Designing Light Weight Cluster Based Routing Protocol for Mobile Ad Hoc Networks

Abdulkerim Heyder Mohammed

A Thesis Submitted to the Department of Computer Science and Engineering

School of Electrical Engineering and Computing

Presented in the partial Fulfilment of the Requirements for the Degree of Master's in Computer Science and Engineering

Office of Graduate Studies

Adama Science and Technology University

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Advisor: Tiruveedula Gopi Krishna (PhD)

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DECLARATION

I hereby declare that this Master Thesis entitled "**Designing Light Weight Cluster Based Routing Protocol for Mobile Ad Hoc Networks**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Abdulkerim Heyder	_______________	_______________
Name of Student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled **"Designing Light Weight Cluster Based Routing Protocol for Mobile Ad Hoc Networks"** prepared under my guidance by **Abdulkerim Heyder** submitted in partial fulfillment of the requirements for the degree of Masters of Science in Computer Science and Engineering.

Therefore, I recommend the submission of a revised version of the thesis to the department following the applicable procedures.

Dr. Tiruveedula Gopi Krishna __________________ ________________

Major Advisor Signature Date

APPROVAL PAGE

I, the advisor of the thesis entitled "**Designing Light Weight Cluster Based Routing Protocol for Mobile Ad Hoc Networks**"**,** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Tiruveedula Gopi Krishna	________________	________________
Major Advisor	Signature	Date

We, the undersigned, members of the board of examiners of the thesis by **Abdulkerim Heyder,** have read and evaluated the thesis entitled "**Designing Light Weight Cluster Based Routing Protocol for Mobile Ad Hoc Networks**" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Computer science and Engineering.

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ACKNOWLEDGEMENT

First and foremost, I'm extremely grateful to the Almighty Allah for giving me health and everything needed in accomplishment of this thesis. Words cannot express my gratitude to my Advisor, Dr. Tiruveedula Gopi Krishna, for his guidance, suggestions and invaluable support.

I would like to extend my sincere thanks to my family and friends for their continuous support from very beginning till the completion of this thesis.

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LIST OF ABBREVIATION

ALOHA	Arial Location of Hazardous Atmospheres
BER	Bit Error Rate
CH	Cluster Head
CSMA	Carrier Sense Medium Access
FWCABP	Flexible Weighted Clustering Algorithm based on Battery Power
GloMo	Global Mobile Information System
GPLv2	GNU Public License version 2
HBFLB	Honey Bee Foraging Load balancing
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
LWECM	Light Weight Efficient Cluster based Routing Model
MAC	Media Access Control
MANET	Mobile Ad-hoc Network
NetANim	Network Animation
NS3	Network Simulator 3
NTDR	Near Term Digital Radio
NWBCA	Novel Weight-Based Clustering Algorithm
PB-WCA	Priority-Based Weighted Clustering Algorithm
PRNET	Packet Radio Networks
RWP	Random Way Point
SURAN	Survivable Adaptive Radio Networks
UDP	User Datagram Protocol

WCA	Weighted Clustering Algorithm
WMCHBFLB	Weighted Multi-Objective Cluster Based Honey Bee Foraging Load Balanced

ABSTRACT

Mobile ad hoc network (MANET) is a network of self-organizing, battery constraint nodes that communicate without pre-existing infrastructure in either distributed or clustered structure. Clustering offers a reliable method of connecting mobile nodes, allocating resources effectively, enhancing data transmission quality and enhance network scalability. However, in clustered mobile ad hoc network, cluster formation and cluster-head selection pose considerable clustering overhead which unnecessarily consumes significant amount of energy that causes cluster head change. Besides, cluster-head is loaded with packet forwarding and network management resulting in early cluster-head death. To solve these problems and extend network lifetime, we designed light weight cluster-based routing protocol to minimize overhead during cluster head selection and cluster formation. Our route selection algorithm minimizes cluster head load by sharing the packet forwarding responsibility to member nodes. Thus, cluster head failure due to energy drain caused by overloading of cluster-head is minimized. Furthermore, route selection considers residual energy of nodes which reduces member node failure. Our proposed solution is implemented in NS-3.35 and its performance is compared to existing works NWBCA and PB-WCA in terms of number of cluster head change at a given pause time, clustering overhead in the overall simulation time, cluster head changes at different node speed and clustering overhead at different mobile node speed. The proposed LWCRP shows better performance than the existing works in all the performance evaluation metrics and improves overall network lifetime and network performance.

Keywords: MANET, CH, *clustering overhead, clustering and cluster head selection,* LWCRP, *NWBCA, PB-WCA.*

CHAPTER ONE

1 INTRODUCTION

1.1 Background of the Study

Nowadays, wireless technologies share for communication in information technology is highly increasing (Al-Omari & Sumari, 2010). Infrastructure based wireless networks like conventional mobile network and cellular networks are among wireless technologies covering the whole world. The good feature of wireless technologies is offering device mobility within specific region of communication range.

Wireless technologies can be infrastructure based or infrastructure-less which we call an ad-hoc network. In an Infrastructure based wireless networks fixed and wired gateways are used at their base stations. In this type of wireless network mobile devices are connected to and communicates with a base station nearest to it. If the device leaves the range of one base station or moves out of communication radius of wired gateway of its base station and enters the communication range of another base station a “handoff” occurs between the old and the new base stations enabling continuous communication throughout the network (Ismail & Ja’afar, 2007).

The other type of mobile wireless network which is called ad hoc network is the infrastructure-less mobile network, does not depend on fixed routers. Devices in infrastructure-less networks are connected arbitrarily and free to move. In this type of network all nodes can serve as a router, capable of discovering routes to other nodes and maintain the route in the network (Ismail & Ja’afar, 2007) .

A mobile ad hoc network (MANET) which is an infrastructure-free wireless technology comprises a group of movable devices that can organize themselves and can directly communicate with each other needless of preexisting infrastructure. Therefore, in order for the nodes in a MANET to forward packets to a particular destination within the network, the routing protocols define how the nodes can serve as host and as router when needed (El-Semary & Diab, 2019).

MANET eliminates the need for the infrastructure typically required in conventional mobile network and cellular networks by creating a network of nodes that communicate wirelessly without depending on any pre-installed infrastructure.

After being remained in the military field for a long time, MANET become popular in different areas outside military battlefield in the middle of 1990s. Consequently, research on mobile ad-hoc networks (MANET) began in 1995 during a conference session of the Internet Engineering Task Force (IETF) (Al-Omari & Sumari, 2010).

Each device in the MANET can operate on its own or be connected to large network. The device knows all relevant network information and can serve as a router to send packets in reliable manner. The nodes in a transmission range of communicating devices receive the information from each other. However, intermediate nodes establish communication path between sender and receiver and forward the packets, if receiver is out of range of sender. Usually cluster head (CH) is used to manage communication in which intermediate nodes forward the packets toward destination.

MANET is characterized by dynamic topology, mobility, energy constraint, restrictions in bandwidth and transmission range (Nirmaladevi & Prabha, 2022).

The usage of MANET in various fields is rapidly grown due to its ability to function without preexisting infrastructure. MANET has been extensively used in various areas, such as disaster recovery, emergency rescue (Ahmad et al., 2019) video conferencing, health care, mining activity(Karthick & Asokan, 2021), industrial, educational applications(Nirmaladevi & Prabha, 2022) and battlefield communications (Chen et al., 2020).

The structure of MANET can be distributed or clustered. All nodes have equal role and network topology is freely adjusted based on node mobility in a distributed network structure of MANET. In the cluster network structure, the key factor is the choosing of most appropriate cluster head because cluster head is tasked with extra load than any other member nodes of the network.

Consequently, selecting cluster-head nodes is a crucial aspect of network clustering. Clustering helps address routing protocol challenges, enhances quality of transmitted data, as well as boosts scalability of network (Song et al., 2020). In a MANET, clusters offer a stable method of connecting mobile nodes, efficiently assign resources, and create a layered network environment to guarantee the MANET's structural stability.

In this study, we designed light weight cluster-based routing protocol to minimize overhead in the process of cluster head selection and dividing network into clusters. Our route formation algorithm minimizes cluster head load by sharing the packet forwarding responsibility to member nodes. Thus, cluster head failure due to energy drain caused by overloading of CH is minimized. Furthermore, route selection considers residual energy of nodes which reduces member node failure.

1.2 Motivation of the Study

Currently, almost all continents of this world are covered by infrastructure-based Internet, making Internet a part of our day to days life. However, infrastructure-less, self-organizing wireless network, helped by the advancements in network technologies like IoT is the perfect fit for the issues like disaster recovery, emergency and etc. where temporary network is needed. Mobile ad hoc network (MANET) suits for such like issues and its infrastructure-less behavior gains it a lot of popularity in the fast-growing world demanding connectivity among people. Ad hoc networks are gaining attention because they operate without the need for infrastructure and applied in various areas (Kaur & Thakur, 2019).

The routing protocol plays a crucial role in the performance of a MANET, as it directly impacts the quality of data transmission between network layer and upper layers (Sathyaraj & Rukmani Devi, 2021). To simplify routing in MANET structuring a network is crucial. The network structure or topology has impact on the protocol efficiency. In a dynamic network, hierarchical or cluster-based structure has been used to enhance routing efficiency (Bentaleb et al., 2013).

Even though clustering simplifies network structure and improves routing efficiency, frequent cluster head change and clustering overhead are the common problems in MANET routing protocols (Pathak & Jain, 2019).

We are motivated by the nature of application of MANET that enables it to be established in areas where the infrastructure of internet network is either damaged or did not establish.

