ENERGY EFFICIENT DESIGN OF WIRELESS AD HOC NETWORKS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor in Technology
In
Computer Science and Engineering

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Department of Computer Science and Engineering

National Institute of Technology

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Under the guidance of

Prof Suchismita Chinara

Department of Computer Science and Engineering

National Institute of Technology, Rourkela
May, 2010

National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the thesis entitled, "**ENERGY EFFICIENT DESIGN OF WIRELESS ADHOC NETWORKS**" submitted by Subhankar Mishra, Sudhansu Mohan Satpathy and Abhipsa Mishra in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Computer Science and Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university / institute for the award of any Degree or Diploma.

Date:

Prof Suchismita Chinara

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Acknowledgement

It is with great satisfaction and pride that we present our thesis on the project undertaken under the “Research Project” paper during 7th and 8th semesters, for partial fulfillment of our Bachelor of Technology degree at NIT Rourkela.

We are thankful to Prof. Suchismita Chinara for being our mentor during this endeavor. She has been the corner stone of our project and has guided us during periods of doubts and uncertainties. Her ideas and inspirations have helped us make this nascent idea of ours into a fully-fledged project.

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Subhankar Mishra, Sudhansu Mohan Satpathy and Abhipsa Mishra

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Abstract

The concept of wireless is not new. When the packet switching technology, the fabric of the Internet was introduced by the Department of Defense, the ARPANET ,it understood the potential of packet switched radio technology to interconnect mobile nodes .The DARPA around early 70's helped establish the base of ad hoc wireless networking. This is a technology that enables untethered wireless networking environments where there is no wired or cellular infrastructure. Wireless Ad hoc Networks since then is a fast developing research area with a vast spectrum of applications. Wireless sensor network systems enable the reliable monitoring of a variety of environments for both civil and military applications. The Energy efficiency continues to be a key factor in limiting the deployability of ad-hoc networks. Deploying an energy efficient system exploiting the maximum lifetime of the network has remained a great challenge since years. The time period from the instant at which the network starts functioning to the time instant at which the first network node runs out of energy, i.e. the network lifetime is largely dependent on the system energy efficiency. This thesis looks at energy efficient protocols, which can have significant impact on the lifetime of these networks. The cluster heads get drain out maximum energy in the wireless ad hoc networks. The proposed algorithm deals with minimizing the rate of dissipation of energy of cluster heads. The algorithm LEAD deals with energy efficient round scheduling of cluster head followed by allocation of nodes to the cluster heads maximizing network lifetime using ANDA.

ABBREVIATIONS

ARPANET	Advanced Research Project Agency Network
DARPA	Defense Advanced Research Projects Agency
ANDA	Ad hoc Network Design Algorithm
LEAD	Low Energy Adaptive Dynamic Clustering Algorithm
IP	Internet protocol
LID	Lowest ID
LEACH	Low Energy Adaptive Clustering Hierarchy
QoS	Quality of Service
WPAN	Wireless Personal Area Network
LAN	Local Area Network
MAN	Metropolitan Area Network
IEEE	Institute of Electrical and Electronics Engineers
WAN	Wide Area Network
PCS	Personal Communications Service
D-AMPS	Digital Advanced Mobile Phone Service
GSM	Global System for Mobile Communication
WISP	Wireless Internet Service Providers
WEP	Wired Equivalent Privacy
WPA	Wi-Fi Protected Access
PRNET	Packet Radio Networks
MANET	Mobile Ad Hoc Networks
VANET	Vehicular Ad Hoc Networks
InVANET	Intelligent Vehicular Ad Hoc Networks
iMANET	Internet Based Mobile Ad hoc Networks

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CHAPTER 1

1 INTRODUCTION

1.1 Overview

The ad hoc network with its mobile and non-infrastructure nature poses new design requirements. The First is **self-configuration**[**1**]in the face of mobility. At the application level, ad hoc users do generally work as a team. These applications thus require efficient group communications. The complexity of mobile ad hoc network designs has challenged researchers since the 70's. The general ad hoc network characteristics[**1**] are

a. **Mobility:** The fact that nodes can be rapidly repositioned and/or move is the raison d'etre of ad hoc networks. Rapid deployment in areas with no infrastructure often implies that the users must explore an area and perhaps form teams/swarms that in turn coordinate among themselves to create a taskforce or a mission. We can have individual random mobility as our base mobility pattern. The mobility can have major impact on the selection of a routing scheme and can thus influence performance.

b. **Multihopping**: a multiple hop network is a network where the path from source to destination traverses several other nodes. Ad hoc often exhibit multiple hops for congestion control, spectrum reuse, and energy conservation.

c. **Self-organization**: the ad hoc network must autonomously determine its own configuration parameters including: addressing, routing, clustering, position identification, power control, etc.

d. **Energy conservation**: most ad hoc nodes have limited power supply and no capability to generate their own power. Energy efficient protocol design is critical for longevity of the network.

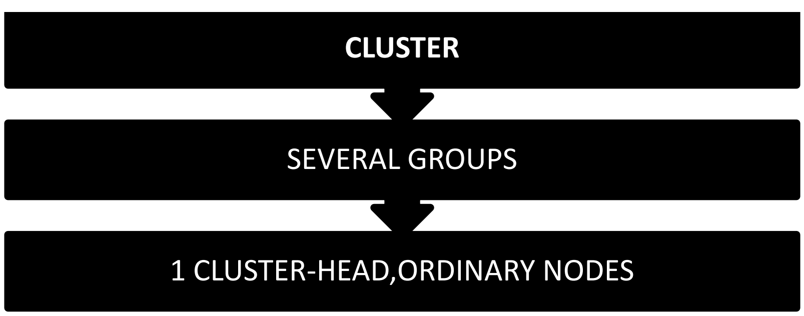
e. **Scalability**: in some applications the ad hoc network can grow to several thousand nodes. Hierarchical construction, Mobile IP or local handoff techniques do dilute the issue but still large scale is one of the most critical challenges in ad hoc design.

f. **Security**: the challenges of wireless security are well known – ability of the intruders to eavesdrop and jam/spoof the channel. Ad hoc networks are more vulnerable to attacks than the infrastructure counterparts. Both passive and active attacks are possible.

The greatest challenge manifesting itself in the design of wireless ad-hoc networks is the limited availability of the energy resources. These resources are quite significantly limited in wireless networks than in wired networks.

CLUSTERING[**2**][**3**], in general is defined as the grouping of similar objects or the process of finding a natural association among some specific objects or data. In sensor networks, clusters are used to transmit processed data to base stations. In cluster-based systems the network nodes are partitioned into several groups. In each group one node becomes the cluster-head and the rest of the nodes act as ordinary nodes. The process of cluster-formation consists of two phases –cluster-head election and assignment of nodes to cluster-heads. The cluster-head needs to coordinate all transmissions within the cluster, so also it handles the inter-cluster traffic, delivers the packets destined for the cluster etc. Hence these cluster-heads experience high-energy consumption and thereby exhaust their energy resources more quickly than the ordinary nodes. It is therefore required that the cluster-heads' energy consumption be minimized (optimal) thus maximizing the **network lifetime**[**4**].

A BASIC CLUSTER BASED SYSTEM



1.2 MOTIVATION FOR THESIS

The Energy efficiency is a key factor in limiting the deployability of ad-hoc networks. With the tight energy constraints in the ad hoc networks, the energy consumed for data transmission, routes establishment and maintenance should be kept as low as possible. The energy consumed is an important QoS measure for the ad hoc networks. There has been significant effort in proposing energy efficient protocols. In clustering, Cluster Heads form a virtual backbone while other nodes in the network associate with these cluster heads to form virtual clusters. The cluster heads get drain out maximum energy in the wireless ad hoc networks.This thesis analyses various energy efficient protocols, which can have significant impact on the lifetime of these networks and proposes an algorithm that deals with minimizing the rate of dissipation of energy of cluster heads. The presented solution greatly outperforms the standard assignment of nodes to cluster-heads, based on the minimum distance criterion.

1.3 ORGANIZATION OF THESIS

This thesis is divided into 6 chapters. The chapter 1, that is here, gives some introduction and motivation for designing energy efficient wireless ad hoc networks.

The chapter 2 deals with the literature study that includes wireless network, wireless ad hoc network, mobile ad hoc network and multi-cluster architecture.

Chapter 3 discusses the previous work done in this field like the ANDA(Ad hoc Network Design Algorithm), LID(Lowest ID Algorithm) and LEACH(Low Energy Adaptive Clustering Hierarchy Algorithm) .In the chapter 4describes in detail the proposed algorithm LEAD which deals with energy efficient round scheduling of cluster head allocation of nodes and followed by allocation of nodes to the cluster heads maximizing network lifetime using ANDA.

chapter 5briefs the simulation environment that has been used to simulate and implement the energy efficient protocols. Then LEAD is compared with the various previous works ANDA and LEACH to reach the conclusion.

