ENERGY CONSTRAINT ANALYSIS IN APPROXIMATION ALGORITHMS FOR MANETS

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

INFORMATION SYSTEMS

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MAY, 2022

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I, Tikam Chand Mahawar, Roll no. 2K20/ISY/23 student of M.Tech. Information Systems, hereby declare that the project dissertation titled "Energy Constraint Analysis in Approximation Algorithms for MANETs" which is submitted by me to the Department of Information Technology, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and is not copied from any source without proper citation. This work has not previously formed the basis for the award of any degree, Diploma Associateship, Fellowship or other similar title or recognition.

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I hereby certify that the Project Dissertation titled "Energy Constraint Analysis in Approximation Algorithms for MANETs" which is submitted by Tikam Chand Mahawar, Roll No. 2K20/ISY/23 Department of Information Technology, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

A mobile ad hoc network is a simple network configured for a temporary basis without any physical infrastructure and can be dismantled when the required goal is achieved. In this type of network, nodes are allowed to move around in the geographical area i.e., nodes are mobile. A clustering MANET consists of two phases i) Cluster Formation and ii) Cluster Maintenance, and this project report suggests a customised optimization algorithm. All these clusters are formed by moving nodes and they contain a very limited number of resources which provides the fundamentals for clustering in MANETs:

1. Dynamic Topologies – nodes are mobile and hence topologies keep on changing.

2. Limited battery – mobile nodes are battery operated and a good algorithm is required to manage that as well.

3. Limited bandwidth – capacity of wireless links is less and they are also susceptible to interference and noise.

4. Limited Security – a node is allowed to join or leave any network, so it is risky to allow connection without checking.

Limited resources of CH depleted most and when a CH reaches a min threshold, it transfers its duties to another node, which is elected by CH itself. This report considers various Approximation algorithms which have been utilised to optimise the search results of various problems. A CH selection in Clustering MANETs is also a multi-objective problem which can be solved using these approaches. In this thesis, GA and PSO are applied on top of the LEACH protocol for better CH selection.

ACKNOWLEDGEMENT

I sincerely thank my Guide Professor Mrs Anamika Chauhan for her guidance and support are given. I have been amazingly fortunate to have a guide who gave me the freedom to explore on my own and at the same time the guidance to recover when my steps faltered. Her patience and support helped me to finish this dissertation.

I would like to thank my family and friends and the one above all of us, the omnipresent God for the support they provided

Finally, I would like to thank the family of DTU.

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LIST OF SYMBOLS, ABBREVIATIONS

S.No	***Symbol***	***Meaning***
1	CH	Cluster Head
2	GA	Genetic Algorithm
3	PSO	Point Swarm Optimization
4	LEACH	Low Energy Adaptive Clustering Hierarchy
5	DC	Direct Communication
6	GAECH	GA+LEACH

CHAPTER 1

INTRODUCTION

Mobile ad-hoc networks are multi-hop wireless communication networks that allow users to send and receive messages without forming any physical infrastructure. In these kinds of networks, nodes are mobile and managing address and topology information is a difficult task.

Networks had been the foundation of today's internet which allow multiple users to communicate with people. Having access to worldwide facilities is the modern enhancement of connecting just two computing nodes.

In the beginning, networks were formed using computing devices by interconnecting them with wired media, then it is replaced with high-speed optical fibers and now, these devices are connected using radio waves; but as we got free from wires nodes become mobile. Now, this is our new challenge to connect these mobile nodes without leaving or compromising the existing network functionalities. So, we have to find a way to track them as well as consider what kind of topology structures they can form.

Ad-hoc Network – definition

A type of network formed without any existing architecture. It means a network that didn't exist in any physical state until it is required by its users and those users formed that network when they need it, they can destroy it when they don't need it. There is no need for wired media or setting up complex infrastructure

Ad-hoc networks can be formed by connecting two computers either wired or wireless. Wired- In the wired approach the nodes are connected using a simple Ethernet LAN cord and the network can be configured to access each other. Wireless – In the wireless approach, the nodes become mobile and there is a need for some invisible media to connect them like Bluetooth or Wi-Fi.

A wired connection again will lead to the formation of the internet that is implemented worldwide and is a huge success. But in wireless, each computing node connecting is connected to other nodes and hence the number of connections becomes $O(\frac{n(n-1)}{2})$, where n is no of nodes.

Saleh and Putra[1] *described Mobile Ad Hoc networks as a collection of two or more nodes which has wireless communication and networking capability without the* *aid of a centralized administrator and also wireless node that can dynamically form a network.*

1.1. FUNDAMENTALS OF MOBILE AD HOC NETWORKS

i. Dynamic Topologies – nodes are mobile and hence topologies keep on changing
ii. Limited battery – mobile nodes are battery operated and a good algorithm is required to manage that as well.
iii. Limited bandwidth – capacity of wireless links is less and they are also susceptible to interference and noise.
iv. Limited Security – a node is allowed to join or leave any network, so it is risky to allow connection without checking.

The above mentioned are the most crucial things that need to be kept in mind while designing a new topology.

In the conventional approach of the internet where each node is assigned an IP address or for simplicity an address to communicate, mobile nodes are not bound to any fixed location so that approach cannot be applied here. This problem is solved using a fixed access point networking device such as a router which can have a fixed IP and users can connect with that router to get internet access. The router keeps pools of addresses to assign to various devices which get connected to it so not all the devices can get an IP when they want to connect to the internet.

There have been 30+ years when approximation algorithms have been used to optimize the results and this dissertation is about how energy constraints have been utilized to improve network lifetime and performance.

CHAPTER 2

CLUSTERING IN MANETS

As explained in the previous chapter nodes in MANETs are mobile and these nodes have shortcomings or they can be considered as something that can’t be ignored in MANETs. Anything new proposed must adhere to these shortcomings to get maximum throughput from the networks. This chapter describes what leads to the formation of clusters in MANETs.

In the formation of ad-hoc networks, it is the core idea that all the devices should be connected without an infrastructure. We can connect two devices wirelessly and call it point-to-point communication, both can send data to each other; a very simple and basic network.

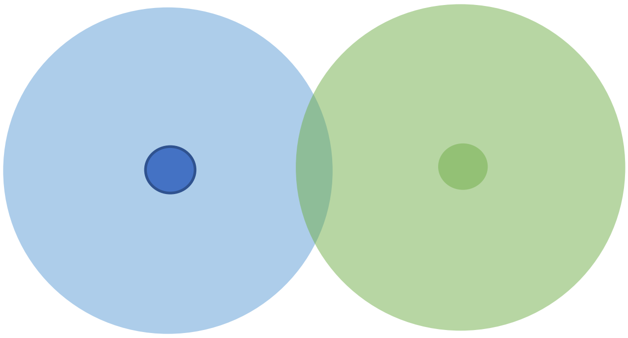

Fig 2.1: P2P Communication

Now try to increase the number of devices to three nodes, it's again simple – each node within the range can send data to other nodes.

