PROJECT REPORT

(January 2015 to May 2015)

PERFORMANCE ANALYSIS AND IMPROVEMENTS FOR ENERGY EFFICIENT ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORKS

Submitted by

Sunidhi Sarpal (11103029)
Tejal Singla (11103030)
Amla Srivastava (11103031)

Under the Guidance of

Prof. Padmavati
Assistant Professor
Department of Computer Science and Engineering
PEC University of Technology

Department Of Computer Science & Engineering
PEC University of Technology, Chandigarh

January to May, 2015

DECLARATION

We, hereby declare that the project work entitled '**Performance Analysis and Improvements for Energy Efficient Routing Protocols In Wireless Sensor Networks** is an authentic record of our own work carried out as requirements of Capstone project for the award of degree of B.E. Computer Science and Engineering, PEC University of Technology, Chandigarh, under the guidance of Prof. Padmavati during January to May,2015.

Sunidhi Sarpal (11103029)
Tejal Singla (11103030)
Amla Srivastava (11103031)

Date: ____________________

APPROVAL AND DECLARATION SHEET

This project report entitled **—** "**Performance Analysis and Improvements for Energy Efficient Routing Protocols In Wireless Sensor Networks**" was prepared and submitted by **Sunidhi Sarpal (11103029), Tejal Singla (11103030)** and **Amla Srivastava** (**11103031**) has been found satisfactory in terms of scope, quality and presentation as partial fulfillment of the requirement for the Bachelor of Engineering (Computer Science and Engineering) in PEC University Of Technology (Deemed University), Chandigarh.

Prof. Padmavati
Assistant Professor
Department of Computer Science & Engineering
PEC University of Technology, Chandigarh

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Sunidhi Sarpal

Tejal Singla

Amla Srivastava

ABSTRACT

The main task of wireless sensor network (WSN) is to detect and report the events of the physical world. In most cases, nodes are batteries powered with limited energy resources. In such energy-constrained wireless sensor networks, energy efficiency is critical for prolonging the network lifetime. In the past decade, WSNs have gained great achievements both in the academic circle and the industrial field with widespread applications. One of the major aspects of understanding the WSNs is the routing algorithm they utilize. As and when a node runs out of power and stops working, the original transmission paths will be changed. Nodes nearby will suffer from heavier work, because of sharing responsibility of the exhausted node which casts heavy burden of them. The energy dissipating rate of these nodes will become faster which will further cause the packets loss or even network congestion. Moreover, the performance of the network depends on the persistence of the sensors to a large extent. Hence, the main challenge for the energy-constrained network is to design energy-efficient routing protocols which guarantees the persistence and balances the energy consumption of the network. The ant colony optimization (ACO) is one of the most useful swarm intelligence which has been successfully applied in many optimization problems such as TSP, CVRP as well as routing in WSNs. A variety of combinations and variants of ACO are available to introduce energy efficiency into routing which has been studied in this project. It is important to analyze the routing methodology taking into consideration the energy aspects possible and the computational effort required to ensure balanced consumption. This project primarily aims to study and analyze some proposed protocols for different applications and based on that give some proposals for further improvement.

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LIST OF ABBREVATIONS

WSN……………………………………………………………................Wireless Sensor Network
ACO……………………………………………………………….…Ant Colony Optimization
DAACA……………………………………………..Data Aggregation Ant Colony Algorithm
ES-DAACA ……………………………………………….… Elitist Strategy based DAACA
MM-DAACA……………………………………………………..Max–Min based DAACA
ACS-DAACA ……………………………….……..Ant Colony System based DAACA
OSI…………………………………………………….............Open Systems Interconnection
TCP………………………………………………………………Transmission Control Protocol
ISM ....Industrial Science and Medical
GPS………………………………………………………..….........Global Positioning System
MAC………………………………………………………..….........Medium Access Control
MANET…………………………………………………..….........Mobile ad-hoc Network
FACR…………………………………………….........Feedback-enhanced Ant Colony Routing
TACR………………………………….…………….Traditional Ant Colony Routing

CHAPTER 1

INTRODUCTION

In this chapter, the introduction and motivation behind the work has been mentioned. Here the objectives of this project have been defined and the overview of energy efficient routing protocols in wireless sensor network has been presented. Also the organization of the project has been presented.

1.1. Wireless Sensor Networks

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. The more modern networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on.

The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust, although functioning "motes" of genuine microscopic dimensions have yet to be created. The cost of sensor nodes is similarly variable, ranging from a few to hundreds of dollars, depending on the complexity of the individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and communications bandwidth. The topology of the WSNs can vary from a simple star network to an advanced multi-hop wireless mesh network. The propagation technique between the hops of the network can be routing or flooding.

At present, agent-based modeling and simulation is the only paradigm which allows the simulation of complex behavior in the environments of wireless sensors (such as flocking). Agent-based simulation of wireless sensor and ad hoc networks is a relatively new paradigm. Agent-based modeling was originally based on social simulation.

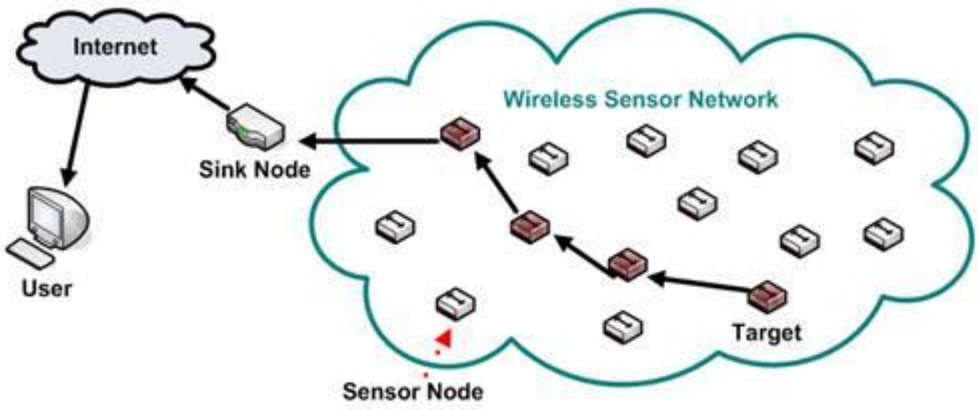

Figure 1.1: Wireless Sensor Network

Network simulators like OPNET, NetSim, NS2 and OMNeT can be used to simulate a wireless sensor network.

1.2 Energy Efficient Routing in WSNs

Over the years, Wireless Sensor Networks (WSN) have attracted in increasing interest from researchers due to its ubiquitous nature, easy deployment, and the range of applications they enable. Networks of thousands tiny sensor devices, which have low processing power, limited memory and energy, play important roles for an economical solution to some of the challenging problems, such as, real-time traffic monitoring, building safety monitoring, military sensing and tracking, wildlife monitoring, measurement of seismic activity and so on. These sensors have the ability to communicate either among each other or directly to an external base-station (BS).

Routing is a process of determining a path between source and destination upon request of data transmission. Sensor nodes are constrained in energy supply and bandwidth. Thus, innovative techniques that eliminate energy inefficiencies that would shorten the lifetime of the network are highly required. Routing in WSNs is very challenging due to the inherent characteristics that distinguish these networks from other wireless networks like mobile ad hoc networks or cellular networks. First, due to the relatively large number of sensor nodes, it is not possible to build a global addressing scheme for the deployment of a large number of sensor nodes as the overhead of ID maintenance is high. Thus, traditional IP-based protocols may not be applied to WSNs. Furthermore, sensor nodes are deployed in an ad hoc manner. Second, in contrast to typical communication networks, almost all applications of sensor networks require the flow of sensed data from multiple sources to a particular BS. Third, sensor nodes are tightly constrained in terms of energy, processing, and storage capacities. Thus, they require careful resource management. Fourth, in most application scenarios, nodes in WSNs are generally stationary after deployment except for, may be, a few mobile nodes. Fourth, sensor networks are application specific. Fifth, position awareness of sensor nodes is important since data collection is normally based on the location. Currently, it is not feasible to use Global Positioning System (GPS) hardware for this purpose. Finally, data collected by many sensors in WSNs is typically based on common phenomena, hence there is a high probability that this data has some redundancy. Such redundancy needs to be exploited by the routing protocols to improve energy and bandwidth utilization.

Due to such differences, many new algorithms have been proposed for the routing problem in WSNs. These routing mechanisms have taken into consideration the inherent features of WSNs along with the application and architecture requirements. To minimize energy consumption, routing techniques proposed in the literature for WSNs employ some well-known routing tactics as well as tactics special to WSNs such as data aggregation. The key idea is to combine the data coming from different sources which eliminates redundancy, minimizes the number of transmissions and thus saves energy. This method shifts the focus from the traditional address centric approaches for networking to a data centric approach. Ant colony optimization (ACO) is one of the most useful swarm intelligence which has been successfully applied in many optimization problems such as TSP as well as routing in wireless sensor networks. The idea of Ant Colony Optimization is originated by Marco Dorigo, in observing the exploitation of seeking shortest path between their nest to the food source although limited cognitive abilities are owned by ants. In Ant Colony Optimization, artificial ants are implemented to search for heuristic solutions of the problems. The solution of ACO will gradually approach to the global optimal solution in terms of adjusting the quantities of pheromones.

Ant Colony Optimization

It is a probabilistic technique to search an optimal path in the graph based on the behaviour of ants seeking a path between their colony and source of food.

Behavior of Ants in Nature

The ants wander randomly at first, laying down a pheromone trail. If food is found, they return to the nest laying down a pheromone trail. If pheromone is found, then with some increased probability the ants follow the pheromone trail. Once they are back at their nests, they go out again in search of food. However, pheromones evaporate over time, such that unless they are reinforced by more ants, the pheromones will disappear.

Concept of ACO

- Ants navigate from nest to food source as the ants are blind.
- Then the shortest path is discovered via pheromone trails.
- Each ant moves at random.
- Pheromone is deposited on path.
- More pheromone on path increases probability of path being followed

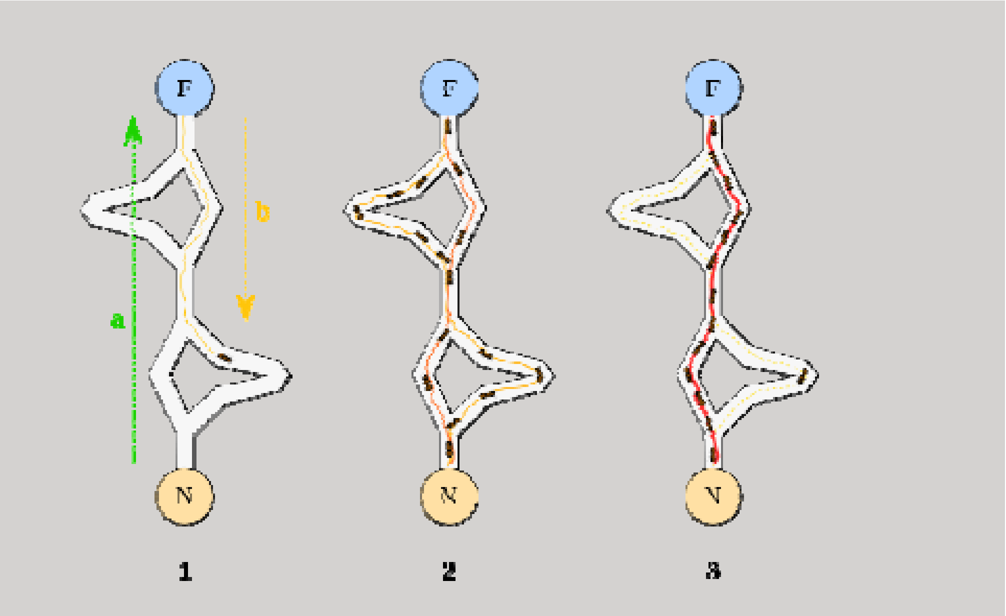

Figure 1.2: Movement of ants between food source (F) and nest (N)

The first ant wanders randomly until it finds the food source (F), then it returns to the nest (N), laying a pheromone trail.