Chapter 6 concludes the thesis.

CHAPTER 2

2 WIRELESS NETWORKS

2.1 WIRELESS NETWORK

Wireless network[**5**] is any type of computer network which is wireless and can be associated to telecommunications network where interconnection among nodes is done without the use of wires. Wireless Telecommunications networks are usually implemented by a type of remote transmission system for information using electromagnetic waves, like radio waves, for carrier. It is usually implemented at the physical level or layer of the network

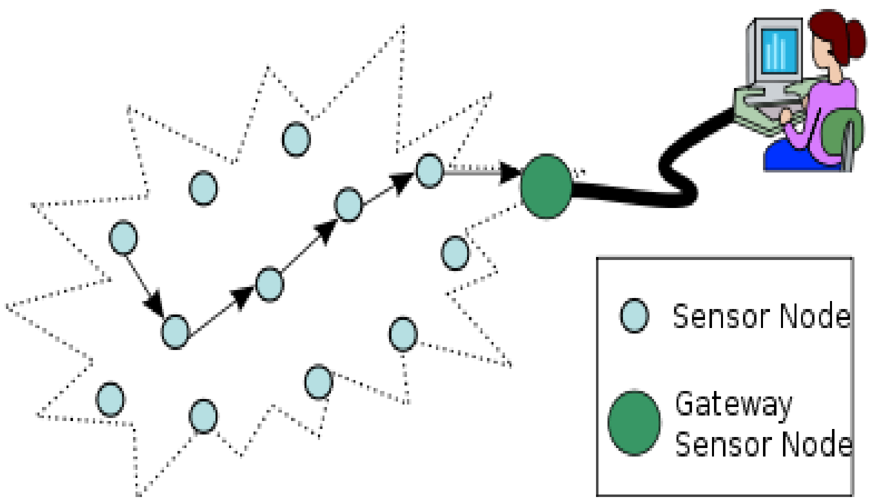


Figure 1 : A Typical Wireless Sensor Network Architecture

2.1.1 Types

a) Wireless PAN

Wireless Personal Area Networks (WPANs)[**6**] is interconnection of devices within a area which is relatively small. The place is within the reach of a person generally.WPAN by Bluetooth to interconnect a laptop and a headset. WPAN applications are also supported by ZigBee.

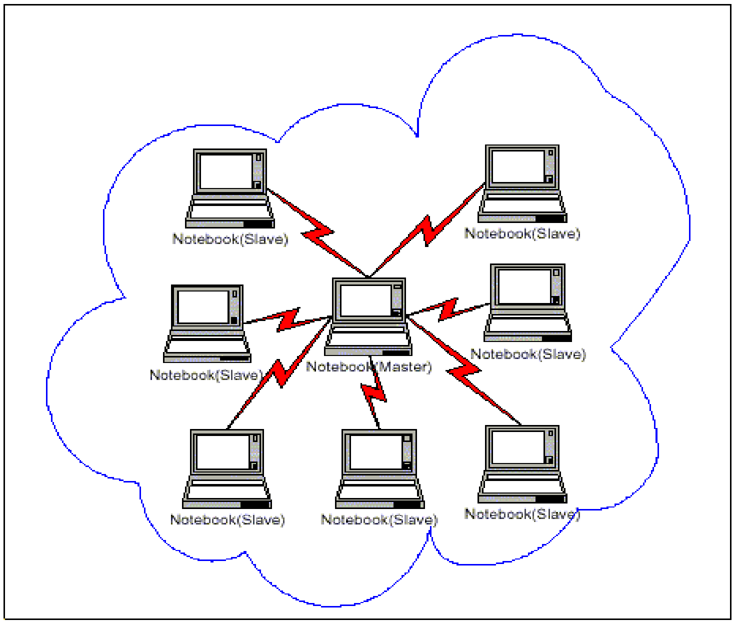


Figure 2 : A Typical PAN Network

b) Wireless LAN

- *Wi-Fi: Wi-Fi* is the name given to 802.11 WLANs, although it is technically a certification of interoperability between 802.11 devices.

- *Fixed Wireless Data:* This implements point to point links between computers or networks at two locations, often using dedicated microwave or laser beams over line of sight paths. It is often used in cities to connect networks in two or more buildings without physically wiring the buildings together.

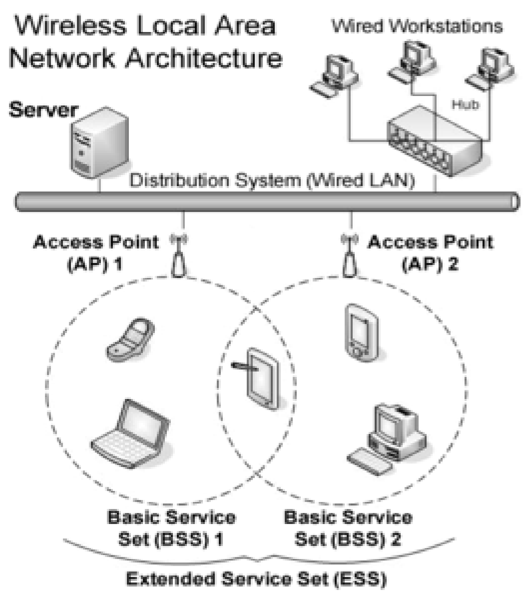


Figure 3 : A Wireless LAN Architecture

c) **Wireless MAN**

- Wireless Metropolitan area networks are a type of wireless network that connects several Wireless LANs.

- WiMAX is the term used to refer to wireless MANs and is covered in IEEE 802.16d/802.16e.

d) **Wireless WAN**

Wireless Wide Area Networks[**6**] are wireless networks that typically cover large outdoor areas. Wireless WANs use cellular towers to transmit a wireless signal over a range of several miles to a mobile device. These networks can be used to connect branch offices of business or as a public internet access system. When combined with renewable energy systems such as photo-voltaic solar panels or wind systems they can be stand-alone systems.

e) **Mobile devices networks**

With the development of smart phones, cellular telephone networks routinely carry data in addition to telephone conversations:

- *Global System for Mobile Communications (GSM)*: The GSM network is divided into three major systems:
    - Switching system,
    - Base station system
    - Operation and support system.

  The cell phone connects to the base system station which then connects to the operation and support station; it then connects to the switching station where the call is transferred to where it needs to go. GSM is the most common standard and is used for a majority of cell phones.

- *Personal Communications Service (PCS)*: PCS is a radio band that can be used by mobile phones in North America and South Asia. Sprint happened to be the first service to set up a PCS.

- *D-AMPS*: Digital Advanced Mobile Phone Service, an upgraded version of AMPS, is being phased out due to advancement in technology. The newer GSM networks are replacing the older system.

2.1.2 Uses

- Efficient and reliable transmission of information to far-off places. Cellular phones bears a testimony to it. Communication across the world is possible through wireless network systems using satellites and other signals.

- With recent developments in the Wireless Networks field, new and innovative medical applications based on this technology are being developed in the research as well as commercial sectors. Wireless Networks are going to become an integral part of medical solutions due to its benefits in cutting down healthcare costs and increasing accessibility for patients as well as healthcare professionals.

- Wireless network provide an inexpensive and rapid way to connect to the internet. It increases the flexibility of the network because it is easy to add new workstations at any time without the need to extend the cable.

- Wireless networks support voice talks which is a useful solution when people need to stay constantly in connection with each other.

2.2 WIRELESS AD HOC NETWORK

A **wireless ad hoc network**[**1**]is a decentralized wireless network. A networking environment in which the users are mobile, the topology changes, interference occurs when multiple transmissions take place over (possibly different) links on the same or different codes, real-time multimedia traffic must be supported as well as datagram traffic, there is no stable communication infrastructure, and there is no central control. The kind of application scenarios that motivate this research include many that require instant infrastructure network support and multimedia network support.

The earliest wireless ad hoc networks were the "packet radio" networks (PRNETs) from the 1970s, sponsored by DARPA after the ALOHA net project.

The decentralized nature of wireless ad hoc networks make them suitable for a variety of applications where central nodes can't be relied on, and may improve the scalability of wireless ad hoc networks compared to wireless managed networks, though theoretical and practical limits to the overall capacity of such networks have been identified.

Minimal configuration and quick deployment make ad hoc networks suitable for emergency situations like natural disasters or military conflicts. The presence of a dynamic and adaptive routing protocol will enable ad hoc networks to be formed quickly.

Wireless ad hoc networks can be further classified by their application:

- Mobile ad hoc networks (MANETs)
- Wireless mesh networks
- Wireless sensor networks.