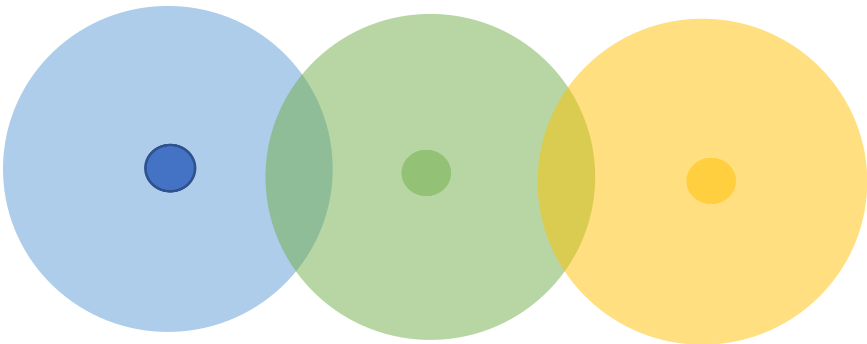

Fig 2.2: 3 Devices Communication

Here, the B device is acting as the central node of communication, acting as an access point for both nodes A and C. Also B is mobile like these two nodes so in mobile communication, these devices forming a network must be able to send, receive as well as transmit/pass data packets. Since these all nodes are mobile and there is no need for any fixed routing device, each node has to store routing information among them.

Let's consider a simple example of connecting three nodes A, B, and C. To store connection information in a general 2D matrix it will have a 3x3 grid

$$\begin{matrix} 1 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 1 \end{matrix}$$

According to Belding-Elizabeth[2], the communication overhead of proactive protocols is $O(x^2)$ where, x is the number is nodes. We required space of 3x3=9 i.e., it has a space complexity of $O(x^2)$.

So, it trying to make a simple LAN the number of connections required will become huge, and storing all the topology information on all the devices and then managing them by updating them is already a cumbersome task and also consider the fact that these nodes are mobile adding removing connections, assigning an address. It becomes unmanageable.

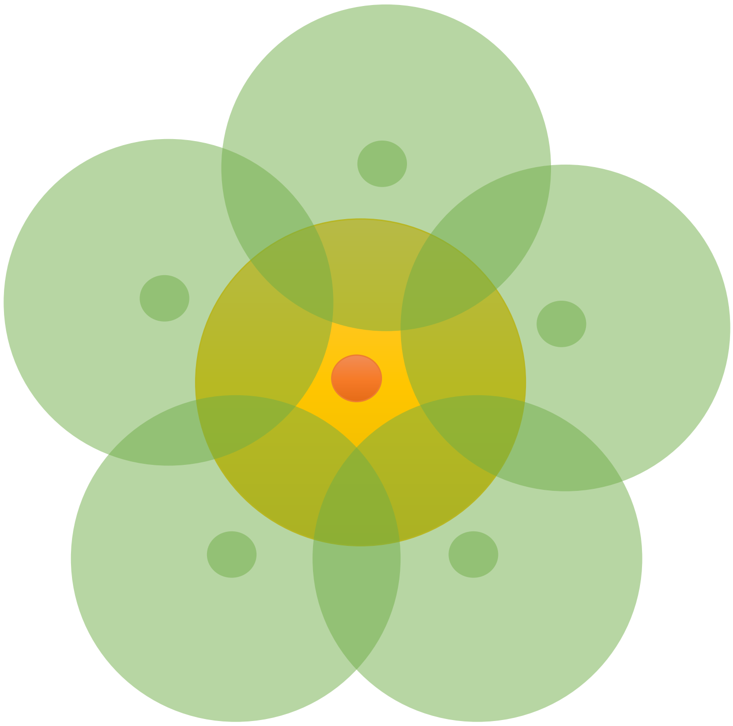

Fig 2.3: 5 Nodes with Central Head Node

In this network, the central node is acting as the coordinating node so other nodes need to keep track of topology changes, it will be handled by the central node.

The role of clustering comes into existence because the network formed by nodes in plain topology is not scalable.

In plain topology, interconnecting each of the nodes will form a mesh-like network often treated and wireless-mesh-network. As described by Adebanjo, Kamalrulnizam, and Ogunnusi[3], the implementation of plain topologies is not very easy because of the multi-hop and dynamicity of these networks also there is a limitation on bandwidth. Various authors suggested clustering of communicating devices to tackle these problems.

2.1. ISSUES AND CHALLENGES IN PLAIN TOPOLOGIES

Following are the problems in Plain Topologies for mobile Ad-hoc networks

1. Not scalable
   The plain topology structure is not scalable as the number of nodes increases it will become difficult to keep track of which node is on which side. Forming a routing table to route packets will become very time-consuming and the nodes are mobile so, keeping track of which nodes are in the network and which are left the network is; again a difficult task.
2. Limited Bandwidth
   The nodes are battery-powered computing devices and they have limited energy to transmit. If the nodes keep moving around it will take forever to update the topology structure as the whole bandwidth will be consumed by packet routing information only.
3. Collecting and maintenance of topology information are time-consuming and difficult.
   In the 2nd point, it is already explained, that because of limited bandwidth if the topology information will keep on propagating the network and reaches far most nodes might become dead.
4. Storage Limitation
   Every mobile node has limited storage capacity and hence it can only store a limited amount of information, having a very large network will put a limit on storage capability.

2.2. WHAT IS THE CLUSTERING APPROACH?

When the numbers of nodes become too many, a clustering approach can be applied to group them and form clusters of nodes. Many authors suggested this approach so that nodes can be arranged in hierarchical orders and topology information need not be shared among other clusters, hence, dynamic topology changes can be adapted; which gave rise to many dynamic on-demand routing protocols.

This approach can be closely understood with the implementation of the internet, where each device is connected to a local ISP, and many ISPs are connected to a global ISP. Each of them is responsible for managing their local region like adding or removing new devices. There is no need to propagate whole topology information to complete the network.

The concept of Clustering has been in discussion for around 35+ years, this technique has been applied to various disciplines of computers. Plain topologies do wonderful work for sharing a quick and efficient amount of data but it’s not scalable. By forming clusters a large number of computing nodes can be connected.

Internet is a multi-hop packet-switched network and can handle up to 10^9 nodes[4]. Every node has a 32-bit IP address that is assigned in such a way that all the nodes in that subnet can same network prefix. This approach allows the internet to form a hierarchical topology. All nodes need not store the IP address of all nodes instead they can use prefixes to forward data to a proper subnet.

