A
Dissertation
On

# ENERGY AWARE ALGORITHM FOR IMPROVED AODV ROUTING PROTOCOL

Submitted in Partial Fulfilment of the Requirement
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**Master of Technology**
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## ABSTRACT

A Mobile adhoc network is a collection of wireless mobile nodes which can provide scalability and independence for mobile topologies. These wireless mobile nodes are battery powered hence the need for energy conservation in order to allow an increase in network lifetime. Energy conservation is very important in applications such as Military operations and Emergency Rescue operations where network infrastructure is not readily available. Other application areas where the Wireless Sensor networks have gained a considerable recognition include security and surveillance, vehicular movement, weather monitoring, industry applications etc. Sensor nodes can sense the environment in which they are deployed and together in a cooperative fashion can propagate sensed data either directly or through one another in a well-coordinated strategy (routing) to the desired destination.

In this thesis we developed an **energy aware algorithm** which uses **K-means algorithm** as the Clusterhead head selection method that is aimed at improving the network performance of AODV (adhoc on-demand distance vector) routing protocol. The improved energy idea uses the concept of drain count in sensor nodes which works as follows:

*Each node is set with an initial energy value which basically determines how long it's going to last in a network and to make sure our network has the highest lifetime possible we set up a threshold energy value. If a particular path has a single node with its energy lesser than that of the set threshold, then the drain count of that particular path is incremented by a factor of one (1). The drain count will serve as the parameter on which we can choose the path that is most likely to prolong the network lifetime. The path with the least drain count obviously will be the one that is chosen because it has few nodes with energy below the energy threshold. We then introduce* ***K-means*** *in the energy efficient system for the formation of clusters in our system and again this will help in shortening the transmission path. Performance evaluations are done with respect to network lifetime, throughput, end-to-end delay, packet delivery ratio using* ***Ns2 simulator.***



Keywords: Network lifetime; energy efficiency; Drain count; Ns2

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## CERTIFICATE

This is to certify that the dissertation titled **"Energy Aware Algorithm for Improved AODV Routing Protocol"** is a bona fide record of work done by **Arthur Ndlovu, Roll No. 2K13/CSE/35** at **Delhi Technological University** for partial fulfilment of the requirements for the degree of Master of Technology in Computer Science & Engineering. This project was carried out under my supervision and has not been submitted elsewhere, either in part or full, for the award of any other degree or diploma to the best of my knowledge and belief.

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# List of Abbreviations

| | |
|---|---|
| **AODV** | **Adhoc on-demand distance vector** |
| **IEE_AODV** | **Improved energy efficient adhoc on-demand distance vector** |
| **WSNs** | **Wireless Sensor Networks** |
| **CHs** | **Cluster Heads** |
| **BS** | **Base Station** |
| **WANETs** | **Wireless ad-hoc Networks** |
| **LEACH** | **Low Energy Adaptive Clustering Hierarchy** |
| **ISO** | **International Organization for Standardization** |
| **SPIN** | **Sensor Protocols for Information via Negotiation** |
| **GAF** | **Geographic Adaptive Fidelity** |
| **GEAR** | **Geographic and Energy Aware Routing** |
| **SEP** | **Stable Election Protocol** |
| **APTEEN** | **Adaptive Periodic Threshold sensitive Energy Efficient sensor Network Protocol** |
| **CHATSEP** | **Critical Heterogeneous Adaptive Threshold Sensitive Election Protocol** |
| **GEH** | **Greedy Efficient Hops** |
| **FSPM** | **Free Space Propagation Model** |
| **TRPM** | **Two-Ray Propagation Model** |

# Chapter One: Introduction

## 1.1 Background

Wireless networking is an existing technology that allows users to communicate and access information and services electronically regardless of their geographical position. Wireless communication is now popular in every communication network environment and it owes it success to an outburst of research and performance advancements which in turn has enabled wireless networks to transmit higher data rates at reasonably lower prices. This has largely been the key to wireless network's success in recent years.

We currently have two main approaches for enabling Wireless communications between hosts namely **Fixed Network Infrastructure** and **Adhoc-Network Infrastructure** [6].

a) **Fixed Network Infrastructure**

This is also known as the **Cellular network**, mobile hosts communicates with each other through a fixed and wired gateway (access point) within the network. These fixed base stations are connected to each other through wires and the transmission range of a base station constitutes a **cell**. All the mobile nodes lying within this cell connects to and communicates with the nearest bridge (base station). A **hand off** occurs as mobile host travels out of range of one Base Station and into the range of another and thus, mobile host is able to continue communication seamlessly throughout the network.. In this infrastructure **Handoff** is the main problem because it is difficult to transfer a connection from one base station to another without compromising the packets or without a risk of disconnection. Packets maybe lost or disconnections may occur.

In order for this type of network to exist a fixed infrastructure has to be there therefore it is depended on the existence of the infrastructure.

b) **Adhoc-Network Infrastructure/Infrastructureless**

These type of networks have no fixed routers like the case of fixed infrastructure networks. All nodes are capable of movement and can be connected dynamically in arbitrary manner. The responsibilities for organizing and controlling the network are distributed among the terminals themselves. The entire network is mobile and the individual terminals are allowed to move at will relative to each other. In this type of network some pairs of terminals may not be able to communicate directly to with each other due to some transmission distance restrictions of individual terminals and relaying of some messages is required so that they are delivered to their destinations. The nodes of these networks also function as routers which discover and maintain routes to other nodes in the networks.

The chief difference between ad hoc networks and cellular networks is the apparent lack of a centralized entity within an ad hoc network. There are no base stations or mobile switching centers in an ad hoc network.

The interest in wireless ad hoc networks stems from their well-known advantages for certain types of applications. Since there is no fixed infrastructure a wireless ad hoc network can be deployed quickly. Thus such networks can be used in situations where either there is no other wireless communication infrastructure present or where such infrastructure cannot be used because of security, cost, or safety reasons.

Ad-hoc networks were mainly used for **military applications**. Since then they have become increasingly more popular within the computing industry. Some applications include **emergency search and rescue operations, deployment of sensors, conferences, exhibitions, virtual classrooms and operations in environments where construction of infrastructure is difficult or expensive.** Ad-hoc networks can be rapidly deployed because of the lack of infrastructure.

### 1.1.1 Characteristics of MANET:

- **Dynamic Topologies:** Since nodes are free to move arbitrarily the network topology may change randomly and rapidly at unpredictable times. The links may be unidirectional or bidirectional.
- **Bandwidth constrained, variable capacity links:** Wireless links have significantly lower capacity than their hardwired counterparts. Also due to multiple access, fading, noise, and interference conditions etc. the wireless links have low throughput.
- **Energy constrained operation:** Nodes are battery powered and it’s impossible to replace the batteries during a mission and the design criteria is therefore to prolong the network lifetime hence energy conservation.
- **Limited physical security:** Mobile wireless networks are generally more prone to physical security threats than are fixed- cable nets. The increased possibility

of eavesdropping, spoofing, and denial-of-service attacks should be carefully considered. Existing link security techniques are often applied within wireless networks to reduce security threats. As a benefit, the decentralized nature of network control in MANET provides additional robustness against the single points of failure of more centralized approaches.

## 1.2 Wireless Sensor Network

These are a group of sensor nodes working together in a collaborative fashion to achieve a common objective or to perform a common application. Sensor nodes are distributed across a geographical area in a manner which is adhoc in nature. The sensors collaborate with the other nodes in sensing a particular event and each node information is aggregated in order to give a broad investigation of the subject matter. The sensor network environment can be categorized as being an IT Framework, physical, or Biological [40].

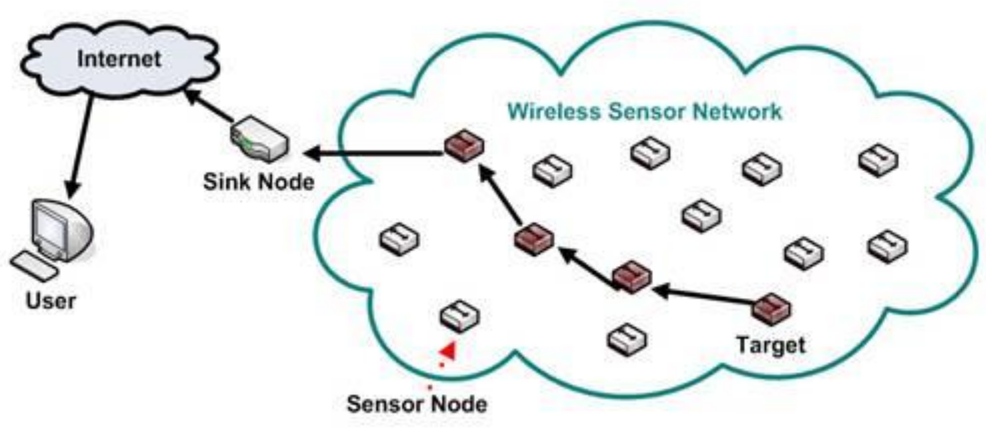


**Figure 1.1: wireless sensor network**

### 1.2.1 Sensor

A sensor can also be called a Transducer meaning that it is a device that can convert physical phenomenon like vibration, sound, motion, motion, light, heat into electrical signals.

## 1.3 Sensor Node Architecture

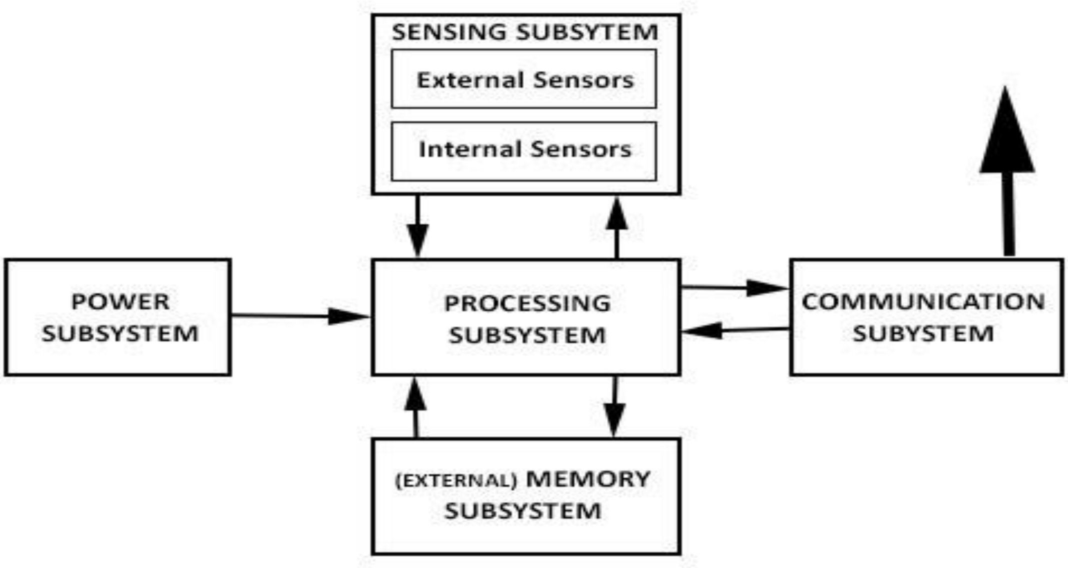


**Figure 1.2: sensor node architecture**

The following are the 5 major components of a sensor node:

- ❖ Sensing Subsystem
- ❖ Processing Subsystem
- ❖ Memory Subsystem (optional)
- ❖ Communication Subsystem
- ❖ Power Subsystem

### 1.3.1 Sensing Subsystem

A sensing device would be composed of some tiny devices (sensors) with an ability to produce measurable response which is in most cases a change in voltage. The responses are forwarded to the Analog to Digital Converter (ADC) which converts the analog signal to digital signal. The converted analog signal (digital signal) is sent to the Processing unit to undergo further processing.

### 1.3.2 Processing Subsystem

This forms the brain of the sensor node (central processing unit) and is also called the Controller. The advantages that the micro-controllers have that makes them clear favorite option in sensor node architecture are:

- ❖ Low power consumption
- ❖ Small size

- ❖ Easy programming

However there are other alternative processors that can be used and these include the following:

- ❖ DSP (Digital Signal Processor)-usually used for complex processing like in image processing
- ❖ FPGA (Field Programmable Gate Array) - has an advantage of some unique features of reprogramming and reconfigurations.

### 1.3.3 Communication Subsystem

This facilitates the actual transmission of packets from one sensor node to another. This subsystem has a wireless antenna which can use the following as the transmitting medium:

- ❖ Radio frequency (RF)
- ❖ Infrared waves

The Radio has a capability to transmit and receive the wireless signal and hence it is sometimes called a **Transceiver**. Communication technologies used in wireless sensor networks are as follows:

- ❖ Wi-Fi
- ❖ Bluetooth.
- ❖ ZigBee (IEEE 802.15.4)
- ❖ WiMax

**Figure 1.3** below shows some of the connectivity technologies.

| Connectivity Technology | IEEE Standard | Frequency Band | Licensed or Unlicensed band | Data Rate | Typical Range | Application |
|---|---|---|---|---|---|---|
| ZigBee | 802.15.4 | ISM bands : 868 MHz in Europe, 915 MHz in US and 2.4 GHz worldwide | Unlicensed | 250 Kbps | 70-100m | Sensor Networks |
| WiFi | 802.11x | 2.4 GHz, 5 GHz | Unlicensed | 5.5 - 600Mbps | 100m | Wireless LAN, Internet |
| WiMax | 802.16 | Initially 2-11GHz, now updated to 2-66GHz | Licensed | 75 Mbps | 50km | Metro area broadband internet connectivity |
| Bluetooth | 802.15.1 | ISM band 2.400-2.483GHz | Unlicensed | 1-24Mbps | 10m | Wireless PAN, pervasive computing |

**Figure 1.3: connectivity technologies**

## 1.3.4 Power Subsystem

The sensor nodes uses a battery powered system and hence the lifetime of the network becomes an issue. This is so because the sensor node is small in size and hence this has an effect in the overall lifetime of the network.  So energy conservation is a critical area in wireless sensor nodes hence this thesis looks at this phenomenon closely.

# 1.4 Sensor Network Protocol Stack

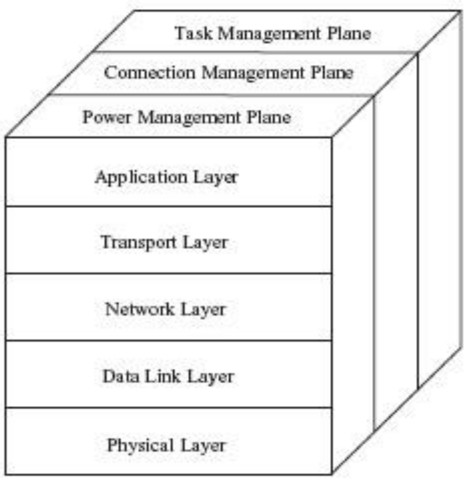


**Figure 1.4: sensor network protocol stack**

The protocol stack has five protocol layers mainly:

1. Physical layer
2. Data link layer
3. Network layer
4. Transport layer
5. Application layer

**1. Application Layer**

On this layer various sensor network applications are handled with application layer protocol and these applications include node localization, time synchronization, query dissemination, and network security.

**2. Transport Layer**

This layer is there to ensure end-to-end packet delivery between sensor nodes. Due to some restrictions of sensor node (computational power, energy, storage) traditional transport protocols cannot be used directly without any modification.

**3. Network Layer**

This layer performs the routing of the data that has been sensed by various sensor nodes in a network. The source node can transmit the packets in two ways:

❖ Single hop which is usually long range wireless communication

❖ Multi hop which is short range communication

Multi hope is however used mostly because the long range communication has more strain on energy consumption and has implementation complexities.

**4. Data Link Layer**

Data link layer handles the noise and mobility of the nodes in the network and are power aware. Data link layer is also responsible for reducing the collision with the neighbors' broadcast. Medium access control (MAC) is a function that enables efficient way of sharing the medium among the available sensor nodes in a way to avoid congestion.

**5. Physical Layer**

Transmission, modulation and receiving techniques are handled by physical layer of the protocol stack.

This thesis looks at one of the traditional routing protocols called AODV (adhoc on-demand distance vector) and its performance and then design and implement an improved version of this protocol with particular focus on the **Energy consumption** of the protocol using **K-means Algorithm**. The performance of the AODV routing protocol is then compared to the newly designed strategy in order to evaluate the effectiveness of the designed strategy.

## 1.5 Related Work

Several researches have been carried out particularly on the performance evaluation of the AODV routing protocol against other traditional protocols like DSDV and DSR routing protocols [2], [4], [33], and [36]. However none of these researches have attempted to borrow algorithms from other fields to improve network operations of AODV routing protocols. Some research has been done however to optimize the network using multipath routing [7], [8], [9]. The proposed work is aimed at developing energy efficient AODV routing protocol that uses K-means algorithm to create clusters in the network. This section documents some of the many energy efficient schemes based on AODV developed by researchers in the field. In [6], Jin-Man Kim and Jong-Wook Jang proposed an enhanced AODV routing protocol which is a modified version of AODV which uses an algorithm called Energy mean value algorithm to improve the network lifetime by considering energy aware in node selection for route discovery. Increase in the number of applications which use Ad hoc network has led to an increase in the development of algorithms which consider energy efficiency as the cost metric.

In [7], Yumei Liu, Lili Guo, Huizhu Ma and Tao Jiang propose a multipath routing protocol for mobile ad hoc networks, called MMRE-AOMDV, which extends the Ad Hoc On-demand Multipath Distance Vector (AOMDV) routing protocol. The key idea of the protocol is to find the minimal nodal residual energy of each route in the process of selecting path and sort multi-route by descending nodal residual energy. Once a new route with greater nodal residual energy is emerging, it is reselected to forward rest of the data packets. It can balance individual node's battery power utilization and hence prolong the entire network's lifetime. In [8], Zhang Zhaoxiao, Pei Tingrui and Zeng Wenli propose a new mechanism of energy-aware routing named EAODV which aims to improve the classical AODV protocol. EAODV adopted the backup routing strategy in case the chosen route fails.

