M.Tech. Thesis

INVESTIGATIONS ON ENERGY AWARE ROUTING IN WIRELESS SENSOR NETWORKS

Submitted in partial fulfillment of the requirements for the degree of Master of Technology in Electronics & Communication Engineering

by

Meenaxi (96436882803)

Under the Supervision of

Dr. Satvir Singh

PUNJAB TECHNICAL UNIVERSITY

Jalandhar-Kapurthala Highway, Jalandhar

SHAHEED BHAGAT SINGH
STATE TECHNICAL CAMPUS
Moga Road (NH-95), Ferozepur-152004 (PB) INDIA

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CERTIFICATE

I, **Meenaxi (96436882803)**, hereby declare that the work being presented in this thesis on INVESTIGATIONS ON ENERGY AWARE ROUTING IN WIRELESS SENSOR NETWORKS is an authentic record of my own work carried out by me during my course under the supervision of Dr. Satvir Singh. This is submitted in the Department of ECE at Shaheed Bhagat Singh State Technical Campus, Ferozepur (affiliated to Punjab Technical University, Jalandhar) as partial fulfillment of requirements for award of the degree of Master of Technology in Electronics & Communication Engineering.

Meenaxi (96436882803)

To the best of my knowledge, this thesis has not been submitted to Punjab Technical University, Jalandhar or to any other university or institute for award of any degree or diploma. It is further understood that by this certificate, the undersigned do/does not endorse or approve any statement made, opinion expressed or conclusion drawn therein, however, approve the thesis only for the purpose for which it is submitted.

Dr. Satvir Singh [Supervisor]

The M.Tech Viva-Voce Examination of Meenaxi (96436882803) is held at Department of ECE, SBS State Technical Campus, Ferozepur on ....

External Examiner
Name: ....

Dr. Satvir Singh
M.Tech. Coordinator, ECE

All powers are within you, you can do anything and everything.

Arise, Awake and Stop Not till the Goal is achieved.

. . . ***Swami Vivekananda***

Dedicated to

My Family

Thesis Outcomes

International/National Journal Publications

1. S. Singh and Meenaxi, "An Optimized Low-Loss Energy-Aware Routing Protocol for Wireless Sensor Networks", in *International Journal of Computer Applications*, Vol. 65 - No. 21, March 2013, Pages 1-4.
2. S. Singh and Meenaxi, "A Survey on Energy Efficient Routing in Wireless Sensor Networks", in *International Journal of Advanced Research in Computer Science and Software Engineering*, Vol. 3 - Issue. 7, July 2013, Pages 184-189.
3. S. Singh and Meenaxi, "Prolonging the Network Lifetime using ACO in Wireless Sensor Networks", Communicated.
4. S. Singh and Meenaxi, "Improvements in QoS Parameters using ACO in Wireless Sensor Networks", Communicated.

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Place: Ferozepur

Date: August 31, 2013 Meenaxi (96436882803)

ABSTRACT

A Wireless Sensor Network (WSN) is a network consisting of wirelessly connected sensor nodes. These small, low-cost, low-power, multi-functional sensor nodes can communicate in short distances. Each sensor node consists of sensing, data processing, and communication components. A large number of these sensor nodes collaborate to form wireless sensor networks. A WSN usually consists of tens to thousands of such nodes that communicate through wireless channels for information sharing and cooperative processing. To ensure scalability and to increase the efficiency of the network operation, sensor nodes are often grouped into clusters. The Sensor networks are used to sense environmental factors, like temperature, pressure, etc. These can also be deployed in factories so as to monitor different parameters and process. They are also used to measure the weakness in building structures, vehicles, airplanes, etc. A lot of work is being done in this field, however, there is a scope of improvement with modern meta-heuristic route optimization technique inspired from natural swarm.

This thesis is intended to describe Ant Colony Optimization (ACO) and investigate the optimization of WSN design to achieve prolonged network lifetime. However, establishment of a sensor network involves the determined locations of source node, destination node, other sensor nodes with suitable radio transmission range, battery constraints, routing algorithms and security issues, etc. The performance parameters of ACO algorithm reported are investigated in this thesis for optimization of routing of packets/information in WSN.

In this thesis, Low-Loss Energy Aware Routing Protocol (LLEAP) is explored which is simply an enhancement of Energy Aware Routing Protocol (EAP) [Mohammad El-Basioni et al., 2011] that moves around Low Energy Adaptive Clustering Hierarchy (LEACH); a

hierarchical based routing (clustering) protocol. LEACH algorithm mainly includes two-layer routing where one layer is used to select cluster-heads and other layer is used for routing. Algorithm is based on the large number of high-density sensor nodes with a focus on the route scalability. The main feature is to divide the whole WSN area into a number of clusters. EAP works around LEACH in terms of selection of cluster-heads and improves the QoS parameters without maximizing the network lifetime of the WSN.

ACO is a probabilistic technique for solving computational problems which is used for finding the shortest path and was proposed by Marco Dorigo in 1992. The first algorithm aimed to search for an optimal path in a graph, based on the behavior of ants seeking a path between their colony and a source of food. Real ants initially move randomly, and upon finding food return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep travelling at random, but to instead follow that trail, returning and reinforcing it if they eventually find food. The original idea after improvements is capable of solving a wider class of numerical problems.

After some time the pheromone trail starts to evaporate, thus reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more the pheromones have to evaporate. The shortest path is followed more frequently, and thus the pheromone density becomes higher on shorter paths as compared to the longer ones. Pheromone evaporation also has the advantage of avoiding the convergence to a locally optimal solution. If there were no evaporation at all, the paths chosen by the first ants would tend to be excessively attractive. Thus the exploration of the solution space would be constrained. In this thesis, ACO performance is compared with LLEAP algorithm.

During simulations in MATLAB, the WSN is deployed for investigating network lifetime using ACO. From the experimental outcomes, it is concluded that as the target is achieved the network becomes more energy efficient as compared to the previous result [Mohammad El-Basioni et al., 2011].

This thesis is outlined as follows: Chapter 1 is devoted to introduction to the thesis as a whole that includes introduction to Research Topic, Motivation, Methodologies, Contribution, Research findings and Organization of thesis. Literature review on WSN, ACO and other routing algorithms is represented in Chapter 2. Chapter 3 is devoted to algorithmic flow of ACO. Chapter 4 is dedicated to LLEAP and its past outcomes. Chapter 5 is dedicated to problem formulation where various design parameters are represented including scenario followed in this thesis. In Chapter 6, Firstly MATLAB software is introduced to carry out simulations, secondly, implementation flow of LLEAP and ACO in MATLAB is discussed. A comparative study was conducted where better results were observed and presented along with discussions in the ending sections. Chapter 7 involves the conclusions and future scope of this research.

Place: Ferozepur　　　　　　　　　　Meenaxi (96436882803)

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ABBREVIATIONS

Abbreviations	Description
ACO	Ant Colony Optimization
SI	Swarm Intelligence
WSN	Wireless Sensor Network
NP	Non Polynomial
EA	Evolutionary Algorithm
LEACH	Low-energy Adaptive Clustering Hierarchy
M-LEACH	Multi-hop LEACH
PEGASIS	Power Efficient Gathering in Sensor Information Syatem
PEACH	Power-Efficient and adaptive Clustering Hierarchy
GPS	Global Postioning System
TEEN	Threshold Sensitive Energy Efficient Sensor Network Protocol
SOP	Self-Organizing Protocol
MAC	Medium Access Control
HEED	Hybrid Energy Efficient Distributed Clustering Protocol
HEEP	Powered by ambient Energy Haervesting
EEABR	Energy Efficient Ant Based Routing
OLE	Optimized Lifetime Enhancement

Abbreviations	Description
BACCA	Based On Ant Colony Clustering Algorithm
PSO	Particle Swarm Optimization
EEHC	Energy Efficient Heterogeneous Clustered Scheme
EAAR	Environmental Monitoring Aware Routing
ECRPW	Energy Efficiency Clustering Routing Protocol Based On Weight
ADRP	Adaptive Decentralized Reclustering Protocol
CH	Cluster Head
FLS	Fuzzy Logic System
BS	Base Station
EEUC	Energy Efficient Unequal Clustering Algorithm
UCFIA	Unequal Clustering Fuzzy Logic Improved ACO Algorithm
EC	Energy Efficient Clustering
DCR	Data Collection Round
EAP	Energy Aware Routing Protocol
QoS	Quality Of Service
LLEAP	Low-Loss Energy Aware Routing Protocol
MLDG	Maximum Lifetime Data Gathering
MLDA	Maximum Lifetime Data Aggregation
MLER	Maximum Lifetime Energy Routing
EAQSR	Energy Aware QoS Routing Protocol

NOTATIONS

Symbols	Description
r_i	Neighbor nodes
d	Destination node
$\tau(r, s)$	Pheromone value
$\eta(r, s)$	Value of heuristic related to energy
$tabu^r$	List of received data packages
R	Receiving node
I	Initial energy
e_r	Current energy level of receiver node r
$\Delta\tau^k(t)$	Quantity of pheromone deposited
$J_w^k(t)$	Total number of nodes visited by ant k on tour w at t iteration
p_c	Amount of pheromone at each connection
ρ	A control coefficient used to determine the weight of evaporation for each tour
P	Percentage of cluster heads
G	A set of nodes those have not been cluster heads
E_a	Average residual energy
$E_{residual}$	residual energy
RSS_i	Node i's received signal strength

Symbols	Description
RSS_{max}	A constant which is determined by location of base station
D	Distance between node i and the base station

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CHAPTER 1

INTRODUCTION

This thesis presents investigational studies in Ant Colony Optimization (ACO) and their use in Wireless Sensor Networks with a certain routing protocol. This introductory chapter presents an overview of thesis. This include introduction to research topic, motivation, methodologies, contributions, research findings and organization of thesis.

1.1 Introduction

Wireless sensor networks (WSNs) consist of a large number of tiny, cheap, computational, and energy-constrained sensor nodes that are deployed in network area. Energy efficient routing is being done so as to improve the lifetime of network. Our focus in this thesis is on energy efficient routing improved by using one of the Swarm Intelligence (SI) techniques namely ACO. So many researchers have proposed different algorithms for the optimized design of WSN.

ACO is a relatively novel meta-heuristic technique and has been successfully used in many applications especially problems in combinatorial optimization. ACO algorithm models the behavior of real ant colonies in establishing the shortest path between food sources and nests. Ants can communicate with one another through chemicals called pheromones in their immediate environment. The ants release pheromone on the ground while walking from their nest to food and then go back to the nest. The ants move according to the amount of pheromones, the richer the pheromone trail on a path is, the more likely it would be followed by other ants. So a shorter path has a higher amount of pheromone in probability, ants will tend to choose a shorter path. Through this mechanism, ants will eventually find the shortest path. Artificial ants imitate the behavior of real ants, but can solve much more complicated problem than real ants can. The below sections contribute the introduction of WSN and ACO.

1.1.1 Wireless Sensor Network

A Wireless Sensor Network (WSN) is a network consisting of wirelessly connected sensor nodes Fig. 1.1. These multi-functional sensor nodes can communicate in short distances. A large number of these sensor nodes collaborate to form wireless sensor networks. A WSN usually consists of tens to thousands of such nodes that communicate through wireless channels for information sharing and cooperative processing. To ensure scalability and to increase the efficiency of the network operation, sensor nodes are often grouped into clusters. The communication in WSN includes node to node communication. This communication includes optimal route selection, route maintenance etc. to compete with user expectations and better network performance.