But this approach can now be applied to mobile ad hoc networks are they are not stationary if we consider, the mobile but in a limited region, there will be no drastic change in topology, and these minor network changes can be handled locally.

Multiple authors defined the following terminologies that are considered significant in clustering ad hoc networks:

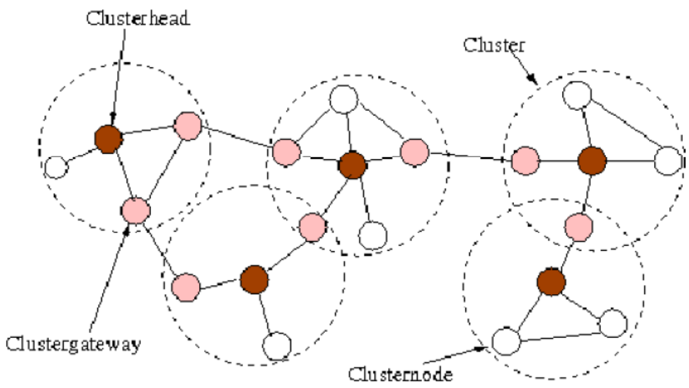

Fig 2.4: Cluster Topology

Cluster – A group of computing nodes that connect to form a local network.

Cluster Head – A node that is elected as coordinator of the cluster.

Cluster Member – It is a neighbor or cluster head or accessible to the cluster head (most authors consider them at one hop distance).

Gateway Node – A node that is common to two or more clusters.

A simple network problem can be considered as a graph problem to suggest some solution to it. Here, in this case, also, MANETs is a graph problem. So, here are some pre-requisites that the reader must get familiar to:

The clustering problem can be defined formally as

Network = $G(V, E)$, an undirected graph

$|V| = n$, Number of wireless nodes in the network

$E = \{ (u, v): u, v \ \in V\}$, Both u and v can mutually transmit data to each other.

$distance(u, v) = \{(u, v): u, v \ \in V \ and \ no \ of \ nodes \ between \ u + v = k\}$, Distance function.

$Range(u, v) = \{(u, v): u, v \ \in V \ \ and \ distance(v) < distance(u)\}$, in the range of u.

$N[v] = \{v \ \in V, vertices \ adjacent \ to \ v \ including \ v\}$, a neighbor of v.

$N[S] = \{S \subseteq V \ and \ \cup_{v \in S} N[v]\}$, Set of nodes in the neighborhood of v.

$Cluster(v) = \{ (S, v): v \in V , S \in S[v]\}$, a cluster is represented by CH id.

$Power(v) \propto \frac{1}{distance(v,CH(v))}$, power consumption.

$Life(v) \propto \frac{1}{Power(v)}$, Life of node v.

CHAPTER 3

CLUSTERING APPROACHES IN MANETs

For a basic understanding, a network is considered a graph and various graph algorithms have been proposed to find optimal routing paths in networks. All the algorithms use some kind of graph-solving algorithms like D'jkshtra or Bellman-Ford.

The most intuitive approach is to divide the network into clusters by using those fundamental constraints. Most authors suggested these techniques which try to consider the limitations a single MANET node has like battery, mobility, and bandwidth. Most authors applied techniques for optimizing cluster head selection. As all the nodes are mobile and have various constraints like mobility, battery, and bandwidth limitation, they suggested using these factors for CH selection.

When reading all these suggestions, we thought about how basically a cluster is formed?

Adekiigbe, Adebanjo Bakar, Kamalrulnizam Abu Simeon, and Ogunnusi Olumide[3] provided a quick description of how cluster establishment is done. Also, a similar kind of work is done by Bentaleb, Abdelhak Boubetra, Abdelhak Haros, and Saad Harous[5] which is much more detailed. These authors provide some of the general algorithms, and some kind of modifications are later suggested by later researchers.

Every algorithm or scheme tries to form a cluster based on two following criteria

1] Cluster Head(CH) Selection
2] Cluster Maintenance

During cluster formation, a representative node is to be selected that maintains the connection information with other clusters and it is responsible to manage all the member nodes so other nodes need not keep connection information. But this makes the CH node most vulnerable to battery limitation, if the CH node's battery runs out the network will again go to a re-clustering state and the same procedure will repeat which eventually degrades the throughput of the network. Here comes the role of *cluster maintenance*, it is responsible for keeping the network stable as much as possible by reducing the chances for re-clustering. A network will go into re-clustering, if:

1] the CH node is no longer available or becomes dead

2] A new node leaves a cluster but isn’t accessible to any other cluster head.

Almost every author focussed on how to elect CH to reduce the CH re-election as CH handles all the complex tasks locally. If the battery of CH runs out or the member node leaves a cluster it must join another cluster otherwise it will trigger CH re-election. So every algorithm proposed tries to take care of those two tasks.

3.1. CLASSIFICATION OF CLUSTERING SCHEMES:

3.1.1. Identifier Based Clustering

This approach assigns a unique ID to every node. Node broadcasts their IDs to their neighbors and node with min ID or max ID is chosen as CH.

Linked Cluster Algorithm (LCA) – LCA has a pre-set broadcast time interval in which every node broadcasts its ID to its neighbors, after every ID is received, every node configures itself to be a *CH, gateway node, or normal node.* It selects the node with the lowest ID as CH.

Least Cluster Change (LCC) – LCC is an improved version of LCA. It works similar to LCA for cluster formation but LCA has the drawback of maintenance i.e., there are chances of re-clustering when a node can’t find a new cluster, to solve this LCC put forth. It introduced two maintenance steps to LCA, i) if a node leaves a cluster and can’t find a new cluster then it will become a CH itself. ii) It tries to merge two close CH into a single cluster by comparing their IDs if two CH comes in contact with each other, one must leave its role as CH and start acting as a member node.

Optimized Stable Clustering Algorithm (OSCA) – OSCA put forward a solution for what happens when CH leaves the cluster itself either due to mobility or becomes dead. OSCA follows the same approach as LCA but it also elects a secondary node called a *backup node*. If CH dies or leaves the cluster there is no immediate need to re-elect CH.

K-Hop Clustering – Above mentioned Algorithms assumed that the member nodes are one hop away from CH. Here in K-Hop Clustering, the distance between CH and other nodes can be ‘k’. It simplifies the problem of a node leaving the cluster as a free node can now become part of the cluster having CH k-hops away.

Min-Max Leader Election – It is a heuristic approach with selects CH based on node ID. It involves three steps:

1. Broadcast ID to neighboring nodes at d-hops
2. Preserve responding node IDs.
3. From the remaining nodes, the node having the highest ID is permitted to broadcast

These steps are repeated until all the nodes are exhausted.