## 1.6 Motivation

Energy saving mechanisms are key design areas for mobile ad hoc networks (MANET) since sensor nodes are small and hence have limited battery power [7]. In AODV many researchers have recorded successes in optimizing the routing with the lowest delay without consideration of power usage as the metrics. It is however a fact that from an energy perspective the shortest path is not always the optimal path [1]. MANET routing protocols most of them considers the shortest path routing without regard to energy usage as a metric. Low batteries in a wireless network node leads to disconnection as the node switch off if they have low power [24]. If a node experience a power failure then it affects the overall performance of the network and hence lifetime is reduced. The thesis looks at the existing AODV routing protocol with particular focus being **energy conservation** and it proposes an **improved energy aware system** that looks at all the energy aspects of the sensor node and distance as well so that the network can achieve the efficiency in all regards. The proposed system is aimed at improving the network lifetime and improved other performance metrics of the network as well. It introduces **K-means algorithm** as it works together with the **IEE_AODV routing protocol** to achieve the set objectives. The thesis will enable an energy model in the existing AODV for the purpose of comparing it with the proposed system in terms of energy. Other performance metrics of importance are throughput, end-to-end delay, and packet delivery ratio [1], [9], [16], [17]. Simulation is done in **Ns2 Simulator** and results indicate that the routing scheme of our proposed method is more energy efficient than the traditional AODV routing protocols and it improves the network in all facets as will be shown in the results section.

## 1.7 Research Objective

Trying to come up with a new strategy to efficiently increase the network life time of AODV routing protocol without compromising the other important parameters like packet delivery ratio, congestion, delay etc. is always a challenge. The researcher has to strike a balance between all these parameters otherwise the research will improve in energy efficiency utilization at the same time negatively affecting other vital areas. Therefore our objective is as follows:

- ❖ Create an improved energy efficient AODV routing protocol
- ❖ To combine an algorithm called K-means with IEE_AODV routing protocol
- ❖ Compare this to AODV routing protocol in terms of network lifetime, throughput, average end-to-end delay, and packet delivery ratio.
- ❖ Simulate these networks and analyze results.

The thesis will be implemented and simulations will be done after which corrections will be done until the required results are obtained.

## 1.8 Scope of work

The main objective of this thesis is to improve the **network lifetime** by introducing an energy efficient routing strategy in AODV and then compare it to the Expanding ring strategy that AODV uses to discover the route from source node to the destination node in the wireless network. Furthermore the proposed system will introduce a clustering technique called **K-means** algorithm to create clusters which are is key to the transmission of data packets in this proposed system.

The process involves researching existing routing protocols to determine their strengths and weaknesses. Using this analysis a new strategy is developed that enhances routing in the mobile ad-hoc environment with particular focus being in **Energy Efficiency**. The proposed strategy is then implemented in NS-2 environment after which simulation and analysis is also performed on the proposed strategy against the existing one to clearly see the advantages of proposed strategy over the existing.

The researcher also critically analysis the routing overheads after implementation of the thesis to see if the introduction of energy efficiency has not degraded the other critical aspects of the protocol like:

- ❖ Throughput
- ❖ End-to-end delay
- ❖ Packet delivery ratio

The thesis was implemented in NS-2 simulation environment, comparisons were made between the AODV’s expanding ring search mechanism and the new Improved Energy efficient AODV which uses K-means algorithm as its cluster head selection model to evaluate the advantages and disadvantages of the two mechanisms.

The goals of this thesis are as follows

- ❖ **Get the general idea of routing in wireless adhoc networks**
- ❖ **Then study the AODV routing protocol focusing mainly on its strength and weaknesses**
- ❖ **Develop an improved technique to save energy in the AODV routing protocol**
- ❖ **Implement the technique**
- ❖ **Analyze the improved mechanism against the existing routing protocol theoretically and through simulation.**

- **Conclusion**

## 1.9 Thesis Structure

The rest of this thesis is organized as follows:

**Chapter two** gives an overview of wireless adhoc networks clearly explaining their usage and characteristics. It gives further insight on the types of routing that we can find in wireless adhoc networks.

**Chapter three** explores the general wireless adhoc routing protocols paying particular attention to the AODV routing protocol.

**Chapter four** focuses on our proposed Improved Energy Aware Algorithm for AODV using K-means algorithm as the cluster head selection method. Introduces the basic idea about the K-means and how it is used in the system.

**Chapter five** is the implementation stage where we evaluate our proposed system against the other existing system and see the results. Implementation and results are documented in this phase.

**Chapter six** we give the conclusion about the work done and its implication in the world. We also discuss future work that can be improved on our proposed system.

# CHAPTER TWO: Literature Review

## 2.1 Wireless Ad-Hoc Networks

This is a network of mobile nodes that can be able to communicate in an Infrastructureless environment. Every node within this network is equipped with a wireless interface and communication is done through radio or infrared channels. Laptops and mobile phones are inbuilt with the technology to communicate directly to each other and hence can be examples of mobile nodes in an adhoc network. The nodes can be stationary in an adhoc network but more research is being done in MANET (Mobile adhoc networks)

**Figure 2.1** is a simple example of an adhoc network where communication can be achieved between three nodes with some nodes being out of reach of each other. In the diagram the outer nodes cannot directly communicate with each other because there are out of reception ranges of each other and hence the middle node act as the intermediate node which can forward packets to and from these outer nodes. So all these three nodes can communicate with each other regardless of their limited communication ranges using a multihop technique.

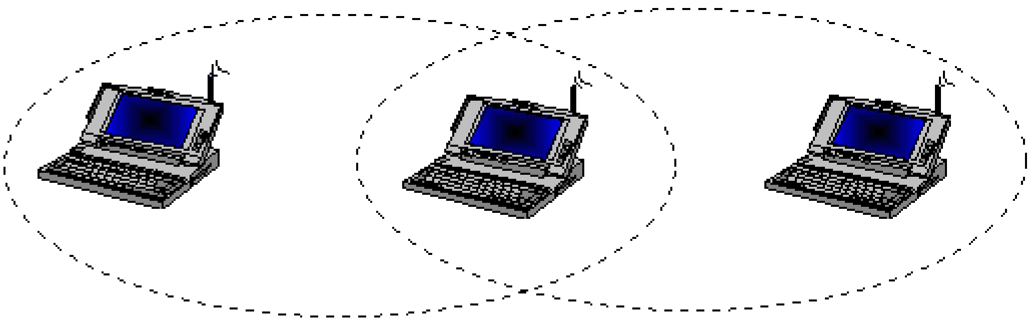

**Figure 2.1: Example of simple ad-hoc network.**

This type of network doesn't use any central access point and this has an advantage of not having a single point of failure. The network can self-configure itself if a mobile node moves out of range of the others. Nodes can move in and out of the network range without affecting the overall operation of the network. Nodes have limited transmission range due to power constraints and hence to achieve packet transmission to wider nodes multiple hops are needed. Therefore every node within a wireless sensor network will act as a router and a host at the same time. As the nodes move within this type of network topology changes and because this there is need for a routing protocol that should run on each node. This is important in creation and maintenance of routes in this network.

### 2.1.1 Usage

Wireless sensor networks research and advancement has seen this field attracting a lot of interest in major sectors. Its application areas are so diverse and it owes its growth to its ability to function in an Infrastructureless environment. WSN is convenient and in some cases can be less costly to deploy this network compared to a wired network infrastructure. Nodes within a wireless sensor network can be deployed in emergency and rescue requirements. Since it doesn't need any fixed infrastructure it can also be helpful where communication is needed for a short duration of time. In remote and under developed areas such technologies can be helpful if communication is to be realized. Some well-known examples where this technology can be used are as follows:

- **military applications**
- **disaster recovery**
- **search and rescues**
- **health**
- **conferencing**

Several application areas have been outlined by R. Royer and C. Toh in [17]. The applications of this technology are so many and can go as far as document exchanges in an organizations to resource sharing (printer sharing).

### 2.1.2 Characteristics

Adhoc networks being dynamic in nature implies that node movement is common in this network and this node change in physical location has its up and downs. Efficient routing mechanisms are then needed to take care of this ever changing network topology. The topology changes impacts heavily on the packet delivery ratio and some packets may be lost due to the topology change.

Senor nodes are tiny in size and hence they have a limit in the following very important parameters:

- battery power
- Storage capacity
- CPU capacity

- ❖ Bandwidth

Of particular importance to this thesis is the battery power which is limited and the design principle of this thesis is to have a mechanism that will conserve that limited power so that the network can last longer.

The radio transmission environment also called the access medium also has some characteristics with the common one being the uni-directional links. If two sensor nodes have different transmitter power strengths this allows only one sensor node to hear the other at a time. Multi-hop transmission will enable nodes to transmit packets to neighbor nodes which are much closer and hence low output power is used.

## 2.2 Routing

Routing is a technique which creates a path for data packets to be transmitted from the source node to the intended destination. It is therefore important to have a routing protocol since there maybe multiple paths to a single destination in a network. The data packets can traverse intermediate nodes before it reaches its intended destination node. Therefore the main functions of the Routing protocol are as follows:

- ❖ Selection of routes for any source and destination pair within a network.
- ❖ Assured delivery of the packets to their intended destination.

There is a lot of sensor mobility in these networks and this will prompt frequent topological changes. It is therefore crucial for the routing protocol to guarantee efficient packet delivery to intended destination. Routing protocols are categorized into two groups based on time the routes are discovered and how. The two groups are Table-Driven routing protocols and On-Demand routing protocols [17].

Table driven routing is when each node in the network maintains a routing table which contains some route to every node in the network. Any changes to the network due to node movements and link failures has to be updated in the routing tables so that they are always up to date at all times. Update control messages are propagated throughout the network each time the network topology changes, this ensures that the network maintains up to date and consistent routing information about the network. Every node in this network maintains update routing information at all times.

There are two main types of table driven routing namely:

- ❖ Distance Vector
- ❖ Link State [52]

However in on-demand nodes need not maintain up to date routes but routes can be created only when there is need for communication. Whenever a node wants to send some packets it initiates a route discovery process to find the path which it can use to transmit the packets. Control messages are communicated between the sender and receiver after which the actual transfer is done. The communication is maintained for the duration of the packet delivery or when the destination has moved out of range. Some well-known examples of on-demand routing protocol are AODV (Adhoc On-demand Distance vector) and DSR (Dynamic Source Routing) [3], [12], [13].

## 2.2.1 Distance Vector

This is sometimes referred to as the Bellman-Ford algorithm named after the people who created the algorithm. As stated in the distributed Bellman-Ford Algorithm [53] the following occurs:

- ➢ Every node ***i*** is to maintain a routing table with the following as its contents:
    1. Distance information for every destination ***j*** – the shortest distance from node from ***i*** to ***j.***
    2. Successor information for every destination ***j*** – successor can be defined as any node next to ***i*** that lies on the shortest path to ***j***.
- ➢ Bellman-Ford succeeds in maintaining the information of shortest path up to date by doing the following:
    1. Each sensor node periodically would exchange its routing table with its neighbors and based on this routing information received node i will learn the shortest distances there is to all the destinations from its neighbors.
    2. Therefore node ***i*** will selects a specific node ***k*** from its next hop nodes (neighbor nodes) as the next hop or the successor on route to a destination node such that the following holds true:
        - ❖ The network will achieve the minimum distance from ***i*** through ***k*** to ***j.***
    3. Finally this new routing information will be kept in the routing table of node ***i*** and then propagated in the next routing update cycle.

It focuses on every node's distance to destination **D**. this is explained as follows:

- D initiates the communication by transmitting its distance vector and its cost which are (next(D)=D) and (dist(D)=0) to node 1 respectively.

- Upon receipt of the information from D, node 1 will calculates its distance vector to D which will be distance (dist(D)=1) going through D (next(D)=D) and propagates this information to nodes 2 and 3.

- The process will continue until all sensor nodes have the next hop and cost metrics information to D in their routing table.

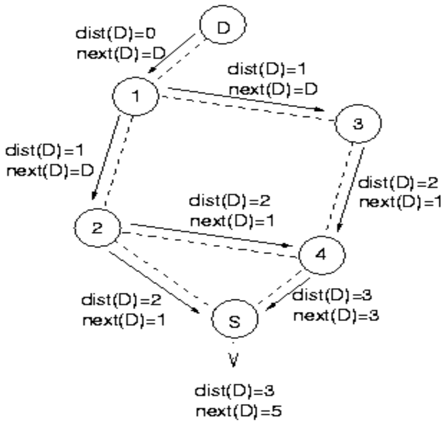


**Figure 2.2: Example of Distance Vector Routing**

**Advantages of Distance Vector**

- It is a simple algorithm with easy to follow steps and that makes it a favorable approach by many.

- Computation

The main disadvantage is that distance vector routing has slow convergence when dealing with topological changes [54]. This is so mainly because sensor nodes select their next hop nodes in a distributed fashion using information that is not up to date. This will result in the formation of routing loops which can be short live or long lived routing loops [53].

**Figure 2.3** is a typical example of a routing loop. The focus is every node's distance to the destination C. the process is as follows:

- B calculates its distance to C as 1represented by (Dist(C)=1)

- A calculates its distance to C as 2 represented by (Dist(C)=2) through B which is (Next(C)=B).
- When there is a link break between B and C it is imperative that B recalculate its distance vector to its neighbor C.  B doesn't rush to conclude that C is unreachable rather B decides that the distance is 3 from C based on the distance vector that B get from A.
- Now B's distance vector has changed then it propagates the changes to A upon which A will conclude that C is now 4 away.
- A and B believe that the best path to C will be through the other node and the continuation of this process will cause the count to infinity problem.

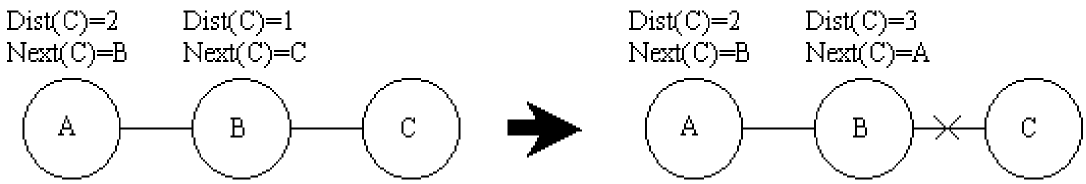


**Figure 2.3: Routing Loop example**

They have been researches to solve these kinds of problems and some partial solutions have been proposed and these include ***split-horizon*** and ***poison-reverse*** [53].

**Poison-reverse**

Is when a node explicitly report that it can't reach a node rather than ignoring or not mentioning it. This approach is used together with split horizon.

**Split Horizon**

In split horizon if A propagates packets to destination C through a node B, then A will report to B that the distance of A to C is infinity. Since the routing order is node A to node C through node B and A's actual distance to B doesn't matter to B and B's distance to C doesn't depend on A's distance to C.

It doesn't however work all the time there are some cases were it doesn't work like in the following scenario:

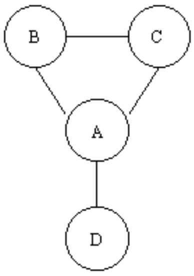


**Figure 2.4: Count-to-infinity with split horizon**

If the Link to D breaks, A's conclusion will be that D is unreachable since B and C have reported to node A that node D is unreachable because of split horizon rule. D's unreachability is propagated to node A and B by node A. Upon receipt of the report B will conclude the path to destination node D is through node C. the following is what node B conclude:

1) The distance of node B is now 3 from node D
2) Because of split horizon node B will report destination node D as being unreachable to node C.
3) Destination node D will be reachable to node A at a cost of 3.

Node A thinks that a cost of 4 is the correct cost to reach D through node B. The counting to infinity problem is still there.

### 2.2.2 Link State

**Basic Idea**

In link state every node will create a full view of the connectivity of the network and this graph will show which nodes are connected to another. Each node will then choose the path to destination which is deemed the best logical path and the collection of best paths will lead to formation of the routing table of that node.

**Link-state routing protocols characteristics**

Link-state Packet (LSP) / Link-state advertisement (LSA)

- This is a packet sent between nodes in a network containing routing information.

Topological database or Link-state Database

- Is where information gathered from LSAs is kept.

SPF (shortest path first) algorithm

- The result from calculations performed on the database leads to SPF tree.

Routing table

- All the interconnections and known paths are kept in the routing table.

**Link-state routing algorithm**

1. It's a responsibility of each node to know its neighbors and learn their identity.
   - Nodes use a Hello Protocol by sending a data packet containing RID with network address where the packet is sent.
   - Every node then constructs a **LSP/LSA** which will consists of the cost and names for all its neighbors in a list.
2. Then after the **LSP/LSA** is sent to all nodes with each node storing the most recently created LSP/**LSA** from other nodes.
   - Link-state flooding: **Sequencing** and **Aging** procedures
   - Each node stores the identical **Link State Database**
3. Complete information is used by each node on network topology to come up with the *shortest path* to any destination node.
   - Use **SPF or Dijkstra's algorithm** to calculate the shortest path

**Figure 2.5** is an example of link state routing where each node broadcasts to all the other nodes its immediate neighbors and an associated cost. There will be broadcasts in the network with node 1 broadcasting to its neighbors {D, 2, 3}, node 2 also to {S, 1, 4} and this goes on up to the last node in the network.