1.3 Statement of the Problem

MANET is a multi-hop network with a rapidly changing topology that changes frequently because of the mobile nature of its nodes. Therefore, MANET network management requires efficient routing protocol that constructs communication paths among nodes in the network while reducing control overhead or minimizing computation load of energy constraint devices of MANET network (Hoebeke et al., 2004). One way to manage resource effectively in MANET is dividing the network into clusters. Clustering approach solves capacity and scalability problems by providing stable way of connecting nodes in the network and allocating resources efficiently in mobile ad hoc network that operates in the absence of pre-installed infrastructure. (Aissa et al., 2013).

In a network segmented into clusters, every cluster has a dedicated cluster head tasked with managing packet transmission between different clusters (Chauhan et al., 2011). Energy consumption and load balancing are the problems to be given higher consideration and addressed during routing process to prolong network lifetime (Nesa Kumar & Saravanan, 2018).

Different researchers designed protocols aimed at reducing consumption of energy and balance the load of transmitting packets in MANET network. WMCHBFLB proposed by (Nesa Kumar & Saravanan, 2018) is multi-objective protocol which used residual bandwidth and residual energy of mobile nodes to form cluster. They compared load of cluster heads to threshold specified beforehand using HBFLB. The load of cluster heads in the network are compared to the threshold and the cluster head with optimum load is chosen to transmit data. WMCHBFLB does not consider sharing the load to other member nodes and does not consider intermediate nodes residual energy which is one of the main causes of re-clustering. LWECM (Dixit et al., 2020) minimized burden of cluster head by sharing the load to member nodes. However, its one hop clustering yields multiple clusters and refugee nodes adds extra load to cluster head. To achieve reduced overhead and minimum number of cluster head change we proposed two-hop clustering protocol that takes node degree and residual energy into account in the process of choosing cluster head and forming cluster.

During the routing process a route having a combination of nodes with highest remaining energy is selected to minimize the chance of intermediate nodes death.

1.4 Research Questions

This study addresses the issues formulated below.

RQ1. How to select cluster head and form cluster for MANET with minimum overhead while ensuring efficient network operation?

RQ2. How to minimize number of cluster head change?

1.5 Objective of the Study

1.5.1 General Objective

The primary goal of this study is designing light weight cluster-based routing protocol for mobile ad hoc networks.

1.5.2 Specific Objectives

- Developing an algorithm that selects cluster head and forms cluster by computing weight of each node from residual energy and degree of nodes.
- Establishing a route from a combination of nodes having highest remaining energy
- Simulate and evaluate the performance of the proposed work against NWBCA and PB-WCA

1.6 Significance of the Study

The designed lightweight cluster-based routing protocol establishes clusters with minimal overhead and fewer cluster head changes while distributing the load among nodes. This method minimizes the consumption of energy and extends the network's lifetime. So, it can yield good profit in: -

- **Military Battlefield:** the proposed solution reduces the early death of MANET nodes to sustain an information network among military information headquarters, vehicles and soldiers.

  Local Level: the proposed solution autonomously establishes a transient and instantaneous multimedia network, enabling information sharing and dissemination among attendees at conferences or courses using notebook or palmtop computers.
- **emergency/rescue operations:** in rescue operations, the proposed solution facilitates the use of ad hoc networks for disaster recovery efforts, such as during fires, earthquakes and floods, where infrastructure is either nonexistent or damaged.
- **Personal Area Network (PAN):** the proposed solution facilitates intercommunication among different portable devices, like cellular phones PDAs and laptops.

- ✧ **Future researchers:** scholars can use this work as a contribution for providing better performing protocol in different scenarios.

1.7 Scope and Limitation of the Study

1.7.1 Scope of the Study

This study simulates 100 mobile nodes in the area of $250x250m^2$ at different mobility speed. The emphasis of this study is minimizing the consumption of energy and extend the lifetime of MANET network by designing a lightweight cluster-based routing protocol. The protocol employs a weight-based clustering scheme for cluster formation and cluster head election. Weight based clustering routing scheme uses a combination of two or more parameters to form cluster and elect cluster head. The proposed work reduces clustering overhead to minimize energy consumption during clustering process and reduces cluster head change by sharing the load of cluster head to another member nodes of the network to keep the network stability.

1.7.2 Limitation of the Study

This study aims at reducing the overall consumption of energy in MANET network by reducing clustering overhead, minimizing cluster head change, reducing re-clustering and sharing the load among nodes during packet transmission. The design and development of proposed solution focuses on clustering and cluster head selection, cluster maintenance and load sharing problems while security which is one of the main issues in ad hoc network is not considered because of the requirement of additional study and security is out of our scope.

1.8 Application of the Study

This study addresses clustering overhead and cluster head change problems of cluster-based MANET routing protocols. The proposed protocol reduces calculations during cluster formation and cluster head election. It reduces cluster head change due to CH death. Node degree and residual energy are used to calculate the weight of each node and the node with higher weight will be selected as cluster head. The benefit of this study is its applications in education, emergency rescue, disaster recovery, health care and battlefield communication.

1.9 Organization of the Study

This thesis is organized into six chapters. Chapter one covers the background of the study, including the statement of the problem, objectives, significance, and scope. Chapter two provides a literature review of related works, offering a summary of existing research in the field and highlighting the specific problems that this study aims to address. The third chapter discusses methodology used in developing the proposed solution. Chapter four details the proposed lightweight cluster-based protocol. The five chapter covers the simulation of the proposed clustering algorithm and analyzes the simulation results. The final chapter, chapter six presents the conclusions and recommendations for future work. References and appendices follow the fifth chapter.

CHAPTER TWO

2 LITERARURE REVIEW AND RELATED WORK

2.1 Overview of Mobile Ad hoc Network

Mobile ad hoc network (MANET) is an autonomous, self-organizing, infrastructure-less, dynamic topology wireless network consisting mobile nodes that operate as both router and host (Muneeswari & Manikandan, 2019).

MANETs evolution came through different stages which can be categorized into three generations. Generation one, known as PRNET (packet radio networks) and emerged around 1972 (Islam et al., 2018) is the earliest form of ad hoc networks. United States' Department of Defense sponsored the development of PRNET. The PRNET integrated distance-vector routing with the ALOHA and CSMA approaches for medium access. It is a packet-switched ad hoc network utilized in mobile battlefield.

MANET’s generation two networks, called SURAN was emerged in the beginning of 1980s. later the performance improvement of electronic devices like handphones, laptops and other portable network devices brought the idea of applying MANET in commercial (non-military) activities (Raja & Santhosh Baboo, 2014).

Two communication mechanisms developed during MANET’s second generation were NTDR and GloMo. GloMo offers Ethernet-like multimedia connectivity in office environments for handheld devices, accessible anytime and anywhere. NTDR was used in self-organized two-tier ad hoc network and it used link state routing and clustering method.

A third generation of MANET claimed to be commercial network was evolved in 1990’s. The advancements in notebook computers, equipment operating on radio frequency and infrared as well as open-source software had facilitated the emergence of third generation MANET. Since MANET got popularity various routing protocols have been developing and standardized by IETF’s performance group (Puri & Arora, 2014).

In the MANET, nodes are allowed to randomly move freely anywhere throughout its network. They are free to move on unpredictable time at different speed and with different momentum.

Therefore, identifying which protocol to employ is imperative to get the best performance from multiple nodes connected in MANET (Saudi et al., 2019). Figure 2.1 shows MANET structure.

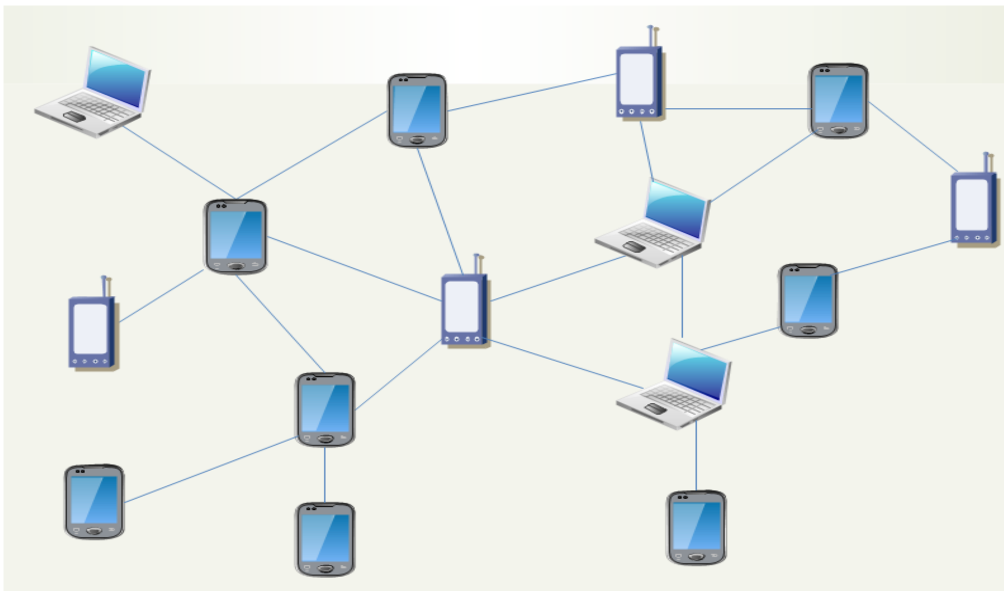

Figure 2.1 MANET structure (Soomro et al., 2022)

In a MANET, nodes cooperate with one another to carry out the task of routing, which involves moving packets from source to destination nodes. Nodes that are within each other's transmission radius can communicate directly with one another. But, in the case when sender and receiver are located at a distance higher than the communication range rerouting packets is mandatory. For this purpose, intermediate nodes are involved in the rerouting process by accepting the packet from sender and forwarding the packet to the desired destination (AL-Dhief et al., 2018). It is not a point of dispute to say MANET are very important wireless network with few issues, caused by its infrastructure-less nature, nodes mobility, dynamic topology etc., are still in process to be addressed.