Authors claim that the structure created by this algorithm is robust but the overhead; however, computational overheads for CH formation are significant since a large amount of information is exchanged in the process.

Adaptive Clustering Algorithm (ACA) – ACA looks for clusters in the network. It is a simple algorithm that was proposed to find the communities in complex networks. Authors of this approach have suggested that there is no need for CH after the cluster formation is done. Every node has to keep track of its neighbors at 2-hops, if the distance becomes more than 3-hops apart re-clustering algorithm is imitated.

Vote Count (VC) Clustering Algorithm – VC uses no of votes to find the max degree node in the cluster. The node which gets max no of 'Hello' messages from its neighbors is elected as CH. In cases where the number of mobile hosts as cluster head, exceeds the threshold number, more new coming nodes are not discounted.

3.1.2. Topology Based Clustering

This approach follows how many neighboring nodes are connected to CH. The node having the highest no of neighbors is elected as CH.

High Connectivity Clustering (HCC) – HCC chooses the node which has the highest connectivity i.e., it has max no of nodes in neighbors as CH. If two nodes have the same connectivity then the node with the lowest ID is selected as CH.

Clustering-based new Link State Routing (CLSR) – CLSR is an advanced version of LSR, it applies two messages "Hello" and "CTC" for route discovery. For cluster formation, each node sends a "HELLO" message to 2-hops neighbors, and responses are noted for local routing. For global routing, it sends "CTC" which is broadcast throughout the whole network. This allows nodes to compute inter-cluster routes.

3-hop Between Adjacent Cluster heads (3hBAC) – 3hBAC also follows the same approach where the distance between two CH is 3 hops to reduce the chances of small cluster formation. Authors claim the algorithm also reduces frequent changes in CH selection thereby improving the CH lifetime, and average node membership time which in turn improves the cluster maintenance efficiency, and overall computational efforts for CH management thus resulting in relatively less maintenance requirement and relatively more stable cluster.

Associativity-based Cluster Formation and Cluster Management use a score count termed 'associativity'. It increments the value of the counter as a new member joins, and also increments the value of associativity each time it checks for new members. The node with higher associativity is elected as CH.

3.1.3. Mobility Bases Clustering

Mobility is the most crucial factor in MANETs, every node is mobile and they can move in any direction which makes this kind of network very unstable. In the mobility-based clustering approach, the node which has the least mobility is considered stable or the nodes which have common mobility patterns are assumed to form stable clusters.

Lowest Relative Mobility Clustering Algorithm (MOBIC) – MOBIC employs mobility metrics to find the relative mobility of the node. The node with the lowest value is considered for the CH election. It works similar to LLC but here it considers mobility as a factor to elect CH.

Mobility Prediction-Based Clustering (MPBC) – MPBC calculates the relative speed of nodes and forms the clusters of high-speed nodes. Its goal is to find the mobility pattern between nodes and form clusters which are having common mobility patterns to adhere to frequent changes to MANET. MPBC algorithm has two phases initial clustering phase and the cluster maintenance phase. The algorithm depends on the estimates of mobility information.

MobDHop – It is a d-hop-based mobility clustering algorithm. As in the case of mobility-based models, it also works on relative mobility prediction. The authors have used a new parameter to compute the deviation of the distance between two mobile nodes to calculate relative mobility. It uses d-hop measures to flexibly change the diameter of the cluster. MobDHop can provide a basic hierarchical routing structure and it is also able to address the scalability issues of routing protocol.

Mobility Aware Clustering (MAC) – MAC is a distributed clustering technique that works in combination with Hi-Degree or Low-Degree to choose CH. Authors have used various theoretical concepts for finding the most suitable way to indirectly calculate the mobility of a node. It strictly avoids the use of an external device (GPS) for estimating device mobility instead it calculates mobility using the change in the neighborhood.

Mobility Adjustment Routing (MAR) – MAR uses the remaining battery and mobility as parameters for cluster election. This algorithm RREQ packets to find the route. Mobility values of the intermediate node are transmitted via the RREQ packet during the setup of the route between the source and destination node. After the receiving of an RREQ packet at the destination node, there is a minimum mobility value for a particular path. The path found by this algorithm remains mostly steady.

Link Prediction Routing (LPR) – LPR does a local link repair to the node dissociation. Due to mobile nodes often network nodes are dissociated very frequently. LPR uses a reliability measure for each node to find if any node has become malicious. LPR's goal is to improve network performance and the energy consumption model of the network.

3.1.4. Energy Based Clustering

The battery is one of the main constraints on MANETs, in this approach, algorithms focus on forming clusters with the least energy used or use energy as a parameter to elect CH. Network lifetime has a direct effect on battery energy. Managing energy efficiently is a challenging task. Tasks like transmission during cluster formation and routing consume access to the power of CH.

Multicast Power Greedy Clustering (MPGC) – MPGC is an algorithm that uses a heuristic method to form clusters, it works in three phases i) Beacon Phase, where each node sends a beacon signal and tells everyone how much battery it has; ii) Greedy Phase, in this phase nodes with a threshold level battery, choose themselves as CH and sends for nodes to join having a particular battery level; iii) Recruiting Phase, in this phase all the nodes have information about its neighbor's battery. Node with the highest battery is elected as CH.

Flexible Weighted Clustering Algorithm based on Battery Power (FWCABP) – FWCABP optimizes the MGPC by putting a constraint on the minimum battery requirement for CH election, so, the number of clusters is reduced. The CHS election is based on the weight values of the degree of nodes, the sum of the distance to its neighboring nodes, nodes' mobility, and remaining battery power.

Enhanced Cluster-based Energy Conservation (ECEC) – ECEC algorithm and ECEC (Enhanced Cluster-based Energy Conservation Algorithm) both are most suitable in the case of energy-efficient algorithms in clustering MANETs. It powers off nodes that are selected as member nodes as they are not going to form any more CH. Then it starts electing nodes for broadcast nodes. CEC chooses a node as CH having maximum battery power after that ECEC starts looking for broadcast nodes to join with other clusters.

Enhanced Sectorized Clustering (ESC) – ESC algorithm focuses on the node selection procedure based on factors: residual energy and transmission range. This algorithm uses calculations based on residual energy along with the transmission range of the CH.

There are many algorithms present for energy-efficient clustering. Some authors also suggest selecting a super CH apart from CH. CH is selected on the criteria of communication range, hop count, battery energy, transmission range, and relative velocity.