In most wireless ad hoc networks the nodes compete to access the shared wireless medium, often resulting in collisions. Using cooperative wireless communications improves immunity to interference by having the destination node combine self-interference and other-node interference to improve decoding of the desired signal.

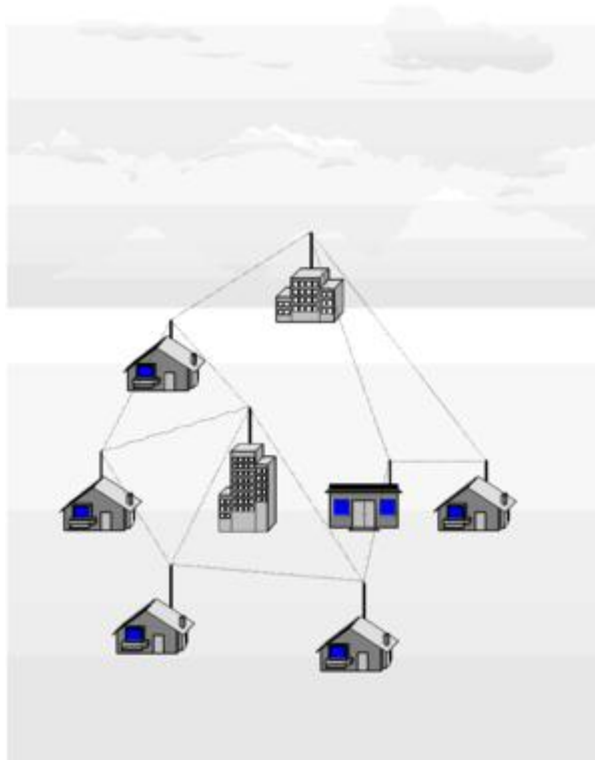


Figure 4 : A Wireless MESH Network

Figure 5 : An Ad-hoc Connection

2.3 Mobile Ad Hoc Network

A **mobile ad hoc network** (**MANET**)[**7**], A MANET is a self-configuring network consisting of mobile platforms simply referred to as "nodes" which are free to move about arbitrarily. A MANET is an autonomous system of mobile nodes. The system may operate in isolation, or may have gateways to and interface with a fixed network.

MANET nodes are equipped with wireless transmitters and receivers using antennas which may be omni-directional (broadcast), highly-directional (point-to-point), possibly steerable, or some combination thereof. The ad hoc topology may change with time as the nodes move or adjust their transmission and reception parameters.

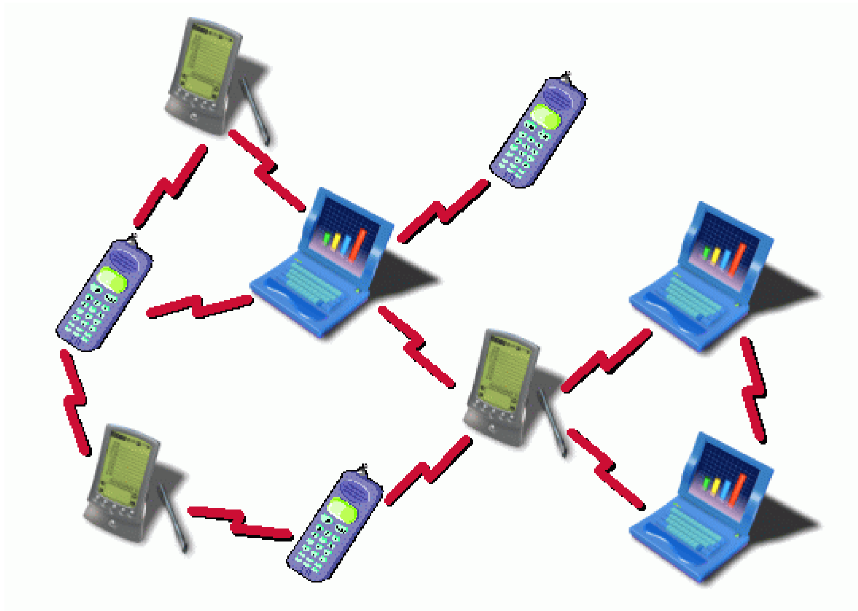


Figure 6 : A Typical MANET Network

2.3.1 Types

- Vehicular Ad Hoc Networks (VANETs) are used for communication among vehicles and between vehicles and roadside equipment.
- Intelligent vehicular ad hoc networks (InVANETs) are a kind of artificial intelligence that helps vehicles to behave in intelligent manners during vehicle-to-vehicle collisions, accidents, drunken driving etc.
- Internet Based Mobile Ad-hoc Networks (iMANET) are ad-hoc networks that link mobile nodes and fixed Internet-gateway nodes. In such type of networks normal ad-hoc routing algorithms don't apply directly.

2.3.2 Practical use

- MANET technology provide an extremely flexible method for establishing communications for fire/safety/rescue operations or other scenarios requiring rapidly-deployable communications with survivable, efficient dynamic networking.

- Commercial applications of MANET involves cooperative mobile data exchange

2.4 BASIS FOR CLUSTERING IN AD HOC NETWORKS

In the Internet, which is basically a multihop packet-switched communication network, each node in the network is given a 32-bit IP address that is assigned in a way such that all the nodes in the same subnet share the same address prefix. This very important property allows us to build a hierarchy in the Internet topology. Unfortunately, due to mobility, nodes in an ad hoc network cannot be assigned such aggregate addresses. This is an obstacle for scaling up ad hoc networks. Clustering [**8**]is a process of defining an abstracted structure of a network. It can be applied recursively to obtain a multi-level hierarchy. After clustering, each node in the hierarchy can be assigned a hierarchical address that indicates its position in each level of the hierarchy. Routing can easily be carried out using such addresses.

Wireless mobile ad hoc networks consist of mobile nodes which can communicate with each other in a peer-to-peer fashion (over single hop or multiple hops) without any fixed infrastructure such as access point or base station. In a multi-hop ad hoc wireless network, which changes its topology dynamically, efficient resource allocation, energy management, routing and end-to-end throughput performance can be achieved through adaptive **clustering** of the mobile nodes.

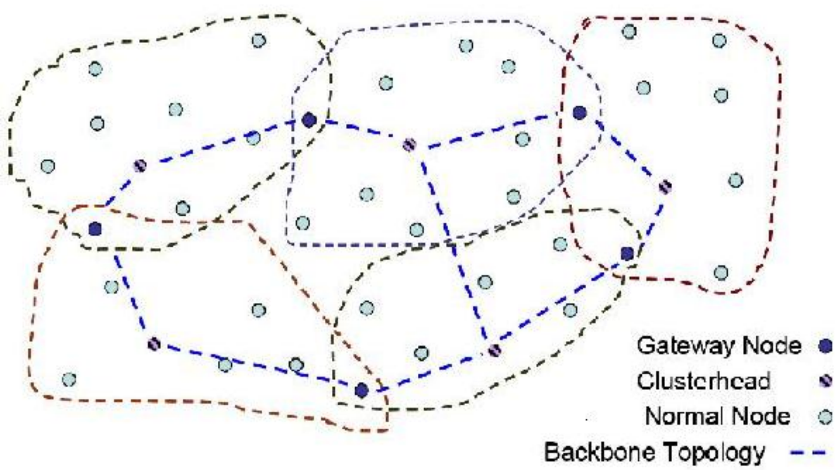


Figure 7: Clustering Network

CLUSTERING[**2**][**3**], in general is defined as the grouping of similar objects or the process of finding a natural association among some specific objects or data. With an ad hoc clustering network, the nodes are separated into groups called clusters. There are usually three types of nodes in clustering networks, as shown in Figure 7[**9**]:cluster-heads (CHs), gateway nodes and normal nodes. In each cluster, one node is elected as a CH to act as a local controller. The cluster-head needs to coordinate all transmissions within the cluster, so also it handles the inter-cluster traffic, delivers the packets destined for the cluster etc. Hence these cluster-heads experience high-energy consumption and thereby exhaust their energy resources more quickly than the ordinary nodes. It is therefore required that the cluster-heads' energy consumption be minimized (optimal) thus maximizing the **network lifetime**[**4**]**.**

The process of cluster-formation consists of two phases –cluster-head election and assignment of nodes to cluster-heads. The size of the cluster (the number of nodes in the cluster) depends on the transmission range of the nodes in single hop cluster and the number of hops made by the cluster in multi-hop clusters. The normal node sends or relays data to the CH which transfers the collected packets to the next hop. The gateway node, belonging to more than one cluster, bridges the CHs in those clusters. Both CHs and gateway nodes form the backbone network, yet the presence of gateway node is not compulsory in the clustering network.

Some basic advantages of the clustering scheme are[**9**]:
1) Only the CHs and gateway nodes form the backbone network, results in much simpler topology, less overhead, flooding and collision.
2) The change of nodes only affects part topology of the networks, making the topology more stable.
3) Only CHs or gateway nodes need to maintain the route information.