Creating stable network and managing communication is the most challenging issue in MANET. This challenge is caused by the frequent change of MANET network's topology because of random mobility of nodes (Pathak & Jain, 2017).

Routing protocol is the main issue of concern in MANET, attracting researcher's attention than other issues like privacy and security. When it comes to a large network, multicasting can also be a problem. Additionally, consideration must be given to the nodes' mobility, efficiency, and power consumption. Ad-hoc networks include nearly all generic devices (smart devices, smartphones, laptops, palmtops, etc.) that can connect to any kind of network. Understanding the computing capacity, storage capacity, power consumption, and communication capabilities of each connected device is also essential because they differ greatly depending on the paradigm. The function of an ad hoc devices is detecting the existence of nearby devices and to determine the characteristics of the connected devices (Kaur & Thakur, 2019).

Delivering packets to desired location needs stable topology. Hence, quick response must be given to the topology change detected in the network. Designing a robust routing strategy was challenged by limited resources of MANET devices. Therefore, routing algorithm that uses these limited resources effectively is required. The algorithm should be capable of determining best path, reduce overhead, reduce power consumption, minimize time to converge and maximize bandwidth usage after topology modification (Ghazy et al., 2019). Some of the advantages of MANETs (Singh & Prakash, 2020) are:

- Fast and easy network establishment of wireless network
- Capability of the network system to be extended from any place
- Increased reliability due to multiple path routing
- Flexibility of MANET network and easy change of network configuration

2.1.1 Characteristics of Mobile Ad-Hoc Network

As stated in (Puri & Arora, 2014) and (Yadav & Chug, 2019) MANET have the following characteristics described below and shown in the figure 2.2.

- **Dynamic Network Topologies: -**a free movement of nodes in MANET causes topology change at occasional times.
- **Low Bandwidth: -** Compared to settled foundation networks, the transmission range of MANTET networks is shorter. Because of the influence of different access, blurring, clamor, and impedance conditions, the throughput of remote correspondence is lower than that of wired correspondence.
- **Restricted Battery Power: -** nodes operate on limited batteries and other limited energy sources. Therefore, energy conservation is the most critical design improvement criterion.

- **Decentralized Control: -** Due to unreliable connections, the functionality of MANET relies on the collaboration of participating nodes. As a result, implementing a protocol that relies on a centralized administration becomes challenging.
- **Inconsistent Communications: -**Wireless connections' shared medium and erratic channel characteristics can result in high packet loss rates and routing instability, which are frequent problems that lower throughput in multi-hop networks. This implies that security solutions for wireless ad hoc networks should not rely on stable communication.
- **Physical Protection: -** MANETs are more exposed to physical security damages compared to fixed wired networks. Mobile nodes are smaller, fragile, and handheld. As portable devices become increasingly compact, they are more easily damaged, lost, or stolen, making them susceptible to misuse by adversaries. The heightened risk of various types of network attacks must be carefully considered.
- **Adaptability: -** Scalability is a critical concern because of the constrained memory and processing capability of mobile devices, particularly in the context of large network sizes (10,000 or possibly 100,000 nodes).
- **Security Threats: -** Mobile wireless networks are generally more susceptible to physical security concerns than stationary cable networks. The heightened danger of spoofing, denial-of-service, and eavesdropping must be considered.

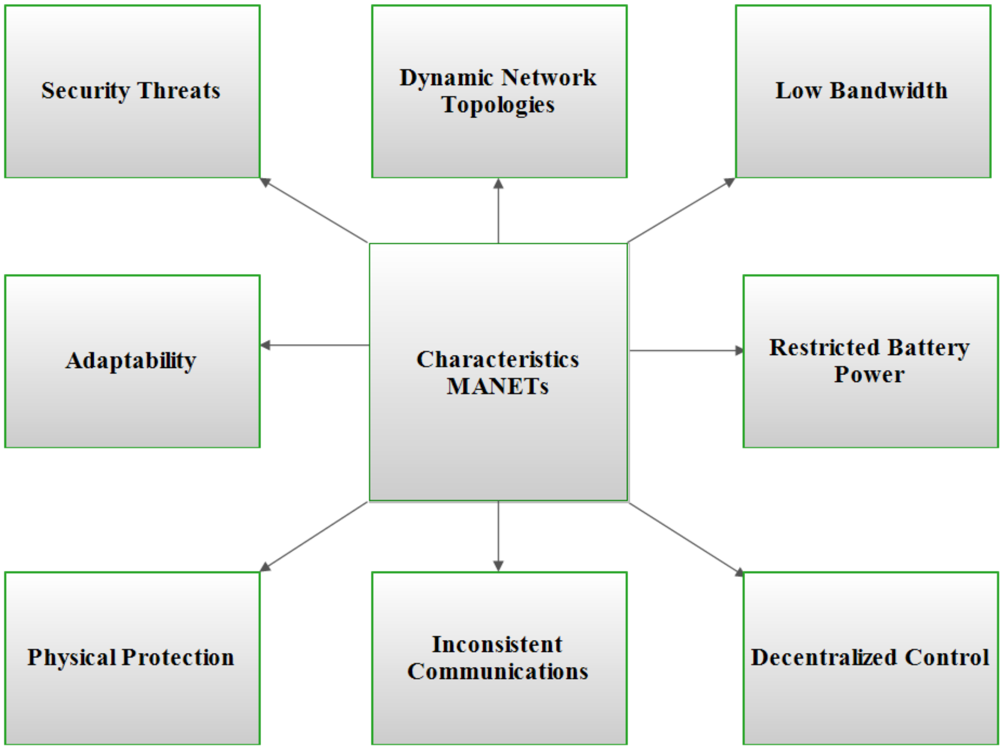

Figure 2.2 Characteristics of MANET

2.1.2 MANET's Architectural Model

According to (S. Naga Mallik Raj & S. Neeraja, 2019) the MANET architecture is composed of three layers: (1) Enabling Technologies (2) Networking (Systems administration) and (3) Middleware and Application. The figure 2.3 below shows the architecture of MANET with their technologies.

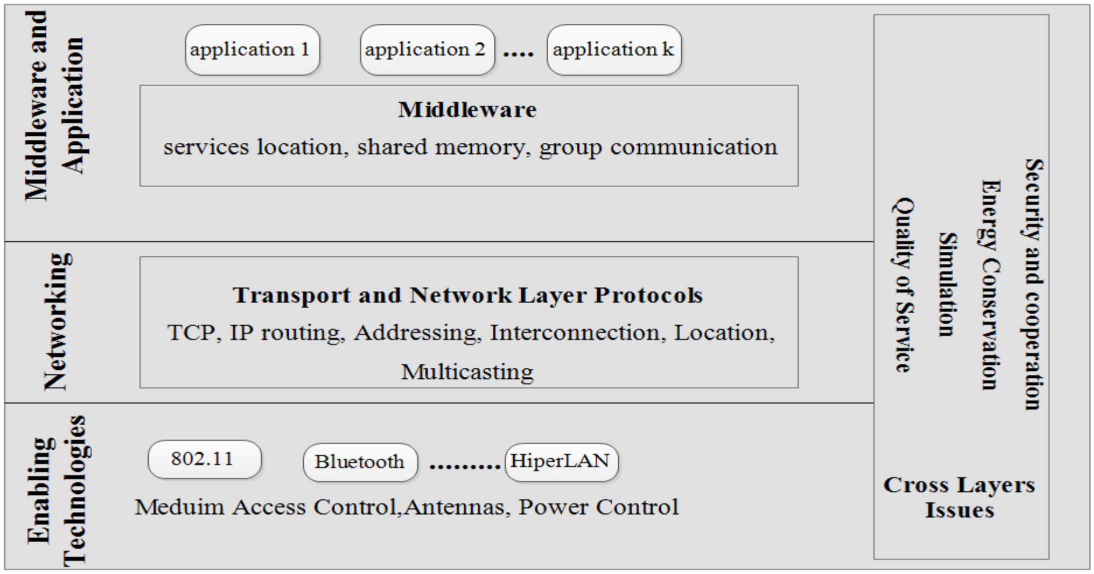

Figure 2.3 Architecture of MANET (Alrkiyan, 2016)

Each component of the above architecture is discussed below.

- **Enabling Technologies**: - are basic technologies implemented in MANET application. The technologies include Bluetooth, Wide Area Network (WAN), Local Area Network (LAN), Personal Area Network (PAN) and 802.11 standards.
- **Network layer: -** maps the exact location of a device with its logical address and ensures reliable communication between source and destination.
- **Middleware and Applications: -** more integrated with user-side applications which are managed by middleware services like service location, shared memory in the network, and group communication.

2.2 Design Issues of MANET Routing Protocols

Factor to be considered while designing MANET routing protocol include (Iram Nausheen Ahmed, 2021):

- **Limited wireless transmission range**: the frequent fluctuations in MANET topology require more control overhead to preserve up-to-date topological data at every node, resulting in greater bandwidth waste.

- **Broadcast nature of the wireless medium**: any node in a node's direct transmission range receives all transmissions that the node makes. Designing a protocol that addresses broadcasting is challenging.
- **Packet losses due to transmission errors**: packet loss caused by factors like a high BER in the wireless channel, more collisions because of hidden points, interference, unidirectional links, and node mobility cause path breaks.
- **Mobility-induced route changes**: nodes movement in ad hoc wireless networks, make the topology of MANET very dynamic. So, path break occurs frequently to the communication session resulting the frequent change of route.
- **Battery constraints**: since battery capacity is fixed, nodes are extremely energy constrained. Power conservation and considering power-aware path selection is important.
- **Frequent network partitions**: network partitions in ad hoc networks can be caused by the nodes moving at random mobility. The intermediate nodes are typically the ones who suffer the most from this partitioning.

2.3 MANET Routing Protocols

The sending of data from a source node in the network to a destination node, either directly or through the assistance of network intermediary nodes, is known as routing. The routing process involves one or more intermediary nodes. The routing concept essentially entails two steps:

- locating the optimal routing paths and
- sending data throughout a network.