3.1.5. Weight Based Clustering

This approach considers various factors to provide weight to nodes such as transmission power, node degree, distance difference, mobility, battery power of mobile nodes… etc. This is the most widely used clustering algorithm and there are a lot of versions available based on this method. There are many factors to choose from that make it the right choice for many authors to look for solutions that can efficiently use bandwidth and improve network life by saving energy. Some authors use statistics and approximation-based algorithms to choose the right CH which is most suitable for a particular application. WBC takes into account multiple factors that make it suitable to find the most efficient node for CH selection.

Flexible Weight-Based Clustering Algorithm (FWCA) – This algorithm was introduced with the goals of yielding a low number of clusters, maintaining stable clusters, minimizing the number of invocations for the algorithm, and maximizing the lifetime of mobile nodes in the system. It is based on node capacity and maintenance procedure invoked using link lifetime.

Enhanced Weight Clustering Algorithm (EWCA) – This algorithm defines a global parameter to restrict the number of nodes a CH can address. Authors claim it to have a high degree of stability and ultimately leads to efficient load balancing.

Flexible Weight Based Clustering Algorithm based on Battery Power (FWCABP) – This algorithm performs similarly to FWCA but here battery energy is the main constraint. Low battery nodes are restricted to participate in cluster elections. FWCABP invokes a maintenance procedure when a node leaves the cluster or the battery level of CH decreases below a predefined threshold value.

Forecast Weight-Based Clustering Algorithm (FWCA) – It improved the already existing WCA algorithm. There might be some communication problem or due to interference if any eligible node is not able to send its weight to neighboring nodes then it might miss the chance of being the cluster head. To overcome this issue FWCA uses the previous weight value by calculating the exponential moving average (EMA) value for weights.

Trust-based cluster routing algorithm (TEBACA) – TEBACA uses a metric named trust value. The authors consider the node as trustworthy to be a CH. If a node has a high trust value, it is considered malicious. It strictly required that only trustworthy nodes participate in cluster elections.

Virtual Link Based Weighted Clustering (VLWBC) – VLWBC calculates the virtual link value for each node and on that factor, the weight of the node is considered for CH election. It considers four parameters: energy, stability, neighborhood, and link length to determine the weight value. Authors claim it improves network stability and network lifetime by reducing power consumption.

Score Based Clustering Algorithm (SBCA) – SBCA works on metrics called *scores*. While transmitting to other nodes during cluster formation, every node shares a score with its neighbor and based on that score CH is elected. SBCA proposed to minimize the number of clusters and overall increase the lifespan of the network. The score is calculated using the factors battery life, node stability, and node degree.

3.1.6. Heuristic Approaches for Cluster Formation in MANETs

Although the schemes discussed so far are more theoretical and had been performing well in real practical scenarios. But there are some cases were due to interference in transmission, latency, or any other factor, some nodes might not able to communicate well but they are the real contender for the CH node. To counter this without using any system approach multiple heuristic and approximation algorithms are also applied to MANETs clusters but more of them are used to optimize the basic cluster formation that all other authors trying to suggest. But it is to be noted clearly that these approximation algorithms need not be accurate and there is a significant amount of literature available on various classical problems.

Efficient Heuristics Based Clustering[6] – EHC is based on the density and ID of nodes, this algorithm applies an LSR routing algorithm to find the optimal path. It used d-hop to share node information with its neighbors. The algorithm modifies the LSR to heuristically found the local minima to find the CH.

3.1.7. Meta-heuristic Techniques and Swarm Intelligence in Mobile Ad Hoc Networks[7]

Meta-heuristics and swarm intelligence is the feature of natural and artificial systems in which multiple individuals interact with each other to find the most favorable outcome of a problem.

Swarm Intelligence is the property exhibited by organisms that walk or reside in groups like a colony of ants and termites, flocks of birds, schools of fish, and herds of land animals. This natural way of interacting with individuals leads to the solution that we can get by applying the most optimal algorithms. The problem can be designed to behave as if it's a herd of animals and each animal is its solution. In MANETs the number of nodes is large so here, this technique can be applied.

Examples of Swarm Intelligence algorithms that some of the authors applied on MANETs are *Ant Colony Optimisation (ACO).*

A swarm intelligence system can have the following properties:

- ✓ it is composed of many individuals;
- ✓ the individuals are either all identical or belong to a few typologies;
- ✓ the interactions among the individuals are based on simple behavioral rules that make use of local information exchanged directly or via the environment;
- ✓ the overall behavior of the system results from the interactions of individuals with each other and with their environment.

Meta-Heuristic Algorithms are the natural way of selecting the best fit for survival, a most common example is the *Genetic Algorithm(GA)*, which has the number of chromosomes that go through crossover and elimination to find the best-fit individual. A similar kind of technique can be applied to MANETs to elect CH, here we can design the problem like which node can become CH, and the fitness function can be the most efficient node in terms of weights like battery energy, farthest node, transmission power, etc. and each chromosome can be represented as a solution i.e., CH for that cluster.

A meta-heuristic approach can have the following properties:

- ✓ it is composed of many individuals (solutions);
- ✓ the individuals are either all identical or belong to a few typologies;
- ✓ the interactions among the individuals are based on simple behavioral rules, here they are called functions: fitness function, crossover, mutation;
- ✓ the overall behavior of the system results from the interactions of individuals with each other.

GA-based WCA[8] – GA is one of the most widely used algorithms to solve NP problems. Before forming the actual cluster a virtual cluster is formed within 2-hop neighbors. In the clustering process of GA-WCA, use a genetic algorithm to search in a virtual cluster and at the same time, also hope that this algorithm can converge as soon as possible to save the battery energy of node and improve the surviving ability of clustering.

CHAPTER 4

APPROXIMATION ALGORITHMS IN MANETs

As far now, major clustering algorithms and their focus is discussed like mobility, energy, or data transmission. MANET nodes forms cluster to manage resources that are limited in nature and which leads to optimizes results and hence improves network quality as well as network lifetime. MANETs elect CH with more energy which is evenly spread all over the network and this can be as NP-Hard problem. Like many other graph traversal problems, the nodes here have to operate on a multi-objective function to find optimal results.

Let's define approximation algorithms, "it is a class of algorithms dealing with completeness for optimization problems. The goal of the approximation algorithm is to come close as possible to the optimal solution in polynomial time.[9]"

Features of Approximation Algorithms:

- ✓ There is a guarantee to terminate in polynomial time yet the solution may not be the best.
- ✓ The algorithm results in among the top 1% optimal solution

In much literature, the problems that have been solved with approximation algorithms are generally NP-Hard, because of their ability to solve in polynomial time as well the results obtained closer to the best solutions makes them a better choice for solving network problems. The problems faced in MANETs are multi-node problems and hence population-based algorithms can be adopted like GA and Swarm Intelligence. Along with that, these problems work with multiple parameters which have been discussed in chapter 2, defining a multi-objective function is easy in approximation algorithms as they utilize fitness functions to converge. The methods discussed in [9], suggest algorithms for solving minimization problems with approximation algorithms.