2.5 MULTICLUSTER ARCHITECTURE

Most hierarchical clustering architectures for mobile radio networks are based on the concept of *clusterhead.* The clusterhead acts as a local coordinator of transmissions within the cluster. It differs from the base station concept in current cellular systems, in that it does not have special hardware and in fact is dynamically selected among the set of stations. However, it does extra work with respect to ordinary stations, and therefore it may become the bottleneck of the cluster. To overcome these difficulties, in our approach we eliminate the requirement for a clusterhead altogether and adopt a fully distributed approach for cluster formation and intra-cluster communications.

In cluster based systems, network nodes are partitioned into several groups . In each group, one node is elected to be the cluster-head while the rest of the nodes become ordinary nodes. The cluster size is controlled by varying the cluster-head's transmission power. The clusterhead coordinates transmissions within the cluster, handles inter-cluster traffic and delivers all packets destined to the cluster; it may also exchange data with nodes that act as gateways to the wired networks. The cluster-based network architectures, the lifetime is strongly related to cluster-head's failure. Clusterheads therefore experience high energy consumption and exhaust their energy resources more quickly than ordinary nodes do.

The procedure of cluster formation consists of two phases:

- Cluster-head election
- Assignment of nodes to cluster-heads.

Although several algorithms have been proposed in the literature, which address the problem of cluster formation, little work has been done on energy efficient design of cluster-based networks.

2.6 NEED FOR ENERGY EFFICIENY

The greatest challenge manifesting itself in the design of wireless ad-hoc networks is the limited availability of the energy resources. These resources are quite significantly limited in wireless networks than in wired networks. Energy-efficient communication is critical for increasing the life of power limited wireless ad hoc networks.

In recent years, multihop wireless ad hoc networks have found extensive use in various fieldsdue to their potential applications in civil and military domains. Some of the applications include mobile computing in areas where other infrastructure is unavailable, law enforcement operations, disaster recovery situations, large sporting events or congresses when it is not economical to build a fixed infrastructure for a short temporary usage, and tactical battlefield communications where the hostility of the environment prevents the application of a fixed backbone network.

A multihop wireless ad hoc network is dynamically formed by a collection of mobile nodes. Each of these mobile nodes is operated by a limited-energy battery and usually it is impossible to recharge or replace the batteries during a mission. The communication between two mobile nodes can be either in a single hop transmission in which case the two nodes are within the transmission ranges of each other, or in a multihop transmission where the message is relayed by intermediate mobile nodes. Since wireless communications consume significant amounts of battery power, therefore, the limited battery lifetime imposes a severe constraint on the network performance. Energy efficient operations are critical to enhance the network lifetime. Extensive studies on energy conservation in wireless ad hoc networks have been conducted.

Wireless communications consume significant amounts of battery power[**10**], and therefore, energy efficient operations are critical to enhance the life of such networks. Some amount of power is lost even when a node is in idle mode. A recent study[**11**] shows that the power consumed in transmitting and receiving packets in standard WaveLAN cards range from 800 mW to 1200 mW. During the past few years, there has been increasing interest in the design of energy efficient protocols for wireless ad hoc networks.

Most mobile nodes in a wireless ad hoc network are powered by energy limited batteries, the limited battery lifetime is a hindrance to network performance. Therefore, energy efficiency is of vital importance in the design of protocols for the applications in such networks, and efficient operations are critical to enhance the network lifetime.

Since the Nodes are battery-powered; thus energy is a precious resource, that has to be carefully used by the nodes in order to avoid an early termination of their activity, and hence the study and implementation of energy-efficient algorithms for wireless networks, quite constitutes a vast area of research in the field of ad-hoc networks.

CHAPTER 3

3 RELATED WORKS

Ad hoc networks do not use a fixed architecture for communication. In order to provide efficient communication there need to be a wireless backbone. The backbone must change to reflect the changes in the network topology as the nodes move. The algorithm to choose the backbone should be very fast and efficient as they involve mobile nodes powered by battery. Clustering is a solution to the above problem. Even clustering suffers overhead from cluster formation and maintenance. Since the nodes are powered by limited supply of power, the main objective is to design energy efficient clustering algorithms.

Many clustering algorithms are proposed till date. Thesis presents study of some of the popular energy efficient clustering algorithms which include ANDA, LID and LEACH.

3.1 ANDA

ANDA[**2**] is based on the concept that cluster heads can dynamically adjust the size of the clusters through power control, and, hence, the number of controlled nodes per cluster. Energy is evenly drained from the cluster-heads by optimally balancing the cluster traffic loads and regulating the cluster heads' transmission ranges. The ANDA algorithm maximizes the network lifetime by fixing the optimal radius of each cluster and the optimal assignment of the nodes to the clusters.

We assume the following system parameters are known:

- Number of cluster heads(C)
- Number of nodes in the network(N)
- Location of all cluster-heads and nodes, and initial value of the energy available at each clusterhead.

3.1.1 THE PROBLEM FORMALIZATION

- Let $S_C = \{1,\ldots\ldots,C\}$ be the set of cluster-heads,
- $S_N = \{1,\ldots\ldots.,N\}$ be the set of ordinary nodes to be assigned to the clusters
- Let d_{ik} =distance between cluster-head i and node k(i=1,……C ;k=1……..,N)
- $r_i=d_{ij}$ when j is the farthest node controlled by cluster-head i
- Matrix $L=\{l_{ij}\}$,dimension=$|S_C|$ x $|S_N|$ where each entry l_{ij} represents the lifetime of cluster-head i when its radius is set to $r_i=d_{ij}$ and it covers $n_{ij} = \{k \in S_N | d_{ik} \le d_{ij}\}$

$$l_{ij} = \frac{E_i}{\alpha d_{ij}^2 + \beta |n_{ij}|}$$

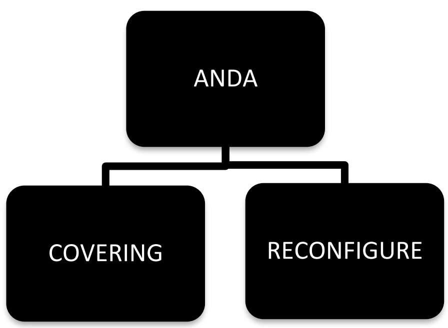
Once matrix L is computed, the optimal assignment of nodes to cluster heads is described by the binary variable $X_{\mathbf{ij}}$

$\{X_{ij} = 1$ if cluster-head i covers j else $0\}$

3.1.2 THE OPTIMIZATION PROBLEM

Maximize L_s subject *to*
$\sum x_{ij} \geq 1 \quad \nu j \epsilon S_N$
$L_s \leq l_{ij} x_{ij} + M\,(1 - x_{ij})\ \nu\ i \epsilon S_C,\ j \epsilon У S_N$
$x_{ij} \epsilon \{0,1\},\ L_s \geq 0\ \nu\ i \epsilon S_C, j \epsilon S_N$

- Each node is covered by one cluster-head i
- If node j is assigned to cluster-head i, the system cannot hope to live more than l_{ij}



Covering Algorithm

begin Covering
  for (*every* jϵS_N)
  set *max*=0
    for (*every* iϵS_C)
      if($l_{ij} \geq$ max)
        set *max*= l_{ij}
        set *sel* = i
      end if
    end for
    Cover node j with cluster-head *sel*
  end for
endCovering

In static scenario, only the covering algorithm is used and nodes once assigned to a clusterhead remains attached to it till the clusterhead runs out of energy.

Reconfigure Algorithm

begin Reconfigure
for (*every*iϵS_C)
    set E_i=initial energy of cluster-head i
    for (every jϵS_N)
        Compute d_{ij},$|n_{ij}|$,l_{ij}
    end for
end for
$L_s^{(new)} = L_s^{(old)} = L_s$
$\Delta=0$
while($L_s^{(new)} \leq L_s^{(old)} - \Delta$)
    $\Delta=\Delta+1$
    for (every iϵS_C)
        for (every jϵS_N)
            Recompute $E_i=E_i-\Delta(\alpha r_i^2+\beta|n_{ij}|)$
            Update l_{ij} $\forall$ iϵS_C, jϵS_N
        end for
    end for
    Call *Covering* and update L_S
    $L_S^{(new)}=L_s$
end while
end*Reconfigure*

In dynamic scenario, both the covering and reconfigure algorithm are used. By Scheduling periodical node re-assignments based on the recomputed values of E_i , the system energy consumption can be leveled. Through function Reconfigure, the new value of the available energy at clusterhead i (i=1,2,………C) is computed as

$$E_{i(new)}=E_{i(old)}-\Delta(\alpha r_i^2+\beta|n_{ij}|)$$

The drawback of ANDA is that the number of clusterheads is fixed which is practically impossible. Another problem in ANDA is that energy is only drained from selected nodes i.e. clusterheads, thus affecting the lifetime of the whole network. If the energy drain would have been uniform the lifetime might have been increased.