Other ants follow one of the paths at random, also laying pheromone trails. Since the ants on the shortest path lay pheromone trails faster, this path gets reinforced with more pheromone, making it more appealing to future ants. The ants become increasingly likely to follow the shortest path since it is constantly reinforced with a larger amount of pheromones. The pheromone trails of the longer paths evaporate.

1.3. Objectives

The objective behind this project is– **Performance Analysis and Improvements for Energy Efficient Routing Protocols in Wireless Sensor Networks.**

Wireless sensor networks (WSNs) are widely used for applications such as environmental monitoring, airport safety, health care, etc. It usually consists of one or more base stations and lots of sensor nodes which are densely deployed either inside the phenomenon or very close to it. Wireless sensor networks have attracted increasing researchers by their ubiquitous nature, easy deployment, and the range of applications they enable. These sensor nodes usually need to be tiny for not affecting the monitored environment. Recently a number of schemes based on Ant Colony Optimization have been proposed. These try to optimize the average energy cost, energy difference, network lifetime, time complexity for topology construction and maintenance, robustness, fault tolerance and scalability. Over the past few years a number of enhancements have also been proposed.

In this project, we have studied a number of such techniques for energy efficient routing using ACO and its applications to gain a broad understanding of the existing work in this field. We then selected four schemes that have been presented over the past five years and implemented them, using Java. The complete working, features, computational costs and performance of these was then comparatively analysed to identify relative strength. Finally we proposed enhancements to further improve performance and applicability. The objectives are summarised below:

---

1. To study and analyze the existing energy data aggregation efficient routing schemes in Wireless Sensor Networks using ant colony algorithms.
2. To implement the basic DAACA algorithm.
3. To analyze the performance of the DAACA algorithm, EELP scheme and MMACS scheme in terms of energy efficiency.

4. To propose and implement enhancements of DAACA algorithm in terms of energy efficiency and performance.

1.4. Content of Chapters

Chapter 2 describes the **background** of wireless sensor networks. This section introduces the WSNs in detail by comparing them with the traditional wireless networks and analyzing the requirements of the WSNs. Then typical architecture of a WSN node is presented and protocols which are used in data transmission are analyzed. Finally this chapter ends with the characteristics and applications of WSNs.

Chapter 3 contains the **literature survey**. This includes a brief overview of all research papers we studied before starting with the project. A short description of the learning from each research paper is given. This helped us to get a know-how of the existing practices and technologies in the field of Wireless Sensor Networks.

Chapter 4 describes in detail the four schemes which we studied, implemented and analyzed as our base for proposing improvements in enhancing energy efficiency in Wireless Sensor Networks. In this section all these algorithms are presented along with the proposed enhancements.

Chapter 5 contains **implementation details** which begins with the characteristics of the software used for the project, i.e. Java. Once we are familiar with the software we go into how the implementation of the novel approach has been carried out and finally finishing the chapter with its conclusion.

Chapter 6 presents results and discussion of the implemented schemes. It contains performance analysis along with detailed comparisons of the schemes.

Chapter 7 presents conclusion of the project as well as future scope in this field finally followed by reference

CHAPTER 2

BACKGROUND

2.1 Introduction

One of fundamental goals for Wireless Sensor Networks (WSNs) is to collect information from the physical world. Comparing to existing infrastructure – based networks, wireless sensor networks can virtually work in any environment, especially those where wired connections are not possible. WSNs are often deployed to sense, process and disseminate information of targeted physical environments. In general, WSNs consist of battery-operated sensor devices with computing, data processing, and communicating components. The ways the sensors are deployed can either be in a controlled environment where monitoring and surveillance are critical or in an uncontrolled environment. In the uncontrolled environments, security for sensor networks becomes extremely important.

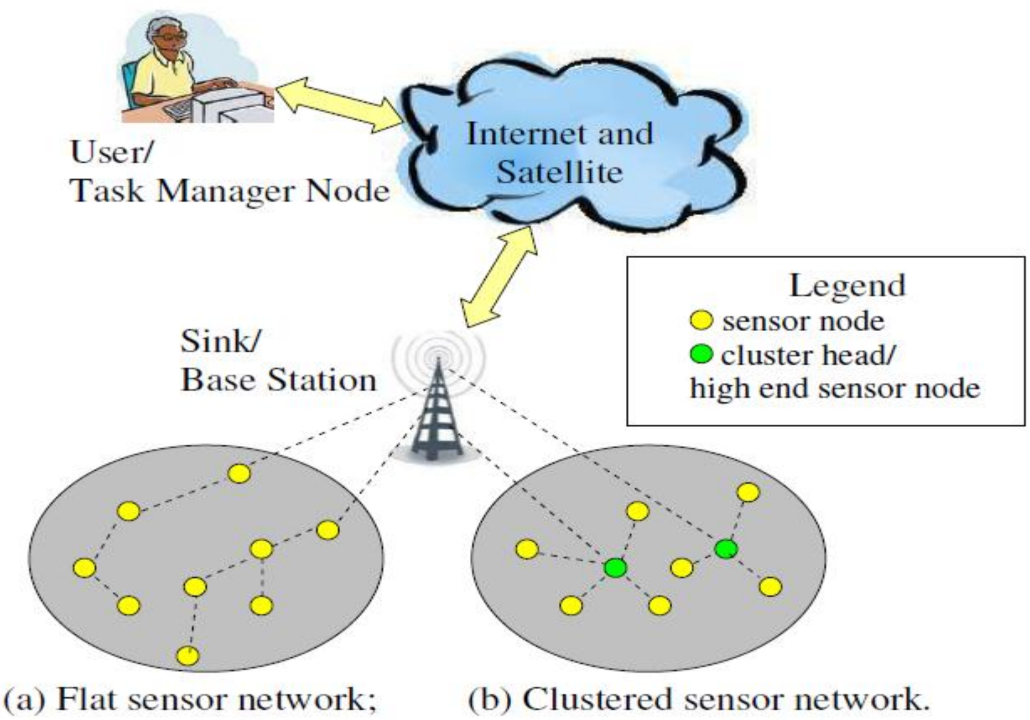

Figure 2.1: Basic architecture of a WSN

2.2 Types of WSNs

Categorization of sensor networks on the bases of interfaces in which nodes are deployed:

- **Underwater Wireless sensor network**

  In this sensor network sensor nodes are deployed under water. Sensor nodes communicate through acoustic waves. Underwater wireless communication today is expensive, sparsely deployed, typically communicating directly to a base-station over long ranges rather than with each other. This network is difficult to establish due to limited bandwidth, long propagation delay and signal fading problem.

- **Underground Wireless sensor network**

  This network is basically established under the ground and used to monitor the underground situations. It is a challenge to communicate via this network due to signal loses and high attenuation. In this network communication is carried out through electromagnetic waves. Underground sensors are expensive because the special components should be used for reliable communication through interfaces like soil rocks, water and other minerals. This type of WSN is also very expensive.

- **Earthbound Wireless sensor network**

  This type of networks also called terrestrial WSNs. This network is cheaper to deploy than the above two. In this thousands of nodes are deployed in ad hoc or in a pre-planned manner. In former case nodes are placed randomly into target area while in latter there can be grid, optimal, 2D, 3D placements.

- **Mobile Wireless Sensor Network**

  In this type of network once the nodes are deployed they move to gather the information. And sensor node has ability to reposition and organize itself in network. Localization, self-organizations, navigation and control, coverage, energy, maintenance, data process etc. are main features of mobile WSNs.

- **Multi-media Wireless sensor networks**

  These are used to monitor and track events in the form of multimedia. These networks consist of a number of low cost sensors equipped with cameras and microphones.

Main features of multi-media WSNs are high bandwidth/low energy, Quality of service, filtering, data processing and compressing techniques.

- **Wireless Nano sensor network**

  The concept is based on integrated machines at the nano scale, which interact on cooperative basis by means of wireless communications. At the present stage, the design of the protocol suite for wireless nano sensor networks represents a fundamental issue to address for accelerating the deployment process of such a technology. [19]

2.3 Wireless Sensor Network Architecture

WSN architecture includes both a hardware platform and operating system designed.

- **Sensor Field**: The area in which sensor nodes are deployed.
- **Sensor Nodes**: Sensor nodes are the sensors which are responsible for gather information and routing this information back to a sink.
- **Sink**: It is also a sensor node which performs a special task of receiving, processing and storing data from other sensor nodes. This node is responsible for reduction of messages need to be sent and also reduce the energy requirements.
- **Task Manager (Base Station)**: It is a centralized point of control within the network used to extract information from the network and passes control information back to the network. It is one or more distinguished components of the WSN with much more computational, energy and communication resources. It acts as a gateway between sensor nodes and the end user as they typically forward data from the WSN on to a server. [19]

Other special components in routing based networks are routers, designed to compute, calculate and distribute the routing tables. Many techniques are used to connect to the outside world including mobile phone networks, satellite phones, radio modems, high power Wi-Fi links etc.

Each sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for:

- Interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting.
- Gateway or Access points – A Gateway enables communication between Host application and field devices.
- Network manager – A Network Manager is responsible for configuration of the network, scheduling communication between devices (i.e., configuring super frames), management of the routing tables and monitoring and reporting the health of the network.
- Security manager – The Security Manager is responsible for the generation, storage, and management of keys. [16]

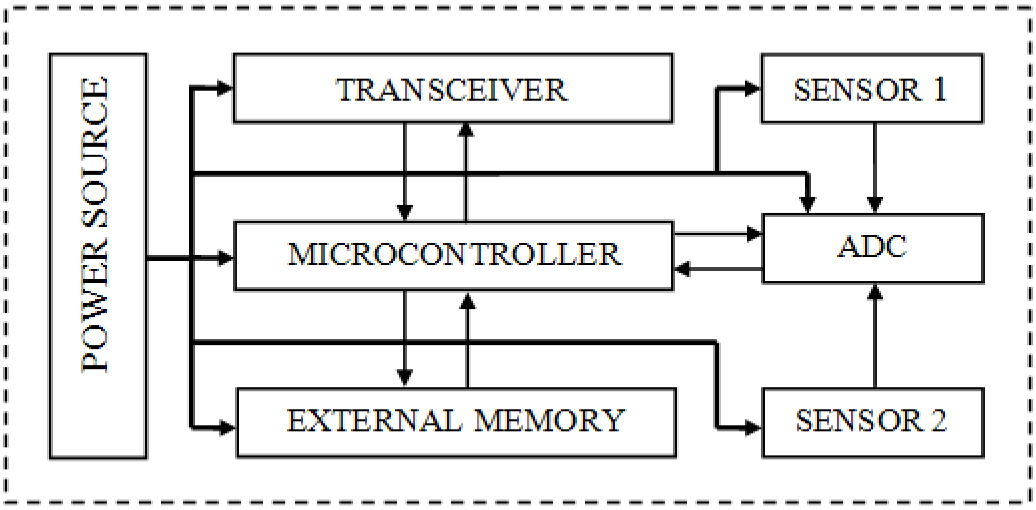

Figure 2.2: Architecture of a Node in a WSN

The main components of a sensor node are microcontroller, transceiver, external memory, power source and one or more sensors.

- **Microcontroller -** Microcontroller performs tasks, processes data and controls the functionality of other components in the sensor node. Other alternatives that can be used as a controller are: General purpose desktop microprocessor, Digital signal processors, Field Programmable Gate Array and Application-specific integrated circuit. Microcontrollers are most suitable choice for sensor node. Each of the four choices has their own advantages and disadvantages. Microcontrollers are the best choices for embedded systems. Because of their flexibility to connect to other devices, programmable, power consumption is less, as these devices can go to sleep state and part of controller can be active. In general purpose microprocessor the power consumption is more than the microcontroller; therefore it is not a suitable choice for sensor node. Digital Signal Processors are appropriate for broadband wireless communication. But in Wireless Sensor Networks, the wireless communication should be modest i.e., simpler, easier to process modulation and signal processing tasks of actual sensing of data is less complicated.