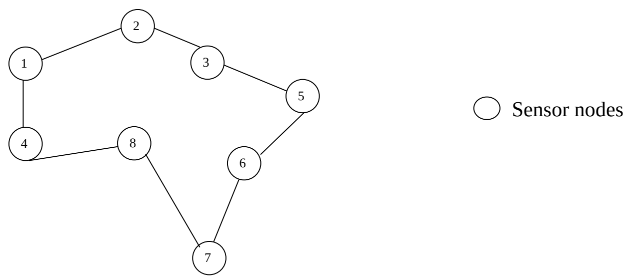

FIGURE 1.1: Sensor nodes deployed in WSN

According to [Acs and Buttyán, 2007] route selection of each message in communication pattern results in either network delay by choosing long routes consisting many sensor nodes or degrade network lifetime in terms of short routes resulting in depleted batteries. Besides, unnecessary load on a network and delay in operation not only degrades application quality but also wastes network resources. Furthermore, as WSN can be seen in critical applications so the demands for application vary according to the requirements. Different applications have different demands from network which cannot be avoided. Therefore, there is a need of efficient routing protocol which should not only be suitable for the application demands but also assists network with respect to its limited resources and performs well. Routing is the process of selecting paths in a network. Routing protocols discover and maintain the routes in the network. The resource constrained nature of WSNs motivates numerous challenges in its design and operations degrading its performance. These challenges include communication management, operational nature, fault tolerance, network life-time [Ahmed et al., 2003]. To identify and select best routing protocol for an application, it is required to understand the demands of that application first and then to select the appropriate protocol to be implemented and simulated. There are several routing protocols developed for WSNs. All these routing protocols have different competing features and qualities. Therefore, the selection of correct routing protocol is vital as routing protocol discover and maintain the routes in the network.

1.1.2 Ant Colony Optimization

Ant algorithms were inspired by the observation of real ant colonies. Ants are social insects, that is, insects that live in colonies and whose behaviour is directed more to the survival of the colony as a whole than to that of a single individual component of the colony. An important and interesting behaviour of ant colonies is their foraging behaviour i.e how ants can find shortest paths between food sources and their nest [Dorigo et al., 1996]. Ants are capable of finding the shortest path from food source to their nest or vice versa by smelling pheromones which are chemical substances they leave on the ground while walking. Each ant probabilistically prefers to follow a path rich in pheromone. This behaviour of real ants can be used to explain how they can find a shortest path [Eshghi and Kazemi, 2006]. The main idea is that it is indirect local communication among the individuals of a population of artificial ants. This indirect local communication between ant agents is called *stigmergy* . The core of ants behavior is the communication between the ants by means of chemical pheromone trails, which enables them to find shortest paths between their nest and food sources. This behaviour of real ant colonies is exploited to solve optimization problems. ACO is a meta-heuristic optimization technique. A heuristic technique is usually defined as a replicable method or approach for directing ones attention in learning, discovery, or problem solving. The research led to creation of more robust, general methods so that they may be applicable for solving various different problems. These more general and improved heuristic methods were called metaheuristics.

1.2 Motivation

Swarm intelligence (SI) is the collective behavior of decentralized, self-organized systems, natural or artificial. The expression was introduced by Gerardo Beni and Jing Wang in 1989, in the context of cellular robotic systems. SI systems are typically made up of a population of simple agents or boids interacting locally with one another and with their environment. The inspiration often comes from nature, especially biological systems. The agents follow very simple rules, and although there is no centralized control structure dictating how individual agents should behave, local, and to a certain degree random, interactions between such agents lead to the emergence of "intelligent" global behavior, unknown to the individual agents.

Natural examples of SI include ant colonies, bird flocking, animal herding, bacterial growth, and fish schooling. In principle, it should be a multi-agent system that has self-organized behaviour that shows some intelligent behaviour. The ant colony optimization algorithm (ACO) is a probabilistic technique for solving computational problems which can be reduced to finding paths. Many reseachers had already implemented various routing algorithms on WSN for better performance. [Mohammad El-Basioni et al., 2011] implemented hierarchical protocols such as EAP, LEAP which works around LEACH and then he improved EAP routing protocol and named the new protocol as LLEAP. The author experimented this protocol and observed better results as compared to previous routing protocols mentioned in the paper. This routing protocol only improves the other parameters except network lifetime over EAP.

1.3 Objectives

The primary objectives of this research work are summarized as follows:

1. Develop a simulated environment of WSN having configurable parameters.
2. To study previous routing protocols and their features.
3. Investigation in ACO algorithm with an application of optimizing WSN.
4. To conduct a comparative performance evaluation for network lifetime, Packet Delivery Ratio, Packet Loss Ratio, End-to-End Delay

1.4 Methodology

To achieve aforesaid objectives, the following methodology has been adopted:

1. A detailed literature survey is done from eminent journals like IEEE, Elsevier and Springer, etc. This will provide the basic and conceptual knowledge of the domain.
2. A MATLAB programming environment is used for development of algorithms for energy aware routing in WSN.
3. LLEAP is supposed to be one of the most significant algorithms proposed in WSN routing. The same will be again implemented here.
4. WSN routing is again experimented with ACO.

5. LEACH protocol is re-investigated in this thesis.
6. A comparative analysis for various network parameters are then conducted.

1.5 Contributions

The main contributions of this report are :

1. To develop the simulated environment for WSN.
2. To create ACO algorithm on MATLAB for optimizing its various parameters.
3. To explore LLEAP and LEACH routing protocols in WSN.
4. To experiment the LLEAP with ACO using MATLAB for better performance in terms of network lifetime and other parameters like packet delivery ratio, packet loss ratio, end-to-end delay.

1.6 Thesis Outline

After the brief introduction to M.Tech. thesis in Chapter 1, detailed study of the historical research leaps on routing in WSN, ACO and other routing algorithms reported till date, are described in Chapter 2.

Algorithmic flow of ACO describing the behaviour of artificial ants as well as application of ACO in WSN is explained in Chapter 3.

Study of LLEAP and LEACH in sensor networks and its past outcomes are discussed in Chapter 4. Cluster head selection in WSN is also introduced in this chapter.

Chapter 5 is dedicated to problem formulation where various design parameters are represented including scenario followed in this thesis.

In Chapter 6, firstly MATLAB software is introduced to carry out simulations, secondly, implementation flow of LLEAP, LEACH and ACO in MATLAB is discussed. A comparative study was conducted where better results were observed and presented along with discussions in the ending sections.

Chapter 7 involves the conclusions and future scope of this research.

CHAPTER 2

LITERATURE SURVEY

The needed detailed of literature survey, to get preliminary knowledge and search scope of investigation, to design WSN for optimization of its various parameters, i.e., network lifetime, packet delivery ratio, packet loss ratio, ene to end delay are explained in this chapter. Design of WSN with Swarm Intelligence (SI) technique that occurred till date, in this domain of research is presented in this chapter.

2.1 Introduction

Wireless Sensor Networks consisting of nodes with limited power are deployed to gather useful information from the field. In WSNs it is critical to collect the information in an energy efficient manner. Ant Colony Optimization, a swarm intelligence based optimization technique, is widely used in network routing. WSNs provide reliable operations in various application areas including environmental monitoring, health monitoring, vehicle tracking system, military surveillance and earthquake observation. Thus survey or work done on ACO used for improving parameters in WSNs are explained in following subsections.

2.2 Survey on ACO for WSN

Although WSNs are used in many applications, they have several restrictions including limited energy supply and limited computation and communication abilities. These limitations should be considered while designing the protocols for WSNs. Because of these considerations specific to WSNs, many routing schemes using end-to-end devices and other adhoc networks are inappropriate for WSNs. In sensor networks, minimization of energy consumption is considered a major performance criterion to provide maximum network lifetime. When considering energy conservation, routing protocols should also be designed to achieve fault tolerance in communications. In addition, since channel bandwidth is limited, protocols should have capability of performing local collaboration to reduce bandwidth requirements [Heinzelman et al., 2000]. The basic method to transfer information from a sensor node to the base is called flooding. In this method, information is disseminated by all the nodes as well as the base node. The broadcasting operation to all over the network consumes too much node resources such as energy and bandwidth.

[Camilo et al., 2006] proposed EEABR which is based on the Ant Colony Optimization heuristic. Initially the forward ants are sent to no specific destination node, which means that sensor nodes must communicate with each other and the routing tables of each node must contain the identification of all the sensor nodes in the neighbourhood and the correspondent levels of pheromone trail. For large networks, this can be a problem since nodes would need to have big amounts of memory to save all the information about the neighboring nodes. The algorithm can be easily changed to save memory. If the forward ants are sent directly to the sink, the routing tables only need to save the neighbor nodes that are in the direction of the sink. This reduces the size of the routing tables and, in consequence, the memory needed by the nodes. The quality of a given path between a sensor node and the sink-node, should be determined not only in terms of the distance, but also in terms of the energy level of that path.

BACCA was proposed [Jiang et al., 2010] for radar sensors which consumes a better balanced energy and increase the life cycle of the radar sensor network. The difference between wireless sensor network and radar sensor network is that there is one more step in radar sensor network, which is radar scanning process, so deduce radar sensor network radio model can be deduced from wireless sensor network radio model. In this algorithm when the new cluster head is chosen, both the residual energy and aggregation of radar nodes are considered. At the same time, when the radar nodes choose to join the corresponding cluster head to form the new cluster, both the residual energy of radar node and energy attenuation of data transmission are considered. With the help of this algorithm, the radar sensor network lifetime can be increased effectively.

Singh et al. [Das et al., 2004] proposed an ant based algorithm for WSN routings. However, this algorithm does not consider the main specifications of WSN structures.

2.3 Developments in Hierarchical Protocols for WSN

[Heinzelman et al., 2000] proposed LEACH which is adaptive clustering protocol for distributing the energy load among the sensor nodes in the network. LEACH uses randomized rotation of the cluster base stations or cluster heads and the corresponding clusters and is able to distribute energy dissipation evenly throughout the sensors, doubling the lifetime. The clusters are used for transmitting data to the base station provides the advantages of smaller transmitting distances for most of the nodes, requiring only a few nodes for transmitting the data far distances to the base station. It increases the performance of classical clustering algorithms by using adaptive clusters and rotating cluster heads, allowing the energy requirements of the system. In addition, this protocol is able to perform local computation in each cluster to reduce the amount of data that must be transmitted to the base station. This achieves a large reduction in the energy dissipation. [Nguyen et al., 2008] proposed another protocol named M-LEACH which is an energy efficient routing protocol for mobile wireless sensor networks. This protocol has some features of LEACH, the location of cluster heads are chosen to reduce the total power attenuation. In this protocol, during the Setup phase, each node sends information including locations, energy level to the base station and during the transmission phase, each node sends data during its allocated transmission time. [Abusaimeh and Yang, 2009] proposed Cluster-tree LEACH which supports single or multi-cluster networks. Each single cluster in multi-cluster network acts as a cluster head and these cluster-heads are fixed in each cluster during the lifetime of the network. This protocol has increased the lifetime of the network by nearly 50% of the original lifetime of the network.

[Lindsey and Raghavendra, 2002] proposed PEGASIS, a greedy chain protocol which resolves the data-gathering problem of the wireless sensor networks. The main thing is for each node to receive from and transmit to close neighbors and take turns being the leader for transmission to the base station. This approach will distribute the energy load evenly among the sensor nodes in the network. Initially the nodes are placed randomly in the field, and the sensor nodes are arranged to form a chain, which can either be accomplished by the sensor nodes themselves using a greedy algorithm starting from some node. Alternatively, the base station can compute this chain and broadcast it to all the other sensor nodes. For constructing the chain, all nodes have global knowledge of the network and then employ the greedy algorithm. A loop will be constructed to ensure that all nodes have close neighbors is difficult as this problem is similar to the traveling salesman problem. The greedy approach to constructing the chain is done before the first round of communication. It shows better results as compared to LEACH by removing the overhead of dynamic cluster formation, reducing the number of transmissions, and using only one transmission to the base station per round and shows better improvement if the network size increases.

