004 (to appear).

[25] Lakshmana Prasanth Nittala Venkata, “routing algorithms for large scale wireless sensor networks”, Master thesis for Computer Science, Texas A&M University, Dec 2004

[26] K. S. Chan, H. P. Nik, F. fekri, “Analysis of hierarchical Algorithms for Wireless Sensor Network Routing Protocols”, in the Proceedings of IEEE Communications Society /WCNC 2005.

[27] T. Melodia, D. Pompili, Ian F. Akyildiz, “ Optimal Local Topology Knowledge for Energy geographic Routing in Sensor networks”, in the proceedings of IEEE INFOCOM, Hong Kong S.A.R., PRC, March 2004.

[28] E. Ilker Oyman and Cem Ersoy, “Overhead Energy Consideration for Efficient Routing in Wireless Sensor Networks”, Computer Engineering Department, Bogazici University, Istanbul, Turkey.

[29] ShiboWu, K. Sel¸cuk Candan, “GPER: Geographic Power Efficient Routing in Sensor Networks”, Proceedings of the 12th IEEE International Conference on Network Protocols (ICNP’04), pp.161-172, Berlin, Germany, October 2004.

[30] http://www.acm.org/crossroads/xrds9-4/sensornetworks.html.

[31] Uk-Pyo Han, Sang-Eon Park, Seung-Nam Kim, Young-Jun Chung, “An Enhanced Cluster Based Routing Algorithm for Wireless Sensor Networks”, in the Proceedings of the International Conference on Parallel and Distributed Processing Techniques and Applications and Conference on Real Time Computing systems ad Applications, PDPTA 2006, pp.758-763, Lasvegas, Nevada, USA, June 2006.

[32] Archana Bharathidasan, Vijay Anand Sai Ponduru**, “**Sensor Networks: An Overview”, Department of Computer Science, University of California, Davis, CA 95616.

[33] K. Zeng, K. ren, W. Lou, and P. J. Moran, “ Energy – Aware Geographic Routing in Lossy Wireless Sensor Networks with Environmental Energy Supply”, The Third International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks, Waterloo, ON, Canada, ACM, Aug, 2006.

[34] Pottie, J. and Kaiser, W. J. "Wireless Integrated Network Sensors," Communications of the ACM, Vol. 43, no. 5, pp.51-58, May 2000.

[35] Shen, C., Srisathapornphat, C., and Jaikaeo, C. "Sensor Information Networking Architecture and Applications," IEEE Pers. Commun., August 2001.

[36] Y. Yi, M. Gerla and T. Kwon, “Efficient Flooding in Ad hoc Networks using On-Demand (Passive) Cluster Formation”, MOBIHOC 2002.

[37] G. Barrenechea, B. Beferull-Lozano, and M. Vetterli, “Lattice Sensor Networks: Capacity Limits, Optimal Routing and Robustness to Failures,” Proceedings of the third international symposium on Information processing in sensor networks, pp. 186–195, Berkeley, California, April 2004.

[38] C. L. Barett, S. J. Eidenbenz, L. Kroc, M. Marathe, and J. P. Smith, “Parametric Probabilistic Sensor Network Routing,” Proceedings of the 2nd ACM international conference on Wireless sensor networks and applications, pp. 122–131, San Diego, California, September 2003.

[39] M. Kaufmann, J. F. Sibeyn, and T. Suel, “Derandomizing Algorithms for Routing and Sorting on Meshes,” Proceedings of the 5th Annual ACM-SIAM Symposium on Discrete Algorithms, pp. 669–679, Arlington, Virginia, 1994.

[40] D. Braginsky, and D. Estrin, “Rumor Routing Algorithm for Sensor Networks,” Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications, pp.22–31, Atlanta, Georgia, 2002.

[41] C. Intanagonwiwat, R. Govindan, and D. Estrin, “Directed diffusion: a scalable and robust communication paradigm for sensor networks,” Proceedings of the 6th annual international conference on Mobile computing and networking, pp. 56–67, Boston, Massachusetts, August 2000.

[42] B. Krishnamachari, D. Estrin, and S. Wicker, “Modeling Data-Centric Routing in Wireless Sensor Networks,” Proceedings of the 2002 IEEE INFOCOM, New York, NY, June 2002.