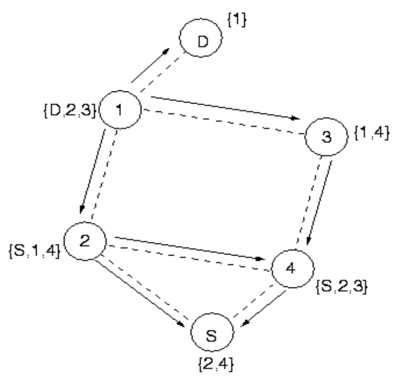


**Figure 2.5: Link State routing example**

The inconsistent topology views can arise because of the existence of a delay in making sure that the whole network has an updated LSP. Those inconsistences in network topology views will lead to formation of routing loops.  It is key to note that the routing loops do not last forever rather they disappear in the period the packet traverse the diameter of the whole network [55].

### 2.2.3 Source Routing

This approach access a route by flooding route request packets to the nodes in the network until they reach the required destination. The route request packet will store the information of the intermediate nodes in its path field. These route requests if they detect the destination node or any intermediate node which contains a fresh route to the destination, will send back the source routed to the initiator node. Several responses may be sent back to the source that means there maybe multiple paths to the destination. In that case these paths are computed and maintained in case of future link failures.

Figure 2.6 is an example of source routing and its focus is on finding the route to node D from the source node S. S will flood the network with route requests to destination D. When a node receives the route request it keeps information concerning intermediate nodes. Finally when D being the destination receives the route request it sends back some reply to source node S. Using the diagram D's reply to node S will be (reply(D)).

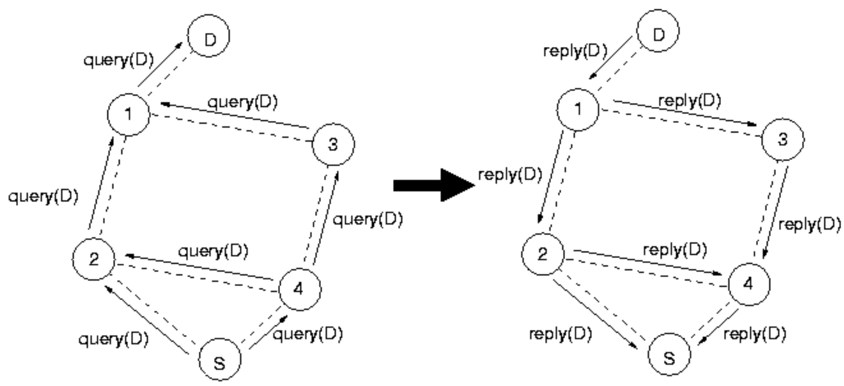


**Figure 2.6: On-Demand Source routing example**

The main advantage of source routing is that it greatly reduces overhead traffic as only those routes which are needed are the ones maintained. The disadvantage of this approach is that each packet sent in this network carries some overhead information because it keeps track of all nodes from the source. As the packet moves hop after hop the overhead grows with it until it reaches the destination. Furthermore there is a latency hit whenever a route discovery process is initiated. This scenario doesn’t do well in high mobility networks because when topology changes frequently more route requests will be generated.

# Chapter Three: Ad Hoc Routing Protocols

## 3.1 Introduction

This chapter will present wireless sensor routing protocols in more detail. The chapter will classify the different types of wireless networks and their routing strategies.

## 3.2 Classification of Wireless Network

Data communications and networks has taken center stage in mainstream economic developmental programs as an enabling tool in virtually every sector. Wireless networks have seen some tremendous growth in the last decade and this is evidenced by the increase in use in many applications. Wireless networks can be classified into four categories which are:

- Wireless adhoc network
- Mobile adhoc network
- Wireless sensor network
- Peer-to-peer network

### 3.2.1 Wireless Ad Hoc Network

This is a decentralized type of network which does not rely on the existence of the infrastructure to function. Network hosts can themselves form a network without any central administration like routers. Ad-hoc networks can be called **mesh networks** because the structure of these networks are organized such that discovery of a path from the source to the destination can be realized.

### 3.2.2 Mobile Ad-Hoc Networks (MANET)

This is also a type of Ad Hoc wireless network. Its uniqueness is in the ability to self-configure of mobile nodes/hosts with their connected links. The resulting network will have an arbitrary topology and nodes in this network are fully independent. The network topology changes unpredictably and nodes can join and move out of the network rapidly.

### 3.2.3 Wireless Sensor Network (WSN)

Nodes dispersed in a geographical area work together in a collaborative fashion monitoring and aggregating real world events the forwarding the finding to a base station. This technology is now being used for measuring environmental conditions and many applications especially in military.

### 3.2.4 Mobile Wireless Sensor Network

WSN can have stationary or mobile nodes in this case nodes can move in or out of any network within a wireless sensor network.

### 3.2.5 Ad-Hoc Wireless Sensor Network

Nodes can automatically configure themselves whenever a topology changes.

### 3.2.6 Peer-to-Peer Network

It's a network where all the connected nodes are equal that is a node can be both a client and a server.

These networks and their relationships can be outlined in the diagram bellow:

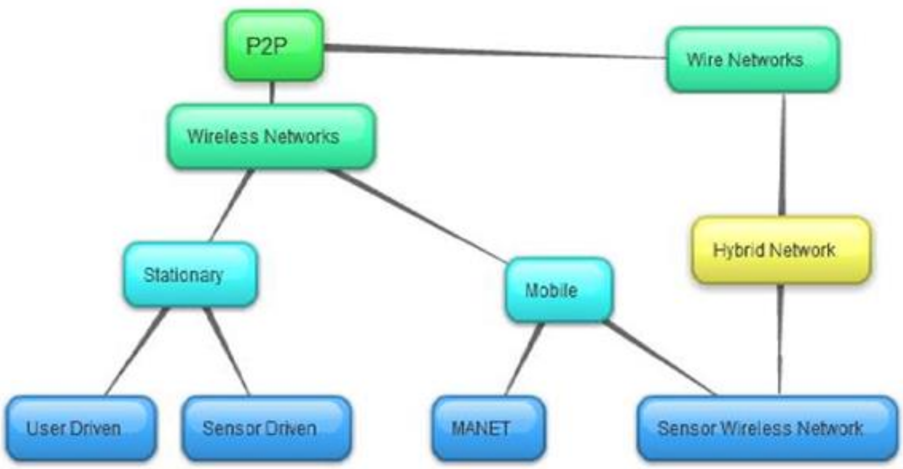


**Figure 3.1 Wireless Network Classification**

## 3.3 Routing protocol properties

Several routing protocols for mobile adhoc networks have been developed since the seventies (1970s) when DARPA (Defense Advanced Research Projects Agency) was founded [56]. The routing protocols would have the ability to address serious MANET limitations which are:

- Power consumption
- low bandwidth
- high error rates
- computational capacity and memory constraints

An ideal routing protocol therefore should exhibit the following desirable properties:

- **Distributed operation:** it means that the protocol should not be centrally controlled, no one sensor node in the network should play the role of a central administration for other nodes in the network. This will result in a system which is not prone to failure as there will be no single point of failure in the network. The system can also grow rapidly without affecting much of the operations.

- **Fast convergence:** Means that if a network topology changes then there should be a fast mechanism of finding new routes so that there is no delay to the network operations. Optimal routes should be realized in a fast way if a network topology changes for such a network to be efficient.

- **Loop free:** it is the routing protocol's task to make sure that the routes that are supplied are loop free. Routing loops waists network resources like bandwidth, energy, and processor usage.

- **Optimal routes:** this will be the most important routing protocol attribute, the protocol should find routes that utilizes less resources that is finding routes with less number of hop count is a desirable attribute. If this is achieved then the network will have less power consumption, less bandwidth, and less CPU consumption. The overall network latency is also reduced in the process.

- **Low overhead control traffic:** as bandwidth is a scarce resource in a wireless network the protocol is there to moderate the number of overhead control messages in a routing environment.

## 3.4 Routing

A wireless sensor network (WSNs) is built up from a number of small sensor network nodes and they are connected to each other via a wireless link which does not require a fixed network infrastructure. In regard to the nodes structure of WSNs nodes structure it has a short transmission range, small processing power and storage capacity and also has inadequate energy resources. WSNs routing protocols have a crucial responsibility to ensure there is a reliable, multi-hop communication between the nodes. WSN's require sophisticated routing algorithms because energy is the core issue in these networks and low power wireless devices are necessary to ensure that there is a low consumption of energy [57].

### 3.4.1 Routing in Wireless Sensor Network

Initially topology-based routing techniques were used in the wireless network. In the past a number of proposals were based on a **proactive routing** mechanism that used to collect information about all the available network paths, although those paths links were certainly not used. Furthermore, in dynamics network topologies proactive routing does not accommodate itself properly. An alternative technique was developed called '**reactive routing**' which only keeps those paths which are presently in use. Recently, location aware routing is introduced in which protocols know the physical location. Furthermore, a number of geographic- or position-based routings are also proposed. Information about physical location is required in advance; it can be taken from GPS or on the basis of a distance estimation of incoming signals. Geographic routing and topology-based routing also address the centric routing algorithm. There is another class of routing algorithm called data-centric and it is an important routing paradigm for the wireless senor network. The data-centric algorithm uses queries for the routing operation and the queries are written out by the sink node in order to acquire the requested data.

Moreover, the routing algorithm in a wireless sensor network can also be classified according to the usage of messages. A single path routing mechanism is used when there is merely one instance of a message existing in the network at any given time. There are some more routing algorithm techniques for WSNs such as partial flooding and multiplexing. In addition to single path, a multi-path, partial, flooding-based routing strategy there is a mechanism which is called the 'guaranteed delivery routing algorithmic technique'. The routing algorithm can also be classified according to the nodes requirements for the management of ongoing tasks in the state information and in the literature it is known as memorization [43].

Furthermore, WSN's routing algorithm is broadly divided into three main classes which are flat routing, hierarchal routing and location-based routing [36].

The algorithm used for the wireless senor network is mostly borrowed from the Ad-Hoc network. In the early days of the wireless sensor network a number of routing protocols were taken from the wireless ad-hoc networks and mobile wireless networks. It is evident that these protocols were built for a general wireless network and it involves no concern for precise communication patterns of WSNs. Hence, the developments of WSNs-oriented new routing techniques, and the customization of existing routing protocols represent a significant area for future research.

## 3.5 Classification of Wireless Senor Network Routing Protocols

Diagrammatical classification of a routing algorithm is shown here:

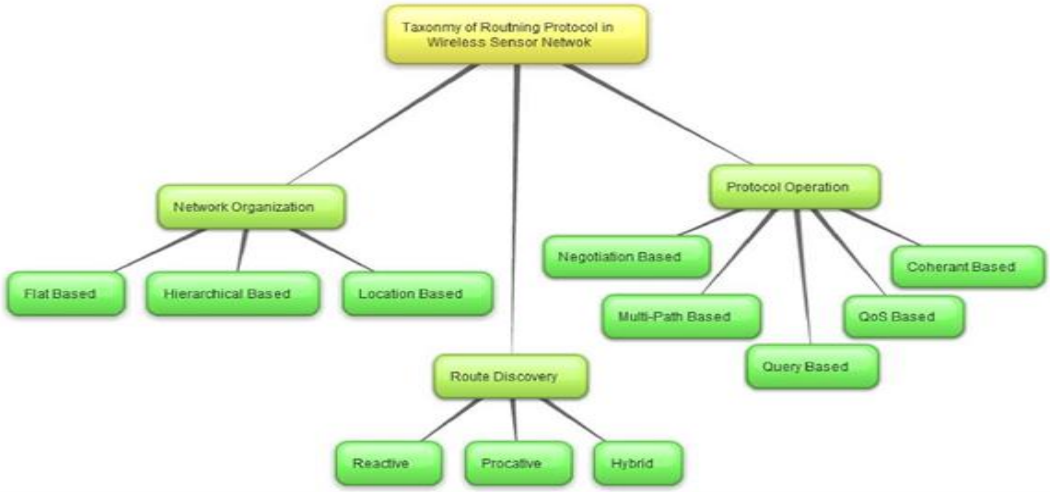


**Figure 3.2 Hierarchical diagram of WSNs routing protocols classification**

Wireless sensor network routing protocols are completely different from conventional wireless routing protocols because the network is more vulnerable to issues like abrupt change network topology, sensor node failure or damage, unreliable wireless network link, energy depletion and so on. Furthermore, the routing protocols of WSNs are obliged to follow cost-effective and strict energy requirements in order to fulfil the needs of overall routing.

WSNs routing protocols are broadly divided into seven categories which are stated in a tabular form as follows:

| Routing Category | List of Routing Protocols |
|---|---|
| Flat/ Data centric Routing Protocols | Rumour, information direct, EAD, COUGAR, ACQUIRE, Directed Diffusion, Gradient based routing, Home agent based |
| Hierarchical Protocols | TEEN, HEED, LEACH, PEGASIS, APTEEN |
| Mobility Protocols | Data MULES, TTDD, SEAD, Dynamic Tree based Data Dissemination, Joint Mobility and Routing |
| Multipath Protocols | Braided Multipath, N to 1 Multipath Discovery, Sensor Disjoint Multipath |
| Heterogeneity Protocols | CHR, IDSQ, CADR |
| Quality of Service (QoS)Protocols | Energy aware routing, SPEED, SAR |
| Geographic Routing Protocols | GAF, GPSR, GEAR, energy aware routing |

**Table 3.3 Seven Categories of wireless sensor routing protocols**

The objective behind the development of the routing algorithm is not only to reduce overheads, increase throughput and minimize end-to-end delay but the other important goal is the **consumption of energy usage** in a wireless sensor network [22]. Routing is one of the significant tasks in a wireless sensor network, and for this reason a large amount of research material is available on this topic. The routing algorithm constructed for IP networks and MANET is not working properly in the wireless sensor network domain in comparison with the IP network that sends packets in a wire connection and there is a slight chance the packet could be damaged but in the wireless sensor network it is not the same. Wireless sensor network is one of the most significant technological advances in this century. In the past decade it received an enormous focus from academia and the industry across the globe [49]. The Wireless Sensor Network (WSN) is a form of distributed wireless network. It is an amalgamation of a number of the latest technologies, such as micro-mechanical technologies, distributed signal processing and an embedded system, integrated microprocessor and wireless communication, ad-hoc networks' routing protocols and so forth. The wireless sensor network technology consists of self-organized nodes which are widely deployed in environmental conditions, wireless communication, military purpose, data processing and so forth at a very low price. Nevertheless, WSN's technology requires a capable mechanism for data processing and forwarding. The core philosophy of WSN is that each node in the network has limited power which is sufficient for the whole proposed project, for instance a node is sensing for military surveillance or environmental monitoring and so forth. In WSN routing protocols find the route between nodes and ensure the consistent communication between the nodes in the network. The nodes are deployed in an ad-hoc structure irrespective of vigilant planning and engineering. In WNS networks the routing contradicts the approaches taken in conventional wireless communication networks. The reason behind this is that it does not have a proper communication infrastructure, the node link is unreliable and on top of all these issues, there is a tight energy consumption constraint and the routing protocol needs to work under these adverse conditions. Currently, a number of wireless routing protocols are being developed in the wireless communication domain. The routing protocols for the wireless sensor network can be divided into seven categories which are:

### 3.5.1 Flat-based routing protocol

In flat networks, every node plays an identical role and all the sensor nodes coordinate to execute the desired sensing task. Due to very high number of sensor nodes and random deployment it is almost impossible to attach a global identifier for each sensor node. Absence of global identifier in the sensor node makes it unrealistic for BS to query a set of specific nodes. Thus it has led to data centric routing, in which the BS sends query not a particular node but to a region of interest and waits for the sensor nodes from that regions to send the sensed information to the BS. Thus even after absence of global identifier, the BS can monitor the network depending on the result of the queries. SPIN [23] and DD [24] are two data centric protocols which performs data negotiation between the nodes to save energy by eliminating the redundant data.

SPIN proposed in [23] is an adaptive data centric protocol which exchanges meta-data among the nodes which is a data advertisement mechanism. The data advertisement is done before the transmission of data. When a node receives new data from other nodes it transmits the data to the neighbors. If any of the neighbors is interested in data it will retrieve the data by sending a request message to the node from which it has received the meta-data message.

SPIN is a 3 stage protocol with messages as ADV, REQ and DATA.

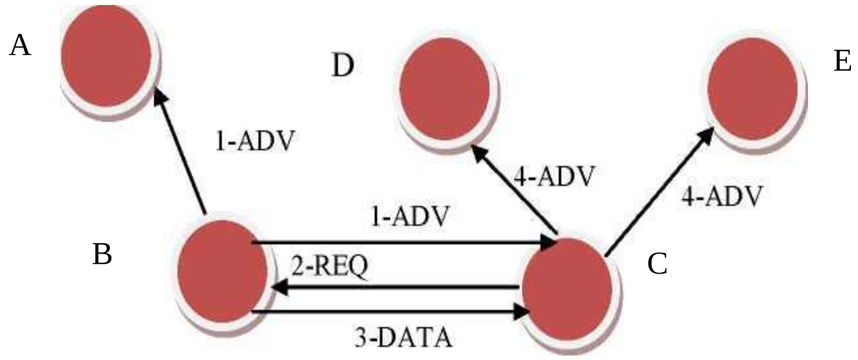


**Figure 3.4: SPIN Protocol**

**Figure 3.4** gives an overview of SPIN protocol. When node B receives data packet, it sends the ADV message to its neighbors with the meta-data. Then interested neighbor (C) sends a REQ message to node B. After receiving request for the data it transmits the DATA to the interested node C. Now as C has received data it sends ADV messages to its neighbors (D and E) with the meta-data. Thus SPIN localizes the topological changes as the nodes are required to know only single hop neighbors. One disadvantage of SPIN is that if some node which is far is interested in the data but the neighbors of the node which has sent the ADV messages are not interested in the data. Then that node will never receive the data even if it was interested in it.