2.3.1 Classification of MANET Routing Protocols

Basically, routing in a network can be classified as a static routing and dynamic routing. In static routing an administrator of the network manually configures the network and maintains routing table. Dynamic routing which is employed by MANET establishes the route based upon the network state (Sharma et al., 2016).

Two general approaches used to classify MANET routing are network structure and routing strategy (Ahmed, 2017). Network structure defines how the nodes in the MANET network are connected and topology is formed while routing strategy specifies whether the employed protocol is table driven or source initiated. The figure 2.4 on the next page shows classification of MANET routing protocols.

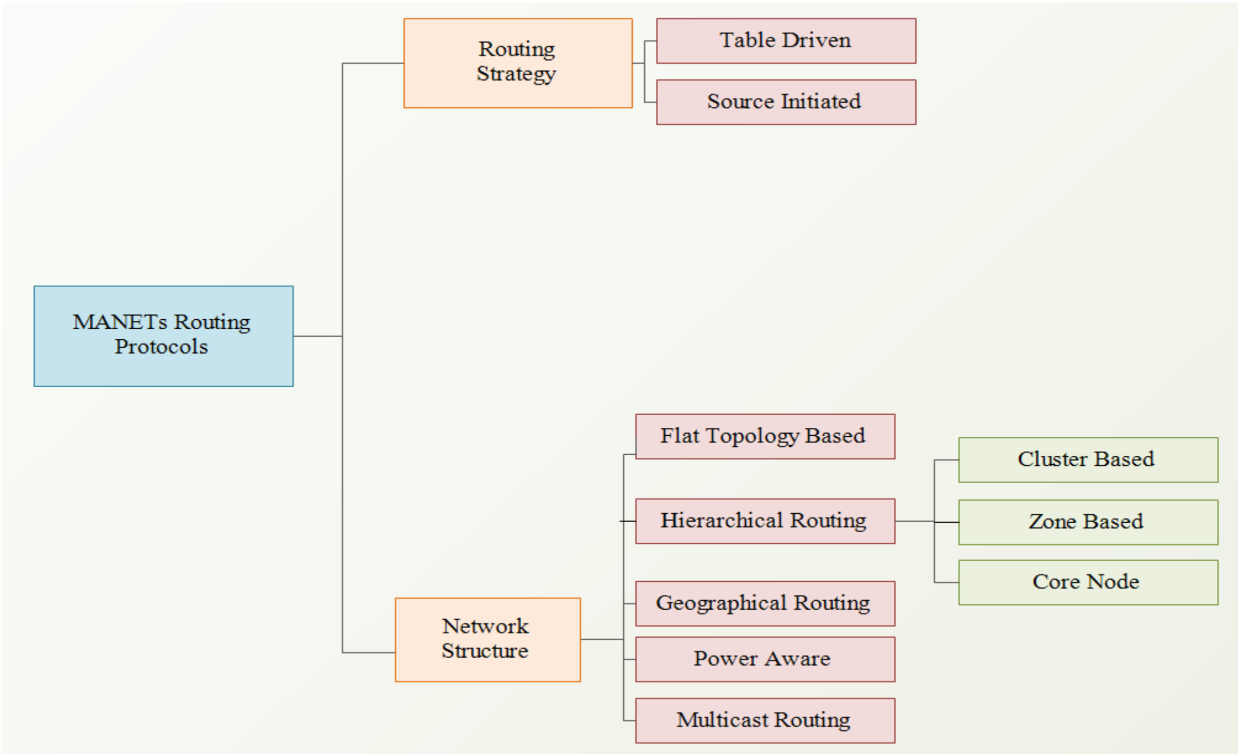

Figure 2.4 MANETs Routing Protocol Classification (Mustafa Ahmed & Othman O. Khalifa, 2017)

From the above figure 2.4 we understand that MANET routing protocols are categorized based on network structure and routing strategy.

Based on routing strategy MANET's routing protocols are classified as:

- **Table Driven (Proactive): -** stores routing table, that contains an updated information of routes to nodes, for each node. Periodically exchanges control message to keep latest routing information.
- **Source initiated (On Demand): -** also known as reactive routing protocols because it creates connections between nodes only when necessary or when existing connections are lost.

From the network structure perspective, protocols are categorized as hierarchical routing, location-based routing (geographical routing), flat routing, multicast routing and power-aware routing.

- **Flat Routing (Uniform) or (Topology Based): -**Routing table stores every identity of a network, making the network summarization difficult. Attempts to arrange the network or its traffic are futile.
- **Hierarchical routing: -** to solve the routing overhead of flat routing, hierarchical routing has come to existence. It enhances network stability as well.
- **geographical (location-based routing): -** When a node uses geographical routing, it notifies its neighboring nodes of its location and records the information it receives from them. When a packet is received for forwarding, the location information is used to route it by combining neighbor nodes that exist between source and destination.
- **power-aware routing: -**power aware routing protocols select a node based on a maximum energy for transmitting packets from source to destination.
- **multicast routing: -** Focuses on packet forwarding to multiple destinations. It determines routes to the different locations while accounting for bandwidth availability and node mobility.

2.4 Hierarchical Routing

The hierarchical routing mechanism divides the nodes in the network into a group of nodes called clusters. A cluster can be overlapping or non-overlapping. It is a good choice to manage network especially if the MANET network size increases. Nodes in the hierarchical routing play different roles according to their level in the tree of hierarchy. Nodes position in the hierarchy determines the way of route construction for packet transmission. There are three subcategories of hierarchical routing protocols namely cluster-based, core-based and zone-based. These protocols are grouped based on how the mobile nodes are set up, how they are managed, and how they perform routing.

- **Zone based: -** every node has a local scope, and different routing strategy is used inside and outside the scope.
- **Cluster based: - c**luster heads oversee membership management and routing operations for the mobile nodes that make up the clusters.
- **Core based: -** critical nodes are dynamically chosen to form the network's "backbone." The "backbone" nodes perform specialized tasks like establishing routing paths and distributing data and control packets.

2.5 Cluster Based Routing Protocols

A cluster-based routing protocol is the most favored hierarchical routing method. It divides the network into connected substructures, referred to as clusters, through a process known as clustering. These clusters may overlap or exist independently.

In a cluster, all nodes are connected to each other either directly or via neighboring nodes. Every cluster has a cluster head (CH), and each is distinguished by particular metrics such as degree, identity, weight, mobility and density (Dhamodharavadhani, 2015). The cluster head does the job of coordination within each substructure and supervises the other nodes in the cluster called member nodes. A node that is shared by two or more clusters is termed a gateway.

Within its assigned substructure, the cluster head (CH) takes on the responsibilities of a coordinator, communicating with other CHs and acting as a temporary base station for the zone or cluster. Clustering is integral for enabling efficient communication among nodes, especially due to the limited battery power of mobile nodes. Since the battery power of mobile nodes is finite and irreplaceable, the depletion of power can lead to nodes becoming inactive, which adversely impacts network performance. Therefore, it becomes crucial to always save mobile nodes' energy, with a focus on maximizing communication range and minimizing energy consumption (Monga et al., 2019a).

The use of clustering represents one of the most effective algorithms for optimizing energy consumption and managing ad hoc networks, as highlighted by (Sharifi & Babamir, 2020). This approach serves to conserve energy within nodes, mitigating rapid battery depletion, and involves the aggregation and consolidation of data by the cluster head node for transmission to other nodes. In addition to the cluster head, other nodes within the cluster include gateway nodes and member nodes. The provided Figure 2.5 illustrates the clusters and the different types of nodes present within a cluster.

A clustering-based network in Mobile Ad hoc Network (MANET) offers a reliable method for efficient resource allocation while ensuring stability in the network structure through the establishment of a hierarchical environment. By implementing a clustering-based network, it becomes possible to achieve the primary characteristics required in MANET (Rahman et al., 2020b).

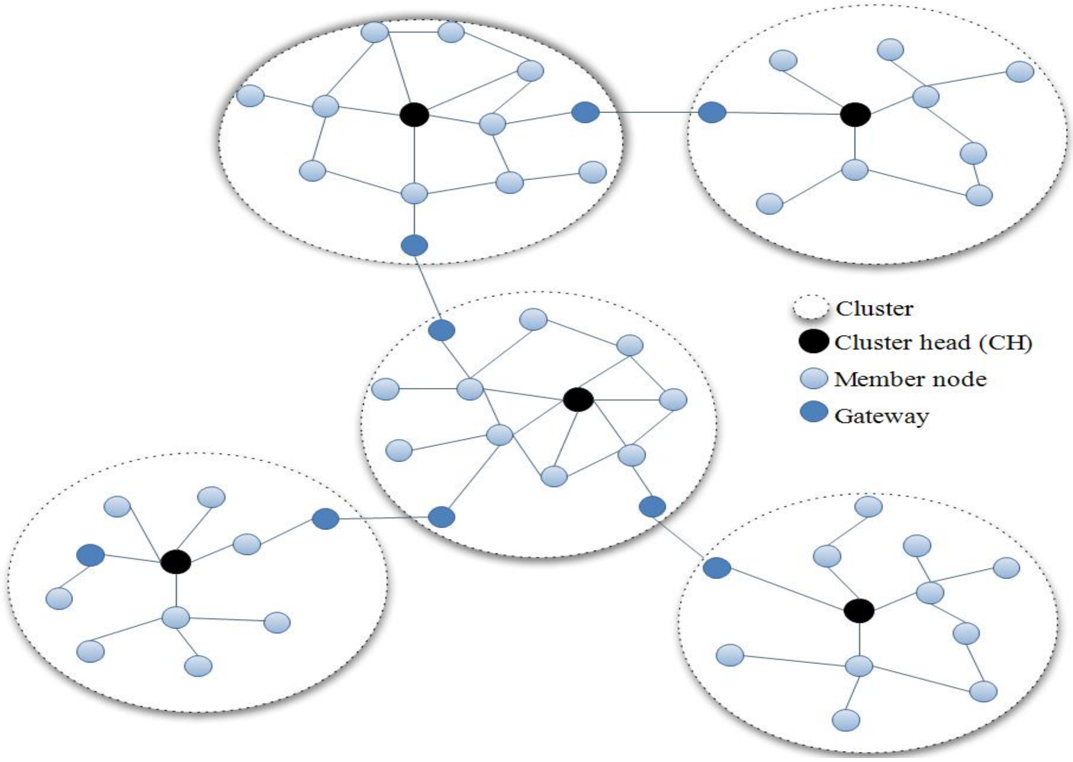

Figure 2.5 Clustering in MANET (Rahman et al., 2020a)

2.5.1 Mobile Ad-Hoc Network Clustering Schemes

The clustering algorithms classification is primarily determined by the algorithms' characteristics and the mechanisms employed for cluster head selection. The prevalent clustering schemes as discussed in (Monga et al., 2019b) include identity-based, topology-based, energy-based, mobility-based, artificial intelligence-based and weight-based methods. MANET clustering schemes are shown in figure 2.6.