3.2 LID

The LID Algorithm[**12**][**13**] is the **Lowest ID Algorithm**. The LID algorithm is used to determine cluster heads and the nodes that constitute the cluster.The LID Algorithm is the Lowest ID Algorithm. The LID algorithm is used to determine cluster heads and the nodes that constitute the cluster. Each node is assigned a unique id and a node with the lowest ID is chosen as the clusterhead, all the nodes within radius R around that node are its members. The process repeats until every node belongs to a cluster.

The ANDA algorithm was extended to implement the LID algorithm along with it. The basic approach is to choose the cluster-heads using the LID algorithm and then implement ANDA to cover the nodes, and calculate the network lifetime

The drawback of LID is its bias towards nodes with smaller ids which leads to battery drainage of certain nodes.

3.2.1 Pseudo code:

```
Random I;
Add I to Sc
While (j є Sc or SN)
        For j belongs to SN
                If j lies within range of i
                        j є i
        end for
        select new lowest ID
        add to Sc
end while
```

3.3 LEACH

LEACH[**3**] is a self-organizing, adaptive clustering protocol that uses randomization to distribute the energy load evenly among the nodes in the network. LEACH, is a clustering algorithm in which there is one node which acts as a clusterhead and controls all the nodes that are under it **.** If the clusterheads were chosen apriori and fixed throughout the system lifetime, nodes chosen to be cluster-heads would die quickly, resulting in a decreased lifetime of all nodes belonging to those clusters. LEACH includes randomized rotation of the high-energy cluster-head position such that it rotates among the various nodes in order to not drain the battery of a single node. In addition, LEACH performs local data fusion to “compress” the amount of data being sent from the clusters to the base station, further reducing energy dissipation and enhancing system lifetime.

Nodes elect themselves to be local cluster-heads at any given time with a certain probability. These clusterhead nodes broadcast their status to the other nodes in the network. Nodes get assigned to cluster-heads on the basis of minimum communication energy. Once all the nodes are organized into clusters, each cluster-head creates a schedule for the nodes in its cluster.

To evenly drain energy from all nodes, clusterhead nodes are not fixed; they are elected in a rotation basis Thus a set S of nodes might elect themselves cluster-heads at time t_1, but at time t_1 + d a new set S_0 of nodes elect themselves as cluster-heads, The decision to become a cluster-head depends on the amount of energy left at the node. In this way, nodes with more residual energy perform the energy-related tasks of the network. Each node makes its decision about whether to be a cluster-head independent of the other nodes in the network and thus no extra negotiation is required to determine the cluster-heads. The system can determine, a priori, the optimal number of clusters to have in the system. This will depend on several parameters, such as the network topology and the relative costs of computation versus communication.

The major advantage of LEACH is that it reduces the energy dissipation. This is on account of rotation of clusterheads which leads to equal drainage of energy from all nodes and nodes die randomly. Another important advantage of LEACH is the fact that nodes die in essentially a "random" fashion.

3.3.1 LEACH ALGORITHM DETAILS

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.

Initially, 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 (determined a priori) 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 T(n), the node becomes a cluster-head for the current round. The threshold is set as:

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

Where P = the desired percentage of cluster heads (e.g. = 0:05), r = the current round, and G is the set of nodes 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. During round 0 (r = 0), each node has a probability P of becoming a cluster-head. The nodes that are cluster-heads in round 0 cannot be cluster-heads for the next 1/P rounds. Thus the probability that the remaining nodes are cluster-heads must be increased, since there are fewer nodes that are eligible to become cluster-heads. After 1/P-1 rounds, T = 1 for any nodes that have not yet been cluster-heads, and after 1/P rounds, all nodes are once again eligible to become cluster-heads.

Each node that has elected itself a cluster-head for the current round broadcasts an advertisement message to the rest of the nodes. 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. 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 ties, a random cluster-head is chosen. After each node has decided to which cluster it 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.

CHAPTER 4

4 THE PROPOSED ALGORITHM Low Energy Adaptive Dynamic [LEAD] Clustering Algorithm

Most of the energy efficient clustering and node assignment algorithms discussed above assume the non-mobility of the nodes and a fixed set of cluster-heads during the cluster setup phase and the node assignment phase. The protocol must be adaptive to the dynamic topology of the network. The previous algorithms deal with static sensor nodes whereas in a mobile ad hoc network the static assumption of nodes is not possible. So designing an energy efficient clustering algorithm for mobile nodes is a challenging issue.

The mobile ad hoc network can be modeled as a set of nodes $S_N = \{1 \dots N\}$ and a set of cluster-heads $S_C = \{1 \dots C\}$ where N is total number of nodes and C is the total number of cluster-heads. The set of nodes S_N remains static throughout the network lifetime but the cardinality of set of cluster-heads i.e. $| S_C |$ changes due to the energy considerations and mobility of the nodes. Each node $n_i \epsilon$ N has a unique integer identifier n_i, a wireless transmission range r_i and initial energy E_i.

The ordinary node is the node that ϵS_N and $\notin S_C$ .Every ordinary node ϵS_N inside the range of the cluster-head ϵS_C is eligible to be assigned to S_C. The communication is assumed to be single hop in nature.

4.1 Basis of the Approach

The proposed clustering algorithm and the protocols have the following features:

- A node can be assigned to a cluster-head iff the node comes within the range of the cluster-head.
- Cluster-heads are selected from among the nodes randomly which is very practical in case of wireless ad hoc networks instead of having a fixed set of cluster heads.
- Set of cluster heads are selected dynamically after a periodic interval in a round schedule balancing the load (energy dissipation) throughout the nodes of the network.
- Every node communicates to other node through a cluster-head and is not directly connected to any other ordinary node (Single hop architecture).

4.2 Cluster-head Selection

The first thing to do select the set of cluster-heads S_C .Initially, when clusters are being created, each node decides whether or not to become a cluster-head for the current round according to the table created periodically and updated every N/C rounds. This decision is based on the suggested percentage of cluster heads for the network (determined a priori) and the number of times the node has been a cluster-head so far. After a broadcast of HELLO messages the total network data is clubbed together and the nodes are sorted according to their current residual energy.

Algorithm ***Selectcluster***

If (N/C divides Δ)
Begin **nodeSort**

```
for (every iєSc)
    for (every jєSN)
            if(energy[i] > energy[j])
            swap(i ,j)
    end for
end for

endnodeSort
end if
```

This is followed by the creation of the *clustertable* at each node which contains the set of cluster heads for 1/P rounds, where P is the percentage of nodes becoming cluster-heads. Thus each node has the idea which node is cluster head for this current round. The clustertable contains C clusterheads each in N/C columns in the sorted order of the energy, where N is the total number of nodes in the network. Thereafter the C clusterheads for the current round are stored in $S_{C,}$ the set of cluster-heads ,and the rest nodes are stored in $S_{N\,,}$ set of ordinary nodes. This is followed by node assignment.

4.3 Node Assignment

S_C = {1…C},set of cluster-heads andS_N= {1…N} be the set of ordinary nodes to be assigned to the clusters. Major Contributions to power consumption in nodes are: power consumed by the digital part of the circuitry, Power consumption of the transceiver in transmitting and receiving mode and output transmission power**.** The lifetime is calculated according to the following equation:-

$$l_i = \frac{E_i}{\alpha r_i^2 + \beta|n_i|}$$

where E_i is the initial amount of energy available at cluster-head i, r_i is the coverage radius of cluster-head i, n_i is the number of nodes under the control of cluster-head i, and α and β are constants. Considering that the limiting factor to the network lifetime is represented by the cluster-head's functioning time, the lifetime is defined by

$$L_s = min_{i \epsilon Sc}\{L_i\}$$

The main objective is to maximize L_s. The Algorithm for assignment of the nodes is as follows:

Begin **Assignnodes**
for (every $i \epsilon S_c$)
    set E_i=initial energy of cluster-head i
    for (every $j \epsilon S_N$)
        Compute d_{ij},$|n_{ij}|$,l_{ij}
    end for
end for
Ls(new)= Ls(old)= Ls
Δ=0
while(Ls(new)≤Ls(old)-Δ)
    $\Delta = \Delta + 1$
    for (every $i \epsilon S_C$)
        for (every $j \epsilon S_N$)
            Recompute $E_i = E_i - \Delta(\alpha r_i^2 + \beta |n_{ij}|)$
            Update l_{ij} $\forall$ $i \epsilon S_C$, $j \epsilon S_N$
        end for
    end for
    Call ***Selectcluster*** and update Ls
    L_s(new)=L_s
end while

end ***Assignnodes***

CHAPTER 5

5 RESULTS AND DISCUSSION

5.1 SIMULATION SETUP

This Section describes the scenario and the movement model used in the study followed by the results and discussion.