Directed Diffusion, proposed in [24] is a data centric protocol with application awareness which uses name scheme for the data to introduce data diffusion among the sensors. Query creation will involve defining an interest using the list of attribute-value pairs such as interval and the name of the object. Then the interest is broadcasted by the sink via its neighbors. When the nodes receive interest from the BS they perform catching. Then the interests in the catches are used in comparing received data with interest values received by the BS. The interests also contain gradients which contains back link to the neighbor from which the interests were received. Gradients are characterized by time stamp of the interest, data rate and duration. Hence with the help of interests and the gradient path between the node and the BS can be derived. Thus then the sink can send the original interest message through the selected pat with smaller time interval to get the data packets of interest frequently. The main objective of DD is to combine the data it receives from the various nodes using in-network data aggregation based on the list of attributes of the form attribute-value pairs. DD differs from SPIN in terms of the on demand data querying mechanism. In DD the sink will query the sensor node only if a particular data of interest is available while in SPIN it advertises the availability of data to the sensor nodes. Some advantages of DD are that the nodes are capability of data aggregation and caching which is a great plus to save the energy of the nodes. No need to maintain global identity of the nodes and it is an on demand protocol so is highly energy efficient. However it should not be used in the situation where continuous monitoring of the data is required like environmental monitoring as it a query driven protocol.

### 3.5.2 Hierarchical based routing protocol

In the scenario when large number of sensor nodes are deployed in large fields it is not possible for the nodes to transmit information directly to the BS. The single gateway architecture is not efficient in larger set of nodes. Thus clustering in the network is performed to address this issue in variety of protocols [25], [26], [27]. In the hierarchical or clustering protocol the process is divided into two phases. First phase is the selection of the cluster and cluster head for the cluster. Selection of cluster head is done on the basis of remaining energy of the nodes. The hierarchical protocol works on probabilistic models or residual energy based models for the selection of the CH. Even the frequency of selection of the cluster head is dependent on the protocols. The second phase is the routing phase, where the data packets are sensed and transmitted to the BS.

The transmission phase varies according to the protocol. It may use single hop for the communication of data packets or multiple hops can be used with any number of levels deepening on the area and density of the network. Different computational capabilities can be assigned to the sensor nodes or the CHs in the hierarchical networks like data aggregation, data compression to achieve optimality as per the needs of the applications.

These techniques can reduce significant size of the data packets to reduce the network traffic. Thus hierarchical protocol increases the overall system lifetime, scalability and energy efficiency. Various routing protocols like LEACH, PEAGIS, SEP etc. uses hierarchical clustering. Each such protocol has some unique characteristics which makes them suitable for the desired environments. We have focused our work in the hierarchical clustering protocols. Reactive clustering is the main area of focus for our work and hence we will discuss clustering protocols in greater detail in later sections.

### 3.5.3 Location based routing protocol

Location based routing protocols are used in the situations when the location of the nodes is needed. In such routing protocols the sensor nodes are referred by their positions in the network. They approximate the distance between two nodes based on the incoming signal strength. Then relative coordinates between the two nodes can be measured by exchanging the information between them. They can also use satellites to get the location of the nodes by using Global Positioning System services if the sensor nodes have a low power GPS receiver [28, 29]. Some of the location based routing protocol uses the locations of the nodes to transmit the data packets in energy efficient way. Like if we know the region and location of the sensors, it will be efficient to diffuse any query as now the query will be diffused only to that specific region. GAF proposed in [28] is one of the energy aware location based routing protocol which was developed for the mobile ad-hoc networks but works for sensor networks too. It aims at conservation of energy by switching off unnecessary nodes keeping the routing fidelity intact. In GAF, the sensor nodes are divided in fixed regions/zones and form a virtual grid. In each of the zones nodes synchronize and take different roles. Every node uses its GPS based location and will be linked to a specific point in the virtual grid. Nodes are said to be equivalent if they link to the same point in the grid with regard to packet routing cost. This equivalence is used to keep some nodes in the sleeping state to save the energy.

The states defined in GAF are *discovery, active* and *sleep.* The discovery state determines the neighbors in the grid. Active state represents the participation of the node in the transmission and sleep state refers to the nodes which have their transmitter switched off to save energy. To handle the routing fidelity, sleeping time of nodes is broadcasted to the neighbors. The neighbors in the sleeping state adjust their sleeping time so that before the active nodes go to sleep, the nodes that are in the sleeping state should wake up. Although it is location based protocol, it also uses clustering as it breaks the sensor nodes into clusters/grids based on the location. In each grid there is a leader node however in GAF no data aggregation or data compression is performed.

GEAR is another location based energy aware routing protocol proposed in [29]. To route a data packet to a particular destination GEAR uses heuristic based neighbor selection and energy awareness. The main objective of GEAR is to reduce the number of interests in the diffusion by sending the interest message only to specific nodes along the path in the desired region rather than broadcasting the interest message. Each node in GEAR knows an estimation cost and learned cost. Estimated cost is based on the remaining energy of the node and the distance towards the destination. Learned cost is the more accurate version of the estimated cost which takes into account the holes in the network to reach the destinations. Hole is the situation when there is no neighbor closer to the target node in that particular region than that node itself. If no holes are available in the path to the destination the learned cost is same as the estimated cost.

GEAR works in two phases. First is forwarding data packets towards the target region and the second is to forward the data packet within the region. In the first phase, node with the data packet/interest checks if there is any node which is closer to the target region than itself. If there are many nodes which are closer to the target region then the closest neighbor is selected as the next hop to reach the target region. In situation when no neighbor is close to the target region than itself, one of the neighbors is selected based on the learning cost to transmit the data/interest to the target region. In the second phase the interest has reached in the target region. The packet can be diffused in the region using restrictive flooding or recursive geographic flooding. In sparse deployment restrictive flooding is better and in densely deployed networks recursive geographic flooding performs better.

### 3.5.4 Operation based routing protocols

Some of the routing protocols incorporate additional computation capabilities in order to access variety of issues. Some adds certain feature to an existing protocol to improve the design issues and enhance the performance. Some of such operation based protocols are discussed:

**Multipath routing protocols:**

- ❖ **Query based**: We have discussed query based protocols like DD in the previous sections. In such protocol destination raises a query in the network. This query reaches the desired node or the region of interest with the help of a particular mechanism like broadcasting, communication in neighbors, location based etc. Then particular group of nodes which matches the area of interest of the query senses the information and sends it back to the destination via a path which is established when the query has reached from destination to source. The queries can be sent in normal or encoded forms.
- ❖ **Negotiation based**: Negotiation based routing protocol reduce the redundancy of data by the usage of data advertisements which are high-level data descriptors containing meta-data. One such routing protocol SPIN we have discussed. The three stats in these protocols are used to broadcast the data only to those neighbors which are interested for that particular data. As the node receives some data ADV message is sent to all the neighbors which then checks if they need this data or not. If they need the data it sends

a REQ message to the node. The node after receiving the REQ message sends the data only those nodes which are interested and hence avoids higher network traffic. One pitfall of such protocols is that suppose a node X is interest in the data but is not in the neighbor of the node Y which has data. Then this node X may or may not receive the data depending on the neighbors of the node Y. If none of the neighbors of Y are interested in the data then X will not receive the ADV message for the data even if it is interested. The nodes in such protocols are capable of little computations like data aggregation which reduces the redundancy of the data. The usage of flooding to send the query of interest is better than broadcasting the data packet even to those nodes who are not interested in it.

- ❖ **Quality of service based**: These protocols are created to address the QoS of network as per the application using WSN. Some of the factors which fall under QoS can be delay in sending the data to the BS. It may be data reliability, location awareness, synchronized processing etc. These factors decide which routing protocol should be used for particular application. Energy is another factor which is kept under consideration while implementing QoS based protocols.
- ❖ **Coherent and non-coherent processing based**: Data processing is an essential element amongst all the operations of WSNs. Data processing is a compulsory as the whole WSN depends on the sensing of sensor nodes and transmission of sensed information of the central authority. Thus vivid techniques of processing of data are developed in different routing protocols addressing large set of applications. Broadly we can divide data processing in coherent data processing and non-coherent data processing. In no coherent data processing the sensor nodes perform a local processing of the raw data before sending for further processing to other nodes. The nodes which perform further processing of data are known as aggregators. In coherent data processing, nodes after sensing the data performs only minimal processing and send the data to aggregator nodes for further processing of the data. The least processing which the node does are some very essential tasks like time stamping, duplicate suppression etc. In direct transmission traditional techniques there used to only one aggregator i.e. BS. But this causes a lot of redundancy and traffic in the network. This is improved by limiting the number of sources and having optimal number of aggregator nodes.

## 3.6 Route Discovery Protocols

These protocols are divided mainly into 2 namely reactive and proactive where reactive protocols can also be called on-demand protocols and the proactive can also be called table-driven protocols [2], [4].

### 3.6.1 Proactive protocols

Each node in this network protocol will maintain a routing table which will be updated on a regular basis. If a change in the topology of the network occurs then each node within this network will broadcast a message. It is however noted that there is an overhead cost to be realized in maintaining route which are up to date. Throughput of this network is actually affected by this. Some well-known examples of these protocols include the following:

- Distance vector protocol
- Destination Sequenced Distance Vector (DSDV) protocol
- Wireless Routing protocol
- Fisheye State Routing (FSR) protocol

### 3.6.2 Reactive Protocols:

This is an on demand routing protocol that means nodes in this network will only discover a route to the destination only when the need arises. When a node wishes to communicate then it broadcast route request packets globally in the network. When the route is discovered then enough bandwidth is allocated for data transmission. There is less overhead in this protocol because there is less routing information that moves around the network. Its disadvantage is that if the network has high mobility it means routes change frequently therefore more control packets will be produced during route discovery process and this will introduce some high latency. Some common examples of this protocol includes the following:

- Ad-hoc On Demand Routing
- Dynamic Source Routing
- Associativity Based Routing

### 3.6.3 Hybrid Protocols:

When you take the strength of both the proactive and reactive protocol you come up with a Hybrid protocol. It is just a combination of the two mentioned protocol, joining their strength to produce a more vibrant protocol.

### 3.6.4 Distance Vector (DV) Protocol:

This proactive protocol uses the principle of distance vectors where all the nodes in the network maintains a routing table which will contain a distance table. The distance table stores shortest distances and next hop address. At first any node within the network only has the distance of the nodes that are directly connected to it and that distance is used to initialize the distance vector. Any other nodes which are not directly connected can be initialized to infinity. A change in the network triggers the updating of all nodes with a direct connection to their neighbors to the distance vector (least cost). Convergence will trigger the stoppage of this process.

Some advantages of distant vector protocol include:

- ❖ Global broadcasting is not necessary
- ❖ There is less delay in route acquisition because routing tables have all information concerning nodes.

Its drawbacks can be summarized as follows:

- ❖ There is a count to infinity problem due to long convergence time.
- ❖ Alternative paths doesn't exist.

### 3.6.5 WRP (Wireless Routing Protocol):

WRP eliminate the count to infinity problem that distance vector protocol exhibits and therefore is regarded as an improvement to the distance vector protocol. Elimination of the county to infinity problem leads to faster convergence time. However there are disadvantages too which are as follows:

- ❖ As a lot of information is involved WRP requires a lot of memory and more processing power.
- ❖ For large networks that has high mobility this approach is not suitable.

Below are the four main tables that each node maintains in WRP protocol.

**Link Cost Table-** this table contains the cost of a connection of each node and identifiers of directly connected nodes. Broken link cost is identified by infinity.

**Distance Table**- this table contains information of nodes that aren't directly connected.

**Routing Table**- will have shortest distance of all the nodes and up-to-date destination information.

**MRL (Message Retransmission List)** - Every node in the network will periodically send Hello message informing its neighbors of its existence and wait for an acknowledgement. If an ACK comes back in a stipulated time then all that information is kept in MRL list. In the next round update message will be sent only to nodes that didn't reply the Hello packet.

### 3.6.6 DSR (Dynamic Source Routing) Protocol:

This protocol uses source routing to create routes in a network and it is one of the reactive routing protocols. DSR requires all path information to be established between the source and the destination nodes in order to transmit packets as each packet uses the same path. Its advantage is that it doesn't employ periodic table updates therefore convergence time of this network is low. This is achieved by limiting the bandwidth. If a node wishes to communicate it first floods route request message in the network. Establishing a route involves two procedures namely:

- **Route Discovery**
- **Route Maintenance**

### Route Discovery:

Like any other on-demand routing protocol it finds route to the destination only when there is need to do so. Initially the source node intending to communicate will look in its route cache if there exist a valid route to destination. If there is a valid destination in its cache then transmission begins signaling the end of route discovery. However if no destination in its cache then it broadcast the route request packet to find the route to the destination. Destination upon receiving the route request will return the path to the source after which the source will start sending packets using that learned path.

## Route Maintenance:

Route maintenance is a process which involves a node broadcasting an informatory message to all other nodes in a network informing them of a link break or node failure. It's a strategy for early link failure detection since hop to hop acknowledgement is used in wireless networks. Advantages of DSR protocol are as follows:

- There is always an alternative path in case there can be a link failure
- There are no routing loops
- It's an on demand routing protocol and hence there is less maintenance overhead cost

  Its disadvantages are as follows:
- There is an increased in latency as the route acquisition process takes time if the network is large.
- This protocol is not efficient if the number of nodes are many and this can affect the speed of the network.
- Can have high overhead in messages in busy periods.

## 3.6.7 AODV (Ad-hoc On-demand Distance Vector) Protocol

Just like DSR this protocol in a reactive protocol that is it will only discover the route to a destination only when the need arises. It's a classical protocol for MANETs that has trade-off problems and of particular importance is the large packet header and increased message overhead caused by periodic updates in proactive protocols. It employs a distributed approach that is, only keeps track of its neighbors only and doesn't establish a number of paths to destination.

## Route Discovery:

A node wishing to communicate can checks in its information for existence of a valid route to destination if it's not there then it broadcast the route request packet to its neighbors. The broadcast message contain the following fields:

- Source address
- Source sequence number
- Destination address
- Destination sequence number
- Broadcast ID
- Hop count

There are two pointers used during the route discovery process namely:

- Forward pointer
- Backward pointer

**Forward pointers**- while route request packet is being forwarded to the destination forward pointers will keep track of intermediate nodes

**Backward pointers-** after the route request has reached the destination the destination node will unicast a route reply message back to the source node and the backward pointer will again keep track of the intermediate nodes in a reverse order. It is distinguished from DSR mainly by its use of destination sequence number. Destination sequence numbers are used to verify the up-to-date paths to destination.

**Route Maintenance:**

Three messages types sent between source and destination include:

- Route error message
- Hello message
- Time out message

**Route error message**- If a node observes a link failure in the network it propagates the route error message to upstream nodes going towards the source node.

**Hello message**- keeps the two pointers from expiring that is the backward and forward pointers.
**Time out message**- deletes a link between a source node and a destination node when there exist no activity for a predefined time.

Some of its advantages are as follows:

- Can be scalable that means the network can grow without affecting the efficiency of the algorithm.
- Its loop free hence has a short convergence time.
- Link failure message overhead is less if we are comparing it with DSR

Its main disadvantage though is the need for more bandwidth in order to maintain those hello messages which are periodically sent by each node.

# CHAPTER 4: PROPOSED WORK

## Proposed work overview

This chapter looks at the proposed work plan to come up with an ***Energy aware algorithm for an improved AODV routing protocol*** that the researcher wishes to contribute and also looks at some improvements and innovations that was introduced. The work is divided into two parts, with the first part looking at the **improved energy efficient AODV protocol** (IEE-AODV) as an improvement of the AODV routing protocol as far as energy conservation is concerned. In this part we will create an improved protocol that improves energy consumption in an AODV routing setup. The second part we will look at the **K-means algorithm** as a means to create clusters in our work so that we incorporate Clusterhead selection method in our **IEE_AODV** protocol. The K-means algorithm will form the basis of our route discovery process and will enable us to find the minimum path from a specified source node to the destination node. Clustering was chosen because it allows **network scalability** and more efficient use of network resources. K-means will gives us the shortest distances of nodes from their centroid point (**cluster head**).  In the process we can achieve an improved packet delivery ratio and the choice of the shortest path will guarantee us the improve lifetime of the network.  Since AODV routing protocol is already available in NS2 simulator in order to have an improved version of this protocol (**IEE-AODV**) it means that we have to create this protocol with modifications being done to the header files of AODV routing protocol.

## 4.1 System Model

We describe the network model and energy model taken for the proposed protocols and mechanism in this section. Network model describes the operations of the networking environment with characteristics and capabilities of the sensor nodes used in the networks. Energy model deals with the energy usage of the sensor node when used for variety of responsibilities like sensing the information, transmission of information, receiving of information etc. We also look at how the K-means algorithm is going to help in improving the system that we put in place. We have divided the work into two parts mainly IEE_AODV routing protocol and the incorporation of the K-means algorithm in our improving routing protocol.

### 4.1.1 Network Model

Below is the diagram that clearly shows how the proposed system is going to be implemented and how the two main techniques used in this thesis (**K-means algorithm and IEE_AODV**) are put together to form a hybrid system which combines the two techniques' individual strengths.