[Yi et al., 2007] proposed PEACH, a clustering protocol for maximizing the network lifetime of the wireless sensor networks. Clustering protocols enable sensor nodes to reduce data packets by data aggregation on WSN. In wireless sensor networks, a node can recognize the source and the destination of packets transmitted by hearing (i.e. sensing) the neighboring nodes. On the basis of heard information, the protocol forms the clusters without additional packet transmission head such as advertisement, announcement, joining, and scheduling messages. This is designed to operate on probabilistic routing protocols, in order to provide an adaptive multi-level clustering. As a result of the protocol design, it is generally more scalable and efficient to the various circumstances than the existing clustering protocols of the wireless sensor networks. This protocol can be used on both location-unaware and location-aware wireless sensor networks. The location-unaware protocol can be used when the location information of each node is unavailable on the network. The location-aware protocol operates when the localization mechanism such as a GPS-like hardware is available on sensor nodes. The communication cost in WSN is decreased by the reducing the data packets, and the clustering protocols improve the lifetime and the energy consumption of the wireless sensor networks. PEACH has no overhead on cluster head selection and forms adaptive multi-level clustering as compared to the existing clustering protocols.

[Manjeshwar and Agrawal, 2001] proposed TEEN which is the first protocol developed for reactive networks. In this, at every cluster change time, the cluster-head broadcasts to its members. Thus, the hard threshold tries to reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest. The soft threshold further reduces the number of transmissions by eliminating all the transmissions which might have otherwise occurred when there is little or no change in the sensed attribute once the hard threshold. TEEN is well suited for time critical applications and is also quite efficient in terms of energy consumption and response time. It also allows the user to control the energy consumption and accuracy to suit the application. The main drawback of this scheme is if the thresholds are not achieved, the nodes will never communicate, the user will not get any data packet from the network and will not come to know about the nodes if they die. Thus, this scheme is not well suitable for applications where the user wants to get data regularly. Another problem is that a practical implementation would have to ensure that there collision-free cluster.

[Zhao and Erdogan, 2006] proposed SOP protocol which includes cluster architecture of LEACH with multi-hop routing to decrease transmission energy. In many WSN multi-hop routing is adopted. This makes a node that wants to transmit data to a destination node find one or multiple intermediate nodes. The communication occurs among all the nodes until the data packets reach the destination [Shah and Rabaey, 2002]. In brief, the data packets take several hops among the nodes in the network. The main advantage of this approach is that transmission energy consumption is reduced. But at the same time latency of the network and delay of data packets will increase. In some cases, no rigid requirements on latency, the multi-hop routing can lead to high energy efficiency. In this protocol when clusters are organized, the cluster heads form a multi-hop routing backbone. Every cluster member node sends data to the cluster head directly for the communication purpose. While for the communication between the cluster head and the base station, a multi-hop routing is adopted to reduce the transmission energy and minimize the difference of energy consumption among all nodes in the network. In order to reduce the probability of collisions at setup phase, some collision avoidance mechanism are added to CSMA MAC protocol. Thus it is more suitable to WSN. The assumptions are considered same as LEACH about the network model as follows. This means that all nodes can use power control to vary their transmission power and range. At the same time, each node has enough processing power to support different protocols and signal processing tasks.

[Younis and Fahmy, 2004] described HEED in which tentative cluster heads are randomly selected based on their residual energy. Therefore, HEED cannot guarantee optimal head selection in terms of energy, since it uses the secondary parameter to solve the problems.

[Eu et al., 2009] proposed HEEP and improved network performance using routing algorithm and improves relay node placement scheme for wireless sensors networks. This protocol uses super-capacitors instead of batteries as energy storage devices, by providing almost unlimited recharge cycles for endless deployment. This protocol is very helpful for the applications where sensor nodes are not easily accessed or replaced. In the proposed approach a multi-hop HEAP deployment that comprises three types of nodes: relay, source and sink nodes. All these three types of nodes are different from each other. The function of the relay node is to forward data packet from source to sink node. These relay nodes are required when the source node is not within the range of the sink for the communication purpose. The source node is similar to the relay node except that if it does not receive any packet in the reception time, it will send its own data packet in that transmission time. The sink node does not need to be charged, sink receives any data packet transmitted by the sensor nodes if sink lies in the range of the sensor.

[Younis et al., 2002] presented an approach for energy aware and context aware routing protocol of data. The researchers mainly focused on the adjustment of topology and the routing mechanism. Data is routed through multiple hops so as to conserve transmission energy. Sensor energy is the major issue while deciding for changes to network topology and for setting routes. Setting routes for sensor data can be obtained by the central node that knows the network topology, like the gateway, or distributed among the sensors themselves. Both centralized and distributed routing requires maintenance of the routing table every time the network topology changes by updating the routing table with the change in topology adopted. On the other hand, centralized routing is simple and is suitable for the wireless sensor networks. The sensor is committed to data processing and communication thus it is beneficial to offload routing decision from the resource-limited sensor nodes. Centralized routing can restrict scalability as the more gateways can be deployed if number of sensors per cluster increases. It is better for the gateway to send commands to the sensors directly without involving relays because the gateway is not energy-constrained as the sensors. The approach used is the transpose of a single-source routing algorithm, i.e. single destination routing. This can reduce the complexity of the problem using a least cost or shortest path unicast routing algorithm.

[Chakraborty et al., 2009] proposed an Optimized Lifetime Enhancement Scheme which shows increased network performance by ensuring a sub-optimal energy dissipation of the individual nodes despite their random deployment. It employs modern heuristics like particle swarm optimization instead of the greedy algorithm as in PEGASIS to establish energy efficient routing paths. In this, chain is formed and the network lifetime is increased by allowing the individual nodes to transmit unequal number of times to the base station depending on their residual energy and location. This algorithm requires centralized knowledge about the sensor network, it would be best to carry out the algorithm in the base station and distribute the result in the network before initiating data gathering. This task is dependent upon the application itself. If frequent communication with the base station is not feasible for all the nodes, this chain formation algorithm can also be applied in individual clusters in the sensor field, where these computations can be done by a local leader in each cluster. This will not only use limited resources as the number of nodes in a cluster is limited but also results in equal energy dissipation among the local leaders. This sort of distributed computation will speed up the process of self-organization of the network. In the end, the base station could connect these local leaders to form the final optimized chain.

[Kumar et al., 2009] proposed an energy efficient protocol called EEHC which involves the advantage of presence of node heterogeneity. The goal of this protocol is to enhance the network lifetime and stability of the network in the presence of heterogeneous nodes. This protocol takes complete advantage of heterogeneity; the stable region is increased in comparison with that of LEACH because super and advanced nodes follow the death process of normal nodes as the weighted probability of selecting cluster heads causes the energy of each node to be consumed in proportion to the node's initial energy. The simulation shows this protocol has 10% increased lifetime of the network as compared to LEACH in the presence of same setting of powerful nodes in the network.

[Misra et al., 2010] proposed EAAR protocol in which a set of paths with similar energy is obtained, but only some nodes will be of distinct type of nodes. Authors used the concept of naturally occurring behavior of real ants [Doerner et al., 2001] and on this basis an energy aware routing protocol is designed. This help in obtaining the better paths because parameter used in this approach is not limited to hop count only. This protocol has very less number of dead nodes as compared to other algorithms. This is multi-path energy-aware routing protocol which demonstrates the better results because once a route has been established it is reliable as far as the energy of that route is concerned. This uses more packets to find routes and large numbers of routes are discovered in a more mobile state. Unlike other protocols, this protocol delivers a constant ratio in comparison with other protocols. The energy consumed, energy per packet, packet loss in this protocol is less as compared to other protocols in small and medium mobility networks. The packet delivery ratio and energy per packet in high mobility networks are not better for this protocol as the other parameters because energy awareness increases the time to estimate the best route for the packet transmission. The results get better for lager data packets. Packet delivery ratio is much improved with the help of this protocol.

[Wenning et al., 2010] intentionally described EMAR which adapt to external node errors. The node's health is most applicable routing criteria affected by sensing. There is an additional criteria like link quality that helps in efficient routing when all the nodes in the network are equally healthy. These parameters are indicating towards exact direction and connectivity to the destination. This approach has demonstrated good performance, if considered in forest fire scenarios. This type of routing can bear multiple sinks excluding additional overhead. This approach is more adaptable than standard protocols the additional environmental parameters can be added simply to the routing algorithm.

[Sun et al., 2011] proposed ECRPW to prolong the lifetime of the network, residual energy of the nodes is to be considered during the election process of cluster-head. The cluster-heads were distributed uniformly as they consider the distance that had been forced to optimize the cluster scheme. The constraint of distance is considered in formation of cluster to avoid extra energy consumption. The network lifetime of this protocol is longer than that of LEACH. The lifetime curve increases with node density. This protocol considers the current residual energy of nodes and the distances among the cluster-heads to optimize the cluster scheme which enhances the lifetime of the network along with load balancing and also equalizes consumption of energy. In the data transmission phase and routing tree can balance the energy consumption of cluster-heads. This protocol has better performance results.

[Bajaber and Awan, 2011] proposed an adaptive clustering protocol for wireless sensor networks called ADRP in which cluster-heads and next heads are elected based on residual energy of each node and the average energy of each cluster having nodes. Cluster-heads rotate to balance the energy released from the sensor nodes. This protocol is used for collecting data from distributed sensor nodes and transmits data to the base station. This protocol is helpful in supporting periodic remote monitoring sensor networks. The sensor nodes switch directly to next heads without communicating with the base station. This protocol has least amount of energy and reduces communication overheads. If single hop communication is used to reach the base station, the sensor nodes located farther away from the base station will be having the highest energy load because of long range communication. If multi hop communication is used to reach the base station, the sensor nodes closer to the base station is having higher load of relaying packets.

[MAO and ZHAO, 2011] proposed energy efficient unequal clustering for large wireless networks which balance the power of node consumption and increase the network lifetime as long as possible. This protocol focuses on inter-cluster routing protocol. Fuzzy logic system is used to determine node's chance of becoming cluster-head and adaptive max-min ant colony optimization is used to construct inter-cluster routing between cluster heads and base station which further balances the energy consumption of cluster heads. Base station broadcasts a beacon message to all the sensor nodes at fixed power. Each sensor node can compute the approximate distance to the base station based on the received signal strength. This proposed clustering scheme is divided into rounds and the main feature of this algorithm is the application of Fuzzy Logic called unequal clustering Fuzzy logic improved ACO algorithm (UCFIA). ACO is used to find the optimal path between cluster head and base station. UCFIA improves the network lifetime over LEACH and EEUC.

[Wei et al., 2011] proposed a distributed clustering algorithm, EC which determines the cluster sizes depending upon the hop distance to the data-sink while achieving equal lifetimes of nodes and reduces energy consumption. Each sensor node produces a single data packet, transmits packet to its associated cluster heads. Then each node collects those packets from its associated member nodes and combines to produce a cluster. Trade-offs, hop distances to the sink and approximate equalization of energy levels are three step processes which are referred to as a single data collection round (DCR) of the WSN operation. This protocol enhances lifetime of the network and provides equalization of energy level of nodes at different hop distances to the sink.

[Khalil and Attea, 2011] proposed EAERP in which authors reformulate the design of important feature of EA (Evolutionary Algorithms) so that the routing protocol provides more robust results as compared to the existing heuristics. The authors have presented a new evolutionary dynamic cluster formation in WSN. This protocol proves to be an important for deriving clustered routes with better trade-off between network stability and network lifetime with well-distributed energy consumption.

[Nayebi and Sarbazi-Azad, 2011] proposed an analytical model for investigating the effect of mobility on a cluster-based protocol called LEACH. This evaluates data loss which can be used to estimate the balanced energy and data loss ratio. As LEACH is type of random clustering scheme so this is used for the applications of random clustering. This approach leads to the geometric model which is presented to evaluate the reliability of links between cluster heads and cluster-members. Distance from cluster heads to cluster members is evaluated with the help of this geometric model. The results showed that packet loss ratio starts from 0.5 and then increasing. This model is highly accurate with or without buffer zone.

2.4 Network Parameters

Important parameters of WSNs such as network lifetime, packet delivery ratio, packet loss ratio, end-to-end delay which are considered in this thesis. The work done by researchers developing various algorithms for improving these significant parameters is summarized in the further subsections.