5.1.1 SCENARIO

The simulator is a software tool designed in Java. The simulated ad hoc network is composed of slowly changing network topology. The topology is a square area with 1000 m length and 1000 m width. The network nodes are randomly distributed. Initial energy of all the nodes in the network is 5000J and it is assumed that even if a node is not a cluster head it loses some amount of energy due to radio transceiver and transmission amplifier. The range of each node is R which is taken as input to the program. The movement speed of a node can vary between 0 and 5 m/sec.

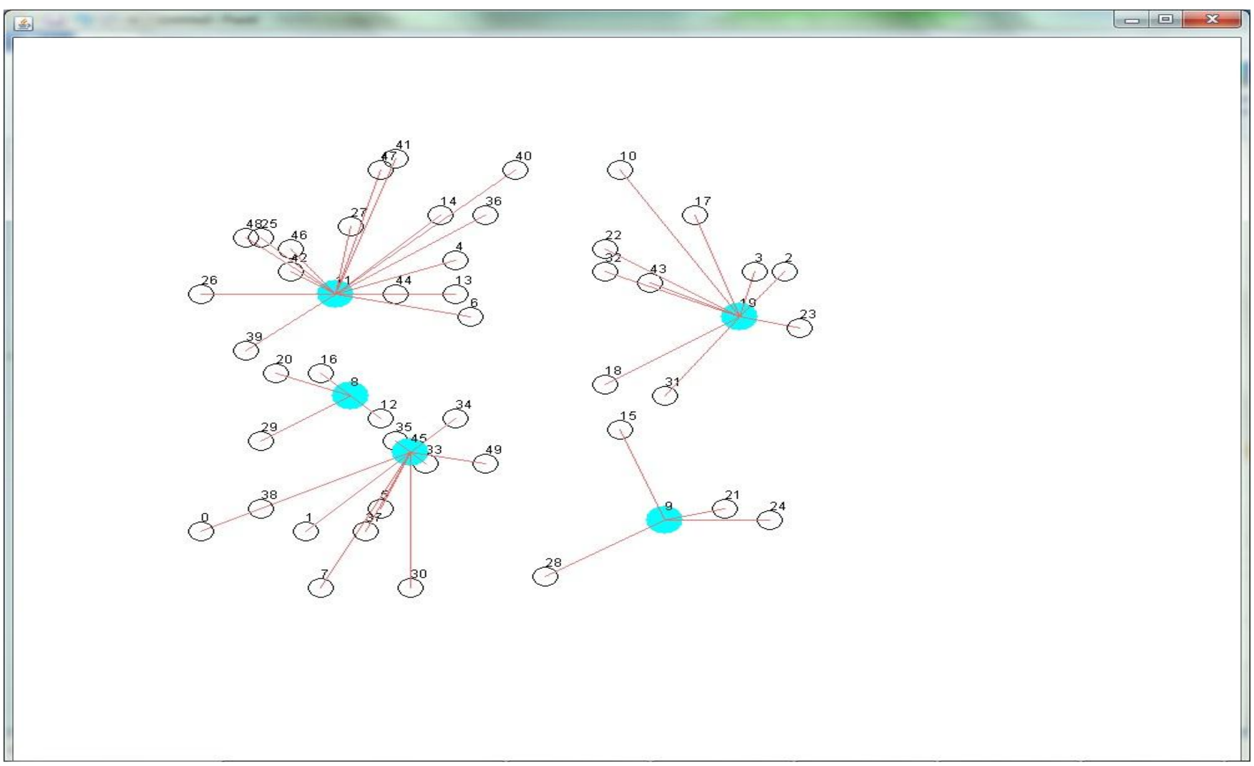


Figure 8 : Simulation Snapshot

5.1.2 MOBILITY PATTERN

In order to propose a new protocol for an ad hoc network, it is necessary to use a mobility pattern which closely represents the mobile nodes(MNs). The nodes cannot be assumed to always move in a straight line with uniform speed. So, using a proper mobility pattern to model the network topology is an important task.

There are basically three different mobility models for ad hoc networks:

1. **Random Walk Mobility Model:**

It is used for depicting the erratic movement of the nodes. In this mobility model, an MN moves from its current location to a new location by randomly choosing a direction and speed in which to travel. The new speed and direction are both chosen from pre-defined ranges, [speedmin; speedmax]. If aMN which moves according to this model reaches a simulation boundary, it "bounces "off the simulation border with an angle determined by the incoming direction. The MN then continues along this new path. The Random Walk Mobility Model is a widely used mobility model which is sometimes referred to as Brownian Motion.

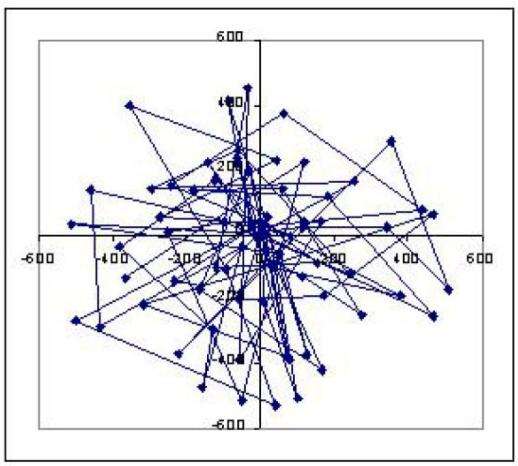


Figure 9 : Random Walk Mobility Model[14**]**

2. **Random Waypoint Mobility Model:**

The Random Waypoint Mobility Model includes pause times between changes in directionand/or speed. An MN begins by staying in one location for a certain period of time (i.e., a pause time). Once this time expires, the MN chooses a random destination in thesimulation area and a speed that is uniformly distributed between [0, Maxspeed].The MN then travels toward the newly chosen destination at the selected speed. Uponarrival, the MN pauses for a specified time period before starting the process again.

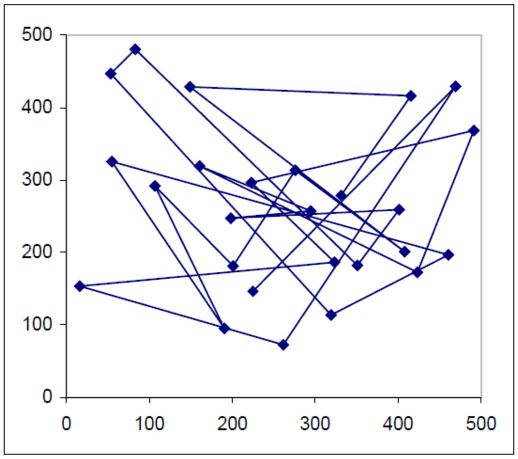


Figure 10 :Random Waypoint Mobility[14**]**

3. **Random Direction Mobility Model:**

The Random Direction Mobility Model was created in order to overcome a flaw discovered in the Random Waypoint Mobility Model. The MNs moving with the Random Waypoint Mobility Model appear to converge, disperse, converge again, etc. In order to alleviate this type of behavior and promote a semi-constant number of neighbors, the Random Direction Mobility Model was developed. In this model, MNs choose a random direction in which to travel instead of a random destination. After choosing a random direction, an MN travels to the border of the simulation area in that direction. As soon as the boundary is reached the MN stops for a certain period of time, chooses another angular direction (between 0 and 180 degrees) and continues the process.