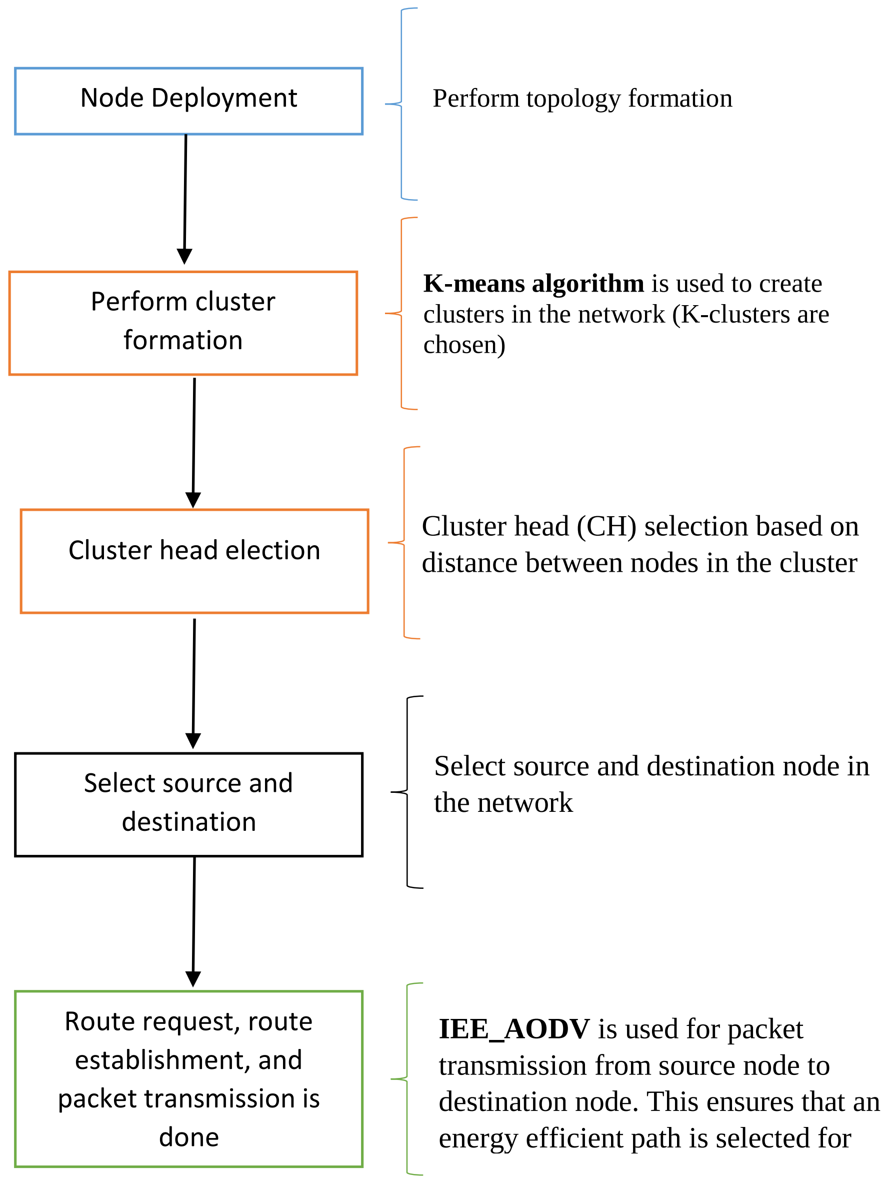


**Figure 4.1: Proposed system model**

### 4.1.2 Energy Model

Of particular importance to our improvements is the inclusion of **Drain count** field to the AODV route request header file. The drain count is a value field that will be used to determine whether a particular path utilizes more energy or not and it works as follows:

Every node in the initial stages is given an energy value which is basically the battery status at the start of the network. As activity happens in the network the nodes will spent their energy in transmitting and reception of control and data packets. Depending with path selection some nodes will have more energy than the others within the network because not every node is used in transmitting or reception. Therefore for total energy consideration there are basically four modes of energy consumption that must be considered and these include:

1. **Transmission mode**- this is the energy spent in transmitting the packet and is actually dependent on packet size.

$$\boldsymbol{T_x = \frac{(330 * Plength)}{2 * 10^6}} \qquad \boldsymbol{P_T = \frac{T_x}{T_t}}$$

   Where $\boldsymbol{T_x}$ is the transmission energy.

   $\boldsymbol{P_T}$ – This is the transmission power.

   $\boldsymbol{T_t}$ – This is the time taken to transmit data packet

   $\boldsymbol{Plength}$-this is the length of the data packet in bits.

2. **Reception mode –** this is the energy that is spent in receiving a packet.

$$\boldsymbol{R_x = \frac{(230 * Plength)}{2 * 10^6}} \qquad \boldsymbol{P_R = \frac{R_x}{T_x}}$$

   Where $\boldsymbol{R_x}$ is the reception energy.

   $\boldsymbol{P_R}$ – This is the reception power.

   $\boldsymbol{T_x}$ – This is the time taken to receive data packet

   $\boldsymbol{Plength}$-this is the length of the data packet in bits.

3. **Idle mode-** this is a mode where the node is either transmitting nor is it receiving but some considerable energy will be used in hearing. Nodes have to listen to the network activity in case there is incoming packets directed to it. In that case it is imperative that the particular

node moves from being in idle state to reception mode. The power consumed in this mode is as follows:

$$P_i = P_R$$

Where $P_i$ is the actual power that is consumed while the node is in idle mode and $P_R$ is the power that is consumed in reception mode.

4. **Overhearing mode-** sometimes nodes may receive packets that do not belong to them and that is called overhearing. Some energy is actually lost because of that.

$$P = P_R$$

Where $P$ is the power consumed in overhearing mode and $P_R$ is the power that is consumed in reception mode.

The above four modes are key to an efficient energy aware system as they cover all node energy usage areas.

## 4.2 Improved Energy Efficient routing protocol AODV (IEE_AODV)

The main purpose of introducing the **IEE_AODV** was to improve the network lifetime as wireless sensor nodes have a constraint in power due to their limited battery power. The lifetime of the network in this proposed system will be determined by the **drain count** energy metric. **Drain rate** is the consumption rate of energy by each node within a wireless sensor network. The key to a successful realization of maximum network lifetime is to choose the path with the least drain rate.

**Energy Calculation**

Let $E_t$ be the amount of energy consumed in transmitting one packet, therefore

$$E_t = P_T * T_t$$

$P_T$ – This is the transmission power.

$T_t$ – This is the time taken to transmit data packet

Therefore the **remaining energy** of a node will be calculated as:

$$E_{new} = E_{curr} - E_t$$

The same goes for the reception energy and the residual energy calculation remains the same. The proposed implementation focuses on two main parameters of the network which are as follows:

1) **Total path energy** – it's the sum of all the energies of nodes that lie within the selected path from source to destination.

2) **Residual power of the node** – this is the remaining power of the node.

**Parameters to be appended on each node**

Each node will be appended with two distinct fields in order to efficiently work within this network system.

1) An **INDEX** field is added to uniquely identify the node.

2) The status of the individual node's battery is shown by $\boldsymbol{E_{res}}$ and is calculated as follows:

   If (**residual node battery < 20% of the node's initial energy**) then

   Set $\boldsymbol{E_{res} = 1}$

   Else if (**20% of the node's initial energy < residual node battery < 60% of the node's initial energy**) then

   Set $\boldsymbol{E_{res} = 2}$

   Else (**residual node battery > 60% of the node's initial energy**) then

   Set $\boldsymbol{E_{res} = 3}$

## Parameters to be added to the route request packet

| Type | Reserved | Hop Count |
|---|---|---|
| RREQ ID | | |
| Destination IP address | | |
| Destination Sequence Number | | |
| Originator IP Address | | |
| Lifetime | | |
| Timestamp | | |
| ***Remaining Energy*** | | |
| ***Drain Count*** | | |
| ***Record*** | | |

**Figure 4.2: Modified AODV route request packet header**

At the route discovery stage the source node broadcast the route request (RREQ) packet to its neighbors with the header of the route request packet appended the above highlighted fields.

So the proposed system will incorporate the last three fields in the route request header and of particular importance is the Drain count. If for instance the energy of a node in a specific path is less than the set threshold value then the drain count value of that path can be incremented by a factor of 1. This can be represented clearly as follows:

- ❖ The number of drained nodes is represented by $\boldsymbol{N_{drain}}$ which in actual fact is the number of nodes whose energy level is less than 20% of their initial residual energy

  Therefore: If ($\boldsymbol{E_{res} = 1}$) Then

$$\boldsymbol{N_{drain} = N_{drain} + 1}$$

From the above operations it can be seen that the path with the least drain count is the most desirable since it will guarantee a prolonged network lifetime compared with the other paths. This will work very fine until we have a scenario where two or more paths have the same drain count. This will require some other working system to overcome such a situation and the researcher introduced the K-means algorithm to help with selection of the shortest route.

### 4.2.1 K-means Algorithm

The algorithm creates K centroids of which each of these K centroids resides in the cluster formed. The main idea is to define k centers, one for each cluster. These centers should be placed in a cunning way because different locations causes different result. So the better choice is to place them far away from each other. The next step is to make an association between the centroid and the nearest data points in the data set. When all is done a recalculation of new K centroids is performed again after which associations have to be made between the data set and their corresponding near centroids. This process results in a loop which means the K centers will be changing their location in a step by step fashion. This process continues until no more changes or up until K centroids cannot move or change location anymore. The algorithm should converge that is its aim is to minimize the following objective function called the **squared error function:**

$$\boldsymbol{J}(\boldsymbol{V}) = \sum_{\boldsymbol{i}=1}^{\boldsymbol{c}} \sum_{\boldsymbol{j}=1}^{\boldsymbol{c_i}} (\|\boldsymbol{x_i} - \boldsymbol{v_j}\|)^2$$

**Where:**

$\|\boldsymbol{x_i} - \boldsymbol{v_j}\|$ is the Euclidean distance between $x_i$ and $v_j$.

$\boldsymbol{c_i}$ is the number of data points in $i^{th}$ cluster.

$\boldsymbol{c}$ is the number of cluster centers.

Since we are going to employ a clustering technique in our thesis we chose this technique because of the following advantages:

1) It is a fast and very robust technique
2) It is actually very easy to understand
3) It has a relative efficiency which is ***O(tknd)*** where ***t*** is the number of iterations, ***k*** is the number of clusters, ***n*** is the number of data sets, and ***d*** is the dimension of each data set.
4) Works perfectly and give results especially when the data set is distinct.

**Algorithmic steps for k-means clustering**

Let $X = \{x_1, x_2, x_3, \ldots, x_n\}$ be data set points and $V = \{v_1, v_2, \ldots, v_c\}$ be the set of centers.

1. Randomly select *'c'* cluster centers.
2. Calculate the distance between each data point and cluster centers.
3. Assign the data point to the cluster center whose distance from the cluster center is minimum of all the cluster centers.
4. Recalculate the new cluster center using:

$$\boldsymbol{v_i = \left(\frac{1}{c_i}\right)\sum_{j=1}^{c_i} x_i}$$

   Where $\boldsymbol{c_i}$ represents the number of data points in $\boldsymbol{i^{th}}$ cluster.

5. Recalculate the distance between each data point and new obtained cluster centers.
6. If no data point was reassigned then stop, otherwise repeat from step 3.

When choosing a clustering technique it is important to understand its operation because it affects the reliability of the clusters. We divide the network into many multihop clusters using the K-mean clustering algorithm. The actual implementation is shown in **figure 4.3** below where K-means is implemented in a network with size that can range from (10-100) nodes and the clusters can be within (2-12) clusters. Nodes within a cluster are selected to perform different tasks depending with the needs of the user. Generally there exist three types of nodes namely cluster heads, ordinary nodes, and gateway nodes [50]. The cluster head plays the most important role in the network as it is responsible for calculating routes for long distance packets. It is the one that is involved in inter-cluster communication and the storage of routing and cluster information [19]. With time nodes can move and the topology changes and this calls for an election of the new cluster head in order to keep the network as efficient as possible. Selection of the new Clusterhead would not require some extra overhead since the outgoing cluster head will inform the other members of the new cluster head. Each and every cluster head should have the following important tables:

a) **Intra cluster table**- this table consists of all the node IDs of that particular cluster.

b) **Cluster head table-** this table contains all IDs of the cluster heads in the entire network.

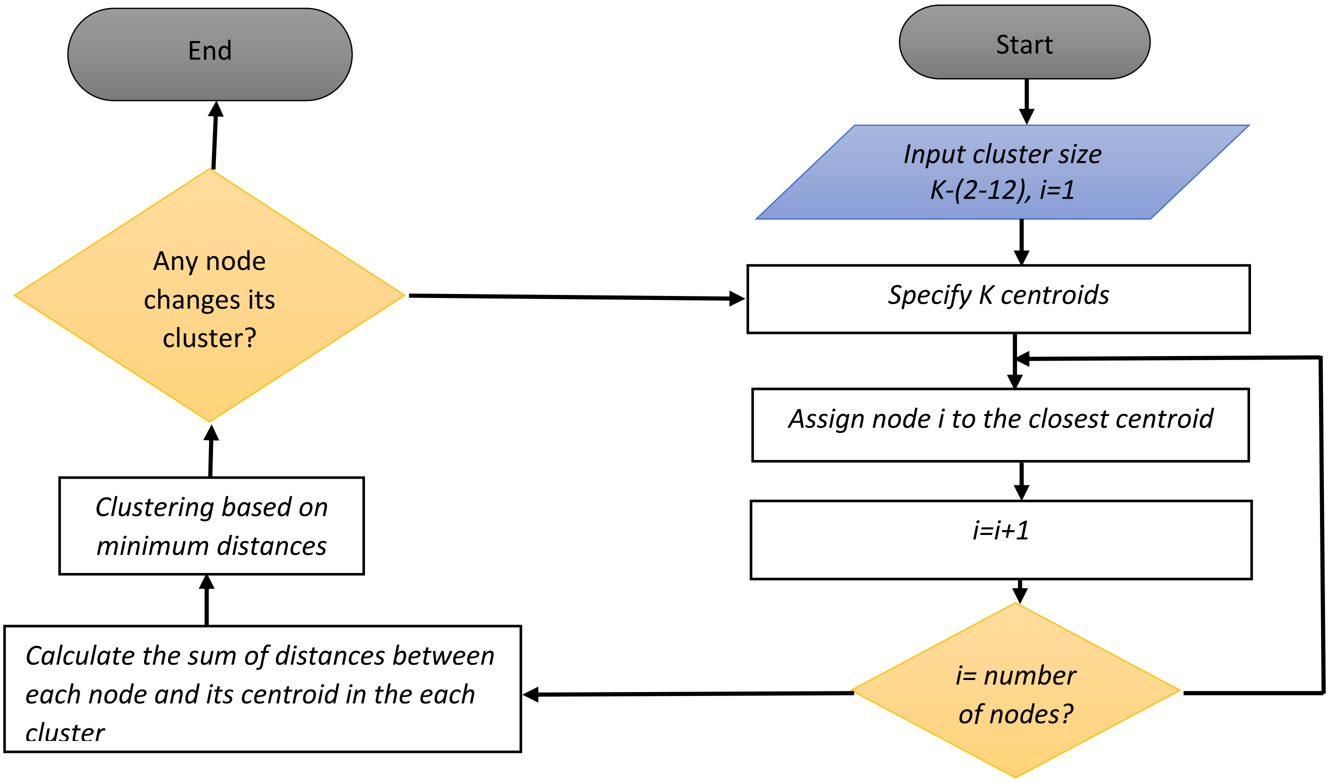


**Figure 4.3: K-means clustering algorithm**

# CHAPTER 5

## SIMULATION RESULTS AND ANALYSIS

Simulation is considered as efficient and flexible tool to evaluate the performance of the protocol working under vivid environmental conditions. We take the proposed techniques (**Energy aware algorithm for an improved AODV routing protocol**) discussed in chapter four and run them on a simulation platform. Then the performance of our proposed system is compared to the existing **AODV routing protocol** using performance parameters like network lifetime, Packet delivery ratio, throughput, and end-to-end delay. We then analyze the outcomes of the simulation in both cases giving reasons for the variations that can be found in these simulations.

## 5.1 Simulation Setup

Simulation in this thesis was done using Ns2 simulation tool. This tool is a discrete event simulator which is used in networking and can model wireless and wired network. Its strength lies in the fact that it can support several network functions and protocols. These include TCP, multicast protocols, and routing. Together with Xgraph (plotting program) we can be able to plot graphical representations of simulation results.

### 5.1.1 About Ns2

Ns2 being a discrete network simulator is written in C++ therefore it is an object oriented simulator. It uses the OTcl interpreter as the frontend. Ns2 uses C++ and OTcl because there is a frontend and a backend and their requirements are different. Simulation of the protocols calls for a robust programming language in order to effectively manipulate things like packet headers, bytes and implementation of algorithms that should run over huge data sets [41][42]. So if such tasks are to be performed turnaround time and run-time speed are vital. Trivial tasks like running a simulation, finding a bug, fixing a bug, recompiling, and re-running are less important.

Many researchers however don’t operate at the backend their research work is mainly varying configurations and parameters or evaluating different scenarios. In such cases changing the model and rerunning is vital (iteration time). This configuration will run only once, when simulation begins therefore runtime is not of importance.

Ns2 is made up of these two languages C++ and OTcl and both are very important for simulation to be successful [43]. C++ is slow in making changes but really fast in running hence its suitability for backend protocol implementations. On the other hand OTcl is an interactive language which can be changed quickly but generally the running is slower hence it works fine as the frontend where simulation configurations are done [41].

Tool Command Language (TCL) handles the frontend programs and C++ is the language used in the backend of the Ns2 simulator. When you write a tcl program for your simulation after compilation of that tcl program a tracefile together with a namfile will be created. The tracefile will keep track of network activities that includes node number of packets sent, hop count, connection type etc. the namfile called the network animator will keep the movement patterns of all the nodes in the network. There is also a scenario file that defines a destination of mobile nodes together with its speeds and the CBR file which is a connection pattern file. Topology and packet type can also be used to create trace files together with nam files which in turn will be used by the simulator in simulating the network. It's also possible to explicitly mention network parameters at creation time of the scenario files using some library functions that available in the simulation.