- **Transceiver -** Sensor nodes make use of ISM (Industrial Science and Medical) band which gives free radio, huge spectrum allocation and global availability. The various choices of wireless transmission media are Radio frequency, Optical communication (Laser) and Infrared. Laser requires less energy, but needs line-of-sight for communication and also sensitive to atmospheric conditions. Infrared like laser, needs no antenna but is limited in its broadcasting capacity. Radio Frequency (RF) based communication is the most relevant that fits to most of the WSN applications. WSN's use the communication frequencies between about 433 MHz and 2.4 GHz. The functionality of both transmitter and receiver are combined into a single device know as transceivers are used in sensor nodes. Transceivers lack unique identifier. The operational states are Transmit, Receive, Idle and Sleep. Current generation radios have a built-in state machines that perform this operation automatically. Radios used in transceivers operate in four different modes: Transmit Receive, Idle, and Sleep. Radios operating in Idle mode results in power consumption, almost equal to power consumed in Receive mode. Thus it is better to completely shut down the radios rather than in the Idle mode when it is not Transmitting or Receiving. And also significant amount of power is consumed when switching from Sleep mode to Transmit mode to transmit a packet.

- **Sensing Unit -** It senses the environment through transceiver.

- **External Memory** - From an energy perspective, the most relevant kinds of memory are on-chip memory of a microcontroller and FLASH memory - off-chip RAM is rarely if ever used. Flash memories are used due to its cost and storage capacity. Memory requirements are very much application dependent.

- **Power Source** - Power consumption in the sensor node is for Sensing, Communication and Data Processing. More energy is required for data communication in sensor node. Energy expenditure is less for sensing and data processing. The energy cost of transmitting 1 Kb for distance of 100 m is approximately the same as that for the executing 3 million instructions by 100 million instructions per second/W processor. Power is stored either in Batteries or Capacitors. Batteries are the main source of power supply for sensor nodes. Namely two types of batteries used are chargeable and non-rechargeable.

- **Sensors** – These are classified into three categories: passive, omni-directional sensors; passive, narrow-beam sensors; and active sensors. Passive sensors sense the data without actually manipulating the environment by active probing. They are self-powered; that is, energy is needed only to amplify their analog signal. Active sensors actively probe the environment, for example, a sonar or radar sensor, and they require continuous energy from a power source. Narrow-beam sensors have a well-defined notion of direction of measurement, similar to a camera. Omni-directional sensors have no notion of direction involved in their measurements.

The overall theoretical work on WSNs works with passive, omni-directional sensors. Each sensor node has a certain area of coverage for which it can reliably and accurately report the particular quantity that it is observing. Several sources of power consumption in sensors are: signal sampling and conversion of physical signals to electrical ones, signal conditioning, and analog-to-digital conversion. Spatial density of sensor nodes in the field may be as high as 20 nodes per cubic meter.

2.4 Protocol Stack

Most common architecture for WSN follows the OSI Model. Basically in sensor network we need five layers: application layer, transport layer, network layer, data link layer and physical layer. Added to the five layers are the three cross layers planes as shown in figure below. The three cross planes or layers are; power management plane, mobility management plane and task management plane. These layers are used to manage the network and make the sensors work together in order to increase the overall efficiency of the network.

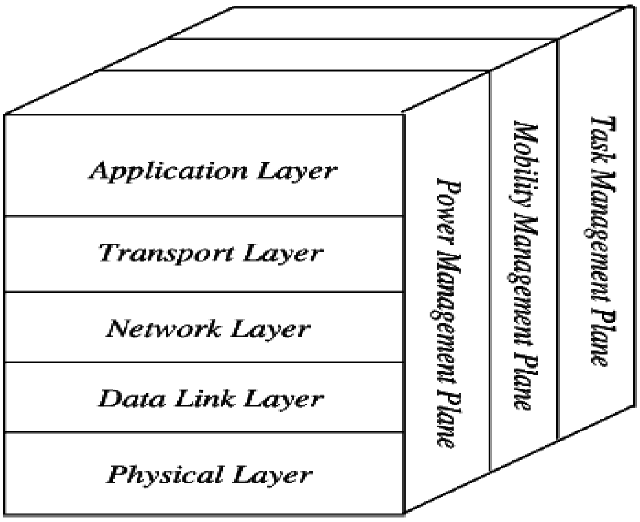

Figure 2.3: Protocol Stack in WSN

- Mobility management plane: detect sensor nodes movement. Node can keep track of neighbors and power levels (for power balancing).
- Task management plane: schedule the sensing tasks to a given area. Determine which nodes are off and which ones are on.[17]

The traditional layers of the stack are described as below:

1. Application Layer

The application layer includes a variety of application – layer protocols that perform various sensor network applications, such as query dissemination, node localization, time synchronization, and network security. For example, the sensor management protocol (SMP) is an application – layer management protocol that provides software operations to perform a variety of tasks, for example, exchanging location – related data, synchronizing sensor nodes, moving sensor nodes, scheduling sensor nodes, and querying the status of sensor nodes.

2. Transport Layer

In general, the transport layer is responsible for reliable end – to – end data delivery between sensor nodes and the sink(s). Due to the energy, computation, and storage constraints of sensor nodes, traditional transport protocols cannot be applied directly to sensor networks without modification. For example, the conventional end – to – end retransmission – based error control and the window – based congestion control mechanisms used in the transport control protocol (TCP) cannot be used for sensor networks directly because they are not efficient in resource utilization.

3. Network Layer

The network layer is responsible for routing the data sensed by source sensor nodes to the data sink(s). In a sensor network, sensor nodes are deployed in a sensing region to observe a phenomenon of interest. The observed phenomenon or data need to be transmitted to the data sink. In general, a source node can transmit the sensed data to the sink either directly via single – hop long – range wireless communication or via multi-hop short – range wireless communication. However, long – range wireless communication is costly in terms of both energy consumption and implementation complexity for sensor nodes. In contrast, multi-hop short – range communication can not only significantly reduce the energy consumption of sensor nodes, but also effectively reduce the signal propagation and channel fading effects inherent in long – range wireless communication, and is therefore preferred. Since sensor nodes are densely deployed and neighbor nodes are close to each other, it is possible to use multi-hop short – range communication in sensor networks. In this case, to send the sensed data to the sink, a source node must employ a routing protocol to select an energy- efficient multi-hop path from the node itself to the sink.

4. Data Link Layer

The data link layer is responsible for data stream multiplexing, data frame creation and detection, medium access, and error control in order to provide reliable point – to – point and point – to – multipoint transmissions. One of the most important functions of the data link layer is medium access control (MAC). The primary objective of MAC is to fairly and efficiently share the shared communication resources or medium among multiple sensor nodes in order to achieve good network performance in terms of energy consumption, network throughput, and delivery latency.

5. Physical Layer

The physical layer is responsible for converting bit streams from the data link layer to signals that are suitable for transmission over the communication medium. For this purpose, it must deal with various related issues, for example, transmission medium and frequency selection, carrier frequency generation, signal modulation and detection, and data encryption. In addition, it must also deal with the design of the underlying hardware, and various electrical and mechanical interfaces.

2.5 Characteristics of WSN

The main characteristics of a WSN include:

1. Power consumption constraints for nodes using batteries or energy harvesting
2. Ability to cope with node failures (resilience)
3. Mobility of nodes
4. Heterogeneity of nodes
5. Scalability to large scale of deployment
6. Ability to withstand harsh environmental conditions
7. Ease of use
8. Cross-layer design

Cross-layer is becoming an important studying area for wireless communications. In addition, the traditional layered approach presents three main problems:

- Traditional layered approach cannot share different information among different layers， which leads to each layer not having complete information. The traditional layered approach cannot guarantee the optimization of the entire network.
- The traditional layered approach does not have the ability to adapt to the environmental change.
- Because of the interference between the different users, access confliction, fading, and the change of environment in the wireless sensor networks, traditional layered approach for wired networks is not applicable to wireless networks.

So the cross-layer can be used to make the optimal modulation to improve the transmission performance, such as data rate, energy efficiency, QoS (Quality of Service), etc.

2.6 Applications of WSNs

WSNs are applicable across various fields and have diverse applications. Some common uses have been listed below:

Process Management

Area monitoring is a common application of WSNs. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored. A military example is the use of sensors detect enemy intrusion; a civilian example is the geo-fencing of gas or oil pipelines.

Health care monitoring

The medical applications can be of two types: wearable and implanted. Wearable devices are used on the body surface of a human or just at close proximity of the user. The implantable medical devices are those that are inserted inside human body. There are many other applications too e.g. body position measurement and location of the person, overall monitoring of ill patients in hospitals and at homes. Body-area networks can collect information about an individual's health, fitness, and energy expenditure.

Environmental/Earth sensing

There are many applications in monitoring environmental parameters, examples of which are given below. They share the extra challenges of harsh environments and reduced power supply.

Air pollution monitoring

Wireless sensor networks have been deployed in several cities (Stockholm, London and Brisbane to monitor the concentration of dangerous gases for citizens. These can take advantage of the ad hoc wireless links rather than wired installations, which also make them more mobile for testing readings in different areas.

Forest fire detection

A network of Sensor Nodes can be installed in a forest to detect when a fire has started. The nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fire in the trees or vegetation. The early detection is crucial for a successful action of the firefighters; thanks to Wireless Sensor Networks, the fire brigade will be able to know when a fire is started and how it is spreading.

Landslide detection

A landslide detection system makes use of a wireless sensor network to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide. Through the data gathered it may be possible to know the occurrence of landslides long before it actually happens.

Water quality monitoring

Water quality monitoring involves analyzing water properties in dams, rivers, lakes & oceans, as well as underground water reserves. The use of many wireless distributed sensors enables the creation of a more accurate map of the water status, and allows the permanent deployment of monitoring stations in locations of difficult access, without the need of manual data retrieval.

Natural disaster prevention

Wireless sensor networks can effectively act to prevent the consequences of natural disasters, like floods. Wireless nodes have successfully been deployed in rivers where changes of the water levels have to be monitored in real time.

Machine health monitoring

Wireless sensor networks have been developed for machinery condition-based maintenance (CBM) as they offer significant cost savings and enable new functionality.[6] In wired systems, the installation of enough sensors is often limited by the cost of wiring. Previously inaccessible locations, rotating machinery, hazardous or restricted areas, and mobile assets can now be reached with wireless sensors.

Data logging

Wireless sensor networks are also used for the collection of data for monitoring of environmental information, this can be as simple as the monitoring of the temperature in a fridge to the level of water in overflow tanks in nuclear power plants. The statistical information can then be used to show how systems have been working. The advantage of WSNs over conventional loggers is the "live" data feed that is possible.

Water/Waste water monitoring

Monitoring the quality and level of water includes many activities such as checking the quality of underground or surface water and ensuring a country's water infrastructure for the benefit of both human and animal.It may be used to protect the wastage of water.

2.7 Differences between WSN and Traditional Wireless Networks

Wireless sensor network applications require wireless networking techniques. Although many protocols and algorithms have been proposed for traditional wireless networks, they are not well suited for the unique features and application requirements of wireless sensor networks. The differences between wireless sensor networks and traditional wireless ad hoc networks are listed here:

- The number of sensor nodes in a wireless sensor network can be several orders of magnitude higher than the nodes in a wireless ad hoc network.
- In a wireless sensor network, sensor nodes are densely deployed. Sensor nodes are prone to failure.
- The topology of a wireless sensor network changes very frequently.
- Sensor nodes mainly use broadcast communication paradigms whereas most traditional wireless networks are based on point-to-point communications.
- Sensor nodes are limited in power, computational capabilities, and memory.
- Sensor nodes may not have global identification because of the large amount of overhead and large number of sensors.
- Another factor that distinguishes wireless sensor networks from traditional mobile ad hoc networks (MANETs) is that the end goal is the detection/estimation of some event(s) of interest, and not just communication.
- To improve detection performance, it is often quite useful to fuse data from multiple sensors. Data fusion requires the transmission of data and control messages. This need may impose constraints on network architecture.
- The large number of sensing nodes may congest the network with information. To solve this problem, some sensors, such as cluster heads, can aggregate the data, perform some computation (e.g., average, summation, highest value, etc.), and then broadcast the summarized new information.[19]

CHAPTER 3

LITERATURE SURVEY

In **[1]**, a family of ant colony algorithms called DAACA for data aggregation has been presented which contains three phases: the initialization, packet transmission and operations on pheromones. After initialization, each node estimates the remaining energy and the amount of pheromones to compute the probabilities used for dynamically selecting the next hop. After certain rounds of transmissions, the pheromones adjustment is performed periodically, which combines the advantages of both global and local pheromones adjustment for evaporating or depositing pheromones. Compared with some other data aggregation algorithms, DAACA shows higher superiority on average degree of nodes, energy efficiency, prolonging the network lifetime, computation complexity and success ratio of one hop transmission. At last we analyze the characteristic of DAACA in the aspects of robustness, fault tolerance and scalability.