Here, in this discussion the approximation algorithms or optimization algorithms solve the problem of CH selection based on multiple parameters that affect the battery life and hence minimize battery consumption so the network lifetime can be improved.

The approximation algorithms have been used in many scenarios to improve networks, some in election mechanisms, some in routing, and some are applied to reduce energy consumption during the re-clustering or maintenance phase.

Before getting deep into the world of Approximation Algorithms, let's understand its roots. As far as the fundamentals of computer science go, people have been solving problems based on heuristics where the steps are decided based on intuition for example problems based on graphs fall in the category of heuristics but these are problem dependent and cannot be applied to other fields. On the other hand, approximation algorithms try to solve the NP-Hard problems (similar to those heuristic-based) with some logical concepts of finding the optimal value of a mathematic function just like local maxima/minima along with finding global maxima/minima. A heuristic algorithm is indeed an approximation algorithm[10]. Heuristic Algorithms are intuitive steps that are followed to get the optimal results but they are problem dependent, so, to enhance the scope of a problem-solving new category of Heuristic Algorithms has been discovered which were defined by some inspiration from various sources which is called Meta Heuristics.

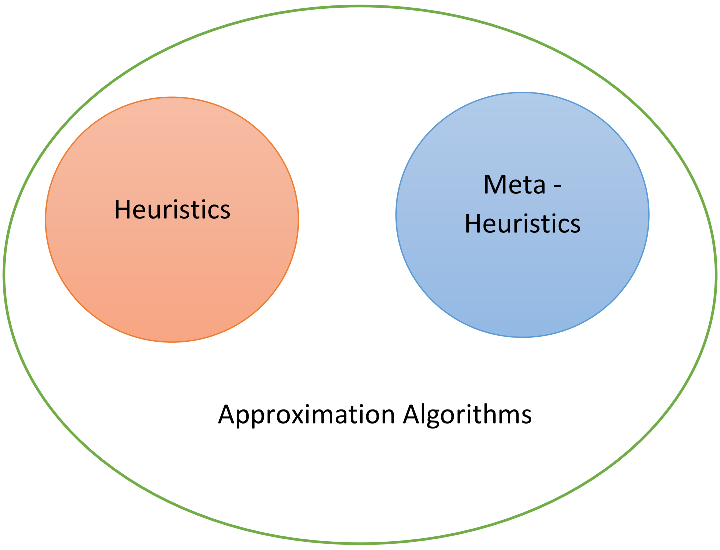

Fig 4.1: Approximation Algorithms Venn diagram

Meta-Heuristic Algorithms are advanced kinds of heuristics that are generalized algorithms or they can be understood as concepts that make them easier to design for every kind of problem. And since they are advanced heuristics that can solve NP-Hard problems in polynomial time, they fall under the category of Approximation Algorithms.

CHAPTER 5

METHODOLOGY AND EXPERIMENT SETUP

This thesis works around the LEACH protocol which is mostly used at the application level in many devices. So, first, here is the overview of the LEACH Protocol[11].

In Low Energy Adaptive Clustering Hierarchy, in this, all the nodes which are dispersed over a region form the cluster and decide on a Cluster Head for themselves that is within its transmission range. The CH(1) is responsible for transmitting all the information from nodes to the next CH(2) and that further transmits it to other nodes. This protocol allows to form a hierarchy with different levels by letting these CHs form the nodes and they elect another level CH.

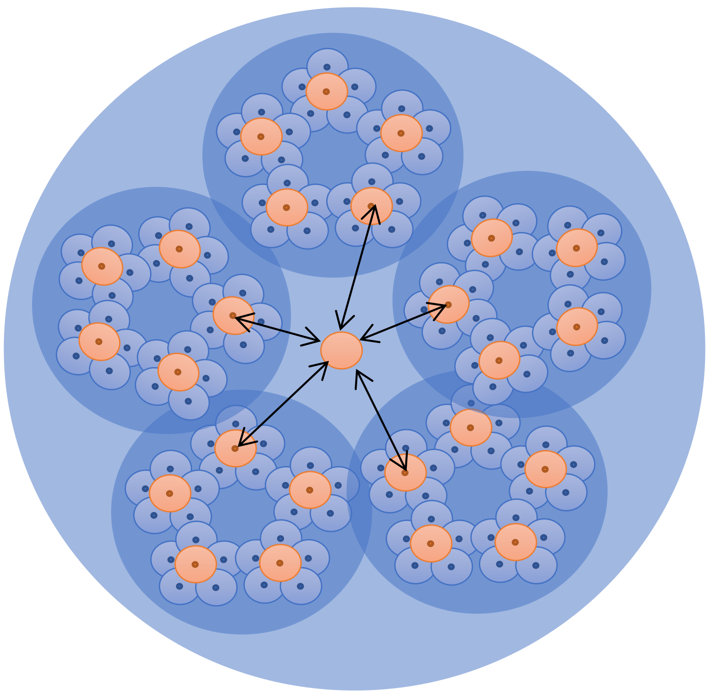

Fig 5.1: Cluster Hierarchy

After studying multiple heuristic algorithms, it’s been observed that these algorithms are somewhat modifications or enhancements of one another. Most used algorithms include GA-Genetic Algorithms and PSO-Point Swarm Intelligence. As both of these algorithms are population-based algorithms they seem fair enough to be used for MANET deployment.

The decision of these algorithms depends on how quickly they converge to provide the most approximate results. PSO converges more quickly than GA and here we will try to find out how this affects the lifecycle of our network.

5.1. Requirements for Setup Configuration

This experiment is performed on a virtual machine provided by VMware which has Ubuntu OS installed over it for a better development environment having the following configurations:

OS	Ubuntu 20.04.4 LTS
Release	20.04
Codename	focal
RAM	3.8GB
OS-Type	64-bit
Processor	Intel Core i7-7500U CPU @ 2.70GHz x 3

Table 5.1: Setup Configuration

5.2. Development Environment

This experiment is extended on a GIT Library available at https://github.com/darolt/wsn, which is developed in Python and C++ (via SWIG) having all the required libraries for analyzing energy consumption for LEACH along with other routing strategies.