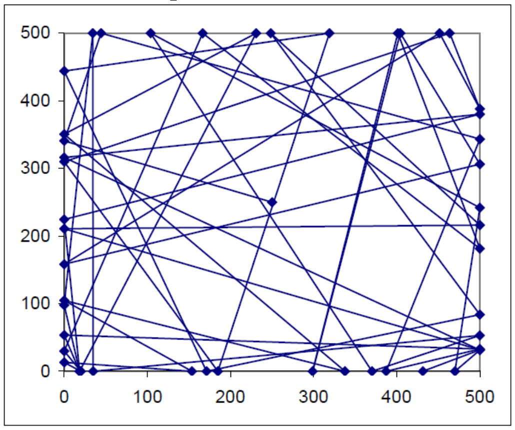


Figure 11 : Random Direction Mobility Model[14**]**

5.2 ANDA

Figure 12 shows the network lifetime as the number of nodes changes for 0.05 percent of cluster-heads and a random distribution of network nodes. The lifetime decreases as the number of nodes grows; however, for a number of nodes greater than 200, the lifetime remains almost constant as the number of nodes increases

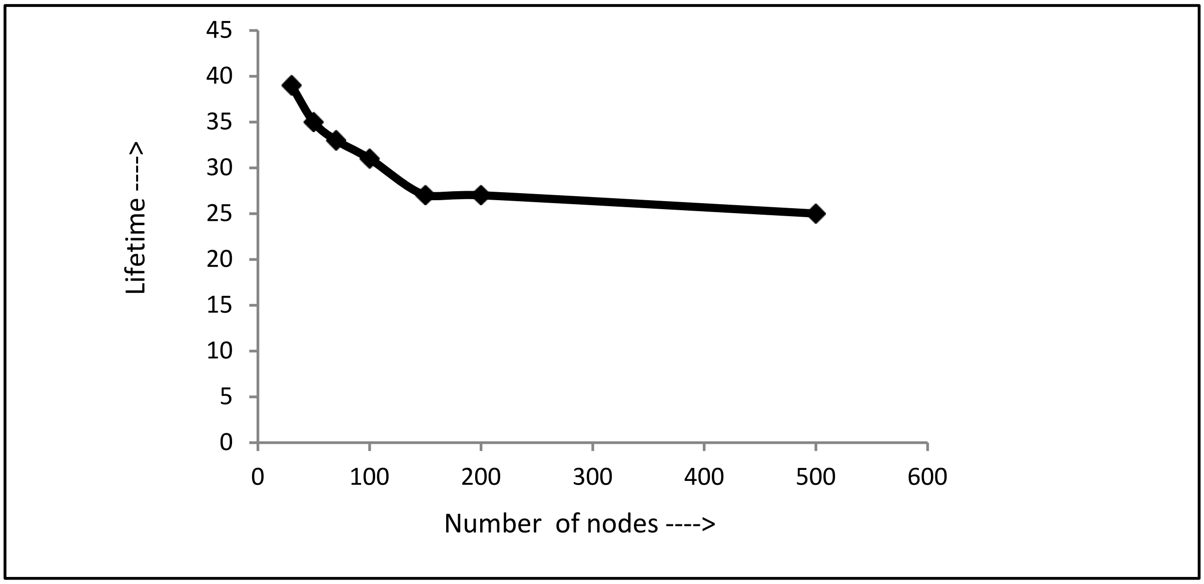


Figure 12 : ANDA - Lifetime as a function of the number of nodes, for a percentage of nodes becoming cluster heads equal to 0.05.

Figure 13 shows the network lifetime as the function of percentage of nodes becoming cluster heads changes for 1000 nodes and a random distribution of network nodes. The lifetime increases as the percentage of nodes becoming cluster heads grows.

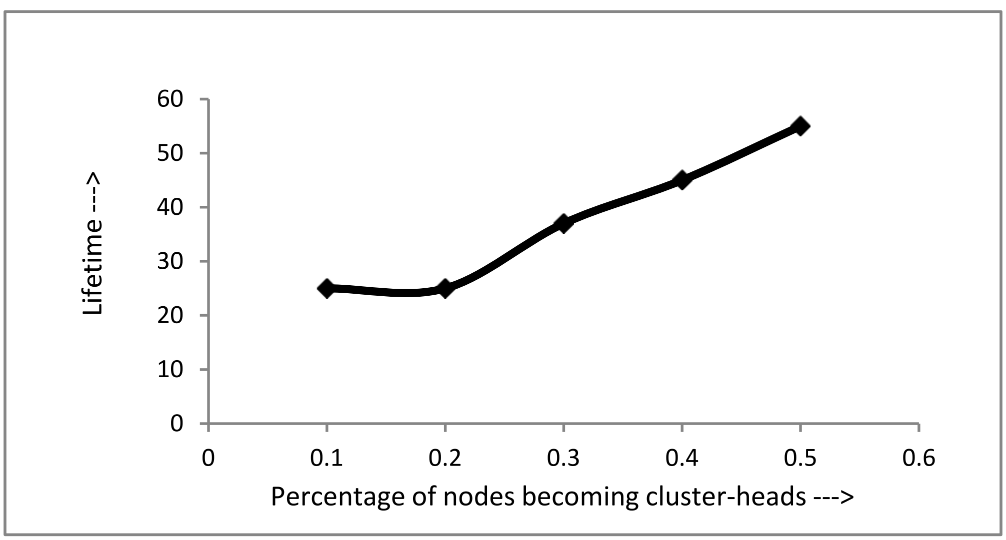


Figure 13 : ANDA - Lifetime as a function of the percentage of nodes becoming cluster-heads for a network of 1000 nodes.

5.3 LEACH

Figure 14 shows the network lifetime as the function of percentage of nodes becoming cluster heads changes for 1000 nodes and a random distribution of network nodes. The lifetime decreases as the percentage of nodes becoming cluster heads grows.

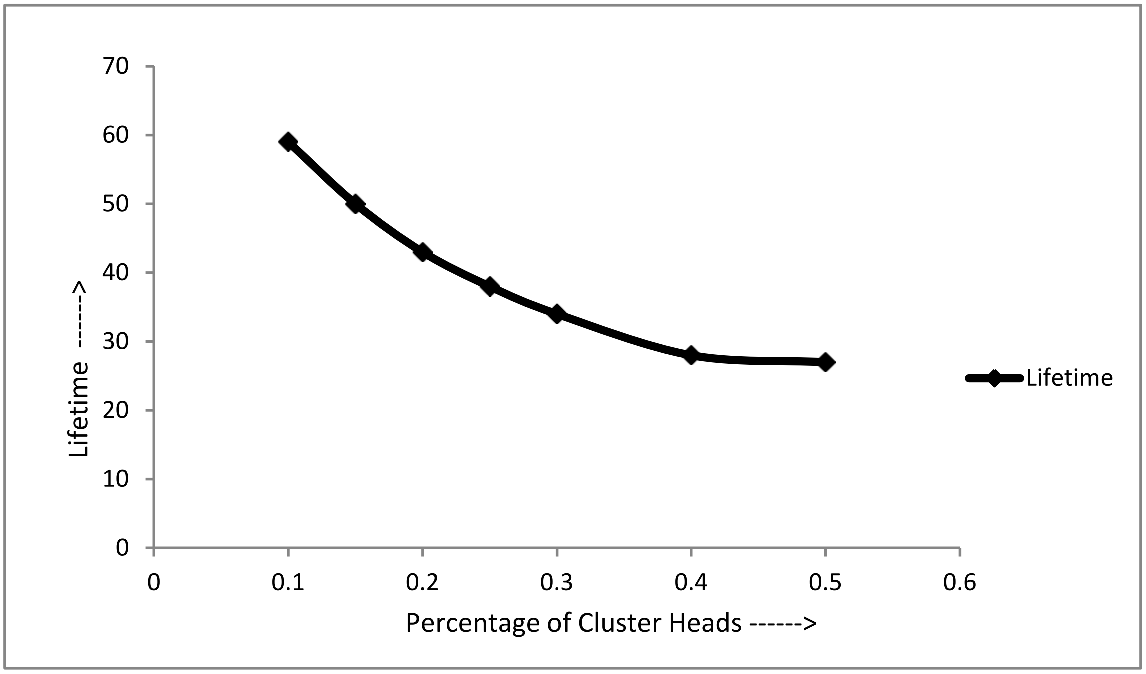


Figure 14 : LEACH - Lifetime as a function of the percentage of nodes becoming cluster-heads for a network of 1000 nodes

5.4 ANDA AND LID

The performance of LEAD was compared with the results obtained by using ANDA in which cluster heads are known apriori. Figure 15 shows the network lifetime as a function of the number of nodes, for a percentage of cluster heads P=0.05. The life-time decreases as the number of nodes grow; however for a number of nodes greater than 100, the life-time remains almost constant as the number of nodes increases. Life-time decreases because Clusterheads have to cover more nodes as the number of nodes in the network increases. But LEAD shows significant improvement over ANDA, this is because in ANDA the cluster-heads are determined apriori but in case of LEAD cluster-heads is chosen in a random rotation basis and each node becomes a cluster head in 1/P rounds i.e. the nodes that are cluster-heads in round 0 cannot be cluster-heads for the next 1/P rounds. From the comparison with the performance of ANDA, it was observed that the improvement achieved through LEAD is equal to 35 %. Energy is uniformly drained from all the nodes and hence the network life-time is significantly increased.