[43] S. D. Servetto, and G. Barrenechea, “Constrained Random Walks on Random Graphs: Routing Algorithms for Large Scale Wireless Sensor Networks,” Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications, pp. 12–21, Atlanta, Georgia, September 2002.

[44] F. Ye, H. Luo, J. Cheng, S. Lu, and L. Zhang, “A Two-Tier Data Dissemination Model for Large-scale Wireless Sensor Networks,” Proceedings of the 8th annual international conference on Mobile computing and networking, pp. 148–159, Atlanta, Georgia, September 2002.

[45] S. Hedetniemi and A. Liestman, “A survey of gossiping and broadcasting in communication networks,” Networks, Vol. 18, No. 4, pp. 319-349, 1988.

[46] W. Heinzelman, J. Kulik, and H. Balakrishnan, “Adaptive protocols for information dissemination in wireless sensor networks,” in the Proceedings of the 5th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom’99), Seattle, WA, August 1999.

[47] D. Estrin, et al., “Next century challenges: Scalable Coordination in Sensor Networks,” in the Proceedings of the 5th annual ACM/IEEE international conference on Mobile Computing and Networking (MobiCom’99), Seattle, WA, August 1999.

[48] A. Manjeshwar and D. P. Agrawal, “TEEN : A Protocol for Enhanced Efficiency in Wireless Sensor Networks," in the Proceedings of the 1st International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing, San Francisco, CA, April 2001.

[49] S. Lindsey and C. S. Raghavendra, "PEGASIS: Power Efficient GAthering in Sensor Information Systems," in the Proceedings of the IEEE Aerospace Conference, Big Sky, Montana, March 2002.

[50] S. Lindsey, C. S. Raghavendra and K. Sivalingam, "Data Gathering in Sensor Networks using the Energy*Delay Metric", in the Proceedings of the IPDPS Workshop on Issues in Wireless Networks and Mobile Computing, San Francisco, CA, April 2001.

[51] A. Manjeshwar and D. P. Agrawal, "APTEEN: A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks," in the Proceedings of the 2nd International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile computing, Ft. Lauderdale, FL, April 2002.

[52] L. Subramanian and R. H. Katz, "An Architecture for Building Self ConFigureurable Systems," in the Proceedings of IEEE/ACM Workshop on Mobile Ad Hoc Networking and Computing, Boston, MA, August 2000.

[53] M. Younis, M. Youssef and K. Arisha, “Energy-Aware Routing in Cluster-Based Sensor Networks”, in the Proceedings of the 10th IEEE/ACM International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems (MASCOTS2002), Fort Worth, TX, October 2002.

[54] M. Youssef, M. Younis and K. Arisha, “A constrained shortest-path energy-aware routing algorithm for wireless sensor networks,” in the Proceedings of the IEEE Wireless Communication and Networks Conference (WCNC 2002), Orlando, FL, March 2002.

[55] M. Younis, P. Munshi and E. Al-Shaer “Architecture for Efficient Monitoring and Management of Sensor Networks,” in the Proceedings of the IFIP/IEEE Workshop on End-to-End Monitoring Techniques and Services (E2EMON’03), Belfast, Northern Ireland, September 2003 (to appear)**.**

[56] Y. Xu, J. Heidemann, and D. Estrin, "Geography-informed energy conservation for ad hoc routing," in the Proceedings of the 7th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom’01), Rome, Italy, July 2001.

[57] V. Rodoplu and T.H. Ming, "Minimum energy mobile wireless networks," IEEE Journal of Selected Areas in Communications, Vol. 17, No. 8, pp. 1333-1344, 1999.

[58] L. Li and J. Y Halpern, “Minimum energy mobile wireless networks revisited,” in the Proceedings of IEEE International Conference on Communications (ICC’01), Helsinki, Finland, June 2001.

[59] W.Heinzelman, A.Chandrakasan, and H.Balakrishnan, “Energy-efficient communication protocol for Wireless Sensor Networks”, in the proceeding of the Hawaii International Conference System Sciences, Hawaii, January 2000.

[60] Y. Yao and J. Gehrke, \The cougar approach to in-network query processing in sensor networks", in SIGMOD Record,
September 2002.

[61] http:// **www.worldsens.net**

[62] Tanya Roosta, Mike Menzo and Prof. Shankar Sastry, “Probabilistic Geographic Routing Protocol for Ad Hoc and Sensor Networks”.