In **[2]**, an algorithm named PEDAP (Power Efficient Data gathering and Aggregation Protocol) is proposed, which generates Minimum Spanning Tree (MST) by utilizing Prim algorithm. It is a near optimal minimum spanning tree based routing scheme. But it cannot guarantee the energy efficiency of the network, then an energy-aware version of PEDAP, namely PEDAP-PA is proposed to maximize the network lifetime. However, the sink node needs to periodically broadcast and calculate the MST of the network, thereby, the workload of the sink node is high.

In **[3]**, a Local Minimum Spanning Tree algorithm called LMST is presented to establish the network topology, although it can effectively reduce the average degree of nodes, some prominent problems still emerge. Each node needs to periodically calculate and update the MST (Minimum Spanning Tree) locally which leads to a high computational overhead for each node. Moreover, each node needs to communicate with its neighbors to obtain the energy condition of neighbors, which still costs much energy.

In **[4]**, a localized, self-organizing, robust and energy efficient data aggregation algorithm named L-PEDAP is proposed which combines LMST with RNG. Although it is proved to have the capability of prolonging the network lifetime, its topology construction procedure is nearly identical with that of LMST, hence, it cannot be considered as an energy-efficient algorithm.

In **[5],** focus on the location privacy problem in sensor network. An energy efficient source location privacy protecting scheme (EELP) has been proposed, which applies the ant colony optimization method to prevent an adversary from back tracing message routing paths to the event source. Whenever a node receives a packet, it will figure out the next hop based on the information of the pheromones, the distance, and the remaining energy according to the routing table. Then each node will update the information. After certain rounds of transmissions, procedure of evaporating and depositing pheromones will be applied which help EELP to adjust the amount of the pheromones. And it can efficiently protect the location information of source node and prolong the network lifetime.

In **[6],** the application of the Ant Colony Optimization meta heuristic was studied to solve the routing problem in wireless sensor networks. A basic ant-based routing algorithm was proposed, and several improvements, inspired by the features of wireless sensor networks (low energy levels, low processing and memory capabilities), were considered and implemented. The resulting routing protocol, called Energy-Efficient Ant Based Routing (EEABR), uses lightweight ants to find routing paths between the sensor nodes and the sink nodes, which are optimized in terms of distance and energy levels. These special ants minimize communication loads and maximize energy savings, contributing to expand the lifetime of the wireless network. The experimental results showed that the algorithm leads to very good results in different WSN scenarios.

In **[7],** it has been proved that the ant colony algorithm may produce redundant states in the graph, its better to minimize such graphs to enhance the behavior of the inducted system. A colony of ants moves through system states X, by applying Genetic Operations. By moving, each ant incrementally constructs a solution to the problem. When an ant complete solution, or during the construction phase, the ant evaluates the solution and modifies the trail value on the components used in its solution. Ants deposit a certain amount of pheromone on the components; that is, either on the vertices or on the edges that they traverse. The amount of pheromone deposited may depend on the quality of the solution found. Subsequent ants use the pheromone information as a guide toward promising regions of the search space. Ants adaptively modify the way the problem is represented and perceived by other ants, but they are not adaptive themselves. The genetic programming paradigm permits the evolution of computer programs which can perform alternative computations conditioned on the outcome of intermediate calculations, which can perform computations on variables of many different types, which can perform iterations and recursions to achieve the desired result, which can define and subsequently use computed values and sub-programs, and whose size, shape, and complexity is not specified in advance.

In **[8]**,the algorithm is mainly used in information acquiring in Wireless Sensor Networks and it can completely use the advantages of ant algorithm to find out the best way in plenty sensors in order to build a shortest path and has the minimal power lost. The most important result is that neither incremental nor concurrent versions of range-aware, anchor free localization algorithms expend a significant amount of energy. This means efforts to reduce the energy costs of localization will not have a significant effect on overall energy savings.

In **[9],** FACR is proposed is to achieve faster routing discovery rate. In the algorithm, when a forward ant is timed out, a backward ant is sent along the reverse path, which makes the corresponding forward ant also contribute to route formation through updating pheromone information on the path. When a forward ant reaches the sink node, a kind of broadcasting ants are sent by nodes on the path to adjust and reinforce the discovered path. Experimental results indicate that FACR's packet loss rate is lower than that of TACR under the same conditions. Moreover, FACR achieves a shorter end to end delay and consumes less energy when it reaches the same packet loss rate as TACR. At present, FACR uses only path length to calculate change in the amount of pheromone during newly added feedback enhanced process. However, in pace with network transmission, network environment will change. There may arise some phenomena like unequal node energy consumption and load imbalance.

In **[10],** an efficient routing planning based on ACO has been proposed. By applying mobility of sink in regular hexagonal structure, the whole system performance can be improved, such as connectedness, sense coverage and energy efficient. Some other advantages of this technique include the safety of network information enhancement within the sink management scope, the sink will mark the position of disconnection area to report to superior management. The nodes can be resting which out of the sink sensing range for energy conservation.

In **[11]**, the ant colony optimization (ACO) algorithm and MMAS algorithms have been introduced. Also some improvements of parameters of MMAS have been proposed. In the proposed algorithm, the local pheromones updating aims at reducing the probability of the selected node, thus the probabilities of unselected nodes will increase. Consequently, the algorithm will generate more aggregation paths through which global optimal solution will be more likely to be found.

In **[12],** Okdem et al. introduced a multipath routing algorithm based on Ant Colony Optimization (ACO) which uses a class of agent-like ants to develop reliable routes between source and sink. It is very effective in dealing with the failure of links and searching for the routes. Due to large number of nodes, the number of ants is quite large so that it may lead to much higher traffic in the network than other algorithms.

BELEGHACHI et al. **[13]** propose routing protocol aimed to find path with least delay, more bandwidth and less number of hops. There are two phases in the proposed protocol; rout discovery phase and rout maintenance phase. When the source node wants to send data will start with rout discovery phase. The data transfer starts when the path is found. Four control messages are used which are: hello packet, route request, route reply and route error. The disadvantages of the proposed protocol are the control messages overhead where there are different control messages used in the route discovery phase, and there is no consideration for energy consumption.

Adamu murtala et al**. [14]** proposes a routing protocol that is an improved version of EEABR protocol. The available power of node and the energy consumption of each path are considered in the routing decision. The memory usage is improved by reducing the routing table. Memory of each ant is reduced to keep only last two records of the last visited nodes. The routing table of forward ants which are sent directly to sink node only needs to save the neighbor node that are in that direction. Each node keeps in its memory record of every ant that was received and sent.

In **[15],** a multi-path routing protocol based on ACO intended for mobile ad hoc networks (MANET) is proposed in. The protocol specializes in carrying multimedia real-time traffic over the MANET. To provide higher bandwidth and delivery guarantees, it uses a multi-path solution. It also supports high mobility for nodes and certain QoS parameters. However, the protocol uses the concept of IP-based routing and must be modified in order to be suitable for WSN.

In **[22],** the authors applied the ant colony optimization algorithm to solve the data aggregation problem and referred to as the ant-aggregation algorithm. In a wireless sensor network with multiple sources and a single destination, artificial ants are assigned to source nodes to construct paths for transmitting data packets to the sink node. The shorter is the path between the source node and the aggregation node, the more pheromone ants will deposit on it. The algorithm uses the Euclidean distance formula to compute for the distance from a source node to an aggregation node and from an aggregation node to a sink node.

Table 3.1: Characteristics of the Ant Colony Optimization Schemes

S.No.	Title	Journal/ Conference	Author	Year	Characteristics
1	Power efficient data gathering and aggregation in wireless sensor networks	ACM Sigmod Record	Tan, Hüseyin Özgür, and Ibrahim Körpeoğlu	2003	1. Based on Power Efficient Data Gathering and Aggregation (PEDAP) 2.Near optimal minimum spanning tree based routing scheme. 3.Does not guarantee the energy efficiency 4. Sink node needs to be periodically broadcast which increases the workload on the network
2	Design and analysis of an MST-based topology control algorithm	Wireless Communications, IEEE Transactions	Li, Ning, Jennifer C. Hou, and Lui Sha	2005	1. Based on Local Minimum Spanning Tree Algorithm (MST). 2. It effectively reduces the average degree of nodes 3.High computational effort for each node. 4.Each node needs to communicate with its neighbors to obtain the energy condition of neighbors, which still costs much energy.
3	An energy-efficient ant-based routing algorithm for wireless sensor networks.	Ant Colony Optimization and Swarm Intelligence (pp. 49-59). Springer Berlin Heidelberg.	Camilo, T., Carreto, C., Silva, J. S., & Boavida, F.	2006	1. Meta heuristic. 2.Energy efficient 3.Less Memory requirements. 4. Minimized communication costs 5. Prolonged Network Lifetime.

4	Routing in Wireless Sensor Networks Using Ant Colony Optimization.	Proceedings of the 1st NASE/ESA Conference on Adaptive Hardware and System-AHS, Istanbul, Turkey	Okdem, S.; Karaboga, D.	2006	1.Uses multipath routing based on ACO 2.Very effective in dealing with the failure of links and searching for the routes 3.May lead to much higher traffic due to increased no. of ants
5	Ant-aggregation: ant colony algorithm for optimal data aggregation in wireless sensor networks	International Conference on Wireless and Optical Communications Networks, 2006.	Misra R, Mandal C	2006	1.Uses ACO to solve data aggregation problem. 2.Uses Euclidean distance to find distances 3.Shorter the path from source to aggrgation node, more the pheromones deposited on it
6	An Ant Colony Optimization Competition Routing Algorithm for WSN.	WiCOM'08. 4th International Conference on. IEEE	Zhong, Zhicheng et al.	2008	1. Minimize energy costs locally. 2.Prolonged Network Lifetime. 3. Robust. 4. Fault Tolerant 5. Scalable. 6. High computational effort for each node.
7	Biologically inspired routing protocol for wireless multimedia sensor networks IEEE Instrumentation and Measurement Technology	IEEE Instrumentation and Measurement Technology Conference Proceedings, Victoria, BC, 2008, pp. 1823–1827.	M.A. Rahman, R. GhasemAghaei, A.E. Saddik, W. Gueaieb, M-IAR:	2008	1.Multi-path routing protocol based on ACO intended for mobile ad hoc networks (MANET) 2.Higher bandwidth and delivery guarantees 3.Supports high mobility for nodes and certain QoS parameters 4.Uses the concept of IP-based routing
8	Ant colony optimization algorithm	UbiCC Journal 4.3	Al Salami, Nada MA.	2009	1. Based on Genetic Operations. 2.Prolonged Network Lifetime. 3. High memory requirements. 4. High communication costs. 5. High computational effort for each node.
9	Feedback-enhanced ant colony routing algorithm for wireless sensor networks	Communications and Networking in China (CHINACOM), 2010 5th International ICST Conference on. IEEE, 2010.	Li, Chao, and Zhidong Deng.	2010	1.Achieves faster routing discovery rate 2.Packet loss rate is lower 3.Shorter end to end delay and consumes less energy 4.Unequal node energy consumption 5.Load imbalance. 6.Uses only path length to calculate change in the amount of pheromone