The main aim in this phase is to simulate our proposed system **Energy aware algorithm for an improved AODV routing protocol** against traditional **AODV routing protocol** with particular focus on network lifetime and check the performance of each of these network implementations. We also look at other performance metrics like throughput, packet delivery ratio, and average end-to-end delay with respect to this two implementations.

## Network Scenario for simulation

Network scenario is the parameters on which our simulation is going to perform in. the network scenario for our thesis is outlined in the following table:

| | |
|---|---|
| **SIMULATOR** | **Network Simulator 2** |
| **NUMBER OF NODES** | **10,20,30,40,50 nodes** |
| **INTERFACE TYPE** | **Phy/WirelessPhy** |
| **CHANNEL** | **Wireless Channel** |
| **MAC TYPE** | **Mac/802_11** |
| **QUEUE TYPE** | **Queue/DropTail/PriQueue** |
| **QUEUE LENGTH** | **201 Packets** |
| **ANTENNA TYPE** | **Omni Antenna** |
| **PROPAGATION TYPE** | **TwoRay Ground** |
| **SIZE OF PACKET (BYTES)** | **Five hundred and twelve (512)** |
| **PROTOCOL** | **IEE_AODV** |
| **TRAFFIC** | **TCP** |
| **Initial Energy** | **10.0 joules** |
| **TxPower** | **0.075** |
| **RxPower** | **0.075** |
| **Idle Power** | **0.005** |
| **PERFORMANCE EVALUATION METRICS** | **Average end-to-end delay, throughput, network lifetime, packet delivery ratio** |

**Figure 5.1: network scenario for Ns2 simulation topology**

## 5.2 Performance evaluation

We have implemented the proposed system and the current system in the same simulation environment for the sake of comparisons. In this phase we implement the new **Energy aware algorithm for an improved AODV routing protocol** and run it in the Ns2 simulation environment with the above network properties. Again the same is done for **AODV routing protocol** and we monitor their performance and a comparison is made out the results. Our proposed system is a combination of **K-means algorithm** for clustering and the **IEE_AODV routing protocol** for energy efficiency, together they form a robust network system that not improves the network lifetime but also have significant performance improvements in other performance metrics. The key to the improvements lies in the fact that **K-means** introduces some optimization in the network before the IEE_AODV routing protocol takes over and this will have a positive impact on the way packets are going to be transmitted from the source to the destination node**. K-means** algorithm will perform clusters within the network and will further more choose a Cluster head which is central to every member node within that cluster. Before packet transmission the routes will be optimized through these clustering technique and this will greatly improve the network operations. **IEE_AODV routing** will then choose the route which is energy efficient in the network and packet transmission is done using the clusters created by K-means algorithm. On the other hand **AODV routing protocol** uses a flooding mechanism to discover routes that is if a node wishes to send packets to some in the network, it broadcast route request packets to its neighbors and wait for a reply. If an intermediate node has the route to the destination in its routing table then it will unicast a route reply message back to the source node or else it will rebroadcast the massage to its neighbors until it reaches the destination. If the source node receives the reply then it can start sending the packets using the route which will be in the routing table. These two strategies will be simulated and results will be shown.

### 5.2.1 Performance metrics

The following are the performance metrics that we are going to use in our thesis:

- **Network lifetime** – this is defined as the time until all the sensor networks in the network runs out of energy.
- **Throughput** – is defined as the amount of data packets delivered successfully from the source node to the destination node in a given time period.
- **Packet delivery ratio** – it is the ratio of data packets successfully delivered to intended destination against those packets that have been sent by the source node. Denoted by the following formulae:

$$\boldsymbol{PDR = \sum number\ of\ packet\ received / \sum number\ of\ packet\ sent}$$

- **Average end-to-end delay** - this is the average time taken by a data packet in a network to arrive to its intended destination. This delay include route discovery delay and data packet queuing delay. The formulae is as follows:

$$\boldsymbol{\sum (arrive\ time - send\ time) / \sum number\ of\ connections}$$

### 5.2.2 Simulation Screenshots

Below are some of the simulation screenshots taken for a 50 node network setup. The process is shown from the initial creation of the nodes and they are deployed in the network. The following screenshot shows the process of the proposed system from the initial stage of node deployment to the final stages where packet transmission is done.