2.4.1 Network Lifetime

[Lu et al., 2012] changed the threshold function of the node so as to increase the network's lifetime and balance the energy consumption of nodes. The randomness of choosing head node, energy load imbalance in cluster-head nodes, energy utilization rate of head nodes are the problems of classical LEACH protocol. The improvement of LEACH protocol includes optimum factor, modified threshold function, and method for normal nodes joining the head nodes which leads to the formation of a new protocol called NEWLEACH. This protocol introduces the optimal factor by considering the residual energy of the nodes, times of the nodes to be elected as a cluster head node, the distance between nodes and base station. This improvement fines the quality of wireless sensor networks. This mainly extends the lifetime of the network. The even distribution of dead nodes exhibits the balanced energy in the network. Thus NEWLEACH protocol has an advantage over classical LEACH routing protocol.

[Zheng et al., 2012] proposed a protocol based on Bayesian game to avoid uneven energy consumption in wireless sensor networks. The authors used the theorems of game theory for routing analysis in wireless sensor networks. Network initialization, cluster-head election, data transmission are the three parts of this protocol. In network initialization, nodes receive initial information from a sink node, then all the nodes broadcasts the data packets to the neighboring nodes and the sink node. The packets include information like ID, residual energy etc. After this all the nodes form a routing table which consists of the information related to those nodes. The real time property of this protocol can be measured by average number of hops from source to sink. This protocol ensures the reliable communication under high real time requirements due to uniformly distribution of cluster-heads and the logical design of utility function.

[Mohammad El-Basioni et al., 2011] proposed EAP which includes the QoS of an energy efficient cluster based routing protocol in terms of lifetime, loss percentage, delay and throughput. EAP works like LEACH and each round consists of two important phases, set-up phase and data phase. The set-up phase is subdivided into two phases, cluster formation phase and cluster heads tree construction phase. The main disadvantage is that the protocol slightly degrades lifetime of the network.

2.4.2 QoS Parameters

QoS parameters in wireless networks include PDR, PLR, End-to-End Delay. The developments made by various researchers is briefly described below:

[Kalpakis et al., 2002] desrcibed the data routing technique which is specified for each period i.e. how data can be obtained and routed to sink. The protocol includes the data aggregation while setting up the maximum network lifetime route.PEGASIS is better than MLDA in terms of delay for data packets.

MLER [Chang and Tassiulas, 2004] is proposed for solving the problem of routing in WSN. The main aim is to maximizing the network defining the link cost as a function of residual energy of the node. Then the energy consumed when a packet is transmitted as a link cost performs better.

[Akkaya and Younis, 2005] described EAQSR to find out an optimal path to the gateway in terms of energy consumption and error rate while meeting end-to-end delay requirements. This protocol is a table-driven multi-path routing protocol with embeded QoS in its routing decisions.

2.5 Conclusion

Typically wastage of battery and energy occurs when we do-not have energy-aware routing protocol. The number of packets collision, limited Bandwidth, link discovery and link establishment all of these factors take a lot of resources in terms of battery and power, especially when large number of wireless nodes are deployed to collect data and there is no actual way to know where energy has been wasted. As these reduce the lifetime of the network. Thus this problem should be solved to provide collision-free, reliable and minimum consumption of energy. Routing protocols have a critical role in most of these activities. Various optimization techniques are used along with different routing protocols. Thus, ACO is preferred for optimal route selection

For improved QoS parameters along with prolonged network lifetime ACO is implemented to acquire optimal routes from source node to destination node assuming the sink node to be random in each simulation round.

CHAPTER 3

ACO ALGORITHM

Swarm intelligence is a new approach for problem solving that takes inspiration from the social behaviours of insects and of other animals. In particular, ants have inspired a number of methods and techniques among which the most studied and the most successful is the general purpose optimization technique known as ant colony optimization.

3.1 Introduction

ACO takes inspiration from the foraging behaviour of some ant species. These ants deposit pheromone on the ground in order to mark some favourable path that should be followed by other members of the colony. Ant colony optimization exploits a similar mechanism for solving optimization problems.

In the forties and fifties of the twentieth century, the French entomologist Pierre-Paul Grasse [Bonabeau, 1999] observed that some species of termites react to what he called "significant stimuli" and observed that the effects of these reactions can act as new significant stimuli for both the insect that produced them and for the other insects in the colony. Grasse used the term *stigmergy* to describe this particular type of communication in which the "workers are stimulated by the performance they have achieved". The two main characteristics of *stigmergy* that differentiate it from other forms of communication are the following.

1. Stigmergy is an indirect, non-symbolic form of communication mediated by the environment: insects exchange information by modifying their environment

2. Stigmergic information is local: it can only be accessed by those insects that visit the locus in which it was released (or its immediate neighbourhood)

Examples of stigmergy can be observed in colonies of ants. In many ant species, ants walking to and from a food source deposit on the ground a substance called *pheromone*. Other ants perceive the presence of pheromone and tend to follow paths where pheromone concentration is higher. Through this mechanism, ants are able to transport food to their nest in a remarkably effective way.

3.2 Application of ACO in WSN

In an experiment known as the "double bridge experiment", the nest of a colony of Argentine ants was connected to a food source by two bridges of equal lengths [Dorigo and Socha, 2006]. In such a pattern, ants start to explore the surroundings of the nest and eventually reach the food source. Along their path between food source and nest,*Argentine ants deposit pheromone*. Initially, each ant randomly chooses one of the two bridges. However, due to random fluctuations, after some time one of the two bridges presents a higher concentration of pheromone than the other and, therefore, attracts more ants. This brings a further amount of pheromone on that bridge making it more attractive with the result that after some time the whole colony converges toward the use of the same bridge. This colony-level behaviour, based on autocatalysis, that is, on the exploitation of positive feedback, can be exploited by ants to find the shortest path between a food source and their nest.

In ACO, a number of artificial ants build solutions to an optimization problem at hand and exchange information on the quality of these solutions via a communication scheme

3.2.1 The Metaheuristic

A metaheuristic is a set of algorithmic concepts that can be used to define heuristic methods applicable to a wide set of different problems. In other words, a metaheuristic is a general-purpose algorithmic framework that can be applied to different optimization problems with relatively few modifications. Examples of metaheuristics include simulated annealing, tabu search,iterated local search, evolutionary computation,and ant colony optimization

3.2.2 Applications of ACO

In recent years, the interest of the scientific community in ACO has risen sharply. Because of its robustness, and adaptive nature, ACO can find its applications in routing, assignment, scheduling, subset and classification rules problem

3.2.3 ACO for Routing: General Principles

ACO routing algorithms take inspiration from the behaviour of ants in nature and from the related field of ACO to solve the problem of routing in communication networks. ACO routing algorithms boast a number of interesting properties compared to traditional routing algorithms.

The properties of ant based algorithm which make them suitable for routing are:

1. Dynamic topology: This property is responsible for the poor performance of many 'classical' routing algorithms in mobile multi-hop ad-hoc networks. The ant algorithm is based on autonomous agent systems imitating individual ants. This allows a high adaptation to the current topology of the network.
2. Local work: In contrast to other routing approaches, the ant algorithm is based only on local information, i.e. no routing tables or other information blocks have to be transmitted to other nodes of the network.
3. Link quality: It is possible to integrate the connection/link quality into the computation of the pheromone concentration, especially into the evaporation process. This will improve the decision process with respect to the link quality. It is important to note that the approach can be modified so that nodes can also manipulate the pheromone concentration independent of the ants, e.g. if a node detects a change of the link quality.

The ant colony optimization algorithm (ACO) is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs. Initially proposed by [Dorigo et al., 1996] in 1992 in his PhD thesis, the first algorithm was aiming to search for an optimal path in a graph, based on the behavior of ants seeking a path between their colony and a source of food as described in Fig. 3.1 .

3.3 ACO Approach

To summarize the operation of the routing scheme, a node having information for the base station initializes the routing task by transferring data in packages to different neighbor

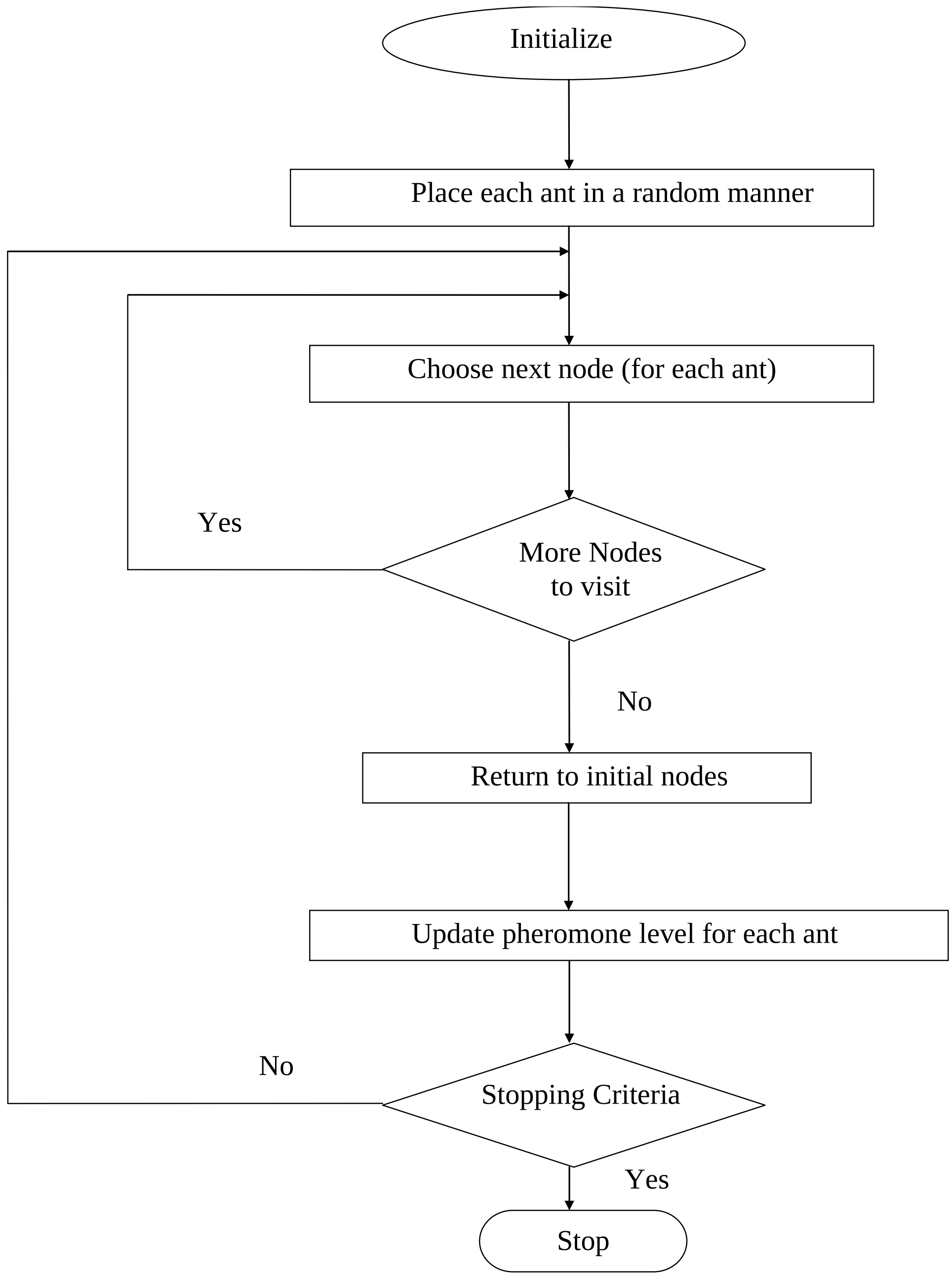

FIGURE 3.1: Flow-chart of ACO.

nodes. Each node then chooses other neighbor nodes and so on. Thus, paths towards the base station are formed and each routing operation supplies some information about optimum paths for the consequent routing tasks or criteria. While performing this operation, some agents i.e. artificial ants are used to acquire efficient routing.