10	Computing localized power-efficient data aggregation trees for sensor networks.	Parallel and Distributed Systems, IEEE Transactions on 22.3	Tan, Huseyin Ozgur, Ibrahim Korpeoglu, and Ivan Stojmenovic	2011	1. Based on L-PEDAP algorithm. 2. Localized 3. Self Organizing 4. Robust 5. Prolonged Networked Lifetime. 6. Uses LMST for topology construction.
11	Ant Colony Optimization Algorithms-Based Routing Planning of Mobile Sink	Knowledge Acquisition and Modeling (KAM), 2011 Fourth International Symposium on. IEEE, 2011.	Jia, Wang, and He Zhimin	2011	1.Based on ACO 2.Applies mobility to sink 3.Improved performance in terms of connectedness, sense coverage and energy efficient 4.Safety of network information enhancement 5.Uses sink sensing range for energy conservation.
12	Ant Based Routing Protocol for Visual Sensors, in Informatics Engineering and Information Science	A. Abd Manaf, et al., Editors. 2011, Springer Berlin Heidelberg. p. 250- 264.	Zungeru, A., et al.,	2011	1.An improved version of EEABR protocol 2.Memory of each ant is reduced to keep only last two records of the last visited nodes 3.Available power of node and the energy consumption of each path are considered
13	Energy efficient ant colony algorithms for data aggregation in wireless sensor networks	Journal of Computer and System Sciences	Chi Lin, Guowei Wu∗, Feng Xia, Mingchu Li, Lin Yao, Zhongyi Pei	2012	1.Based on Data Aggregation Ant Colony Algorithm (DAACA) 2.Energy Efficient 3.Prolonged Network Lifetime 4. Less Computational Complexity 5. Looping may occur in basic DAACA due to lack of accumulated route . 6. Robust 7. Fault tolerant 8. Scalable
14	QoS Based on Ant Colony Routing for Wireless Sensor Networks.	International Journal of Computer Science and Telecommunications,2012	Mohammed, B.M.a.F.	2012	1Finds path with least delay, more bandwidth and less number of hops 2.Route discovery phase and rout maintenance phase are two phases 3.Control messages overhead 4.No consideration for energy consumption.
15	An Ant Colony System based Routing Algorithm for Wireless Sensor Network	International Conference	Luo, Li, and Layuan Li	2012	1. Based on MM- ACS strategy. 2. Energy Efficient. 3. Prolonged Network Lifetime. 4. Selects global optimal paths using local optimization 5. Lower communication costs.
16	Energy Efficient Source Location Privacy Protecting Scheme in Wireless Sensor Networks	International Journal of Distributed Sensor Networks	Zhou, Liming, and Qiaoyan Wen.	2014	1. Focus on privacy protection wireless sensor network. 2. Prolonged Network Lifetime. 3. Robust 4. Relatively energy efficient but but the communication costs for the nodes are still high.

	Using Ant Colony Optimization				

CHAPTER 4

PROPOSED WORK AND APPROACH

4.1 Energy efficient ant colony algorithms for data aggregation in wireless sensor networks [1]

This paper proposed a family of energy-efficient Data Aggregation Ant Colony Algorithms (DAACA for short), which contains Basic-DAACA (i.e. the Basic algorithm of DAACA), ES-DAACA (i.e. Elitist Strategy based DAACA), MM-DAACA (i.e. Max–Min based DAACA) and ACS-DAACA (i.e. Ant Colony System based DAACA). DAACA include three phases: 1) the initialization, 2) packets transmissions and 3) operations on pheromones.

Initially, all the sensors are deployed randomly, then they set up their routing tables in a self-organization manner. Nodes are considered as the artificial ants. The amount of the pheromones of links are recorded in the routing table, whenever a node receives a packet, it will figure out the next hop based on the information of the pheromones, the distance and the remaining energy according to the routing table. Then each node will update the information. After certain rounds of transmissions, procedure of evaporating and depositing pheromones will be applied which help DAACA to adjust the amount of the pheromones. The objective of this process is to guide the aggregation routing path to approach to the global optimal routing path which will conserve energy for the network to some extent.

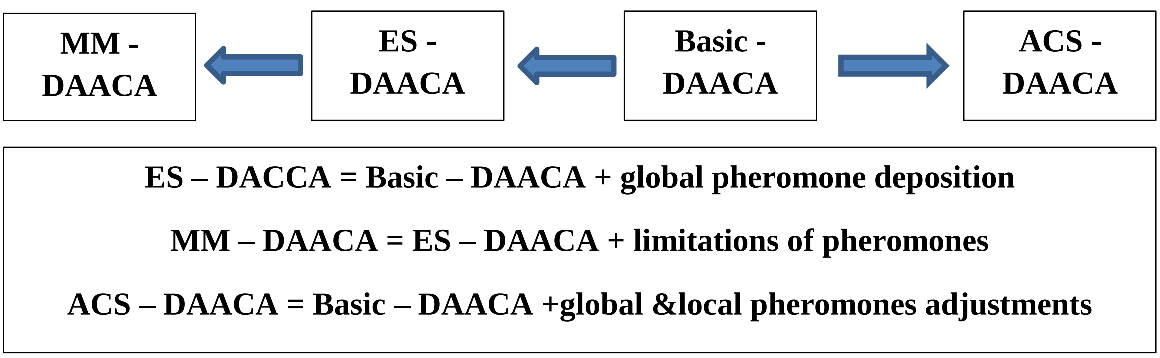

Figure 4.1: Relationship between Basic DAACA, MM-DAACA, ES-DAACA and ACS-DAACA

Basic DAACA Structure

1:Network Initialization, Node Initialization, Neighbor Initialization, Routing Table Initialization. The routing table contains the following elements: {id, $E_{distance}(i, j)$, $E_{estimate}(i, j)$, $\eta(i, j)$, $p(i, j)$}, $j \in Nb(i)$.

2: The source node s begin to send its data packets to the destination hop-by-hop.

3: for all $t \in Nbr(s)$ do

4: s evaluates the energy of t.

5: s calculates $p(i, j) = \tau (i, j)^{\alpha} \times \eta(i, j)^{\beta} / \sum_{j \in Nbr(i)}[\tau (i, j)^{\alpha} \times \eta(i, j)^{\beta}]$.

$\tau (i, j) = 1/E'_{distance}(i, j)$

$E'_{distance}(i, j) = E'_{distance}(i, j) / e1(i) \times e2(i, j)$ for $(0 < e1 < 1, 0 < e2 < 1)$

$e1(i) = E_{cur}(i)/E_{init}$

$e2(i, j) = E_{estimate}(i, j)/ E_{init}$

$E'_{distance}(i, j) = E_{Tx\text{-}elec} \times k + \varepsilon_{amp} \times k \times e_{ij}{}^{2}$

$E_{estimate}(i, j) = E_{init} - [E_{init} - E_{estimate}(i, j)/Times(i, j)] \times [Times(i, j) +1]$

6: s selects the next hop node n based on p(s, t).

7: end for

8: s $\rightarrow$n // s sends the packets to n

9: while $s \neq d$ do

10: c =n

11: c aggregates data packets

12: for all $t \in Nbr(c)$ do

13: c evaluates the energy of t.

14: c calculates p(c, t).

15: c selects the next hop node n based on p(c, t).

16: end for

17: c $\rightarrow$n

18: end while

19: round = round +1

20: if round = roundToUpdate then

21: Evaporating Pheromones.

22: Depositing Pheromones.

23: Updating Routing Table.

24: Energy Broadcasting.

25: end

Adjusting Pheromones of Basic DAACA

1: for all i ∈ V do

2: i evaporates the pheromones according to $\eta(i, j) = (1 - \rho)\times\eta(i, j)$ where ρ stands for the fraction of pheromones that are not evaporated.

3: i searches for the node with the highest $E_{estimate}(i, j)$ where $j \in Nb(i)$ in neighbor set.

4: i deposits pheromones according to $\eta(i, j) = \eta(i, j) + E_{distance}(i, j)$

5: if conj(i)>=2 then

6: for all $t \in Nb(i)$ do

7: t deposits pheromones of i according to $\eta(i, j) = \eta(i, j) + E_{distance}(i, j)$

8: i broadcasts the current energy.

9: end for

10: end if

11: if i receives a broadcast message from j then

12: i updates Eestimate(i, j).

13: i updates the routing table.

14: end if

15: end for

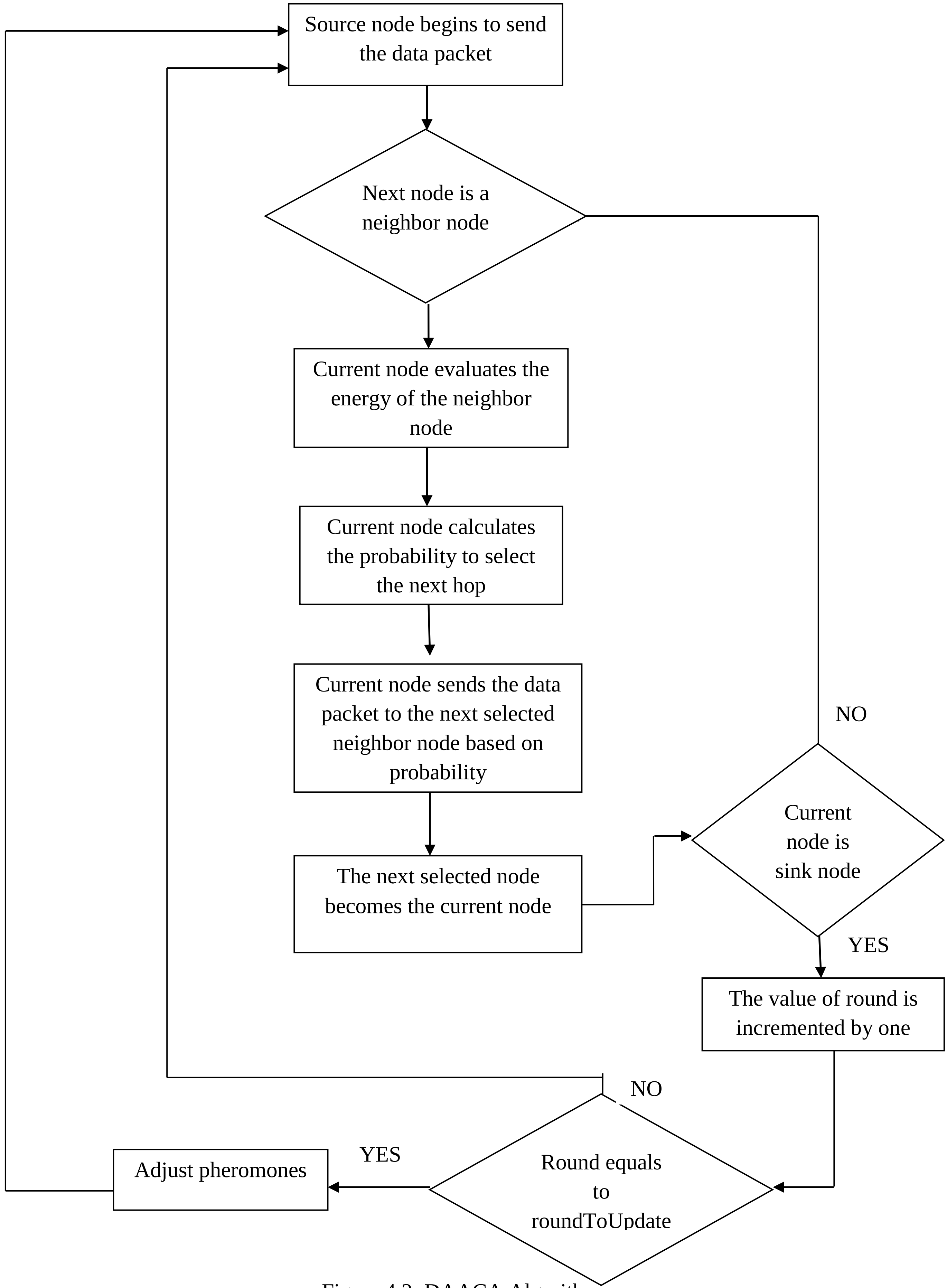

Figure 4.2: DAACA Algorithm

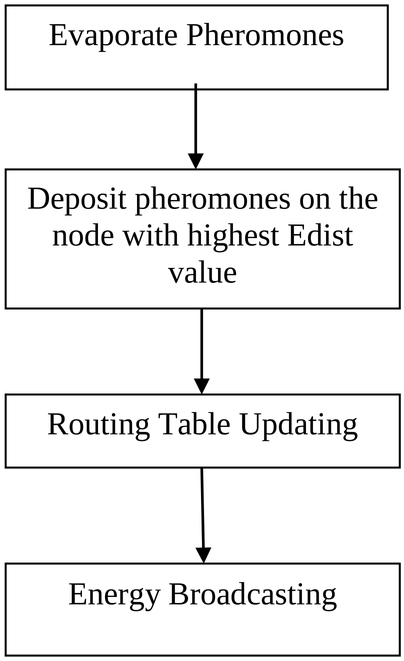

Figure 4.3: Adjusting pheromones in DAACA Algorithm

4.2 Energy Efficient Source Location Privacy Protecting Scheme in Wireless Sensor Networks Using Ant Colony Optimization [5]

In this paper, sensor location information and prolong the network lifetime in wireless sensor networks is preserved. An energy efficient source location privacy protecting mechanism (EELP), which applies the ant colony optimization method to protect the location privacy information.In order to provide strong communication anonymity, a random packet-forwarding strategy is presented. Whenever a node receives a packet, it will figure out the next hop based on the information of the pheromones, the distance, and the remaining energy according to the routing table. Then each node will update the information. After certain rounds of transmissions, procedure of evaporating and depositing pheromones will be applied which help EELP to adjust the amount of the pheromones. So it is unlikely that the adversary will continuously receive event packets from a monitored node because packets are sent through different nodes which can be far from each other. Moreover, even if the adversary could capture the same packet at different relaying nodes, he cannot correlate the packets. When a node sends an event packet, any neighbouring node can be the receiver and it is infeasible to figure out the next-hop node. The adversary cannot also infer the direction to the source node by following the movement of the packets because the packets are sent after random delay.