## Node creation and deployment

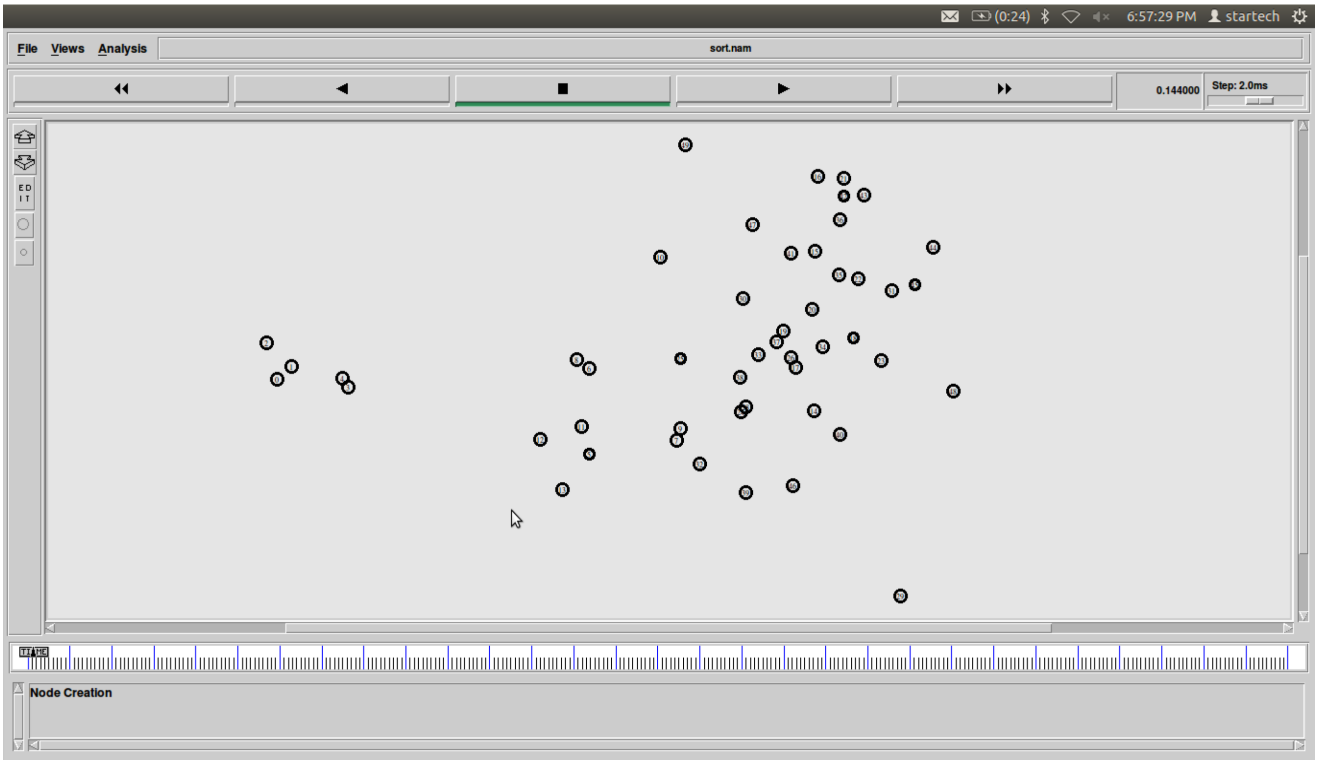


**Figure 5.2: Node deployment**

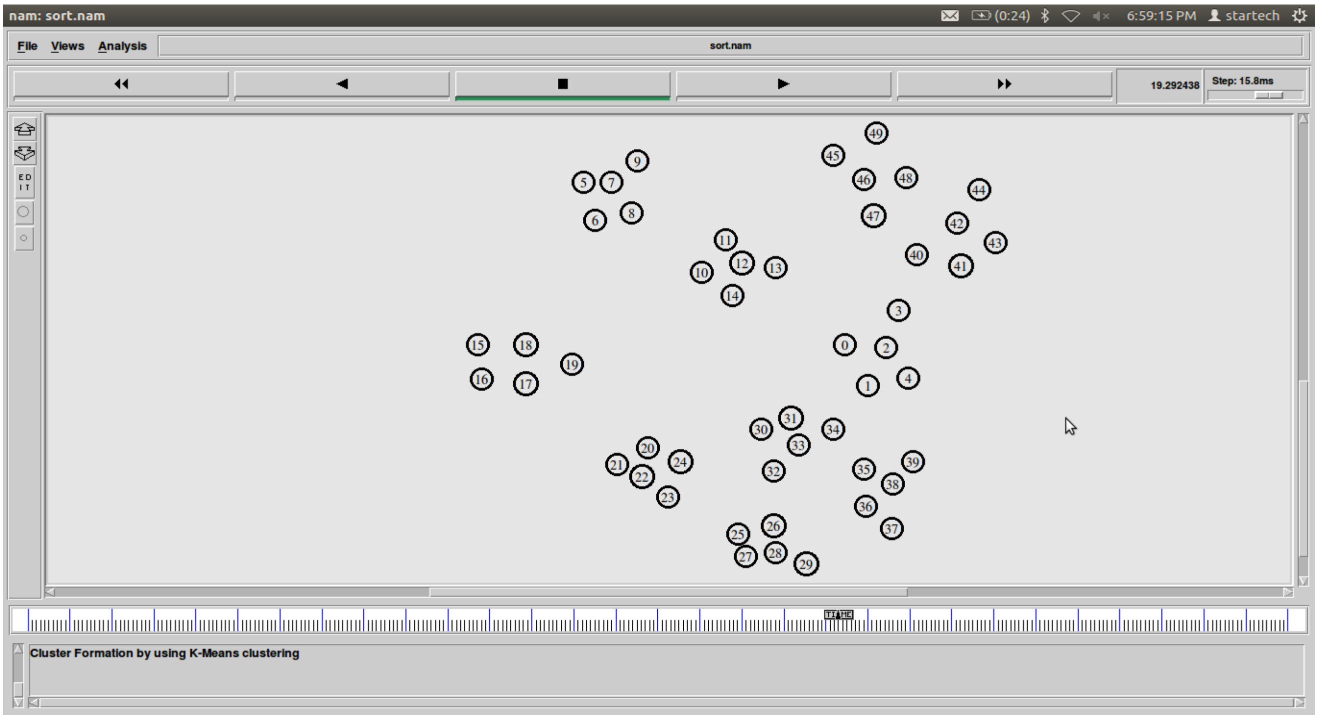


**Figure 5.3: Cluster formation using K-means**

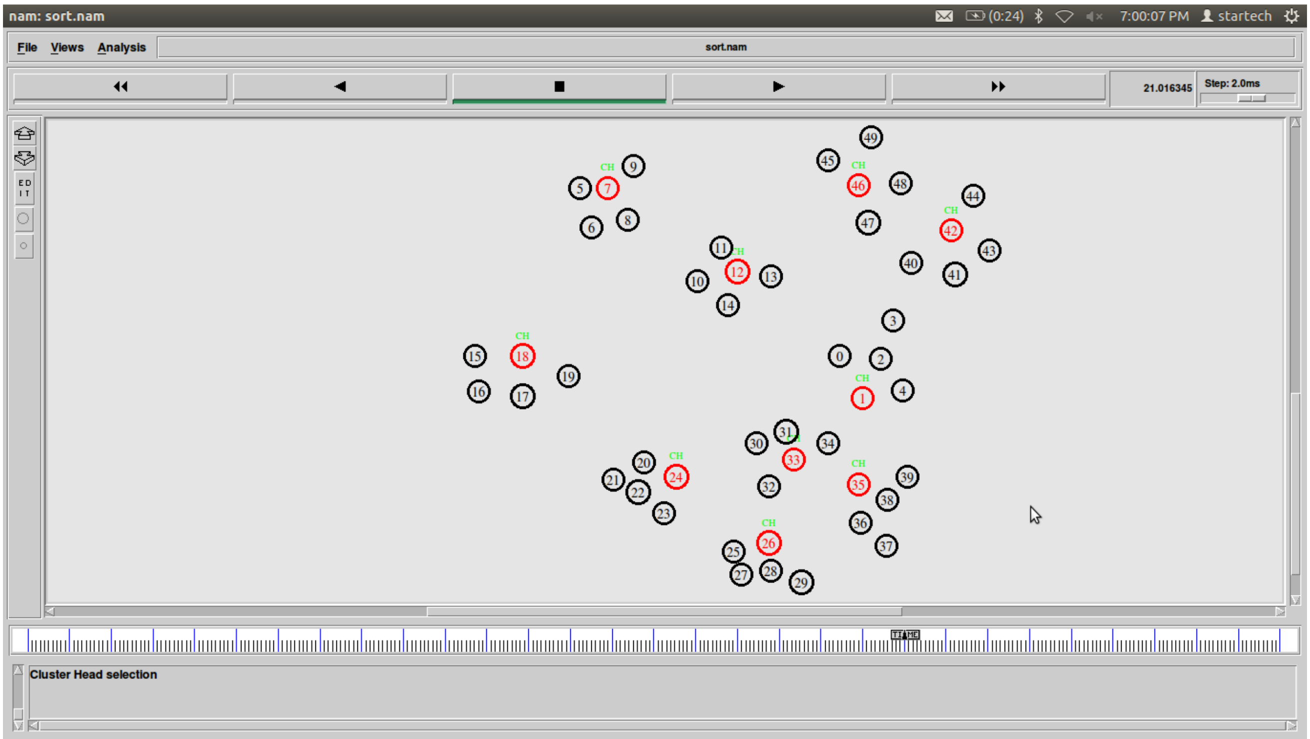


Figure 5.4: Cluster head selection

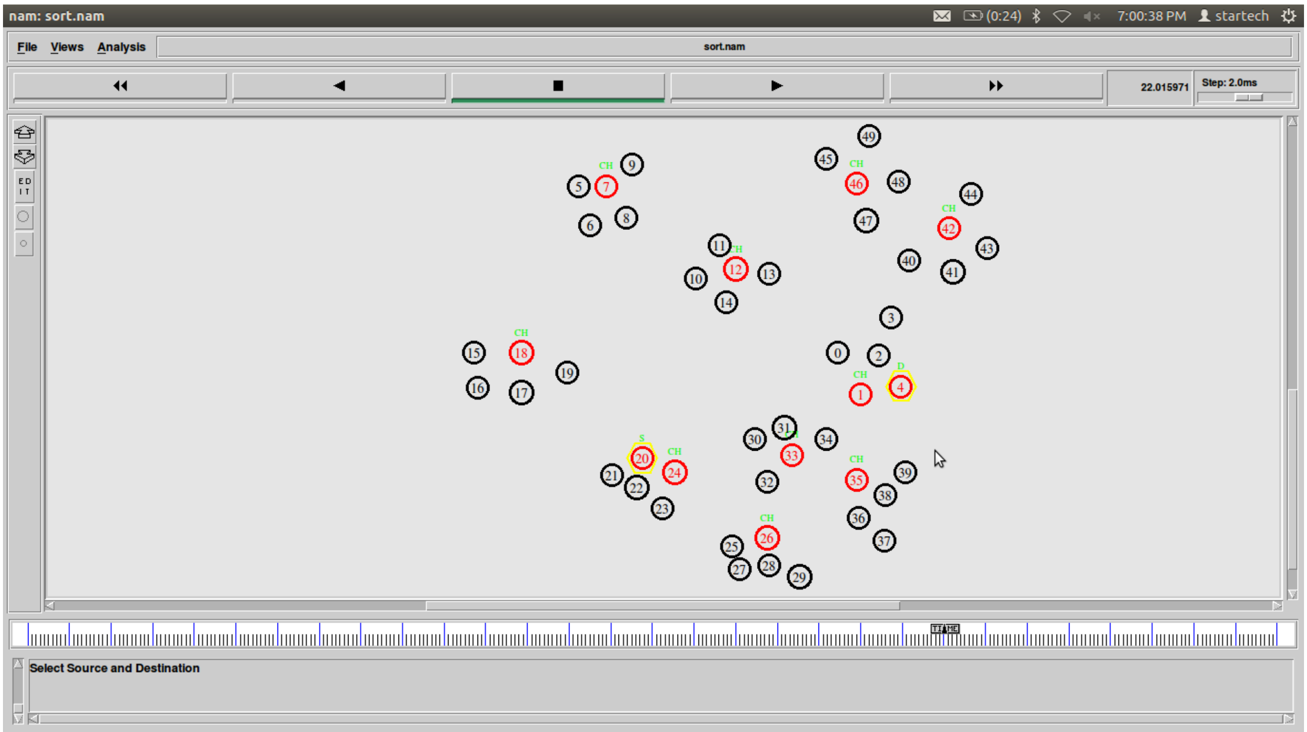


Figure 5.5: Select source and destination nodes

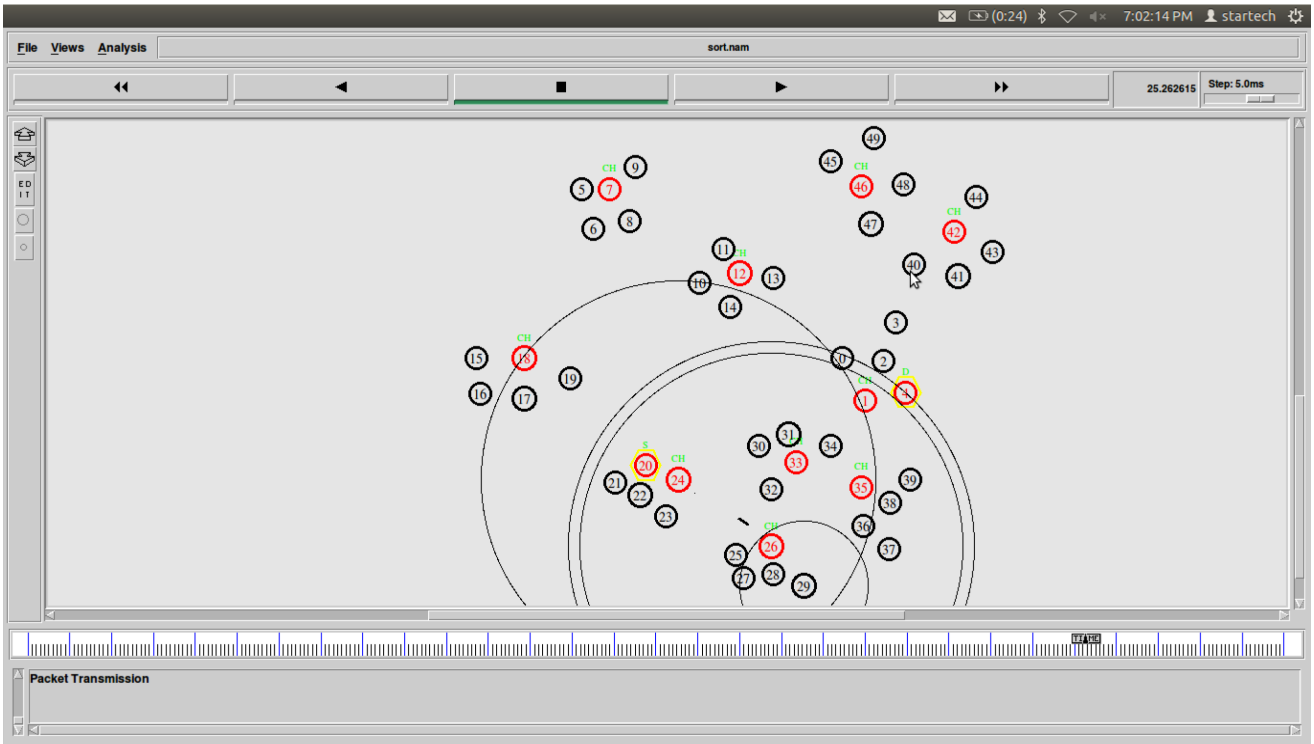


**Figure 5.6: Packet transmission-1**

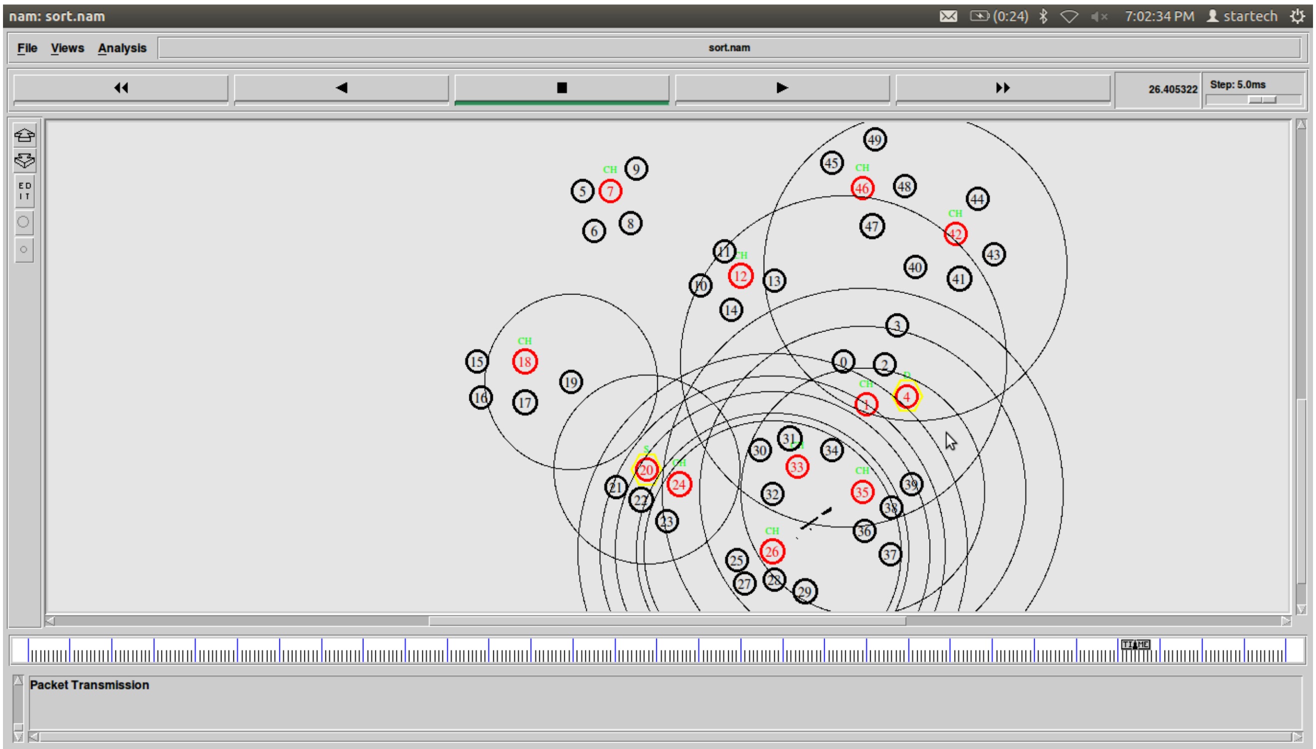


**Figure 5.7: Packet transmission-2**

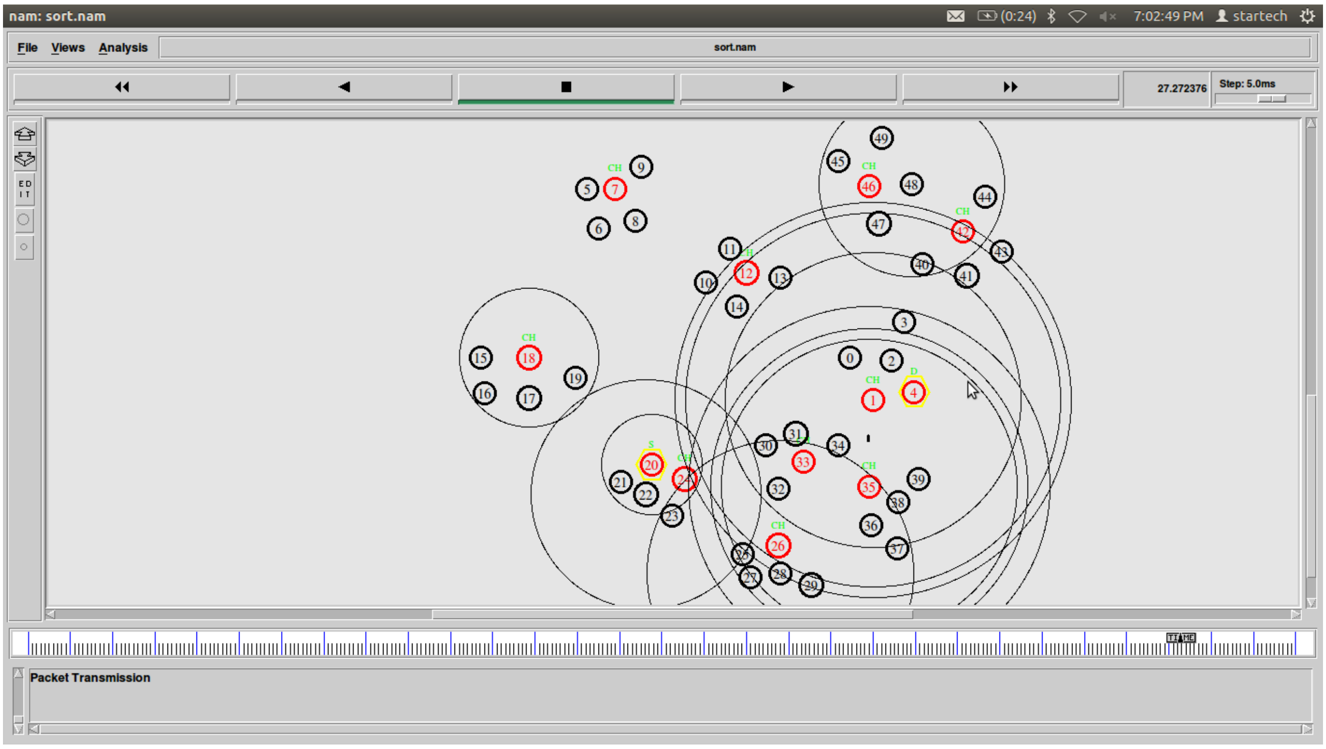


**Figure 5.8: Packet transmission-3**

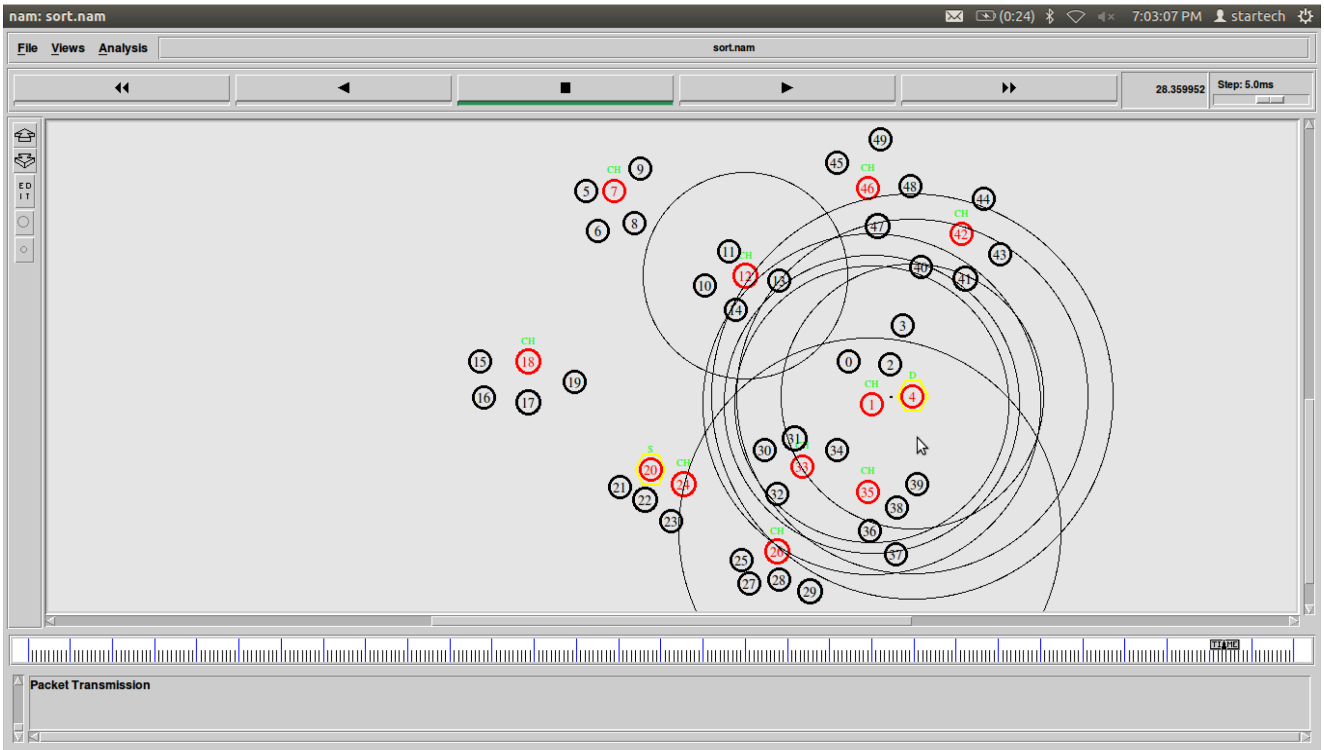


**Figure 5.9: Packet transmission-4**

### 5.2.3 Simulation results and analysis

After completing the implementation phase we then simulate our proposed system together with the conventional AODV routing protocols in similar simulation environment. In order to cover a number of scenarios node density is going to be varied from 10,20, 30,40 and 50 nodes with node density 10 and 20 representing low node density network and 40 and 50 nodes representing high node densities. However we are going to maintain the same pause time in this network because previous research in this area has shown a marginal difference when pause time is changed hence omission of the pause time comparisons. It is however important to note that in this thesis we varied node densities to monitor if our main thesis modifications can handle scalability and at the same time improve the network lifetime on the network.

The results of our simulation is represented in the following graphs:

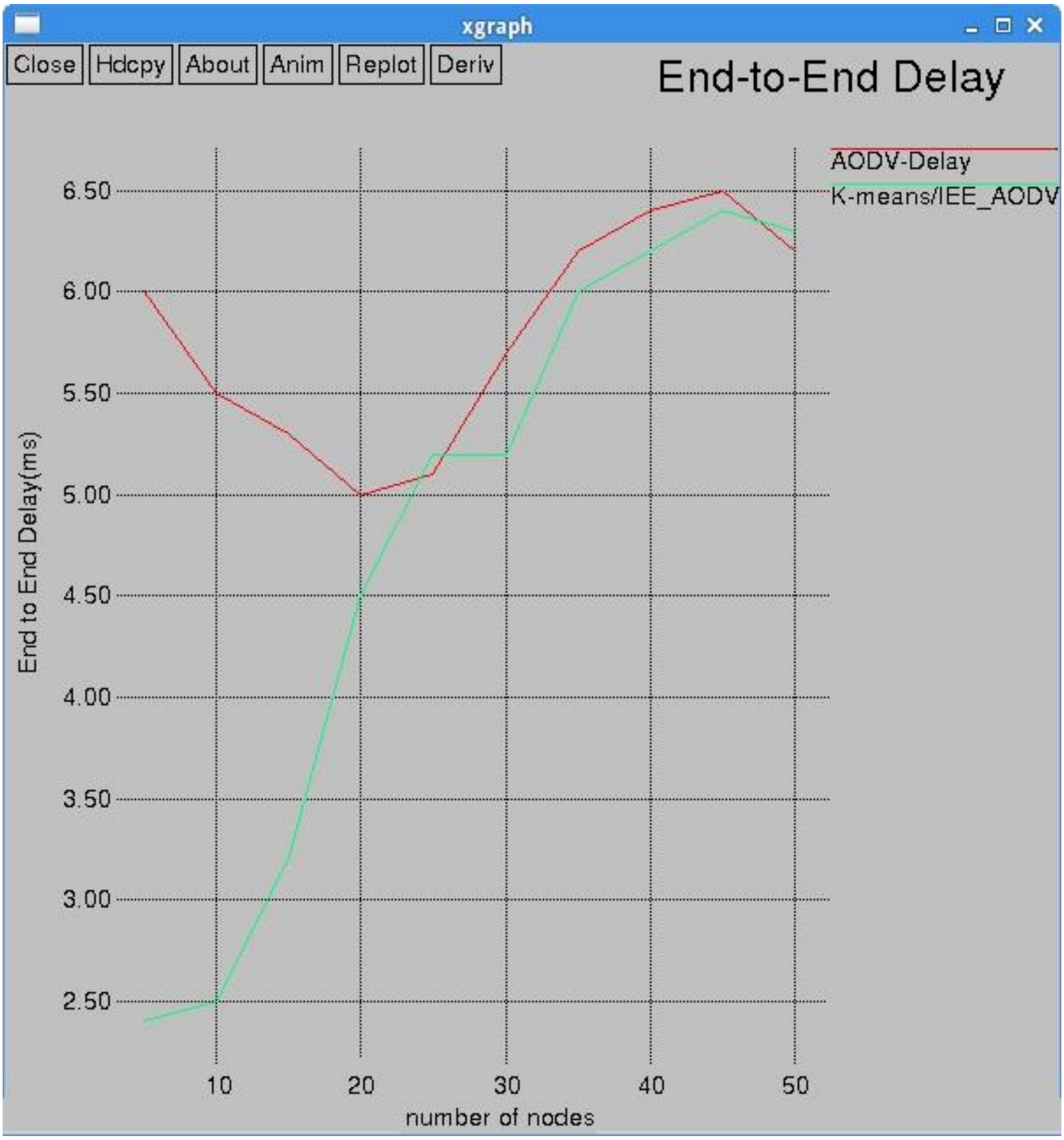


**Figure 5.10: Average end-to-end delay**

| Number or nodes | K-means/IEE_AODV | AODV |
|---|---|---|
| 10 | 2.50 | 5.51 |
| 20 | 4.52 | 5.00 |
| 30 | 5.22 | 5.73 |
| 40 | 6.24 | 6.42 |
| 50 | 6.35 | 6.25 |

**Figure 5.11: End-to-end delay table**

## Average end-to-end delay Analysis

It can be noted that average end-to-end delivery has drastically dropped in our proposed system compared to that of the AODV routing protocol. When node density is low the delay in our proposed system is really low because of the quick convergence that happens with our system as there are few nodes. As the proposed system uses K-means algorithm to optimize its routes if the number of nodes are few then the faster the convergence in the algorithm that is why we have less delay when node density is low. However the delay for AODV routing protocol is high as the route discovery process takes time to find routes to the destination but once the routes are established we see the delay slightly improving but overall as the node density increases (number of nodes ) both systems delay increases too. This is generally the case in almost all systems because an increase in node density would imply more connections to be made and hence this extra addition will introduce some delays compared to lesser node density network. Our proposed approach's use of K-means has greatly improved the performance of the network in that it optimizes the paths so that no delays will be encountered when packet transmission takes place. Also to note is that the reduction in delay for our proposed system has also been caused the creation of a strong virtual backbone in our proposed system.