Each ant tries to find a path in the network, providing minimum cost. Ants are initialized from a source node s and move through neighbor nodes r_i, and reach a final destination node (sink) d . According to [Okdem and Karaboga, 2009] the choice of the next node r is made according to a probabilistic decision rule (3.1).

$$P_k(r,s) = \begin{cases} \frac{[\tau(r,s)]^\alpha \cdot [\eta(r,s)]^\beta}{\sum\limits_{r \epsilon R_s} [\tau(r,s)]^\alpha \cdot [\eta(r,s)]^\beta} & \text{if } k \notin tabu^r, \\ 0 & \text{otherwise ,} \end{cases} \tag{3.1}$$

where $\tau(r,s)$ is the pheromone value,$\eta(r,s)$ is the value of the heuristic related to energy, R_s is the receiver nodes. Here for node r, $tabu^r$ is the list of identities of received data packages previously. α and β are two parameters that control the relative weight or density of the pheromone trail and heuristic value.It is observed that pheromone trails are connected to arcs. Each arc(r,s) has a trail value $\tau(r,s)\epsilon[0,1]$. Since the destination d is a stable base station, the last node of the path is the same for each ant travel. The heuristic value of the node r is expressed as (3.2)

$$\eta(r,s) = \frac{(I - e_r)^{-1}}{\sum_{n \in R_s} (I - e_n)^{-1}} \tag{3.2}$$

where I is the initial energy, and e_r is the current energy level of receiver node r. This enables decision making according to energy levels neighbor nodes i.e. if a node has a lower energy source then it has lower probability to be chosen. Nodes inform their neighbors about their energy levels when they sense any change in their energy levels.

In earlier, ACO consists of special memory of an ant to retain the places visited by that ant. According to (3.1), the identities of the ants that visited the nodes previously are kept in the node's memory instead of keeping in ant's memory. Each receiver node decides whether to accept the upcoming packet of ant k or not, by checking its tabu list. So, the receiver node r has a choice about completing the receiving process by listening and buffering the entire packet. If the receiver node has received the packet earlier, it informs the transmitter node by issuing an ignore message, and switches itself to idle mode until a new packet arrives. When all the ants have completed their tour, each ant k deposits a quantity of pheromone $\Delta\tau^k(t)$ as mentioned in (3.3)

$$\Delta\tau^k(t) = \frac{1}{J_w^k(t)} \tag{3.3}$$

where $J_w^k(t)$ is the length of the tour of $w^k(t)$ which is done by k ant at t iteration.In WSN the $J_w^k(t)$ represents the total number of nodes visited by ant k on tour w at t iteration. The amount of pheromone at each connection or path p_c is given by (3.4)

$$\tau(r,s)(t) \longleftarrow \tau(r,s)(t) + \Delta\tau(r,s)(t) \quad \forall p_c(r,s) \in w_k(t) \quad \text{where } k = 1, ..., m \tag{3.4}$$

The pheromone values are stored in a memory of nodes. Each node has information about the amount of pheromone on the paths to their neighbor nodes. After each tour, an amount of pheromone trail $\Delta\tau^k$ is added to the path visited by ant k. This amount is the same for each arc(r, s) visited on this path. This task is performed by sending ant k back to its source node from the base along the same path, while transferring an acknowledgement signal for the associated data package. Increasing pheromone amounts on the paths according to lengths of tours,$J_w(t)$, would continuously cause an increasing positive feedback. In order to control the operation, a negative feedback, the operation of pheromone evaporation after the tour is also accomplished in (3.5)

$$\tau_{ij}(t) \leftarrow (1-\rho)\tau_{ij}(t) \tag{3.5}$$

where ρ is a control coefficient which is used to determine the weight of evaporation for each tour [Dorigo and Di Caro, 1999] and $\rho \in (0,1)$.The results were experimentally proved to be good by Marco Dorigo in [Dorigo, 1992] when ACO parameter settings are set to values as 1 for α , 5 for β ,0.5 for ρ.

3.4 Conclusion

This chapter concludes the approach followed for the application of ACO in WSNs. The indirect communication takes place with the help of pheromone laid down by each individual ant. Further this chapter includes the flow chart of ACO algorithm which clearly describes the movement of ants from source to destination or vice-versa.

CHAPTER 4

ROUTING IN WIRELESS SENSOR NETWORKS

A classification and comprehensive survey of routing techniques in WSNs is presented. The design of routing protocols in WSNs is influenced by many challenging factors. These factors must be overcome before efficient communication can be achieved in WSNs. In the following, we summarize some of the routing challenges and design issues that affect the routing process in WSNs.

4.1 Introduction

Routing is very challenging in WSNs due to the characteristics that distinguish these networks from other wireless networks like mobile adhoc networks or cellular networks. 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. According to [Al-Karaki and Kamal, 2004], the traditional IP-based protocols may not be applied to WSNs. Furthermore, sensor nodes that are deployed in an adhoc manner need to be self-organizing as the adhoc deployment of these nodes requires the system to form links and cope with the resultant nodal distributions, especially as the operation of sensor networks is unattended. In WSNs, sometimes getting the data is more important than knowing the IDs of which nodes sent the data. 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. This, however, does not prevent the flow of data to be in other forms (e.g., multicast or peer to peer).Sensor nodes are tightly constrained in terms of energy, processing, and storage capacities.Thus, they require careful resource management.

4.2 Routing Challenges in WSN

In most application scenarios, nodes in WSNs are generally stationary after deployment except few mobile nodes. Nodes in other traditional wireless networks are free to move, which results in unpredictable and frequent topological changes. However, in some applications, some sensor nodes may be allowed to move and change their location even with very low mobility. Position awareness of sensor nodes is important because data collection is normally based on the location. Routing protocols in wireless sensor networks are expected to fulfill the following requirements according to [Akkaya and Younis, 2005]

1. Deploying Nodes : Node deployment in WSNs is application-dependent and can be either manual (deterministic) or randomized. In case of deterministic, the sensors are manually placed and data is routed through predetermined paths. However, in random node deployment, the sensor nodes are scattered randomly, creating an adhoc routing infrastructure. If the resultant distribution of nodes is not uniform, optimal clustering becomes necessary to allow connectivity and enable energy-efficient network operation. Inter sensor communication is normally within short transmission ranges due to energy and bandwidth limitations. Therefore, it is most likely that a route will consist of multiple wireless hops.

2. Energy consumption : In a wireless environment, sensor nodes can use their limited supply of energy performing computations and transmitting information. As such, energy-conserving forms of communication and computation are essential. Lifetime of sensor node shows a strong dependence on battery lifetime. The malfunctioning of some sensor nodes due to power failure can cause significant topological changes, and might require re-routing of packets and re-organization of the network.

3. Link heterogeneity : The existence of a heterogeneous set of sensors raises many technical issues related to data routing. For example, some applications might require a diverse mixture of sensors for monitoring temperature, pressure, and humidity of the surrounding environment, detecting motion via acoustic signatures, and capturing images or video tracking of moving objects. Either these special sensors can be deployed independently or the different functionalities can be included in the same sensor nodes.

4. Connectivity : Sensor nodes are expected to be highly connected so as to avoid isolation from each other. This may not prevent the network topology from being variable and

the network size from shrinking due to sensor node failures. In addition, connectivity completely depends on the random distribution of nodes.

5. Quality of service : Data should be delivered within a certain period of time from the moment it is sensed, or it will be useless. Therefore, bounded latency for data delivery is another condition for time-constrained applications. However, in many applications, conservation of energy, which is directly related to network lifetime, is considered relatively more important than the quality of data sent. As energy is depleted, the network may be required to reduce the quality of results in order to reduce energy dissipation in the nodes and hence lengthen the total network lifetime. Hence, energy-aware routing protocols are required to capture this requirement.

4.3 Routing Protocols

Different routing protocols are designed to fulfill the shortcomings of the resource constraint nature of the WSNs. The deployed WSN can be differentiated according to the network structure. Therefore, routing protocols for WSN needs to be categorized according to the nature of WSN operation and its network architecture. WSN routing protocols can be subdivided into two broad categories, network architecture based routing protocols and operation based routing protocols [Akkaya and Younis, 2005] [García Villalba et al., 2009].

4.3.1 Route Selection Base Classification of Routing Protocols

The routing protocols can be classified on the method used to acquire and maintain the information, and also on the basis of path. This classification is based on how the source node finds a route to the destination node.

1. Proactive Protocols : Proactive routing protocols are also known as table driven protocols which maintains consistent and accurate routing tables of all network nodes using periodic dissemination of routing information. Most of these routing protocols can be used both in flat and hierarchal structured networks. The advantage of flat proactive routing is its ability to compute optimal path which requires overhead for this computation which is not acceptable in many environments. While to meet the routing demands for larger ad hoc networks, hierarchal proactive routing is the better solution [Kimura and Latifi, 2005] [Akkaya and Younis, 2005]

2. Reactive Protocols : Reactive routing protocols do not maintains the global information of all the nodes in a network rather the route establishment between source and

destination is based on its dynamic search according to demand. In order to discover route from source to destination, a route discovery query and the reverse path is used for the query replies. Hence, in reactive routing strategies, route selection is on demand using route querying before route establishment. These strategies are different by two ways: by re-establishing and re-computing the path in case of failure occurrence and by reducing communication overhead caused by flooding on networks [Ullah and Ahmad, 2009][Akkaya and Younis, 2005].

3. Hybrid Protocols : These protocols are applied to large networks. Hybrid routing contain both proactive and reactive routing strategies. It uses clustering technique which makes the network stable and scalable. The network cloud is divided into many clusters and these clusters are maintained dynamically if a node is getting added or leaving a particular cluster. This strategy uses proactive technique when routing is needed within clusters and reactive technique when routing is needed across the clusters. Hybrid routing exhibit network overhead required maintaining clusters [Ullah and Ahmad, 2009] [Akkaya and Younis, 2005].

4.3.2 Architecture Based Routing Protocols

Protocols are divided according to the structure of network which is very important for the required operation. These protocols are [Akkaya and Younis, 2005]

1. Flat-Based Routing : Flat-based routing is needed where every node plays same role, huge amount of sensor nodes are required. Since the number of sensor nodes is very large therefore it is not possible to assign a particular Id to each and every node. This leads to data-centric routing approach in which Base station sends query to a group of particular nodes in a region and waits for response. Examples of Flat-based routing protocols are [Akkaya and Younis, 2005].
   (a) Energy Aware Routing (EAR)
   (b) Directed Diffusion (DD)
   (c) Sequential Assignment Routing (SAR)
   (d) Minimum Cost Forwarding Algorithm (MCFA)
   (e) Sensor Protocols for Information via Negotiation (SPIN)
   (f) Active Query forwarding In sensor network (ACQUIRE)
2. When network scalability and efficient communication is needed, hierarchical-based routing is the best match. It is also called cluster based routing. Hierarchical-based

routing is energy efficient method in which high energy nodes are randomly selected for processing and sending data while low energy nodes are used for sensing and sending information to the cluster heads(CH). This property of hierarchical-based routing contributes to the network scalability, network lifetime and minimum energy. Examples of hierarchical-based routing protocols are[Akkaya and Younis, 2005] [Acs and Buttyán, 2007]

(a) Hierarchical Power-Active Routing (HPAR)
(b) Threshold sensitive energy efficient sensor network protocol (TEEN)
(c) Power efficient gathering in sensor information systems
(d) Minimum energy communication network (MECN)
(e) Low Energy Adaptive Clustering Hierarchy(LEACH)

3. Location-Based Routing : In this kind of network, sensor nodes are scattered randomly in an area of interest and mostly geographic position is known where they are deployed. They are located mostly by means of GPS. The distance between nodes is estimated by the signal strength received from those nodes and coordinates are calculated by exchanging information between neighboring nodes. Location-based routing networks are[Acs and Buttyán, 2007][Akkaya and Younis, 2005]

(a) Sequential assignment routing (SAR)
(b) Ad-hoc positioning system (APS)
(c) Greedy other adaptive face routing (GOAFR)
(d) Geographic and energy aware routing (GEAR)
(e) Geographic distance routing (GEDIR)