EELP Structure

1:Network Initialization, Node Initialization, Neighbor Initialization, Routing Table Initialization. The routing table contains the following elements: {id, (i, j), (i, j), $E_{\mathrm{est}}(i, j)$, $E_{\eta}(i, j)$}, and $j \in \Omega(i)$.

2: The source node begin to send its data packets to the destination hop by hop

3: for all nodes i are the neighbors of the node s do

4: the node s evaluates the energy of i.

5: the node s calculates $p\ (s, i)$ by

$p\ (i, j) = [\tau\ (i, j)]^{\alpha} \cdot [\eta\ (i, j)]^{\beta} / \Sigma_{j \in \Omega(i)} [\tau\ (i, j)]^{\alpha} \cdot [\eta\ (i, j)]^{\beta}$ where

$\eta\ (i, j) = 1 / (i, j)$

$(i, j) = E_{\mathrm{dis}}\ (i, j) / e1(i) \times e2(i, j)$ for $(0 < e1 < 1, 0 < e < 1)$,

$e1\ (i) = E_{\mathrm{cur}}\ (i) / E_{\mathrm{init}}$

$e2(i, j) = E_{est}(i, j) / E_{init}$

$E_{dis}(i, j) = E_{Tx\text{-elec}} \times k_s + \varepsilon_{amp} \times ks \times e2_{ij}$

$E_{est}(i, j) = E_{init}$ –[$E_{init} - E_{est}(i, j)/T(i, j) \times [T(i, j) + 1]$.

6: the node s selects the next hop node k based on $p(s, k)$ $(i = k)$.

7: end for

8: the node s sends the packets to the node k

9: while the node s is not the sink do

10: for all nodes j are the neighbors of the node k do

11: the node k evaluates the energy of j.

12: the node k evaluates $p(k, j)$.

13: the node k selects the next hop node g based on $p(k,)$ $(j = g)$.

14: end for

15: the node k sends the packets to the node g

16: end while

17: round = round + 1

18: if round = roundUpdate then

19: Evaporating Pheromones.

20: Depositing Pheromones.

21: Updating Routing Table.

22: Energy Broadcasting.

23: end if

Adjusting Pheromones in EELP

1: for all nodes i do

2: the node i evaporates the pheromones using $\tau(i, j) = (1 - \rho) \times (i, j)$.

3: the node i searches for the node with the highest Eest (i, j) where $j \in \Omega(i)$ in neighbor set.

4: the node i deposits pheromones

5: if the conjunction times of node $i \geq 2$ then

6: for all nodes j are the neighbors of the node i do

7: j deposits pheromones of i according to $\tau(i, j) = (i, j) + E_{dis}(i, j)$.

8: i broadcasts the current energy.

9: end for

```
end if
if the node i receives a broadcast message from j then
the node i updates E_est (i, j).
the node i updates the routing table.
end if
end for
```

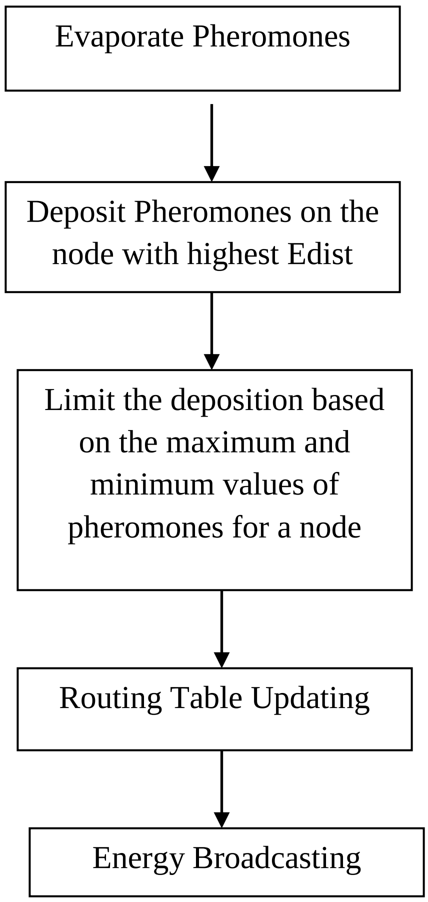

Figure 4.4: Adjusting Pheromones in EELP Scheme

4.3 An Ant Colony System based Routing Algorithm for Wireless Sensor Network [11]

Max-Min Ant System (MMAS) is an excellent heuristic random optimization algorithm based on ant colony optimization. MMAS has better performance than the ant colony optimization in avoiding premature search stagnation. MMAS improved many aspect of ACO, the main three as follows:

1) Pheromone is updated in different ways. In the Max- Min Ant System algorithm, after each round, only update pheromone to the ants those find the optimal solution or the best solution, and in ACO, all ants update the pheromone.

2) The pheromone on each path is limited in range $[\tau_{min}, \tau_{max}]$.

That means when $\tau_{ij}(t) > \tau_{max}$, then $\tau_{ij}(t) = \tau_{max}$; when $\tau_{ij}(t) < \tau_{min}$, then $\tau_{ij}(t) = \tau_{min}$.

By doing this, the stagnation problem can be avoided.

3) For ants to search for more solutions, the pheromone is initialized to τ_{max}.

The $f(s^{best})$ means the target value of the optimal solution. The optimal solution is behalf of the optimal solution, which is the optimal solution in iteration, also can be the global optimal solution that optimal solution can be found so far. In MMAS, we usually use behalf optimal solution.

MMAS Structure

1:Network Initialization, Node Initialization, Neighbor Initialization, Routing Table Initialization. The routing table contains the following elements: {id, $E_{distance}(i, j)$, $E_{estimate}(i, j)$, $\eta(i, j)$, $p(i, j)$}, $j \in Nb(i)$.

2: The source node s begin to send its data packets to the destination hop-by-hop.

3: for all $t \in Nbr(s)$ do

4: s evaluates the energy of t.

5: s calculates $p(i, j) = \tau(i, j)^{\alpha} \times \eta(i, j)^{\beta} / \sum_{j \in Nbr(i)}[\tau(i, j)^{\alpha} \times \eta(i, j)^{\beta}]$.

$\tau(i, j) = 1/E'_{distance}(i, j)$

$E'_{distance}(i, j) = E'_{distance}(i, j) / e1(i) \times e2(i, j)$ for $(0 < e1 < 1, 0 < e2 < 1)$

$e1(i) = E_{cur}(i)/E_{init}$

$e2(i, j) = E_{estimate}(i, j)/ E_{init}$

$E'_{distance}(i, j) = E_{Tx\text{-}elec} \times k + \varepsilon_{amp} \times k \times e_{ij}^{2}$

$E_{estimate}(i, j) = E_{init} – [E_{init} – E_{estimate}(i, j)/Times(i, j)] \times [Times(i, j) +1]$

6: s selects the next hop node n based on p(s, t).

7: end for

8: s →n // s sends the packets to n

9: while s ≠ d do

10: c =n

11: c aggregates data packets

12: for all t ∈ Nbr(c) do

13: c evaluates the energy of t.

14: c calculates p(c, t).

15: c selects the next hop node n based on p(c, t).

16: end for

17: c →n

18: end while

19: round = round +1

20: Evaporating Pheromones of ants on optimal path.

21: Depositing Pheromones of ants on optimal path.

22: Updating Routing Table.

Adjusting pheromones for MMAS

1: for all i ∈ V do

2: i evaporates the pheromones according to $\eta(i, j) = (1 - \rho)\times\eta(i, j)$ where ρ stands for the fraction of pheromones that are not evaporated.

3: i searches for the node with the highest $E_{estimate}(i, j)$ where j ∈ Nb(i) in neighbor set.

4: if conj(i)>=2 then

5: for all t ∈ Nb(i) do

6: t updates pheromones of i according to :

$\eta(i, j) = (1 - \zeta)\times\eta(i, j) + \zeta \times\eta(i, j)^{best}$ and

$\eta(i, j)^{best} = \min_{j\in Nbr(i)}(\eta(i, j))$

If $_{ij} > \tau_{max}$ then set $\tau_{ij} = \tau_{max.}$ If $\tau_{ij} < \tau_{min,}$ then set $\tau_{ij} = \tau_{min.}$

7: i broadcasts the current energy.

8: end for

```
end if
if i receives a broadcast message from j then
i updates Eestimate(i, j).
i updates the routing table.
end if
end for
```

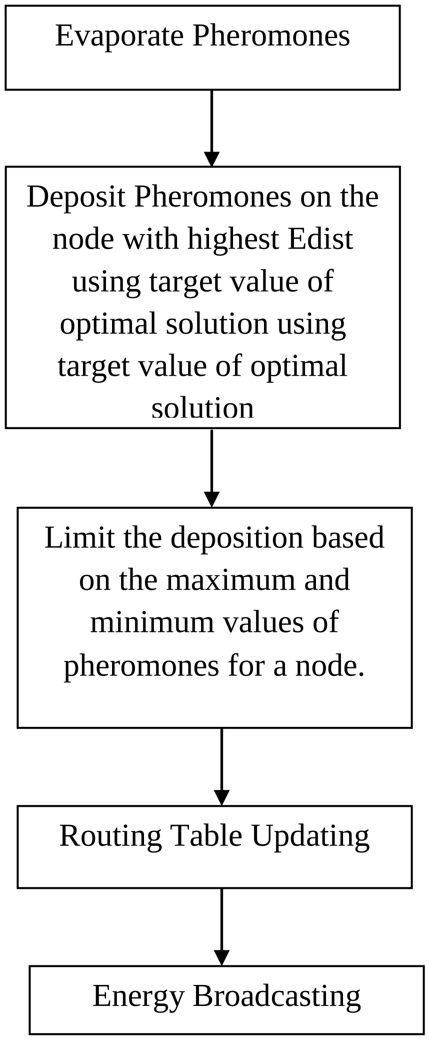

Figure 4.5: Adjusting pheromones for MMAS Scheme

Table 4.1: Notations used in Algorithms

Symbol	Notations
R	The maximum transmission range
id	The identity of the node
Nb(i)	The neighbor nodes of node i
round	The transmission times
roundToUpdate	The number of rounds to update the pheromones
p(i, j)	The probability for node i to select node j as the next hop
$\eta(i, j)$	The pheromone of node i to node j
$E'_{distance}(i, j)$	The energy distance from node i to node j
$E_{distance}(i, j)$	The Euclidean distance between node i and node j
e1(i)	The current value of node i divided by Einit
e2(i, j)	The estimation energy of node i to node j divided by Einit
e(i, j)	The distance between node i and node j
$E_{cur}(i)$	The current energy of node i
$E_{estimate}(i, j)$	The evaluation energy of node i to node j
E_{init}	The initial energy of each node
τ (i, j)	The inverse value of E_distance(i, j)
Times(i, j)	The transmission times from node i to node j
MPCost	The minimum energy cost in a path
ηMax	Upper bound of pheromones
ηMin	Lower bound of pheromones
conj(i)	The conjunction times of node i
source	The source node (s for short) of the network
destination	The destination node (d for short) of the network
current	The current node (c for short) who receives the data packet
next	The next node (n for short) which current will send the packet to
Pmin	The minimum energy cost path
ζ	Rate of evaporating pheromones

4.4 Proposed Enhancements

Node energy cost combines both computational and communication costs. The sensor nodes consume energy during every signal transmission that includes them that is if a sensor node receives a signal, its energy reduces and even if it transmits some signal, its energy is reduced.