To make it compatible with our experiment certain changes have been made.

a. Mobility Model – in our case the nodes are mobile
b. Routing/GAECH – an enhanced version of LEACH + GA[12]
c. Routing/PSO – an enhanced version of LEACH + PSO
d. Additional functions for updating battery information
e. PyCharm IDE for python development

5.2.1. Pre-requisites for deploying setup

a. Python 2.7
b. SWIG
c. Matplotlib 2.0.2
d. Numpy
e. Scikit
f. Logging
g. Inspect
h. Multiprocessing

CHAPTER 6

ANALYSIS

In this thesis, four modes of network formation are designed and analyzed. The network is formed by clusters and each node tries to transmit data to a predefined node that has a fixed location on grid x = 125.0 and y = 125.0. A total of 300 nodes are deployed on a grid of 250x250 where each node has a transmission range of 15 units transmitting data with a header length of 150 bits and message length of 4000 bits with 2 Joules of initial energy.

The whole experiment is performed during 15000 rounds where the energy units are: energy dissipated at the transceiver electronic (/bit) is 50e-9 J, energy dissipated at the data aggregation (/bit) is 5e-9 J, energy dissipated at the power amplifier (supposing a multi-path fading channel) (/bin/m^4) is 0.0013e-12 J, energy dissipated at the power amplifier (supposing a line-of-sight free-space channel (/bin/m^2) is 10e-12 J and with mobility of +5 or -5 in any direction along the axis.

The idea of this experiment is to measure the energy depletion along with LEACH to check which algorithms help in conserving max power and eventually extending the lifetime of the network.

6.1. LEACH

GIT repository provides the implementation of LEACH which has energy depletion information as depicted in the following graph.

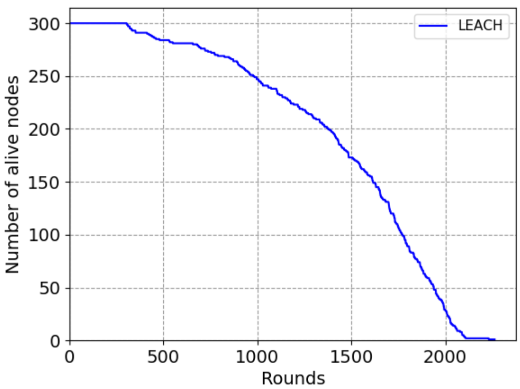

Fig 6.1: LEACH Network Life Cycle

No of the nodes remain alive till 300 rounds because it assigns CH based on the turn, once a node is selected for CH will not get a chance to be selected next time, and keep track of how many times the node is being selected as CH finally around 2300 the network is terminated.

First Depletion	305
30 Percent Depletion	1331
Remaining Energies	0

Table 6.1: LEACH Data

6.2. DIRECT COMMUNICATION

Another mode of network formation is Direct Transmission denoted by DA in the given graph.

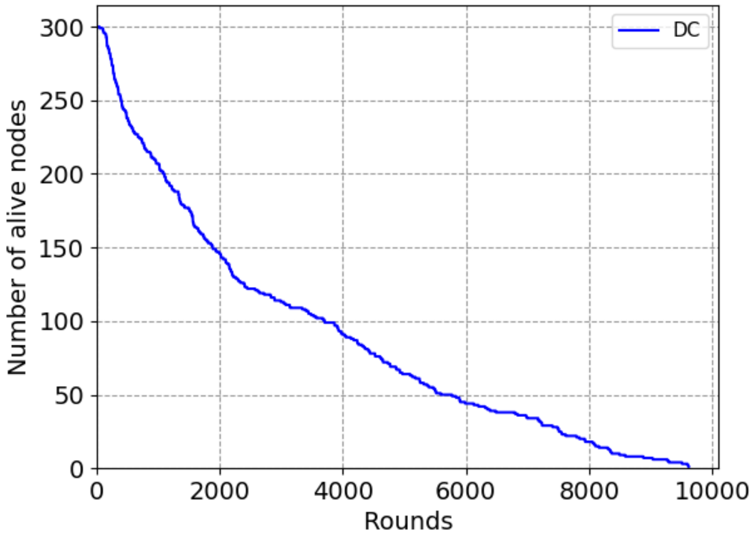

Fig 6.2: Direct Communication Network Life Cycle

The node transmits data using Dijkstra's Algorithm where the node path is discovered end-to-end. This algorithm performs better than LEACH but consumes processor power and is slow.

First Depletion	46
30 Percent Depletion	950
Remaining Energies	0

Table 6.2: Direct Communication Data

6.3. GAECH

GAECH is inspired by Baranidharan and Santhi[12], but here the dispersion of CH is not considered for the CH election as the current CH has no role to play in the next CH election. The fitness function is based on

$$F(node) = \sum Energy + \sigma Energy + \Delta Energy \qquad (6.1)$$

where,

$$\sum Energy \ = \ Total\ Energy\ Consumption\ of\ network$$

$$\sigma Energy = Standard\ Deviation\ of\ Energy\ Consumption$$

$$\Delta Energy_{node} = remaining\ energy\ of\ node$$

Mathematically,

$$\sum Energy \ = Init\ Energy\ \times Total\ Nodes - \ \Delta Energy_{network} \qquad (6.2)$$

$$\sigma Energy = \frac{\Delta Energy_{network}}{No\ of\ Clusters} \qquad (6.3)$$

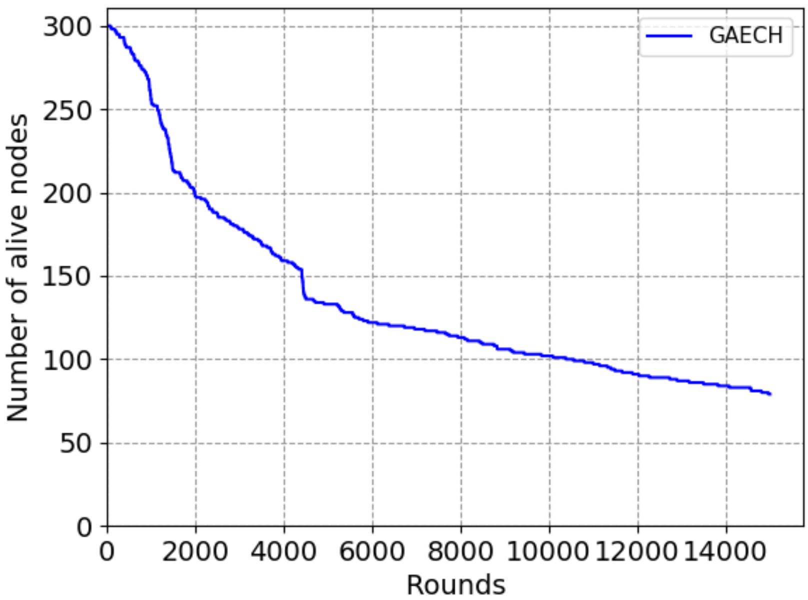

Fig 6.3: GA+LEACH Network Life Cycle

GA+LEACH shows that the node's battery started to get depleted in the early stages and falls around 135 surviving 4200 rounds but after that, the curves start to get parallel to the y-axis because at this stage the nodes get selected for CH have few nodes in their cluster. Energy is a function of multiple parameters which multiple energy consumption.