4.3.3 Operation Based Routing Protocol Classification

WSNs applications are categorized according to their functionalities. Hence routing protocols are classified according to their operations to meet these functionalities. The reason behind their classification is to achieve optimal performance and to save the scarce resources of the network. Protocols classified to their operations are:

(a) Multipath Routing Protocols : These protocols included in this class provides multiple path selection for a message to reach destination thus decreasing delay and increasing network performance. Network reliability is achieved due to increased overhead. Since network paths are kept alive by sending periodic messages and hence consume greater energy. Multipath routing protocols are: [Akkaya and Younis, 2005]

   i. Multi path and Multi SPEED (MMSPEED)
   ii. Sensor Protocols for Information via Negotiation (SPIN)

(b) Query Based Routing Protocols : These protocols works on sending and receiving queries for data. The destination node sends query of interest from a node through network and node with this interest matches the query and send back to the node which initiated the query. The query normally uses high level languages. Query based routing protocols are: [Akkaya and Younis, 2005]

   i. Sensor Protocols for Information via Negotiation (SPIN)
   ii. Directed Diffusion (DD)
   iii. COUGAR

(c) Negotiation Based Routing Protocols : These protocols uses high level data descriptors to eliminate redundant data transmission through negotiation. These protocols make intelligent decisions either for communication or other actions based on facts such that how much resources are available. Negotiation based routing protocols are: [Akkaya and Younis, 2005][Panda, 2012]

   i. Sequential assignment routing (SAR)
   ii. Directed Diffusion (DD)

(d) QoS Based Routing Protocols : In this routing, network needs to have a balance approach for QoS of applications. So to achieve QoS, the cost function for the desired QoS also needs to be considered. Example of such routing are: [Panda, 2012]

   i. Sequential assignment routing (SAR)
   ii. SPEED
   iii. Multi path and Multi SPEED (MMSPEED)

(e) Coherent Data Processing Routing Protocol : Coherent data processing routing is used when energy-efficient routing is required. In this type of routing, nodes perform minimum processing (typically, time-stamping, suppression etc) on the raw data locally before sending for further processing to other nodes. Then it is sent to other nodes called aggregator for further processing known as aggregation [Akkaya and Younis, 2005]. Data processing in non-coherent processing involves three phases. In first phase target detection, its data collection and preprocessing of its data takes place. Then for the cooperative function the node needs to enter in second phase where it shows its intention to neighboring nodes. Here all neighboring nodes must be aware of the local network topology. Finally, in third phase, a center node is selected for further refined information processing. Therefore central node must have enough energy resources and computation abilities [Akkaya and Younis, 2005].

4.4 LEACH Protocol

Low Energy Adaptive Clustering Hierarchy (LEACH) is a TDMA based MAC protocol which is integrated with clustering and a simple routing protocol used in WSNs. The aim of LEACH is to lower the energy consumption required to create and maintain clusters in order to improve the life time of a wireless sensor network. It is a hierarchical protocol in which most nodes transmit to cluster heads, and the cluster heads aggregate and compress the data and forward it to the base station(sink). Each node uses a stochastic algorithm at each round to determine whether it will become a cluster head in this round. It is assumed in LEACH that each node has a radio powerful enough to directly reach the base station or the nearest cluster head, but that using this radio at full power all the time would waste energy.

Nodes that have been cluster heads cannot become cluster heads again for N rounds, where N is the desired percentage of cluster heads. Thereafter, each node has a probability of becoming a cluster head in each round. At the end of each round, each node that is not a cluster head selects the closest cluster head and joins that cluster. The cluster head then creates a schedule for each node in its cluster to transmit its data. All those nodes which are not cluster heads only communicate with the cluster head. The properties of LEACH are:

1. Cluster based
2. Random cluster head selection each round with rotation
3. Cluster membership adaptive
4. Data aggregation at cluster head
5. Cluster head communicate directly with sink or user
6. Communication done with cluster head via TDMA
7. CDMA across clusters

In LEACH, the nodes organize themselves into local clusters, with one node acting as the local base station or cluster head. If the cluster heads were chosen a priori and fixed throughout the system lifetime, as in conventional clustering algorithms, it is easy to see that the unlucky sensors chosen to be cluster heads would die quickly, ending the useful lifetime of all nodes belonging to those clusters. Thus LEACH includes randomized rotation of the high energy cluster head position such that it rotates among the various sensors in order to not drain the battery of a single sensor.

Sensors elect themselves to be local cluster heads at any given time with a certain probability. These cluster head nodes broadcast their status to the other sensors in the network. Each sensor node determines to which cluster it wants to belong by choosing the cluster head that requires the minimum communication energy. Each cluster head creates a schedule for the nodes in its cluster. The radio components of each non-cluster-head node to be turned off at all times except during its transmit time, thus minimizing the energy dissipated in the individual sensors. Once the cluster head has all the data from the nodes in its cluster, the cluster head node combines the data and then transmits the compressed data to the base station. If the base station is far away in the scenario, there is a high energy transmission. However, since there are only a few cluster heads, this only affects a small number of nodes. The operation of LEACH is broken up into rounds, where each round begins with a set-up phase, when the clusters are organized, followed by a steady-state phase, when data transfers to the base station occur. In order to minimize overhead, the steady-state phase is long compared to the set-up phase [Heinzelman et al., 2000].

4.4.1 Advertisement Phase

When clusters are being created, each node decides whether or not to become a cluster head for the current round. This decision is based on the suggested percentage of cluster heads for the network and the number of times the node has been a cluster head so far. This decision is made by the node n choosing a random number between 0 and 1. If the number is less than a threshold, the node becomes a cluster-head for the current round. Where threshold is set as expressed in (4.1):

$$T(n) = \begin{cases} \frac{P}{1-P*(r mod \frac{1}{P})} & \text{if n}\in\text{G,} \\ 0 & \text{otherwise ,} \end{cases} \tag{4.1}$$

Where P is desired percentage of cluster heads (e.g. $P = 0.05$), r is the current round, and G is the set of node that have not been cluster-heads in the last 1/P rounds. Using this threshold, each node will be a cluster-head at some point within 1/P rounds. When $r = 0$ i.e during round 0, each node is having a probability P of becoming cluster head whereas the nodes which are cluster head in round 0 cannot be cluster head for next $1/P$ rounds. Each node that has elected itself a cluster head for the current round broadcasts an advertisement message to the rest of the nodes. For this cluster-head-advertisement phase, the cluster heads use a CSMA MAC protocol, and all cluster heads transmit their advertisement using the same transmit energy. The non-cluster head nodes must keep their receivers on during this phase of set-up to hear the advertisements of all the cluster-head nodes. After this phase is complete, each non-cluster-head node decides the cluster to which it will belong for this round Figure. 4.1. This decision is based on the received signal strength of the advertisement. Assuming symmetric propagation channels, the cluster head advertisement heard with the largest signal strength is the cluster-head to whom the minimum amount of transmitted energy is needed for communication. In the case of tie-ups, a random cluster head is chosen.

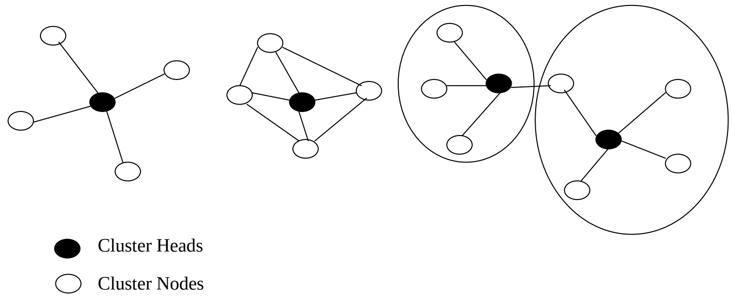

FIGURE 4.1: Cluster Head in WSN.

4.4.2 Set-up Phase

After deciding to which cluster each node belongs,it must inform the cluster head node that it will be a member of the cluster. Each node transmits this information back to the cluster head again using a CSMA MAC protocol. During this phase, all cluster head nodes must keep their receivers active i.e. on.

4.4.3 Creating a Schedule

The cluster head node receives all the messages for those nodes which would like to be included in the cluster. The cluster head node creates a TDMA schedule telling each node when it can transmit which further depends upon the number of nodes in the cluster. This schedule is broadcast back to the nodes in the cluster.

4.4.4 Transmitting Data

Data transmission can begin after creating the clusters and fixing the TDMA schedule. Assuming that nodes are always having data to send, they send it during their allocated transmission time to the cluster head. This transmission uses a minimal amount of energy (chosen based on the received strength of the cluster head advertisement). The radio of each non-cluster-head node can be turned off until the nodes allocated transmission time, thus minimizing energy dissipation in these nodes. The cluster head node must keep its receiver on to receive all the data from the nodes in the cluster as explained in the set-up phase. When all the data has been received, the cluster head node performs signal processing functions to compress the data into a single signal. For example, if the data are audio or seismic signals, the cluster head node can combine the individual signals to generate a composite signal. This composite signal is sent to the base station. Since the base station is far away, this is a high energy transmission.

This is the steady state operation of LEACH in WSN. After some time (which is determined), the next round begins with each node determining if it should be a cluster head for this round and advertising this information, as described in advertisement phase.

4.4.5 Multiple Clusters

The individual clusters communication among nodes in that cluster is described in the above discussion. Transmission in one cluster affects or degrades the communication in nearby clusters as radio is the communicating media. From Fig. 4.2 Node A is transmitting to Node B, corrupts the transmission to Node C.

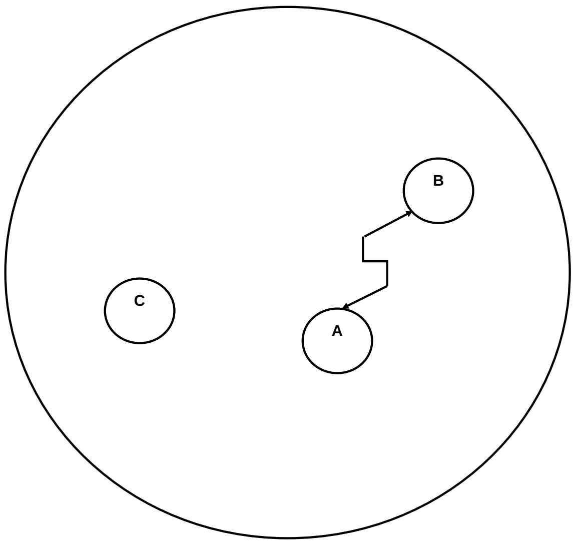

FIGURE 4.2: Radio Interference.

To reduce this interference, each cluster communicates using different CDMA codes. Thus, when a node decides to become a cluster head, it chooses randomly from a list of spreading codes. It is informed to all the nodes in the cluster to transmit using this spreading code. The cluster head then filters all received energy using the given spreading code. Thus radio signals of neighboring clusters will be filtered out and not corrupt the transmission of nodes in the cluster. CDMA codes solve the problem of multiple-access in a distributed manner and does not provide necessarily the most bandwidth efficient solution.

4.5 LLEAP

EAP [Mohammad El-Basioni et al., 2011] works in rounds same as that in LEACH and each round consists of two main phases, set-up phase and data phase. The set-up phase is subdivided into two phases, cluster formation phase and CHs tree construction phase. In the cluster formation phase, each node takes one of three states which are roles played by each node (candidate, plain, or head) while in the tree construction phase, each CH takes additional role(s) to form the CHs tree, these roles are child, parent, and root, so that the CH may be a Child Cluster Head only (CCH), Parent Cluster Head (PCH) which indoors is a child, Root Cluster Head which may be a parent but not a child (RCH/RPCH). The average residual energy E_a of all neighbors in the cluster range is computed from the neighborhood table information by using (4.2):

$$E_a = \frac{\sum_{j=1}^{m} v_j \cdot E_{residual}}{m} \tag{4.2}$$

EAP performs better in terms of lifetime, but it lacks a mechanism that informs member nodes about their CH death and informs CHs about their parents death during the round. So, EAP leads to energy loss that is consumed in sending packets to a dead node and loss in the sent packets, and these losses continue until the end of the round. EAP authors concerned only in their evaluation of the protocol on the network lifetime and they did not consider other important QoS parameters such as delay, packet loss, and throughput. It was found that the common cause of EAP losses is the death of the root during the round when it is overloaded.