The Ant Colony Optimization is concerned with finding optimal paths for data transmissions between the source node and the sink node. The schemes studied suffered from some limitations for which we propose some enhancements. These enhancements have also been implemented and their performance characteristics have been analyzed relative to the basic DAACA algorithm performance.

Issue 1:

In the basic DAACA algorithm, for selecting the next hop, the nodes have no information about the nodes that have already been traversed in the construction of the path which led to excessive looping and in many cases the direction of path moved away from the sink node rather than moving towards it. Also it caused excessive loss of energy in the network.

Enhancement 1:

To solve this problem, we proposed the inclusion of a header to be associated with each node to keep track of the nodes that have already been traversed. This helps to cut down the number of loops and also helps the current node to select the next node in the direction of the sink node.

Issue 2:

Due to the network topology and presence of a single sink node, excessive load is there on the sink node because it has to receive the data packets coming from every possible direction.

Enhancement 2:

To solve this problem, we propose the use of multiple sinks in the network to reduce the load which leads to a more energy efficient network. During hop selection, the nodes try to transmit data in the direction of the nearest sink. Thus, the load is effectively divided among the multiple sinks.

CHAPTER 5

IMPLEMENTATION DETAILS

5.1 Introduction to Java and Eclipse IDE

Java is a general-purpose computer programming language that is concurrent, class-based, object-oriented, and specifically designed to have as few implementation dependencies as possible. It is intended to let application developers "write once, run anywhere" (WORA), meaning that compiled Java code can run on all platforms that support Java without the need for recompilation. Java applications are typically compiled to bytecode that can run on any Java virtual machine (JVM) regardless of computer architecture. As of 2015, Java is one of the most popular programming languages in use, particularly for client-server web applications, with a reported 9 million developers. Java was originally developed by James Gosling at Sun Microsystems (which has since been acquired by Oracle Corporation) and released in 1995 as a core component of Sun Microsystems' Java platform. The language derives much of its syntax from C and C++, but it has fewer low-level facilities than either of them. There were five primary goals in the creation of the Java language:

1. It must be "simple, object-oriented and familiar".
2. It must be "robust and secure".
3. It must be "architecture-neutral and portable".
4. It must execute with "high performance".
5. It must be "interpreted, threaded, and dynamic".

In computer programming, Eclipse is an integrated development environment (IDE). It contains a base workspace and an extensible plug-in system for customizing the environment. Written mostly in Java, Eclipse can be used to develop applications. By means of various plug-ins, Eclipse may also be used to develop applications in other programming languages: Ada, ABAP, C, C++, COBOL, Fortran, Haskell, JavaScript, Lasso, Lua, Natural, Perl, PHP, Prolog, Python, R, Ruby(including Ruby on

Rails framework), Scala, Clojure, Groovy, Scheme, and Erlang. It can also be used to develop packages for the software Mathematica. Development environments include the Eclipse Java development tools (JDT) for Java and Scala, Eclipse CDT for C/C++ and Eclipse PDT for PHP, among others.

The initial codebase originated from IBM VisualAge. The Eclipse software development kit (SDK), which includes the Java development tools, is meant for Java developers. Users can extend its abilities by installing plug-ins written for the Eclipse Platform, such as development toolkits for other programming languages, and can write and contribute their own plug-in modules.

Released under the terms of the Eclipse Public License, Eclipse SDK is free and open source software (although it is incompatible with the GNU General Public License). It was one of the first IDEs to run under GNU Classpath and it runs without problems under IcedTea.

5.2 Implementation of the base algorithm

The algorithms for schemes [1], [5], [11] and the proposed enhancements were implemented using Java. The proposed enhancements were implemented for the base scheme and are discussed in the next chapter. The class structures of the implementation have been described briefly below.

```
/**************************Node Class************************************/
public class node
{    int id;
     int no_neighbours;
     static double sum;
     double E_curr;
     static final int alpha=2;
     static final int beta=2;
     static final int E_init=1000;
     static final double E_tx_elec=50E-9; /* 50nJperbit */
     static final double E_rx_elec=100E-9; /* 100nJperbit */
     static final double e_amp=100E-4; /* Jperbitperm2 */
     final double rho_value=0.2;
     static final int round_update=1;
     struct_1  E_real_dist[];
     double times[];
     struct_1 pheromone[];
     struct_1 send[];
     struct_1 recieve[];
```

```
	static final int k=4098;
	double e1;
	struct_1 e2[];
	int msg;

	//static graph_represent new_graph;
		routing_table r;
	node(int i)
	{
		id=i;
		msg = 0;

	}
	void init_routing_table(List<node> n);
	int select_hop(int n);
	void update_routing_table(List<node> n);
	void adjust_pheromones(int n);

	}
}


/*********************Routing Table Class *****************/

class struct_1
{
	int id;
	double value;
}

public class routing_table
{

	struct_1 E_dist[];
	struct_1 Edash_dist[];
	struct_1 E_est[];
		struct_1 eta[];
	struct_1 p[];

	routing_table(int n)
	{
		E_dist=new struct_1[n];
		Edash_dist=new struct_1[n];
		E_est=new struct_1[n];
		 eta=new struct_1[n];
		 p=new struct_1[n];
		 for(int i=0;i<n;i++)
		 {
			E_dist[i]=new struct_1();
			Edash_dist[i]=new struct_1();
```

```
                    E_est[i]=new struct_1();
                     eta[i]=new struct_1();
                     p[i]=new struct_1();
          }

     }

}
```

The table below shows the experimental values of the various parameters used in the implementation.

Table 5.1: Experimental Parameters

Item	Parameters
Packet size	4098 bits
Initial node energy	1 J
α,β	$\alpha = 2$, $\beta = 2$
Initial pheromone	0.8
ηMin, ηMin	ηMin = 0.5, ηMax = 0.9
ρ	ρ= 0.2
roundToUpdate	1,2
ζ	0.9

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Feature comparison table

The table below shows a qualitative feature comparison of the schemes implemented.

Table 6.1: Qualitative feature comparison of implemented schemes

Scheme	Data Transmission	Network Type	Energy Efficiency	Mobility of Nodes	Communication Cost	Network Lifetime	Fault Tolera-nt	Scal-able
Basic DAACA[1]	Multihop	Homogeneous	Satisfactory	Stationary	Very High	Low	Yes	Yes
Basic DAACA with header	Multihop	Homogeneous	Good	Stationary	High	Medium	Yes	Yes
MMAS[11]	Multihop	Homogeneous	Very Good	Stationary	Low	High	Yes	Yes
EELP[5]	Multihop	Homogeneous	Good	Stationary	Medium	Very High	Yes	Yes
Basic DAACA with multiple sinks	Multihop	Homogeneous	Very Good	Stationary	Medium	Low	Yes	Yes

6.2 Comparison Charts

The analysis was performed by running ten rounds of transmissions on a graph of 30 nodes. The comparison charts are shown below on the basis of following parameters:

1.No. of hops (Basic DAACA and Basic DAACA with header)

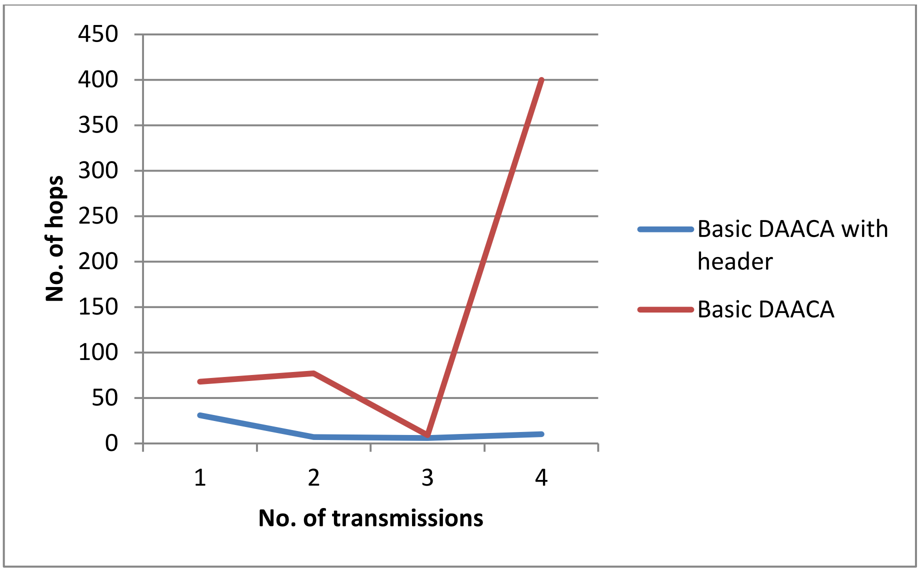

Figure 6.1: Comparison of Basic DAACA with and without header on the basis of number of hops

In Basic DAACA, ants have very limited cognitive abilities so they might loop in the same path again and again. This is due to the reason that a node while transmitting data does not have any idea of the directionality of transfer and does not keep track of the nodes already visited in the path. To overcome this problem a structure is maintained known as header which carries information about the nodes already traversed.

From the above graph it is evident that the number of hops in case of Basic DACCA rise to a very large number after the third iteration. This shows that basic DACCA is not optimal. The number of hops decreases by a large amount when the header is included in the transmission process. Due to the presence of header the nodes do not pass the data packet to their neighbours who have already been a part of the transmission process.

2.Number of hops

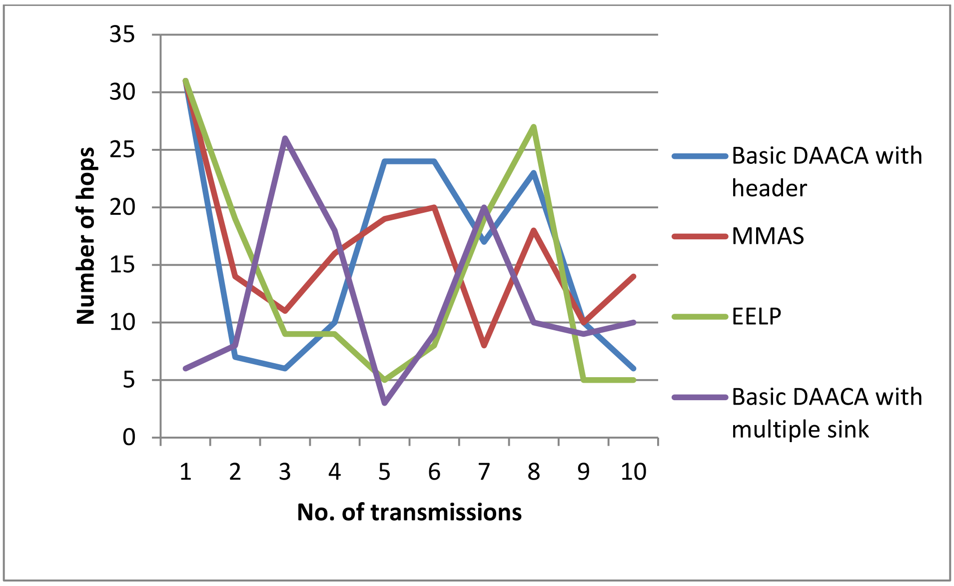

Figure 6.2: Comparison of schemes on the basis of no. of hops.