First Depletion	81
30 Percent Depletion	1674
Remaining Energies	150.532032295

Table 6.3: GA+LEACH Data

6.4. PSO+LEACH

PSO+LEACH uses the LEACH protocol but here the CH is selected among the particles which are found to be the best fit by PSO which checks if fitness is satisfied by uniform distribution and fitness solely depends on the remaining energy of the node. At each iteration, new values are calculated for finding the best particles first, from the given population. Every node possesses current mobility and energy value, using these two factors can be calculated:

$$Stability = \Delta v \quad (6.4)$$

Here, $\Delta v = u - v$ (6.5)

$$\Delta E = E_{initial} - E_{current} \quad (6.6)$$

$$F(node) = \Delta Energy + Stability \quad (6.7)$$

And fitness is given by

$$f(x) = \frac{1}{b-a} < f(node), \; a \leq x \leq b \quad (6.8)$$

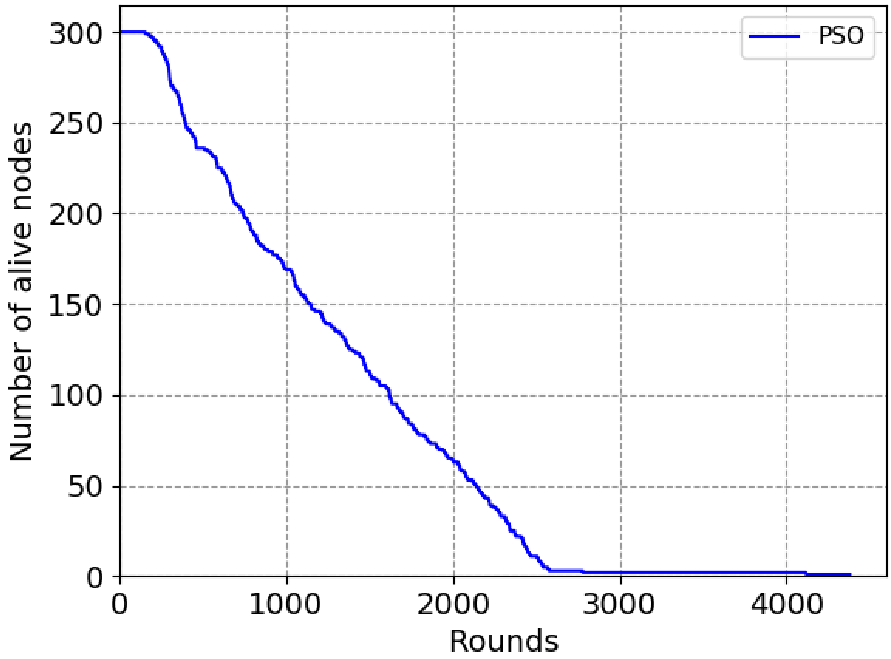

Fig 6.4: PSO+LEACH Network Life Cycle

The curve obtained is almost linear falling near 2500 rounds. This is due to the uniform distribution of nodes over the grid and CH is being selected based on the remaining energy but this algorithm is not considering the energy consumption of the entire network instead chooses the best node as CH first then another in similar order.

First Depletion	88
30 Percent Depletion	708
Remaining Energy	0

Table 6.4: PSO+LEACH Data

CHAPTER 7

CONCLUSION

This chapter deals with the comparison of all the algorithms performed in the experiment.

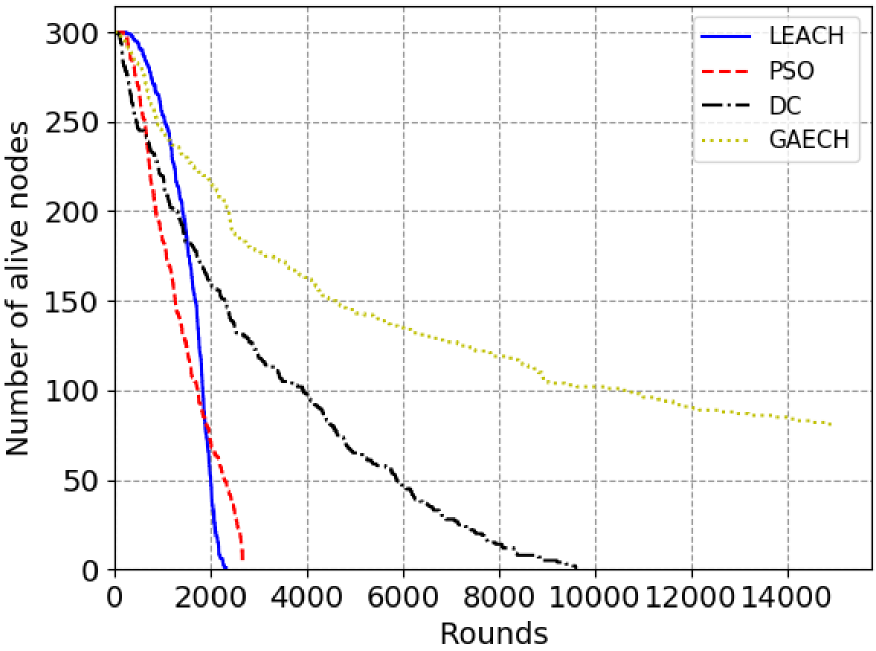

Fig 7.1: LEACH, PSO+LEACH, DC, GA+LEACH Comparison Graph

This curve plotted gives us a better idea of which algorithms are best suited to enhance network lifetime. The experiment is conducted for 15000 rounds and during this period LEACH is the first one to get exhausted near 2100 rounds followed by PSO, the reason being both of these algorithms not considering overall network power consumption. Direct Communication performed better than others where each node responsible for its transmission but the nodes which help in forming the transmission path gets an extra amount of energy consumed and hence it lasts about 10000 rounds. GAECH produced the best results among all and it looks like it can go on for more rounds as the depleting rate started to become constant.

	LEACH	PSO	DC	GAECH
First Depletion	305	147	403	136
30 Percent Depletion	1331	985	1602	2849
Remaining Energies	0	0	0	164.598314974

Table 7.1: LEACH, PSO+LEACH, DC, GA+LEACH Data

It's clear from this observation the results show GA+LEACH provides better life followed by DC, then LEACH, and then PSO+LEACH. But the processing time taken is maximum in GA+LEACH, followed by DC then PSO+LEACH, and LEACH. So, it can be concluded that if nodes lack any processing power then the routing decision is to be made by a single centralized node and in that case, the network will perform best. But if every node processes the transmission data then this energy loss will increase.

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