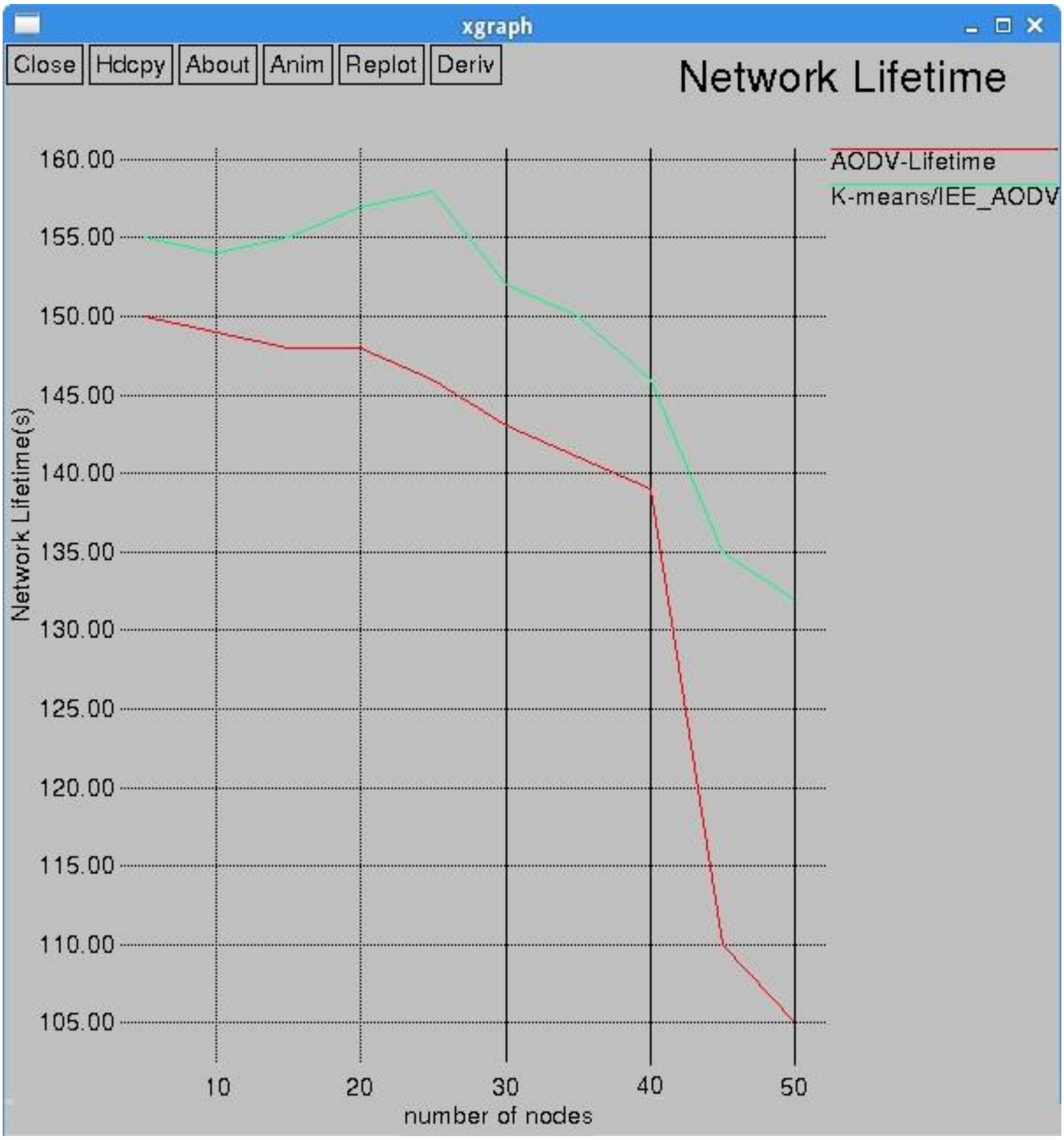


**Figure 5.12: Network lifetime**

| Number or nodes | K-means/IEE_AODV | AODV |
|---|---|---|
| 10 | 154 | 149 |
| 20 | 157 | 148 |
| 30 | 152 | 143 |
| 40 | 146 | 139 |
| 50 | 132 | 105 |

**Figure 5.13: Network lifetime table**

## Network Lifetime Analysis

It can be noted that when there is low node density in the network the lifetime of the network is high for both the K-means/IEE_AODV and the AODV routing protocols. This is attributed to the fact that there are fewer connections for both networks when the network size is low and hence fewer energy usage is realized. There is less traffic running around the network therefore nodes will be saving power. Energy is consumed when nodes transmit or receive packets during packet transmission. It is observed the **K-means/IEE_AODV** strategy has the best network lifetime for the most part of the network life compared to AODV routing protocol for all node densities and this is so because our proposed approach select the most energy efficient path to transmit packets from the source node to the destination node. AODV's energy consumption depreciates drastically as the node increases in the network mainly because there are more connections and hence more energy is going to be spent in making sure that packets are received by the intended destination node. In **K-means/IEE_AODV** however the packets are sent using the route that guarantees the delivery of packets as the route used by this approach is the most energy efficient route from all other route available in the network. This is achieved through the use of drain count as explained in chapter four. The route with less drain count is used by **K-means/IEE_AODV** meaning the chosen route will have the highest energy reserves.

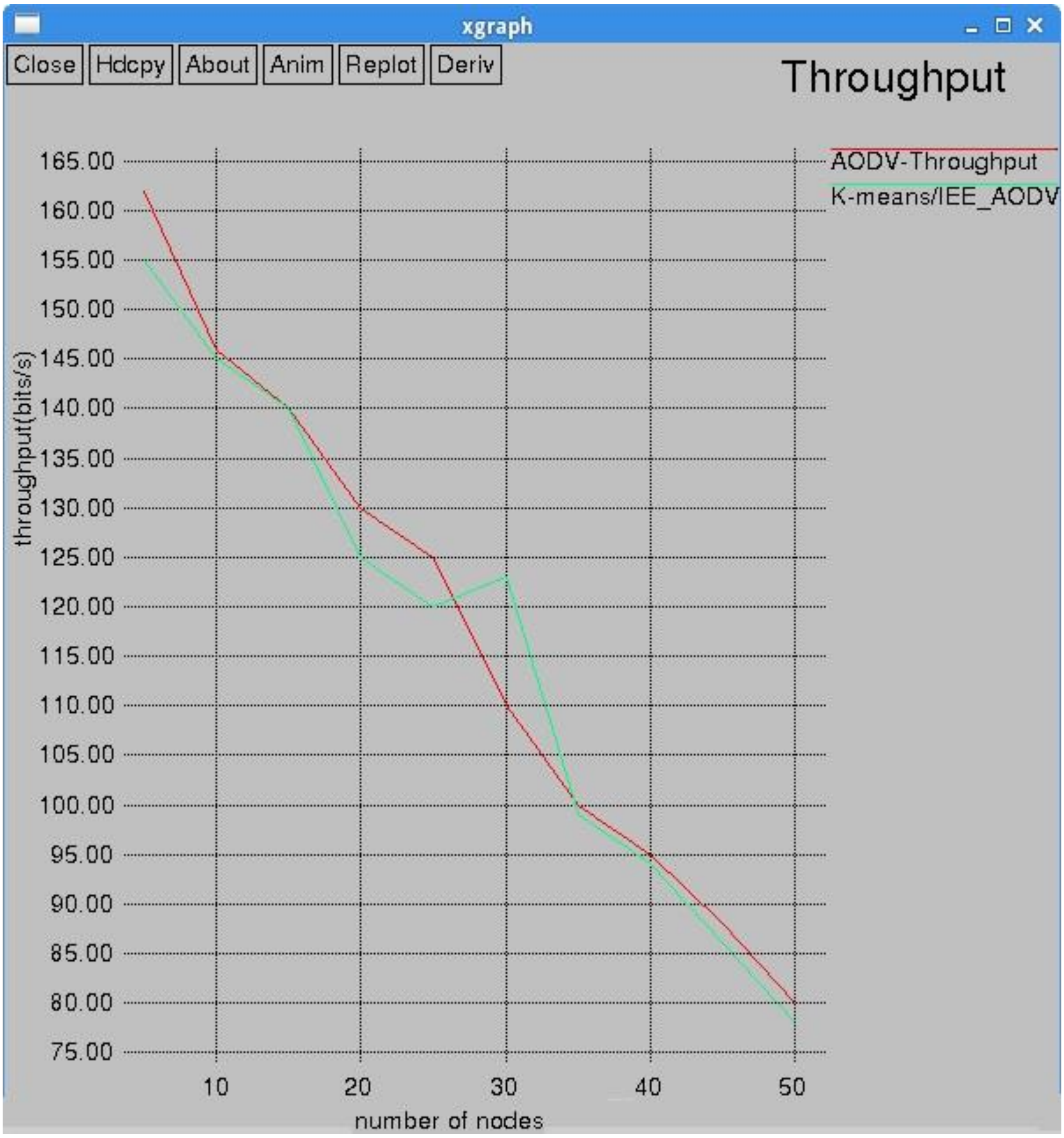


**Figure 5.14: Throughput**

| Number or nodes | K-means/IEE_AODV | AODV |
|---|---|---|
| 10 | 145 | 146 |
| 20 | 125 | 130 |
| 30 | 123 | 110 |
| 40 | 94 | 95 |
| 50 | 78 | 809 |

**Figure 5.15: Throughput table**

## Throughput Analysis

It can be noted that the throughput of AODV routing protocol is higher than that of the proposed system in most situations. AODV routing has consistently better values of throughput and this is caused by the fact that K-means/IEE_AODV has a lot of control packets exchange before the actual transmission of data packets. Furthermore K-means/IEE_AODV computations of drain count occurs on each and every node in the network. The calculations to determine the amount of energy each node has (residual energy) and the incrementing of drain count has to be performed on each and every node and this introduces extra overheads that will affect the network's throughput in our proposed network. Overall it can be noted that in less dense networks the network throughput is high in all system but will drop as the number of nodes increase due to an increase in network connections. AODV has slightly higher throughput because of the extra control packets that K-means/IEE_AODV has but the difference is negligible.

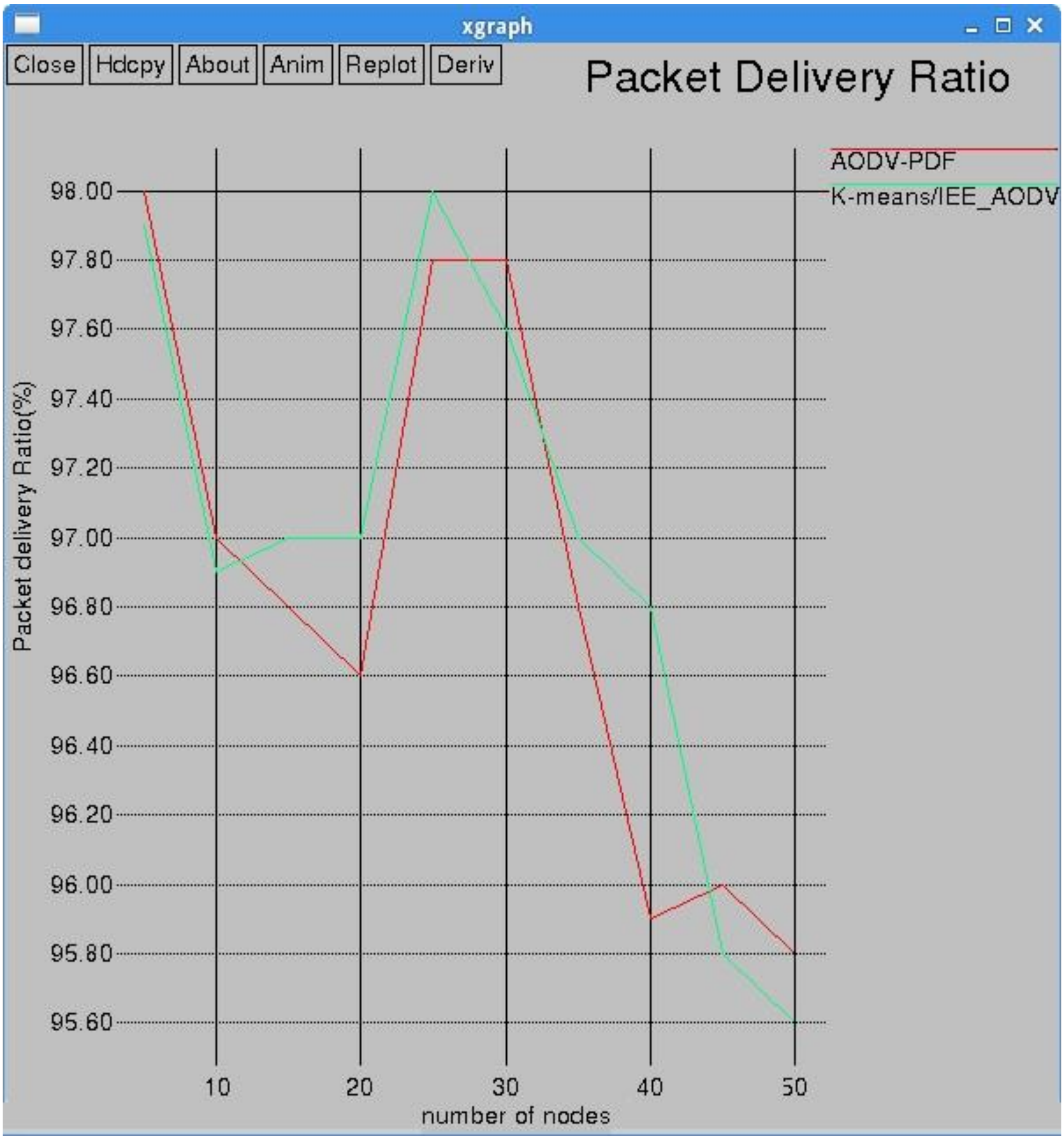


**Figure 5.16: Packet delivery ratio**

| Number or nodes | K-means/IEE_AODV | AODV |
|---|---|---|
| 10 | 96.9 | 97 |
| 20 | 97.0 | 96.6 |
| 30 | 97.6 | 97.8 |
| 40 | 96.8 | 95.9 |
| 50 | 95.6 | 95.4 |

**Figure 5.17: Packet delivery ratio table**

## Packet delivery Ration Analysis

They say the longer the route the higher the chances of packet loss and this principle work in these mobile adhoc networks too. In [1] the researcher give a comparison of AODV routing protocol and IEE_AODV and the analysis says sometimes the most energy efficient path might not be the most reliable path. Apparently an energy efficient path might be too long or the traffic in that path might be too high and all this affects the packet delivery. In our proposed system we address those short comings by introducing the K-means algorithm and the graph below clearly shows that the proposed system has a better edge than the AODV routing protocol. In fewer number of nodes the PDR is really high for both approaches because there are less connections in these networks therefore packet delivery is almost guaranteed. As the nodes increase it can be noted that the packet delivery ratio will decrease as well because more connections means that there will be an increase in the likelihood of packet failing to reach to their destinations. Packets are likely to drop if the multihop network size is increased. However the K-means/IEE_AODV strategy has optimized routes cutesy of the K-means algorithm and therefore its packet delivery ratio is greater than that of AODV routing protocol for the most part of the network life.

## Summary

From the above analysis it can be seen that the introduction of K-means in the AODV protocol as an optimization criteria has greatly improved the network to work efficiently. It is the desire of every scientist to have a network which not only saves energy in its utilization but also improves in packet delivery and other performance metrics. The simulations can however be conducted with different pause time but according to [1] similar results will come out hence that why the researcher has simulated this proposed system without varying the pause time.

# CHAPTER SIX

## 6.1 CONCLUSION AND FUTURE WORK

In this thesis we have implemented an improved energy efficient AODV routing (IEE_AODV) protocol with **K-means** as a network optimization technique, these two techniques where chosen to address critical aspects of mobile adhoc networks. IEE_AODV routing protocol was chosen in order to have a network which is energy efficient that is a network which is mostly likely to have a longer network lifetime by using the route that has nodes with the highest energy levels. K-means on the other hand was used to create clusters in the network and optimize them in such a way that the nodes within a cluster have shortest path to their cluster head. This optimization will ensure that the path or route chosen will achieve packet delivery in the shortest time.

It is observed from the results that the battery life of our nodes in the K-means/IEE_AODV techniques will be fully utilized because the system chooses the path with the maximum energy. Therefore it's been proved that the amount of remaining energy of each node will be important in probabilistically determining the efficient path. This system will avoid link failures due to power issues in the network because routes chosen will have maximum energy.

We also evaluated our system using other performance metrics like packet delivery ratio, throughput, average end-to-end delay and results show that our proposed system has improved in all this regard and of particular importance is the packet delivery ratio. Some recent researches have shown that AODV routing protocol has better PDR than IEE_AODV because not all the energy efficient paths are reliable, some routes might even be longer and hence packet loss will be prone in that regard. It is however clear that that problem has been addressed in this thesis by the introduction of K-means algorithm. This algorithm will optimize the nodes in the network so that a minimum number of nodes are traversed if data packets are to be transmitted for the source node to the destination node.

K-means algorithm is important in these networks because it allows for smooth scalability of networks, networks can grow and even shrink without much effect to the network operations.

The main objective is to show that these protocols are not perfect for every network requirement so they can be tailor made according to one's needs to solve a particular problem. We can also incorporate other algorithms to help us with certain problems that we encounter in wireless sensor networks.

## 6.2 Future Work

The concept on energy efficiency using the drained nodes can be implemented further using Bio-inspired computing techniques like Ant colony optimization and it can be used on hybrid routing protocols to save energy usage.

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