To eliminate EAP losses, a recovery method was directly used from CH (child, parent, or root) death or failure, but this method will exhaust a lot of energy and reduce lifetime and may also affect the other good performance parameters of EAP. So, the protection from loss cause is better. The protection manner used in the modified protocol Low Loss Energy-Aware routing Protocol (LLEAP) [Mohammad El-Basioni et al., 2011] consists of two techniques, the first technique is used to increase the lifetime, so that if a loss occurred, the recovery method does not significantly affect the characteristic of LLEAP with respect to the lifetime, and after the recovery, LLEAP lifetime remains on average as EAP lifetime. The lifetime is increased by developing a schedule for nodes to sleep and wake up to save their energy. The second technique is used to reduce the number of occurrence times of the previously mentioned common cause for loss in EAP to reduce losses and the energy consumed in the recovery from it.

EAP uses the same weight for head selection and tree construction. The equation of head selection weight should satisfy that relation among its parameters for head selection weight:

the less ratio of the average residual energy of node neighbors to its residual energy ($\frac{E_a}{E_{residual}}$) the greater the node weight, the greater the likelihood of that node to become a CH (so that the selected CH will collect in its cluster the maximum number of small residual energy nodes decreasing the load on them and giving the other nodes which have relatively higher energy the chance to become CHs), this requires reversing the ratio $\frac{E_a}{E_{residual}}$ which is used in the equation of head selection weight in EAP. The weight used in LLEAP for head selection uses the reversed ratio is (4.3)

$$\text{LLEAP CH Selection Weight} = \frac{D(RSS_i) \times E_{residual}}{D(RSS_{max}) \times E_a} \tag{4.3}$$

In tree construction phase, E_a has no meaning and no effect, rather, it may have a negative impact on the selection of inappropriate CH as a root. E_a is the average residual energy of all the neighbors in the cluster range, $E_{residual}$ is the remaining energy left. RSS_i denotes node $i's$ received signal strength of the signal broadcasted by the base station. RSS_{max} is a constant which is determined by the location of the base station. D is a function used for estimating the distance between node i and the base station. So, the tree construction weight in LLEAP is mentioned in (4.4):

$$\text{LLEAP Tree construction weight} = \frac{D(RSS_i)}{D(RSS_{max})} \times E_{residual} \tag{4.4}$$

where RSS_i denotes received signal strength of node i of the signal broadcasted by the BS, RSS_{max} is a constant which is determined by the location of the BS.

4.6 Clustering Attributes

The set of attributes [Abbasi and Younis, 2007] that can be use to categorizes and differentiate clustering algorithms of WSNs are:

1. Clustering properties: Often clustering schemes strive to achieve some characteristics for the generated clusters. Such characteristics can be related to the internal structure of the cluster or how it relates to others. The relevant properties are:

   (a) Cluster counts: The set of CHs are predetermined and thus the number of clusters are preset. Randomly picking CHs from the deployed sensors usually yields variable number of clusters.

   (b) Stability: When the clusters count varies and the nodes membership evolves overtime, the clustering scheme is said to be adaptive. Otherwise, it is considered fixed since sensors do not switch among clusters and the number of clusters stays the same throughout the network lifespan.

(c) Inter CH connectivity: When the CH does not have long distance communication capabilities, CHs connectivity to the base-station has to be provisioned. In that case, the clustering scheme has to ensure the feasibility of establishing an inter-CH route from every CH to the base-station. Some of the reseachers published work assumes that CH would be able to directly reach the base-station.

(d) Intra Cluster topology: Some clustering schemes are based on direct communication between a sensor and its designated CH. However, multi-hop sensor-to-CH connectivity is sometimes required; especially when the sensors communication range is limited and/or the CH count is bounded.

2. Cluster-head capabilities: The following attributes of the CH node are differentiating factors among clustering schemes:

   (a) Type of nodes: A subset of the deployed sensors are designated as CHs while in others CHs are equipped with significantly more computation and communication resources.

   (b) Mobility: When a CH is mobile, sensors membership changes dynamically and the clusters would need to be continuously maintained. On the other hand, stationary CH tends to yield stable clusters and facilitate intra-cluster and inter-cluster network management. Sometimes, CHs can travel for limited distances to reposition itself for better network performance.

   (c) Role of CH: A CH can simply act as a relay for the traffic generated by the sensors in its cluster or perform aggregation of collected data from sensors. Sometimes, a CH acts as a sink or a base-station that takes actions based on the detected targets.

3. Clustering process: The coordination of the entire clustering process and the characteristics of the algorithms vary significantly among published clustering schemes. The deemed relevant attributes are:

   (a) Node grouping: This includes fault-tolerance, load balancing, network connectivity, etc

   (b) Cluster head selection: CHs can be pre-assigned or picked randomly from the deployed set of nodes.

   (c) Methodology: When CHs are just regular sensors nodes, clustering has to be performed in a distributed manner without coordination. In few approaches, a centralized authority partitions the nodes offline and controls the cluster membership. Hybrid schemes can also be found; especially when CHs are rich in resources. In the later case, inter-CHs coordination is performed in a distributed manner, while each individual CH takes charge of forming its own cluster.

(d) Algorithm: Depending on the objective and the methodology, numerous clustering algorithms have been proposed. The complexity and convergence rate of these algorithms can be constant or dependent on the number of CHs and/or sensors.

4.7 Conclusion

This chapter concludes routing challenges in WSNs. Classification of routing protocols used in WSNs are discussed. LEACH protocol is explained in detail with its phases for selecting the cluster head. It further includes the LLEAP Protocol desrciption. The improvements observed on LLEAP is experimented in next chapter.

CHAPTER 5

IMPLEMENTATION

In this chapter, firstly, MATLAB software used for deploying WSN is presented. Secondly, implementation of algorithmic flow of ACO and LLEAP are discussed, in detail. ACO is a stochastic optimization technique used for routing in adhoc or wireless networks. Here it is experimented with LLEAP which is a protocol used for routing in WSNs

5.1 Introduction

Today, most of the research is done to develop ultra-low powered WSN which is only possible only if the overall network lifetime increases and the network run with high stability and reliability. To achieve this, many algorithms have been implemented which take their concept from some biological processes. Therefore, they are called bio-inspired algorithms. These algorithms in their basic form have already been implemented on various network protocols including LEACH, AODV etc. However, these bio-inspired algorithms [Dorigo and Socha, 2006] (for e.g. ACO) need further research for getting higher level of optimization in terms of power management, Packet delivery ratio etc. As network observable behavior of bio-inspired processes need to be incorporated in existing algorithms like ACO. The mathematical formulation by which the weights and paths are calculated need improvisation as per the requirement of the routing protocol like LEACH, EAP, and LLEAP.

5.2 MATLAB Environment

The simulation is carried out using Custom Built Iterative Based Simulator in MATLAB 7.12.0.635 (R2011a) which simulates the sending, receiving, dropping and data forwarding etc. MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. Using the MATLAB product, technical computing problems can be solved faster than with traditional programming languages, such as C, C++ and Fortran. It is used in a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis. Add-on toolboxes (collections of special-purpose MATLAB functions, available separately) extend the MATLAB environment to solve particular classes of problems in these application areas.

MATLAB provides a number of features for documentary work. MATLAB code can be integrated with other languages and applications, and gives out various new algorithms and applications. It's features include:

1. High-level language for technical computing
2. Development environment for managing code, files, and data
3. Interactive tools for iterative exploration, design, and problem solving
4. Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, and numerical integration
5. 2-D and 3-D graphics functions for visualizing data
6. Tools for building custom graphical user interfaces

5.3 Algorithmic Flow Implementation

Sensor nodes are deployed in random manner using MATLAB for finding the optimal path i.e shortest path followed by artificial ants. The wireless channel is used because the nodes deployed in the network are communicating wirelessly based on their distance, transmission range etc. Propagation model is used to calculate the received power. When a packet is received, the propagation model determines the attenuation between sender and receiver. This model also computes the received signal strength. The two ray ground propagation model is used. An Omni-directional antenna is used for carrying out transmissions in all the directions i.e. over 360 degree. Omni-directional WSN are designed such that a bi-directional link is established between the neighboring nodes if they are within the communication range.

5.4 Proposed work

The proposed work done in this thesis is mentioned below in steps:

1. Deploy WSN by initializing the parameters.
2. After deploying the network, it is worth-noting to use the appropriate topology for that network.
3. Selecting the cluster head in the sensor network.
4. Initializing the communication by sending the data packets.
5. Implementing ACO, a technique used for finding optimal solution.
6. Identify shortest path as per ACO
7. Evaluating the performance and observing the comparative analysis.

5.4.1 Topologies used in WSN

The four WSN data network topologies discussed here will be Peer to Peer (also called Point to Point), Star, Tree and Mesh [Lewis, 2004]

1. Peer-to-Peer networks allow each node to communicate directly with another node without needing to go through a centralized communications hub. Each Peer device is able to function as both a "client" and a "server" to the other nodes on the network.
2. Star networks are connected to a centralized communications hub. Each node cannot communicate directly with one another; all communications must be routed through the centralized hub. Each node is then a "client" while the central hub is the "server"
3. Tree networks use a central hub called a Root node as the main communications router. One level down from the Root node in the hierarchy is a Central hub. This lower level then forms a Star network. The Tree network can be considered a hybrid of both the Star and Peer to Peer networking topologies.
4. Mesh networks allow data to "hop" from node to node, this allows the network to be self-healing. Each node is then able to communicate with each other as data is routed from node to node until it reaches the desired location. This type of network is one of the most complex and can cost a significant amount of money to deploy properly.

5.4.2 Pseudo Codes of ACO and LLEAP

The traditional and most common ACO procedure is in Algorithm. 1.The Pseudo code of LLEAP is in Algorithm. 2.

Algorithm 1 Pseudo Code for ACO

```
Begin
  Initialize the pheromone trails and parameters
     generate population of m solutions (ants)
     for each individual ant k ϵ m
          calculate fitness (k);
         for each ant determine its best position
     determine the best global ant
     update the pheromone trail
  Check if termination = true
          end
     end
End
```

Algorithm 2 Pseudo Code for LLEAP

```
  for each event in simulation
           for each round
                     for each iteration
                     choose  RN(Root Node)
           consider it as first edge
                      for each cluster
            choose Child Node
     for each time slot t
           If Node is Alive
           If node has residual energy ≥ E_D
           If the forwarding node is in Transmission Range of node source Inter Cluster Range, 2*r
           If value of d0 ratio is < D
                     Send ( ) data
                     Receive ( ) data
                     end
                     end
           end
       end
  end
```

5.4.3 LLEAP with ACO algorithm

The proposed work discussed earlier in the steps can also be explained by the pseudo code written for LLEAP protocol by implementing ACO as in Algorithm. 3.

Pseudo code of the proposed algorithm is given for packet movement in a WSN towards sink with objective of achieving maximum network life time in which Q represents each event in

Algorithm 3 Pseudo Code for LLEAP with ACO

```
 for i = 1 to Q
   for j= R
       for k= I
       choose  RN
   consider it as first edge
for each closed DAG
    choose CH, having highest W
else other
   child nodes
       calculate Inter-cluster Node Matrix
       calculate Distance Matrix
for each time slot t
   If Node is Alive
   If Inter-cluster distance between source and forwarding node is ≤ 3r
   If the forwarding node is an established links
   If value of d0 ratio is < D
   If the link is having selection of Cluster Head weight ≤ D(RSS_i) × E_residual / (D(RSS_max) × E_a)
    Cluster head is selected
       Construct tree construction weights = D(RSS_i) / D(RSS_max) × E_residual
Find links having weights with highest residual energy and smallest distance until
   Sink edge is reached
        end
   end
 end
 end
 end
```

the simulation. R is round in each simulation based on iteration I. Directed Acyclic Graph (DAG) [Tian et al., 2005] is formed by a collection of various vertices and directed edges, each edge connecting one vertex to another, such that there is no way to begin at some vertex and follow a sequence of edges that eventually loops back to vertex again. RN describes the selection of root node, W is the weight of nodes depicting the distance and residual energy of the node and d_0 is the threshold distance.