2.5.1.1 Identity Based Clustering

Every node in the network has a unique ID assigned to it, and it is aware of the IDs of the nodes that are nearby. The node IDs are used to determine who will be the cluster head. The cluster head is designated as the node with the lowest ID or the highest ID.

2.5.1.2 Mobility Based Clustering

In mobility-based clustering scheme, mobile nodes with similar moving pattern are grouped together and form cluster with high stability.

2.5.1.3 Topology Based Clustering

In topology based scheme, clusters are formed through parameter calculations based on network topology. The cluster head is chosen according to the node connectivity metric.

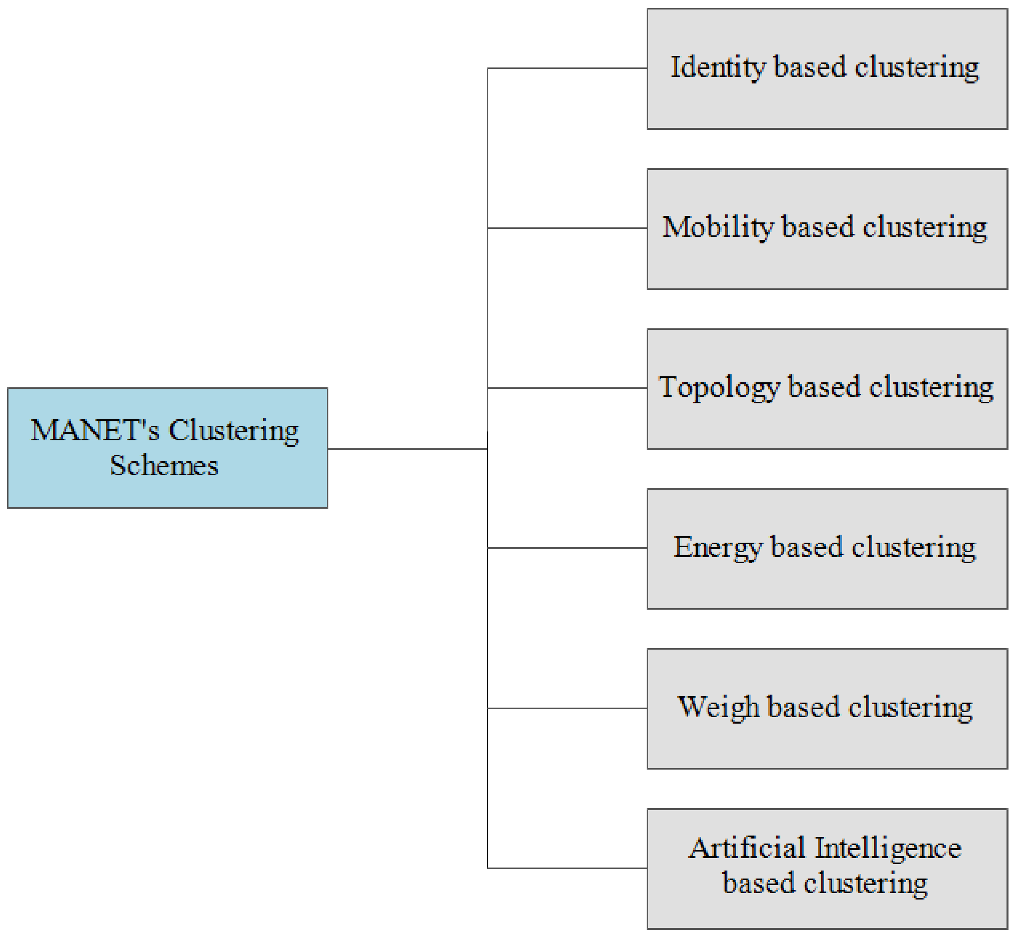

Figure 2.6 MANETs Clustering Scheme

2.5.1.4 Energy Based Clustering

The lifespan of the network is directly impacted by node battery energy. Network performance is severely hampered by the energy constraint nodes of the network. Cluster head is the node with maximum energy.

2.5.1.5 Weight Based Clustering

Weight-based clustering techniques effectively incorporate a variety of parameters, including node mobility, distance difference, battery power, and degree of nodes. The scenario will determine how each metric's weighting factors are changed.

2.5.1.6 Artificial Intelligence Based Clustering

In this scheme artificial intelligent methods like fuzzy logic are employed in cluster head selection and cluster formation.

2.6 Related Work

As it enables the splitting of a big network into smaller sub-networks, clustering is essential to ad hoc networks. Reduced energy consumption and effective MAC and routing protocol implementation, security features, and data aggregation are just a few benefits of cluster-based architectures (Aissa & Belghith, 2014).

In a cluster, a dedicated node called a cluster head is responsible for cluster management tasks. These tasks may include managing the medium access, disseminating control messages, and performing data aggregation. The role of the CH is crucial for the efficient functioning of the network. When a CH fails, it leads to expensive operations such as CH re-election and cluster re-formation, which significantly impact the overall network performance. Therefore, the efficient operation and stability of CHs are of utmost importance in achieving optimal network performance in ad hoc networks.

Researchers have developed different cluster-based routing protocols for mobile ad hoc network (MANET) with different clustering and cluster head selection schemes. These schemes include topology-based, identity-based, energy-based, mobility-based and artificial intelligence-based and weight-based clustering (Monga et al., 2019a).

In MANET, reducing energy consumption is a crucial job in routing processes. One approach to achieving this is by minimizing overhead during cluster formation by using a mechanism that make less computation during cluster formation and forward packets in energy efficient way. Selecting the path constructed from a combination of nodes with highest remaining energy for packet transmission minimizes early node death and helps increase the overall network lifetime.

According to (Monga et al., 2019a), weight-based clustering algorithms, also known as load balancing, have shown good performance over other clustering schemes in MANET. Weight-based clustering considers multiple parameters, like node degree, energy, mobility, and transmission bandwidth, which are referred to as weight factors (Karimi et al., 2014). Weighted cluster-based routing protocols related to our work are discussed below.

(Basagni, 1999) proposed two of the first weight-based clustering algorithms: DMAC (Distributed and Mobility-Adaptive Clustering) and DCA (Distributed Clustering Algorithm). These algorithms consider parameters related to node mobility. Every node in the cluster created by these algorithms has direct access to at least one cluster head, ensuring effective communication between any two nodes within or in different clusters. While DMAC outperforms DCA by adjusting to node mobility in MANET, it is better suited for dynamic networks. DCA is best suited for static or quasi-static networks.

OD-WCA is an on-demand weighted clustering algorithm that was proposed by (Chatterjee et al., 2000). Ideal node-degree, mobility, transmission power and the nodes' battery life are all combined into one algorithm. Better performance in terms of lower communication overhead is attained by OD-WCA. However, the cluster head election process in OD-WCA involves frequent changes, leading to high message passing among nodes, which results in increased control overhead and higher energy consumption of the nodes.

The Weighted Clustering Algorithm (WCA) developed by (Chatterjee et al., 2002) is an integrated weight metric-based clustering method aimed at creating single-hop clusters. WCA utilizes four key parameters – mobility, mobile node degree, transmission power and battery power to determine the optimal cluster head for each cluster. The CH is elected from the mobile nodes according to the lowest combined weight. However, this algorithm consumes more time and bandwidth, leading to delay in cluster formation. Additionally, restricting the cluster size to a single hop hinders scalability in large scale network environments. Furthermore, system efficiency is compromised when a cluster head attempts to serve a number of nodes beyond a predefined threshold. Despite outperforming other clustering algorithms, WCA suffers from the drawback of imposing significant control overhead on nodes for weight calculation as highlighted by (Dixit et al., 2020).

Node position data is combined with other elements including transmission power, battery power, transmission rate, node degree and mobility in the work of (Dhurandher & Singh, 2005) to establish the weight of each node in the clustering approach. By selecting the node with the lowest weight as the cluster head, the number of formed clusters and the frequency of reaffiliations in different scenarios are decreased, improving the stability of the clustered topology.

(Bricard-Vieu et al., 2006) 's study introduces a local cluster head election process achieved by an on-demand distributed clustering algorithm designed for multi-hop wireless ad hoc networks. Distributed mobility prediction is used in this method to calculate the weighted clustering algorithm. To minimize overhead, an interval was introduced between two messages, during which nodes predict the movement of their cluster heads to mitigate stability issues within the clusters. (El-Bazzal et al., 2006) proposed the Flexible Weight Based Clustering Algorithm (FWCA). FWCA claims to minimize number of clusters in the network, maintain stable clusters, minimize the frequency of algorithm invocations, and maximize mobile nodes lifespan. It strives to elect efficient, stable, and low-overhead cluster heads to enhance overall system performance.