The maximum number of hops in case of Basic DACCA with header, MMAS, EELP is same i.e. 31 hops. The minimum number of hops required for Basic DACCA is 6 hops and it fluctuates to minimize the exhaustion of energy by preventing the use of the same path again and again. Minimum hops used in EELP reaches a value of 5 which is less than Basic DACCA and MMAS.EELP uses a variety of paths as if the pheromones are not limited as in the case of other algorithms, only a particular path is chosen again and again and that leads to decrease in energy of the entire network. A maximum MMAS has a stable value in the number of hops required as the pheromone value here is updated after every round. Minimum hops required for MMAS is 8 hops which is more than EELP and Basic DACCA with header. In case of multiple sink algorithms, the energy of the sink node is preserved by using multiple sink nodes. Since the sink nodes are located at different distances from the source node, the number of hops here is not stable. Due to the use of multiple sinks, the sink which is closer to the source requires the minimum number of hops which is 4. Due to different sink nodes, the source can send data to the nearest sink node requiring the minimum number of hops.

3.Average remaining energy

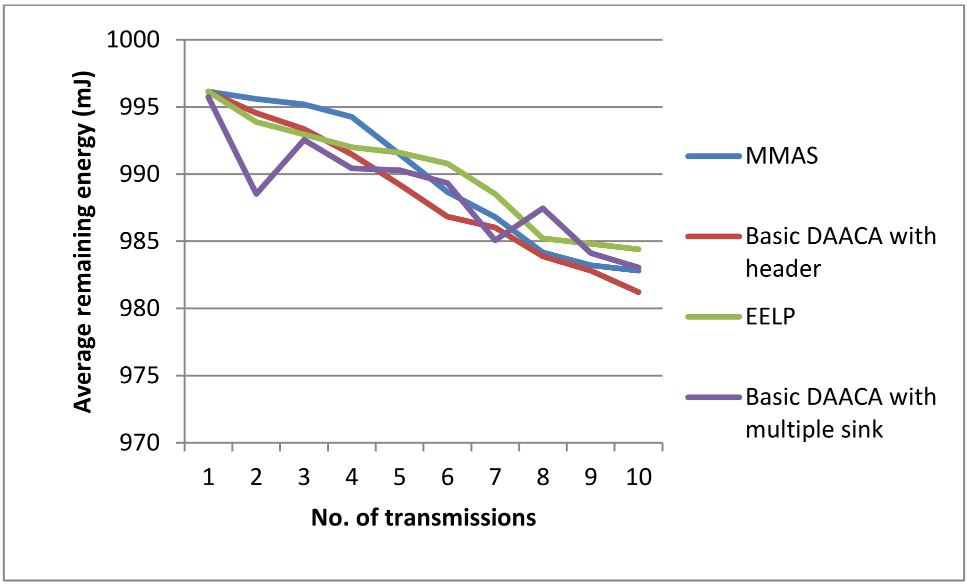

Figure 6.3: Comparison of schemes on the basis of average remaining energy

With increasing no. of transmissions the average remaining energy for the nodes decreases. As the graph shows, EELP has the maximum remaining energy since it has a bound on the maximum and minimum no. pheromones, it does not stay fixed on a particular path but uses a variety of paths due to which energy usage becomes distributed among many nodes. MMAS uses a local pheromone updating strategy to achieve a globally optimum path. However, the remaining energy on average is lower than EELP. The basic DAACA scheme has the lowest average energy remaining at the end of 10 rounds. Remaining energy in case of Basic DACCA with multiple sink nodes have a decent value at the end of 10 transmissions due to the availability of different paths which are variant depending on the sink node to which the data is sent. Less amount of energy is used when the sink node is closer to the source.

4.Energy Difference

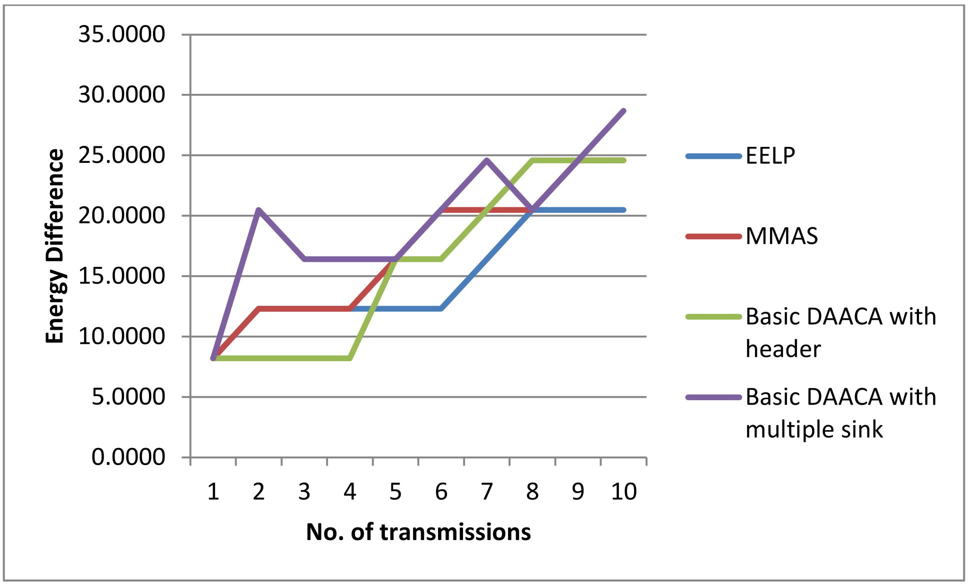

Figure 6.4: Comparison of schemes on the basis of energy difference

The lower the energy difference, the more energy efficient the network. This is because it is better if all nodes lose smaller quantities of energy rather than one node losing large amount of energy and increasing the load on other nodes. The figure above shows that though initially EELP suffers from larger energy difference but with increasing no. of iterations the difference goes down and is lowest at the end of the rounds. Basic DAACA with multiple sink however suffers from large energy difference throughout due to different paths. MMAS and Basic DAACA with header show similar patterns.

5.Remaining energy after 10th round

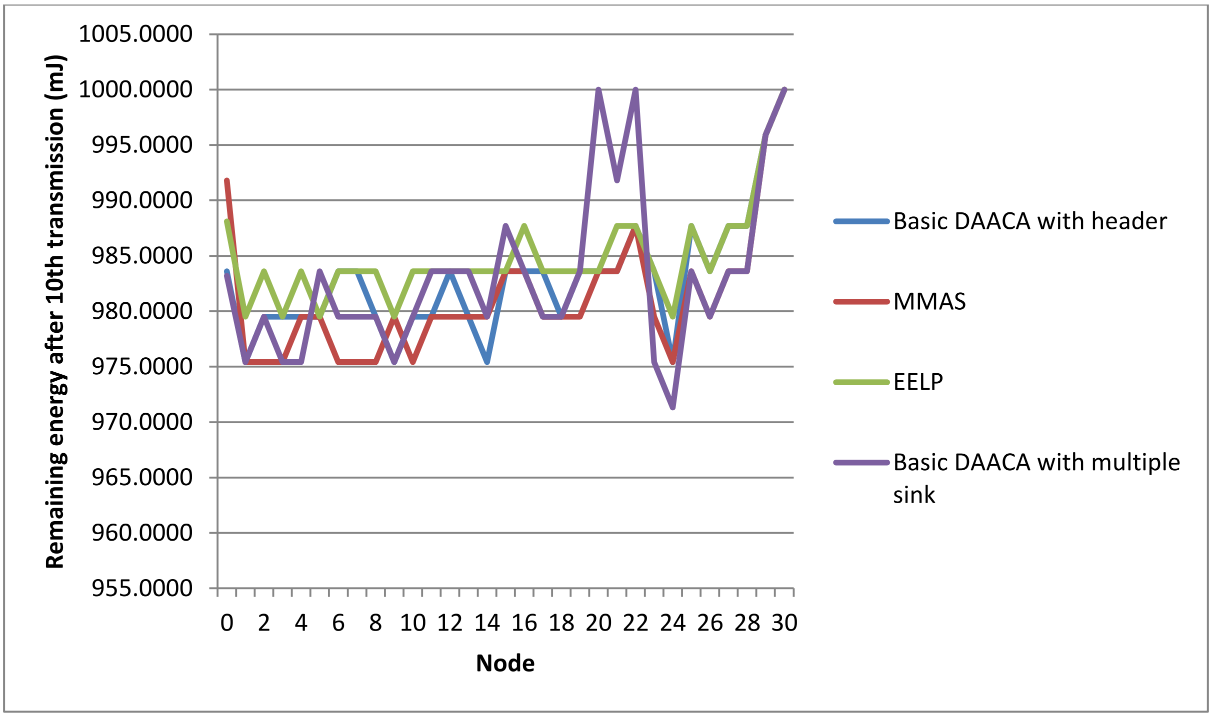

Figure 6.5: Comparison of schemes on the basis of remaining energy after 10th round

Only a negligible amount of energy is consumed in case of receiving data. That is why node 30 which is the sink node in case of Basic DACCA with header, MMAS and EELP has the highest energy. In case of multiple sink, node 22, 20 and 30 are chosen to be sinks therefore they have the maximum amount of energy. Also, EELP and Basic DAACA with multiple sinks show higher remaining energy at the end of the 10th round as compared to the other two due to reasons already mentioned above.

6.Network Lifetime

Network lifetime here has been considered here as the no. of rounds after which the first node in the system dies (First Node Dead). The graph below shows that network lifetime is maximum for EELP, followed by MMAS. Basic DAACA with multiple sinks has the minimum network lifetime as everytime time the path moves towards a different sink, the initial path is very energy intensive. Only with subsequent rounds is the path optimised.

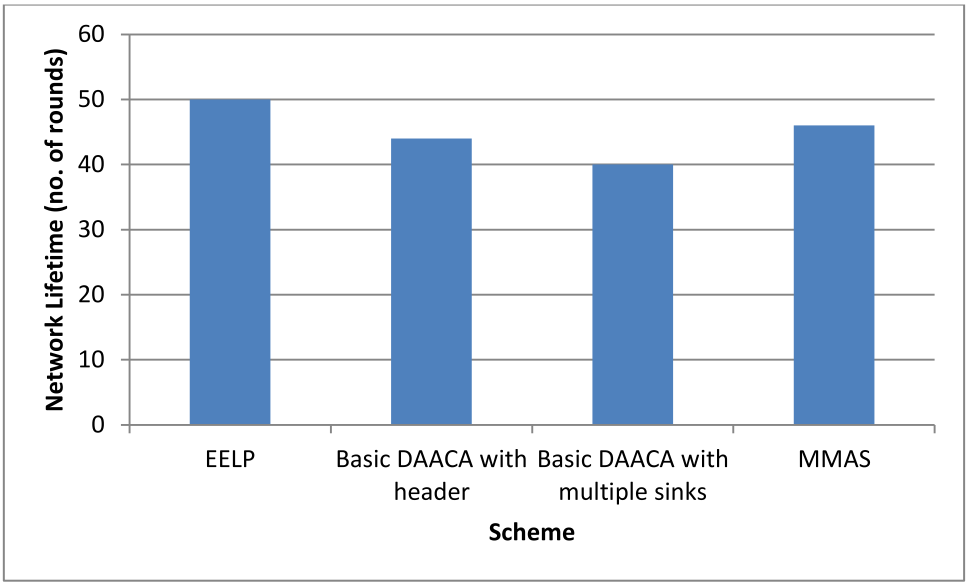

Figure 6.6: Comparison of schemes on the basis of network lifetime

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

This project aimed at carrying out a detailed study of Ant Colony Optimization schemes in Wireless Sensor Networks. Various existing schemes were studied, analyzed and implemented in an effort to achieve a broad understanding of this upcoming research field. The project was carried out in three phases over the course of the project.

Phase one involved a detailed literature survey to explore the existing schemes that exist for ant colony optimization for data transmission in WSNs. Sixteen papers were studied in detail for this. Paper [1] which explains the ant colony optimization for data aggregation was chosen as a base paper to guide the remaining work.

Phase two involved selection and implementation of selected schemes. Papers [1], [5] and [11] were chosen for implementation. These were then implemented using Java to simulate the algorithms given in the research papers. Then these implementations were analyzed in detail to compare performance, efficiency and security.

In phase three, we identified some additional flaws and issues left unaddressed by these schemes and proposed two generic enhancements to increase the feasibility and enhance performance of such protocols.

The existing schemes do not take into account the environmental conditions in which the networks operate. There may arise some phenomena like unequal node energy consumption and load imbalance. In the future work, neighbourhood energy distribution and congestion degree in vicinity may be considered in calculation of pheromone change.

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