5.5 Network Scenario Assumptions

The simulation assumed that there are sensor nodes are randomly and densely scattered in a two-dimensional square field A, and the sensor network has the following properties:

1. Sensor nodes are unaware about their locations, non-rechargeable i.e energy constrained, and always have data to send.

2. There is only one sink in the field, which is deployed randomly.

3. Packets loss due to factors other than node death does not exist or is ignorable.

4. Transmission power varies depending upon the distance between node and receiver.

5. A node is considered to be dead when it is not capable of transmitting data to the sink.

6. It is assumed that the probability of signal collision and interference in the wireless channel is ignorable and the radio transmitter, radio amplifier and data fusion unit are the main energy consumers of a sensor node.

7. The consumed energy in aggregating Lk bit signals into a single k bit signal $= L \times E_{DA} \times k$, where E_{DA} denotes the energy consumed by data fusion.

After considering the assumptions discussed in previous section, the simulated environment execution consists nodes describing their energy level as in the Fig. 5.1. '+' desrcibes the nodes having energy $= 1$, 'o' states the energy level 0 in the network. 'x'represents the sink node in the simulated environment.

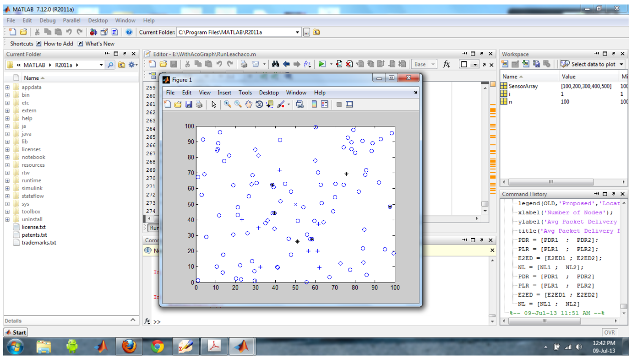

FIGURE 5.1: Simulation Scenario

5.6 Conclusion

In this chapter, various implementation steps of ACO algorithms are discussed. This Chapter includes the description of implementation requirements along with the algorithms developed to acquire the better results. The assumptions of network scenario are mentioned. Simulation results are represented in next chapter for increasing the network lifetime.

CHAPTER 6

RESULTS AND DISCUSSIONS

As already discussed, energy efficient WSN deployment is not an easy task due to large number of parameters, i.e., energy parameters and cluster head selection then their data transmission procedure. MATLAB programming platform is used for coding of ACO algorithms and LLEAP. Finally, the comparative performance of ACO algorithms is explained.

6.1 Introduction

The parameters considered during simulation have their own significance for the better performance of the network. The parameters considered during simulation have their own significance for the better performance of the network. The Table. 6.1 contributes the simulation parameters used.

The important definitions in the WSNs related to this thesis are:

1. Packet delivery ratio: The ratio of number of packets sent from the source to the number of packets received at the destination. The greater the value of PDR means better performance of the protocol.

2. Packet loss percentage: The ratio of number of raw packets lost due to death of the node to the total number of raw packets transmitted in the network until the last node dies.

Table 6.1: Simulation Parameters

Parameters	**Value**
Network Area	500*500
Number of nodes	500
Cluster Radius r	30 m
Sensing Radius	10 m
Initial Energy	0.5 J
E_{amp}	0.0013 pJ/bit/m^4
E_{fs}	10 pJ/bit/m^2
E_{DA}	5nJ/bit/signal
Routing Protocol	LLEAP
Optimization Technique	ACO

3. End-to-End Delay: The average time taken by raw packets to transverse from the simple nodes to the sink inspite of observing the form in which they are received.

4. Network Lifetime: The time for the first node or a certain percentage of sensor nodes to run out of power or it is the time interval from the start of operation (of the sensor network) until the death of the first alive node

Firstly, simulations were obtained for LLEAP Fig. 6.1, a hierarchical routing protocol in which network lifetime was decreased by 7% when compared with the previous routing protocol. Then the ACO, a metaheuristic optimization technique is implemented to find out shortest route by artificial ants because of their foraging behaviour. The results were improved with 19% increase in network lifetime . Instead of increase in network lifetime, better results are found for Packet Delivery Ratio(PDR),Packet Loss Ratio(PLR),End-to-End Delay.

It represents the improved network lifetime of WSN. To assess the performance of the protocols, a set of simulation runs were carried out. The simulation runs were conducted using MATLAB as the simulation platform to generate a network in 500*500 meter square area in which sensor nodes are distributed statically and uniformly. The sink node is located randomly and it is assumed that it has finite power and other resources. The results and analysis conclude that ACO implemented on LLEAP prolongs the lifetime of the network.

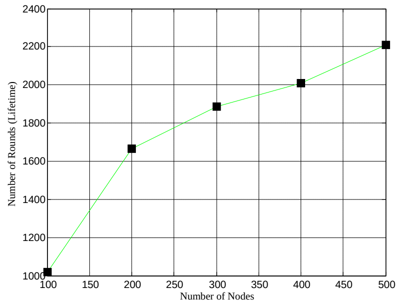

FIGURE 6.1: Network Lifetime of LLEAP

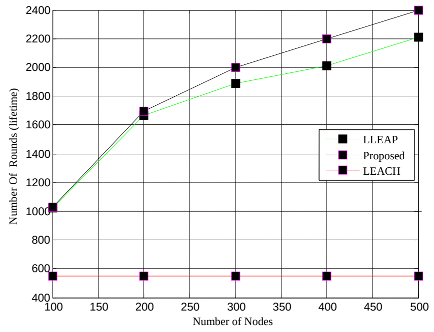

FIGURE 6.2: Network Lifetime of Proposed Algorithm

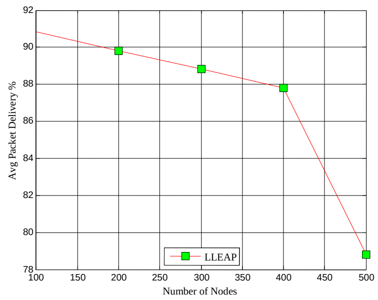

FIGURE 6.3: PDR of LLEAP

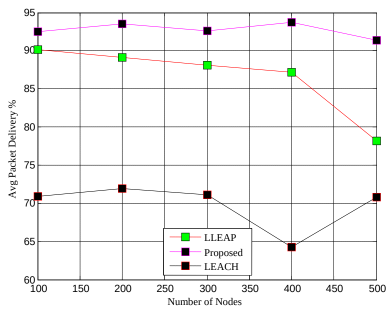

FIGURE 6.4: PDR of Proposed Algorithm

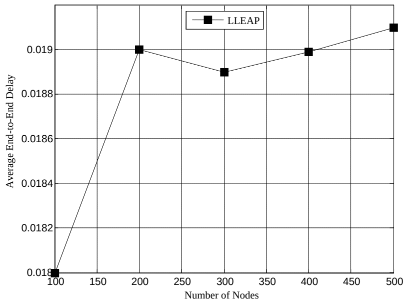

FIGURE 6.5: End-to-End Delay in LLEAP

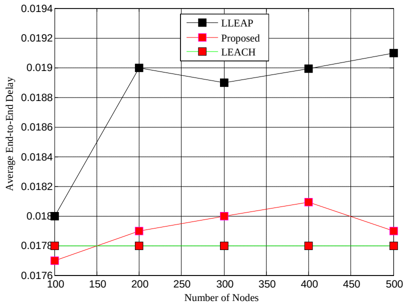

FIGURE 6.6: End-to-End Delay in Proposed Algorithm

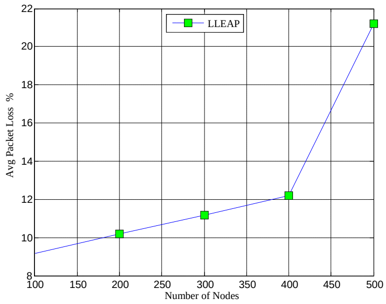

FIGURE 6.7: PLR in LLEAP

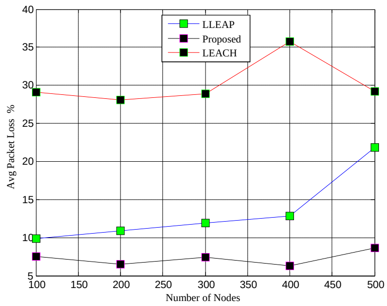

FIGURE 6.8: PLR in Proposed Algorithm

The graphical interpretation Fig. 6.2, Fig. 6.6, Fig. 6.8, Fig. 6.4 shows the better results as compared to LLEAP Fig. 6.7, Fig. 6.5, Fig. 6.1, Fig. 6.3. Thus the average Packet Delivery Percentage graph shows how many packets are successfully reaching the destination i.e sink node. It can be seen from the graph that initially the numbers of nodes are 100; the PDR of proposed algorithm is about 3% more as compared to the previous algorithm shown in Table. 6.2

TABLE 6.2: Results

Parameters	LEACH					LLEAP					Proposed Algorithm				
	n=100	n=200	n=300	n=400	n=500	n=100	n=200	n=300	n=400	n=500	n=100	n=200	n=300	n=400	n=500
Network Lifetime	550	550	550	550	550	1020	1666	1888	2011	2210	1029	1696	1998	2199	2399
Packet Delivery Ratio	70.91	71.91	71.11	64.21	70.81	90.81	89.81	88.81	87.81	78.81	93	94	93.10	94.20	91.80
Packet Loss Ratio	29.08	28.08	28.88	35.78	29.18	9.18	10.18	11.18	12.18	21.18	6.9	5.9	6.89	5.79	8.194
End-to-End Delay	0.017	0.017	0.017	0.017	0.017	0.018	0.019	0.018	0.019	0.019	0.017	0.017	0.018	0.018	0.017

6.2 Conclusion

In this chapter, ACO with LLEAP are experimented and discussed for deploying WSN. In the ending of section average results and the best results are tabulated for overall comparison. The results experimented are much better as compared to the results in [Mohammad El-Basioni et al., 2011]. More discussions are presented in the last chapter.

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

Research is an iterative process very similar to ACO where researchers keep on introducing and implementing new ideas based on their previous successes and the successes observed by other researchers in the area. Various research observations are presented at the end of previous chapter as conclusions . This chapter aims to conclude the thesis as a whole, and to aggregate all the offshoots found throughout the work.

7.1 Introduction

The highlights of this thesis are:

1. ACO is investigated to find out the optimal paths discovered by artificial ants during the course of their tour.
2. LLEAP routing protocol is re-done in this thesis so as to observe the results once without applying ACO
3. ACO is implemented on LLEAP to compare the results with the former algorithm

Section 7.2 presents the concluding remarks about what has been investigated, developed, and contribution throughout the work. In Section 7.3, various offshoots of the work are discussed for future directions.

7.2 Conclusions

Conclusions investigated in the whole thesis work are described as follows:

1. From simulation results,prolonged network lifetime is analyzed after implementing ACO.
2. Along with the network lifetime QoS parameters (e.g., PDR, PLR, End-to-End Delay) are also improved which means reliable communication on dedicated path established by artificial ants.

7.3 Future Scope

1. In this thesis single sink node is used, thus for the improvement multiple sink nodes can be used. Multiple sink nodes increases the complexity of routing algorithms.
2. Sink node used is dynamic in nature, thus for further research prospects the static sink node can be assumed.
3. Research can be done by implementing other algorithms on WSN.

Here the concept of death of nodes in existing algorithms is used which makes it more aware about which node has some battery power left or not assuming that the data is going at Constant Bit Rate (CBR). Therefore for future work, other traffic models like exponential can also be explored. Here, it is assumed that each round of simulation consists of at-least 5 communication rounds. Therefore, this type of simulation is iteration based. However for future work this simulation can also be implemented using another techniques or models.

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