In the WACHM (Yi Wang et al., 2007) approach, cluster head selection and maintenance involve using battery power, average link stability, degree difference and the dependency probability of mobile nodes. This method has shown improved scalability and reduced overhead. On the other hand, the Hierarchical Weighted Clustering Algorithm WACA (Brust et al., 2007) focuses on mitigating the need for frequent re-clustering within the network by taking into account the stability factors of the nodes. It does not take into account metrics like speed, node mobility, or battery, but instead focuses solely on topological characteristics and device parameters, making it simpler to be implemented in mobile nodes. Although it has been demonstrated to establish a stable clustering scheme, the frequent changes in topological parameters brought about by the mobility of nodes in MANET increase the communication overhead for weight calculation.

In the FWCABP protocol introduced by (Hussein et al., 2008), with a static network topology, cluster head is selected according to neighboring node information, and clusters are maintained locally. This method efficiently manages consumption battery power by dynamically changing the role of a nodes from being cluster head to becoming cluster member, thus enhancing load balancing. FWCABP also introduces pre-defined threshold values for the nodes created by the cluster head, resulting in a reduction in the cluster formations average number, improved cluster stability, and maximized mobile nodes lifespan. In the proposed work of (Zou et al., 2008), the performance of WCA is enhanced by mitigating network overhead caused by frequent reaffiliations in the WCA process. This improvement contributes to greater overall network efficiency and stability.

In the study by (Karunakaran & Thangaraj, 2008), the weight value for selecting cluster head is calculated from connectivity, stability and energy level, selecting the node possessing minimum weight as a cluster head.

A linear algorithm was presented by (Adabi et al., 2008) to determine the node's score based on variables like stability, number of neighbors, number of members, and remaining battery power. When compared to both WCA and DWCA, their method produced better end-to-end throughput, less overhead, a longer lifespan, and fewer clusters.

The EWCA (Li et al., 2009) represents an enhanced iteration of the WCA, with its algorithm segmented into clustering setup and cluster maintenance phases. This refinement aims to decrease the frequency of re-affiliations, prolong the lifespan of nodes, and reduce the overall number of clusters. Notably, the EWCA presents limitations in terms of its applicability to isolated nodes seeking to join an existing cluster and become member or declare themselves as a cluster head independently. (Safa & Mirza, 2010) introduced a dynamic energy-efficient clustering algorithm developed to improve overall network lifetime. However, the load balancing issue remained a topic requiring further attention and potential development.

The WACA algorithm, introduced by (Muthuramalingam et al., 2011) improves upon the limitations of the EWCA by computing the combined weight for each node based on factors such as sum of distances and average speed, addressing issues related to clustering and node dynamics. (Chauhan et al., 2011) proposed a distributed weighted clustering algorithm that integrates weight metrics such as transmission range, node degree, energy, and node mobility. Their approach demonstrated superior performance when compared to the distributed weighted clustering algorithm (DWCA).

The work of (Karunakaran & Thangaraj, 2011) devised a service discovery architecture that minimizes communication costs by calculating weight from power level, connectivity, and stability metrics, thereby distributing the communication load more efficiently. (Monsef et al.,

2011) introduced an Efficient Weight Based Clustering Algorithm, the first of its kind to utilize energy in calculating node weight, thereby optimizing the utilization of limited resources such like energy and bandwidth. The algorithm determines node weight based on residual energy, distance from neighboring nodes, and neighbor count, and elects the highest weight possessing node as a cluster head. In the algorithm re-clustering is triggered if a node leaves the cluster or when the cluster head's battery level falls below a predefined threshold.

Authors (Xing et al., 2011) proposed the PMW algorithm, which calculates node weight based on power, mobility, and workload metrics, selecting least weighted node as CH for each cluster. Their approach extended the lifetime of the cluster head, contributing to increased network stability. (Selvam & Palanisamy, 2011) developed a flexible weight-based clustering algorithm with a 2-hop clustering architecture, which increased in the quantity of nodes in the network, transmission range of a cluster, and maximum displacement within mobile ad hoc networks.

The Weight-Based Hierarchical Clustering (WBHC) presented by (Sahana et al., 2012) introduces a weighted protocol used hierarchical clustering, where the weight is derived from mobility of nodes, node degree, and transmission range. This approach aims to provide stable clustering with reduced overhead during cluster establishment and maintenance, contributing to improved network performance and management. (Shayesteh & Karimi, 2012) proposed a two-phase cluster head election process. In the first phase, nodes calculate weight using a weight function based on fuzzy logic. Subsequently, the second phase involves the calculation of relative mobility and prediction of future mobility. Final weight is calculated from these factors, and the least weighted node becomes the cluster head. This approach offers a method for efficient and informed cluster head selection through the incorporation of mobility and fuzzy logic-based weight functions.

The Weight-Based Clustering Scheme (WBCS) developed by (Bentaleb et al., 2013) utilizes mobility, density, energy, and trust of mobile nodes to select the cluster head, demonstrating improved performance in utilization of node resource management, including bandwidth, reduced formation of clusters and cluster maintenance, and improved node lifespan. This approach leverages various parameters to enhance the selection process and overall network efficiency. Authors (Gupta et al., 2013) introduced IWCA (Improved Weighted Clustering Algorithm), which selects the cluster head from mobility, node degree difference, battery power of the node, transmission range. This algorithm outperforms WCA with respect to cluster formation and cluster head changes metrics, highlighting its effectiveness in addressing these key aspects of network optimization.

The authors (Bednarczyk & Gajewski, 2013) proposed an enhanced version of WCA that incorporates parameters like transmission range, transmission power, mobility, and battery energy in weight computation. As a result, this approach reduced the average number of cluster formations, improved load sharing, and enhanced cluster stability, demonstrating the algorithm's potential in addressing these critical network performance factors. The work of (Ratish et al., 2014) introduced the Load Sharing in Weighted Clustering Algorithm (LS-WCA) to increase throughput, end-to-end delay, and load balancing of MANET. However, it was noted that its efficiency in load balancing was lower, calling for further improvements in this aspect.

The FWCA which was developed by (Aissa & Belghith, 2014), computes weight from zonal distance, dissemination degree, and residual energy parameters with specific weighting factors. This approach focuses on efficient weight computation to enhance network stability and performance of mobile ad hoc network. The Research by (Ratish et al., 2014) introduced an energy-aware load balancing clustering algorithm for mobile ad hoc network, which demonstrated improved throughput, load balancing and end-to-end delay, despite its lower load balancing efficiency. This highlights the continuing effort to optimize load balancing within clustering algorithms is needed.

In the study by (Khan et al., 2015), a novel method was presented to address load balancing in MANET. However, it was noted that the throughput of this approach was lower, indicating the need for further optimization in this aspect. (Zhou & Zhang, 2015) introduced an efficient clustering algorithm (ECA), which was an on-demand clustering algorithm and used weighted parameters for cluster head selection and maintenance, specifically focusing on the relative movement speed of nodes. The ECA demonstrated improvements in cluster head selection and maintenance, leading to reduced energy consumption per node and increased network lifetime.

The authors (Labdah & Zulkefli, 2015) introduced a weighted clustering algorithm aimed at load balancing among cluster heads with consideration for cost of computation. However, the utilization energy in process of data transmission was not taken into account, suggesting potential areas for further enhancement.

The Novel Weight-Based Clustering Algorithm (NWBCA) designed by (Pathak & Jain, 2016) aimed at reducing clustering overhead and form more stable clusters by minimizing cluster re-formation. However, its potential drawbacks included increased waiting time for new cluster head joining and the lack of consideration for energy in the weight factor. In a subsequent work (Pathak, S., & Jain, S., 2017) extended a novel weight-based clustering algorithm aimed for stable and durable clusters for mobile ad hoc networks. The method was emphasized on reducing cluster head changes, resulting in more stable and long-lasting cluster heads, ultimately contributing to a more durable network.

In their other work the authors (Pathak, S., & Jain, S., 2017) introduced the Optimized Stable Clustering Algorithm (OSCA) for mobile MANET, which formed clusters with backup nodes to serve the role of cluster heads in the absence of the actual cluster head. This approach aimed to minimize immediate cluster head election processes and reduce clustering overhead within the cluster, potentially improving network stability and performance. The Distributed Weighted Clustering Algorithm (DWCA), as proposed by (Muneeswari & Manikandan, 2019) operates similarly to the Weighted Clustering Algorithm (WCA) but differs in its approach to power management and distributed cluster setup. In DWCA, localization of configuration and reconfiguration of clusters is utilized to optimize power management. The algorithm emphasizes the importance of consumed battery power as a measure of the node's cluster head role, reflecting the actual power usage more accurately than the total time a node serves as a cluster head in traditional WCAs. This approach allows for the conservation of energy and potentially extends the lifespan of the network's topology by transitioning the responsibility of the cluster head to another ordinary nodes in cases of insufficient battery power.

Additionally, (Pathak & Jain, 2019) developed a Priority-Based Weighted Clustering Algorithm (PB-WCA) for mobile ad hoc networks. This algorithm minimizes cluster head changes in the network and clustering overhead by dividing the entire process into three distinct phases. The initial phase focuses on identifying the cluster head by calculating the priority of each neighbor node within the cluster at initial stage. The subsequent phases are dedicated to maintaining a cluster and selecting new cluster head without unnecessary delays. Notably, in PB-WCA, a new cluster head election process is automatically initiated at the instance of the currently serving cluster head’s battery power reaches a predefined threshold, thereby optimizing power utilization and network stability. However, re-clustering affects its energy management and it faces scalability problem due to its one-hop cluster.