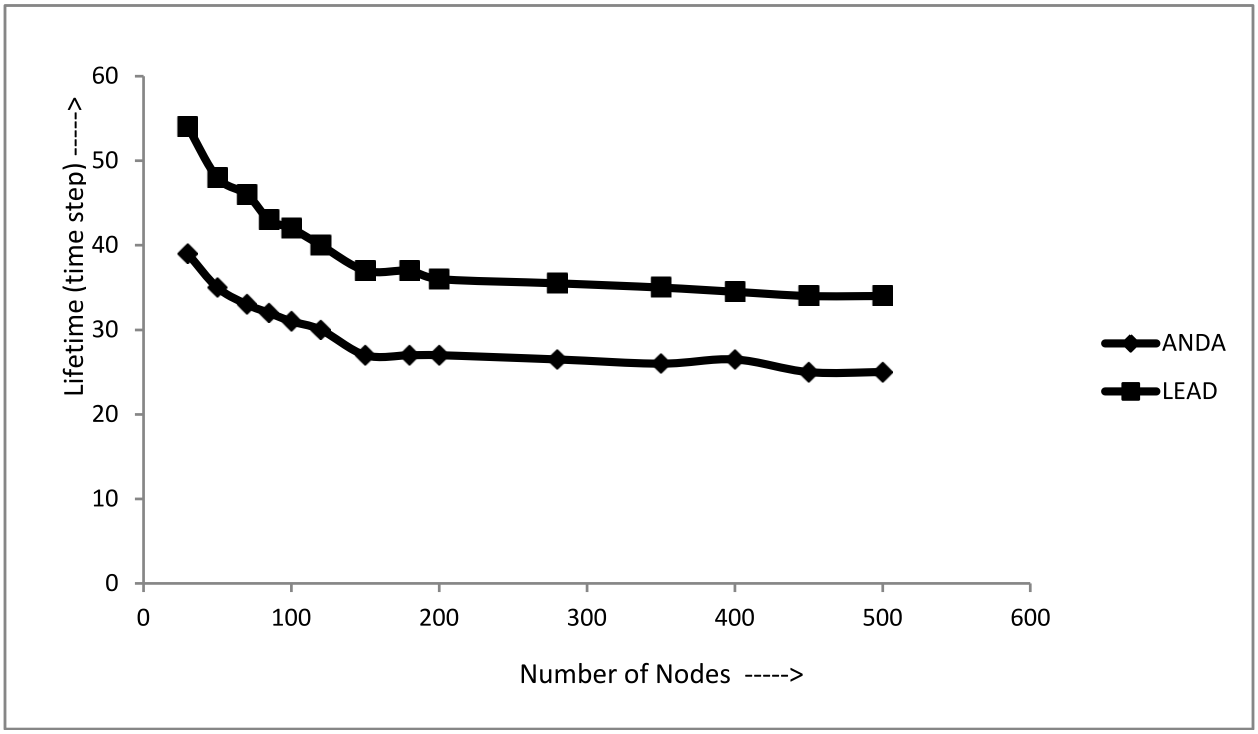


Figure 15 : Lifetime as a function of the number of nodes , for a percentage of nodes becoming cluster heads equal to 0.05 . Results obtained through ANDA and LEAD scheme are compared.

Figure 16 shows the network life-time as the number of cluster-heads, C. Curves are obtained for N=1000 and nodes distributed randomly over the network area. In ANDA it was observed that as the number of cluster heads increases for a given number of nodes, the life-time is increased, this is due to the fact that increasing C , cluster heads now have to cover less number of nodes and energy of each node is drained at a slower rate. But, in case of LEAD it is observed that network life-time decreases with the increase in percentage of nodes becoming cluster-heads (P). For less percentage of nodes becoming cluster-heads the time interval between successive elections of a node as cluster-head is large but if percentage of nodes becoming cluster-heads is high, the time interval is small i.e. a node is again elected as a cluster-head in less number of rounds. So, energy is drained early resulting in a decreased network life-time.

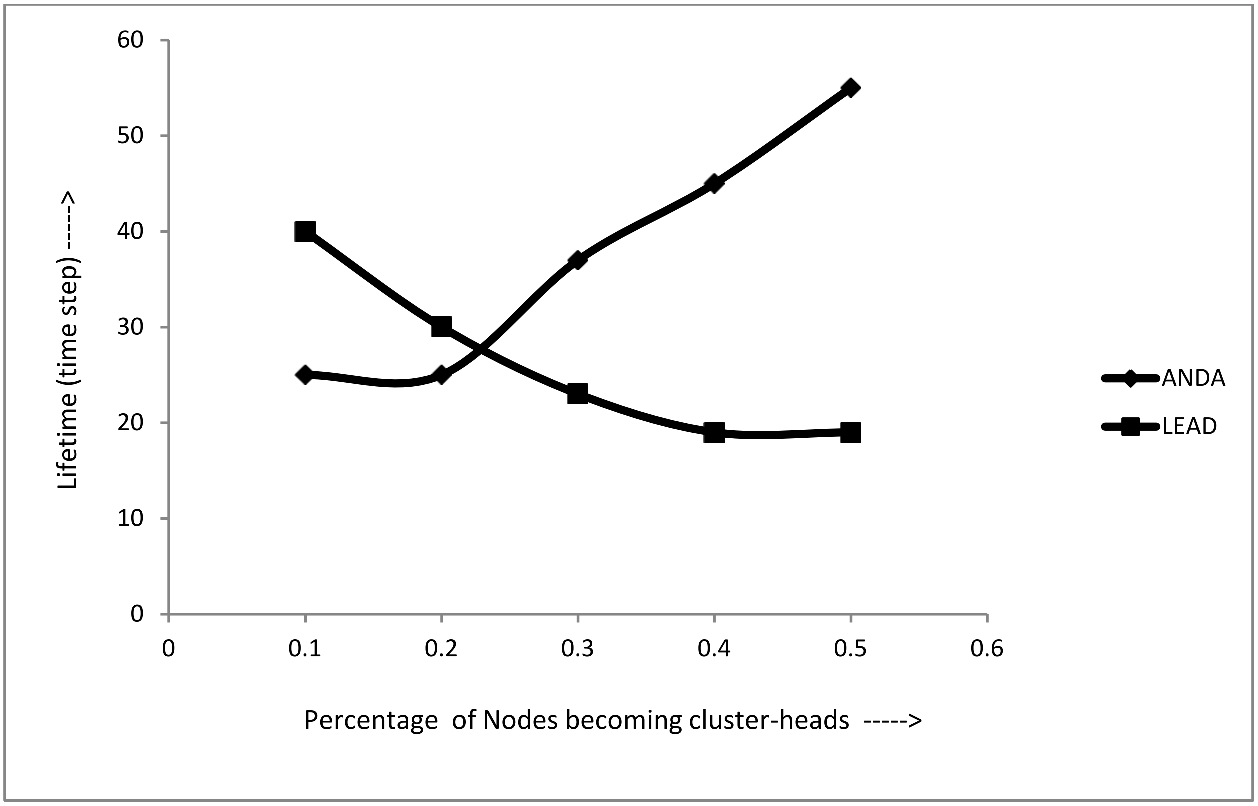


Figure 16 : Lifetime as a function of the percentage of nodes, for a percentage of nodes becoming cluster heads equal to 0.05. Results obtained through ANDA and LEAD scheme are compared.

CHAPTER 6

6 CONCLUSION

One of the most vibrant and active "new" fields today is that of ad hoc networks. Significant research in this area has been ongoing for nearly 30 years, also under the names packet radio or multi-hop networks. Within the past few years, though, the field has seen a rapid expansion of visibility and work due to the proliferation of inexpensive, widely available wireless devices and the network community's interest in mobile computing.

The concept of wireless is not new. When the packet switching technology, the fabric of the Internet was introduced by the Department of Defense, the ARPANET ,it understood the potential of packet switched radio technology to interconnect mobile nodes .The DARPA around early 70's helped establish the base of ad hoc wireless networking. This is a technology that enables untethered wireless networking environments where there is no wired or cellular infrastructure. Wireless Ad hoc Networks since then is a fast developing research area with a vast spectrum of applications.

Energy Efficiency i.e utilizing the available limited amount of energy in deploying the network in the most efficient and reliable way is perhaps the greatest challenge faced by an ad-hoc system. Although there have been certain protocols proposed to deal with it, however they do not provide a complete energy-efficient network.

ANDA for example, provides quite good results with the static and dynamic scenario, however it by any means, doesn't take into account the rotation of the cluster-head. It only visualizes the effect of changing the position of the nodes after a certain time interval.

However, the proposed Algorithm LEAD, provides far better results than ANDA with respect to the network lifetime, as also it considers the rotation of the cluster-heads after regular intervals. Here it is observed that network life-time decreases with the increase in percentage of nodes becoming cluster-heads. For less percentage of nodes becoming cluster-heads the time interval between successive election of a node as cluster-head is large however if the percentage of nodes becoming cluster-heads is high, a node is again elected as a cluster-head in less number of rounds. So, energy is drained early resulting in a decreased network life-time. This decrease however is quite insignificant as compared to the overall increase in network lifetime over all other algorithms and thereby, in spite of this decrease, the LEAD algorithm outperforms many energy- efficient protocols proposed so far. This is successfully proved by the various graphs and tables that have been presented in the thesis.

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