Table 2.1 Summary of Related works

no	Ref & Year	Objectives	Contributions	Limitations
1	(Drishya & Vijayakumar, 2019)	▪ increase the stability of the cluster	▪ less mobile node is selected as CH ▪ increased cluster life time	▪ High number of clusters
2	(Dixit et al., 2020)	▪ minimizing burden of cluster-head	▪ Prolonged life of a cluster-head ▪ low-cost cluster maintenance procedure	▪ Refugee nodes adds extra loads to CH ▪ Energy is not considered in route selection
3	(Pathak & Jain, 2019a)	▪ providing stable routing topology ▪ reducing clustering overhead and cluster head change	▪ less message exchanges ▪ less computations during clustering	▪ Re-clustering cost ▪ Is not scalable due to one-hop clustering ▪ Energy is not considered in route selection
4	(Najafi & Soltanaghaei, 2020)	▪ reducing latency in the network and increasing network lifetime	▪ least overlap clustering weighted method of CH selection	▪ Overloads nodes in the shortest path and increases the chance of early node death
5	(Khatoon & Amritanjali, 2019)	▪ maintaining cluster stability ▪ low number of clusters	▪ Set criteria for node eligibility to be selected as CH	▪ CH is responsible for all kinds of communications which causes early death ▪ No load balancing

2.6.1 Summary

Despite being more effective in network management, cluster-based routing protocols have drawbacks of their own because setting up and maintaining a cluster structure is more expensive (Dixit et al., 2020).

The cluster head of a cluster-based routing protocol is tasked with supervising the other members of the cluster and forwarding all traffic—both inside and outside the cluster—without the having extra resources. As a result, the cluster head becomes a single point of failure and its battery runs out faster than that of other nodes (Dixit et al., 2020) in cluster structure.

From the discussion above, it is evident that the cluster-head is critical to cluster-based routing and that it becomes overburdened with duties. It makes sense to consider whether there is any way to lessen the cluster head's workload. This can be accomplished by relieving the cluster head of certain duties that other members of the group can perform. In order to address these issues, the "Light Weight Cluster based Routing Protocol (LWCRP)" was proposed.

The proposed LWCRP has three phases. The first phase is cluster formation, the second phase is route discovery and the third phase is cluster maintenance. To reduce overhead during cluster formation light weight calculation takes place in clustering and cluster head selection. Node degree and remaining energy parameters are used in clustering. To minimize cluster head burden packet forwarding responsibility is shared among nodes. In order to achieve balancing the energy consumption among all nodes in the network, a route formed from the combination of highest energy nodes is selected in route discovery phase. The proposed protocol balances the load and reduces the energy consumption of nodes improving the overall energy usage of the whole network and maximize network lifetime.

CHAPTER THREE

3 RESEARCH METHODOLOGY

3.1 Methodology of the Study

The research objectives are achieved through the scientific research methodology depicted in figure 3.1.

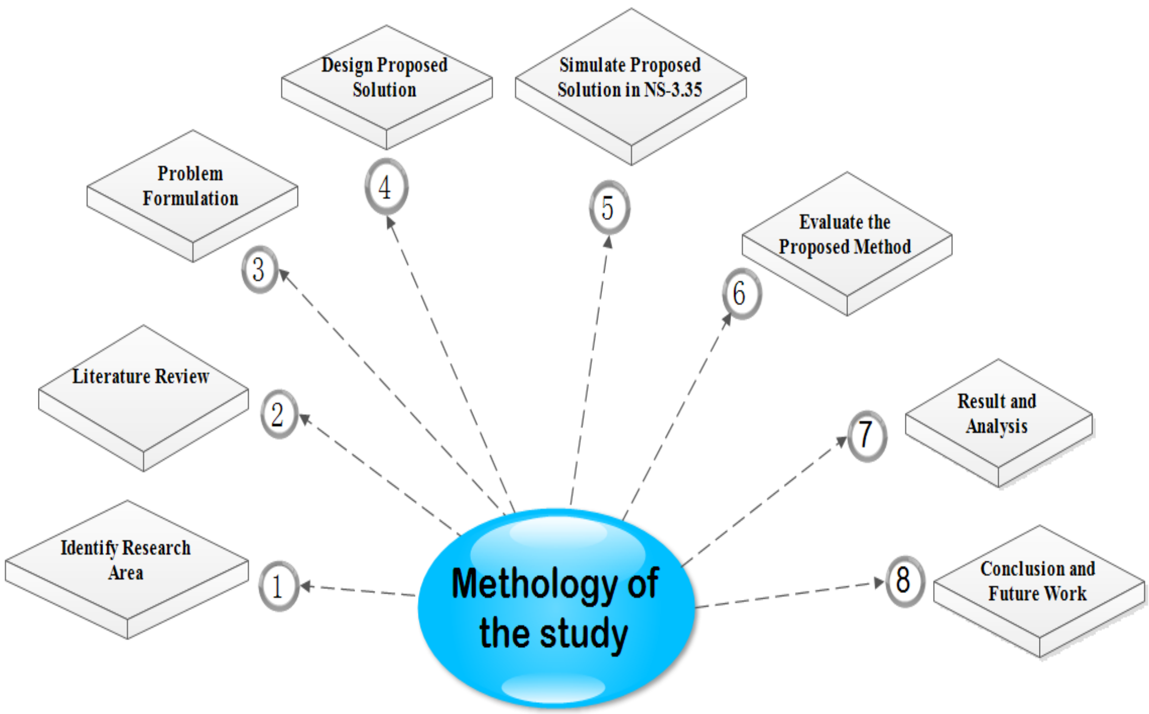

Figure 3. 1 Research Methodology

3.1.1 Literature Review

All genuine recent reference, journals and published papers on cluster-based MANTE routing protocols related to our research are analyzed and reviewed.

3.1.2 Problem Identification

In this phase the limitations of cluster-based routing protocols identified under literature review are formulated into the problem statement of our research.

3.1.3 Design Proposed Solution

At this level light weight cluster-based routing protocol is designed to reduce clustering overhead and minimize cluster-head burden through sharing the load to member nodes. This results in reduced energy consumption and elongates network lifetime.

3.1.4 Simulating the Proposed Solution

The following table 3.1 provides the hardware and software tools used for simulating the proposed work.

Table 3. 1 Hardware and Software Tools

No.	**Hardware tools**	**Software tools**
1	RAM: 8GB	Simulation tools: NS-3.35
2	Hard Disk Drive: 1TB	Operating system: Ubuntu 2204
3	Intel i5 with CPU 3.20 GHz	EdrawMax: to draw different diagrams and flowcharts.

3.1.5 Performance Evaluation

Evaluate the proposed work based on the performance metrics used to compare it with the existing work such as the clustering overhead and cluster head change.

3.1.6 Result Analysis and Discussion

In this phase the result of the research is discussed based on the simulation result. The result obtained from simulation is analyzed and discussed in deep with the help of diagrams and charts. Simulation results were visualized using MS Excel 2021 in the form of graphs and MS office word 2021 was used to write this thesis.

CHAPTER FOUR

4 PROPOSED LWCRP

4.1 Overview of the Proposed LWCRP

Routing protocols designed for mobile ad hoc networks (MANETs) must consider energy consumption because MANET nodes have a limited energy supply and cannot be recharged. Different mechanisms have been deployed to design an energy efficient routing protocol. Among routing mechanisms hierarchical routing yields better network management and effectively reduces energy consumption (Aissa & Belghith, 2014).

A cluster based routing protocol which is a hierarchical routing mechanism divides the network in to a group of nodes each group governed by cluster head. Cluster head selection plays a vital role in the cluster based routing protocols. Various clustering and cluster head selection schemes discussed in chapter 2 have been used to develop routing protocols among which weight-based clustering is claimed to have better performance. As stated in a related work weight-based clustering involves two or more parameters in clustering and cluster head selection process. Clustering overhead which is one of the causes of energy drain increases as more and more parameters are involved in clustering and cluster head selection. Thus, it is imperative to reduce number of parameters participated in clustering to design a routing protocol with less clustering overhead. Cluster head change is another cause of overhead as it causes re-clustering which consumes energy unnecessarily. To address clustering overhead and cluster head change problems we proposed LWCRP that calculates weight from node degree and residual energy of nodes to form cluster and select a cluster head for each and every cluster in the network. Besides, to keep the cluster head alive for longer time the burden of forwarding the packets is shared among nodes which helps to reduce the cluster head changes in the MANET network. Source nodes are able to send data to the destination within its reach without the knowledge of cluster head. The proposed LWCRP has three phases

1. Clustering and cluster head selection
2. Route discovery
3. Route maintenance

4.1.1 Network Structure

The proposed LWCRP uses weighted cluster-based routing scheme which categorizes the network into clusters and chooses one cluster head for each single cluster. The node to be claimed cluster head is selected from the calculation of weight of node degree and residual energy. A node having the highest weight is chosen as a cluster head and announces to other nodes. The nodes within the transmission range of the selected CH or direct neighbors of CH joins the cluster. Other nodes that loin cluster are the nodes within the transmission range of direct neighbors of the selected CH. The cluster head is responsible for forward packets if the node that sends packet cannot locate the receiving node or the destination is located in the other cluster. Nodes are distributed randomly and are homogeneous.

4.1.2 Energy Model

The energy of the nodes plays crucial role in both cluster head selection and route discovery in proposed solution. It can be calculated from a residual energy (Er_n) of the node (Drishya & Devi, 2021).

$$Er_{ni} = E - (E_{Tx}(k,d) + E_{Rx}(k)) \qquad (1)$$

E denotes the energy a node currently possesses while $E_{Tx}(k,d)$ denotes the energy a node needs to transfer a k bits of data to a d distance with amplifier Ea. The $E_{Tx}(k,d)$ is calculated by

$$E_{Tx}(k,d) = k.E_e + k.E_a.d^2 \qquad (2)$$

ERx (k) is the energy utilized by the node to receive k bits of data and is calculated by

$$E_{Rx}(k) = k.E_e \qquad (3)$$

4.2 General Architecture of Proposed Solution

In hierarchical routing protocols the overall network is partitioned into several clusters, each cluster having its own cluster head. Among various clustering schemes the proposed protocol applies weight based clustering scheme to form a cluster and select cluster head for each cluster. Two parameters: node degree and residual energy are used to reduce clustering overhead. The cluster head is burdened with more tasks without additional resource in cluster-based routing protocols. The proposed LWCRP reduces the burden of cluster head by sharing the routing burden to other member nodes. The nodes in the cluster are classified as cluster head, gateway and member nodes based on their responsibility in the cluster.

In general, proposed solution has three stages:

1. Clustering stage
2. Routing stage and
3. Maintenance stage

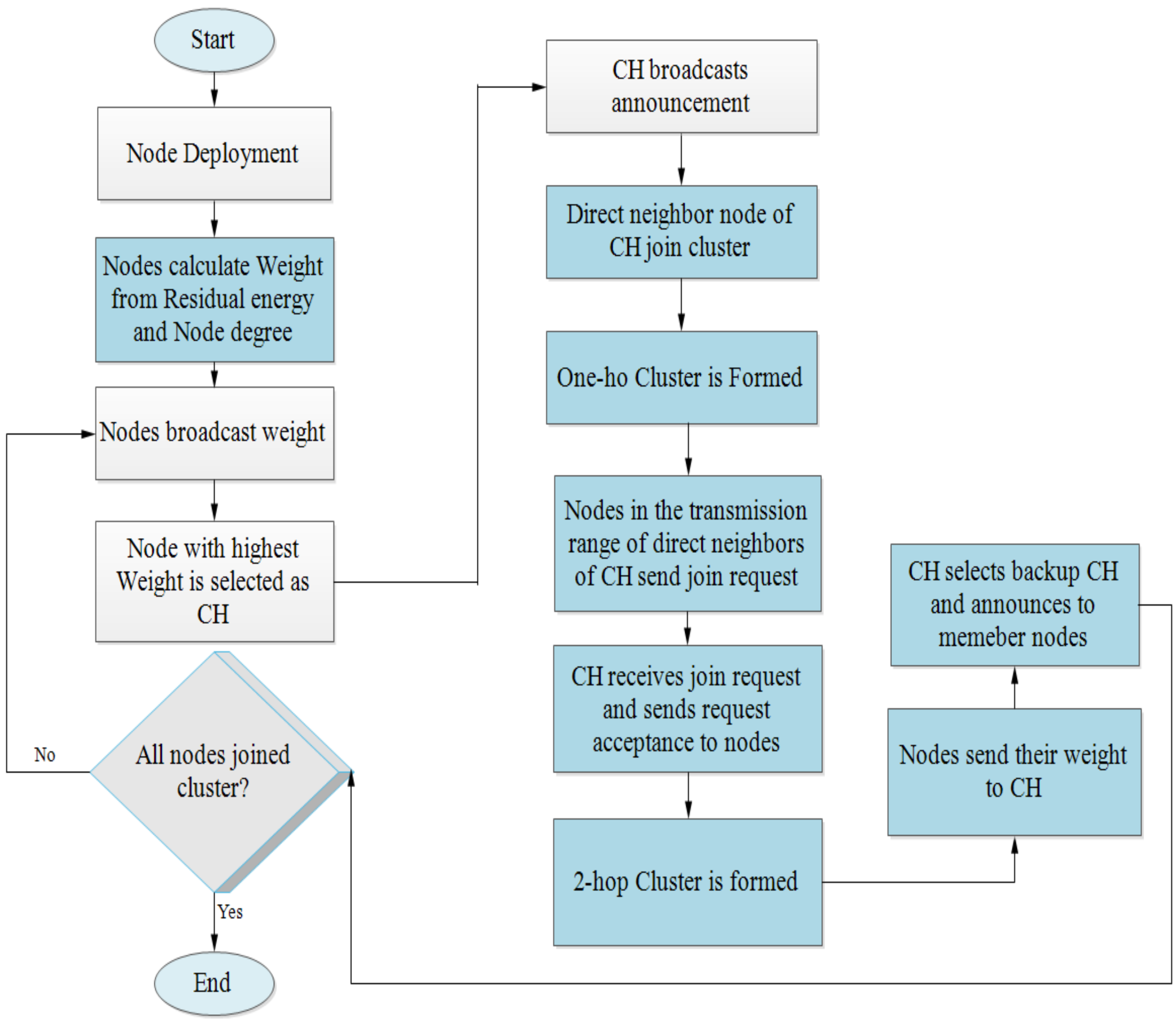

Figure 4.1 Flow chart of proposed solution

4.2.1 Clustering Phase

In MANET networks energy is a very crucial resource. MANET's nodes operate in infrastructure less area where recharging battery is difficult. Therefore, consuming energy in the best possible way is imperative for the applications of every mobile ad hoc network. A clustering method provides a good means of network management under supervision of cluster head for each cluster. However, cluster formation and cluster head selection impose some important calculations which consumes energy even before nodes of MANET starts communication. Furthermore, the frequent change of MANET's topology caused by nodes mobility and cluster head's energy drain due to extra load imposes additional calculation for re-clustering which consume energy for network management. For the purpose of reducing unnecessary energy consumption, reducing calculations made during cluster construction and cluster head selection as well as reducing calculations for re-clustering is important.

To solve issues stated in the above paragraph our proposed solution imposes minimum calculations during clustering and cluster head selection and avoids re-clustering. Only node degree and residual energy are used for clustering and instead of re-clustering due to cluster head failure or cluster head movement, a backup cluster head is assigned the task of cluster management.

The clustering phase includes dividing nodes into cluster and choosing cluster head for each cluster. Cluster head is selected depending on the weight calculated from node degree and residual energy of nodes as in equation 5 below. A node with the highest weight becomes cluster head and announces itself to other nodes. Nodes within the transmission range of the cluster head joins the cluster and a one-hop cluster is formed. After the nodes in the reach of the neighbors of CH joined a cluster a two-hop cluster is formed. For the nodes having equal weight their node degree is compared and the node having highest node degree becomes CH. The highest ID is used to separate between the nodes of similar weight value if the node degrees are also equal.

The residual energy of a node is obtained from the energy model of MANET. Cluster head is chosen by computing a weight for nodes from node degree and residual energy parameters. The residual energy is obtained from eq. (1) and node degree is acquired from the following eq. (4).

$$N(n) = \sum_{n' \in V, n' \neq n}^{n} distance(\mathrm{n}, \mathrm{n}') < Tx_{range} \quad \textbf{(4)}$$

$$\boldsymbol{Weight = N(ni) + Er_{ni}} \quad \textbf{(5)}$$

Table 4. 1 parameters used in algorithm

Variables	Description	Value Range	Source
Residual energy	the amount of energy left in a device's battery.	0J-100J	(Sultan & Zaki, 2017)
Degree of nodes	The number of nearby nodes that can hear HELLO packet	Ranges from one to a number of nodes in the transmission range of broadcasting nodes	(Pathak et al., 2019)

Pseudo code to select cluster head

```
Wi=ri+N(ni)
For nodes in neighbor
Broadcast Wi
If Wi> Wi+1
       Assign node of Wi as cluster head
Else if Wi=Wi+1
Compare Node degree
If N(ni)>N(ni+i)
      Assign N(ni) node as cluster head
Else if N(ni)=N(ni+i)
    Compare ID
            If ni_id>ni+1_id
                 Assign node of ni_id as cluster head
            Else
               Assign node of ni+1 as cluster head
Else
   Assign node of Wi+1
end
```

4.2.2 Routing phase

Routing involves packet transmission among member of same cluster known to be an intra-cluster routing and the transmission of packet among nodes of different cluster known as inter-cluster routing. The routing tables of all the nodes in a cluster store the paths between them. The routing table additionally stores the neighbor nodes' residual energy. Up on sending the message, nodes forward the packets to a node which has higher remaining energy. At the end the selected path will be the path with the combination of the nodes having high remaining energy.

- **Intra-cluster routing: -** nodes residing in the same cluster communicates with one another directly, with the help of intermediary nodes or through cluster head. Cluster head involves in routing if an only if the sender node cannot reach the receiver through other intermediate nodes.
- **Inter-cluster routing: -** the communication between different clusters can be made either through the use of gateways between two clusters without the knowledge of cluster head or through the cluster head.

A node uses its routing table to find available intermediate nodes to reach the destination when sending a packet to an intended node. It then forwards the packet to the intermediate node with the highest remaining energy. As a result, the route with the combination of the nodes with highest remining energy is used to transfer packet from sender node to receiver node.

4.2.3 Cluster maintenance

The need to maintaining a cluster arises when cluster previously formed in the clustering phase requires modification or the pre-established route needs some modification. The problem arises when cluster head fails or leaves one cluster and joins another. The network is highly profited from maintaining the cluster with possible small cost. Cluster head hands off the cluster management responsibility to the backup cluster head if its remaining energy falls below predefined threshold level. Cluster head movement also causes the need of cluster maintenance. Backup cluster head announces itself as cluster head if it notices the main cluster head has failed or moved. A new cluster head is selected up on the failure of the backup cluster head.

Nodes can join any nearest cluster and be a member of that cluster without disturbing the cluster. The node joined a new cluster requires only to know its neighbors and how to communicate with the cluster head of the cluster it joined.

4.3 General Assumptions

The general assumptions considered in our proposed solution are:

- The proposed LWCRP network topology includes cluster head, backup cluster head, member nodes and gateway nodes.
- Nodes are mobile in 250x250m^2 area.
- Nodes are considered static until cluster head is elected and cluster is formed
- Nodes distribution is random and nodes are homogeneous.
- Cluster head is elected by the weight computed from two parameters: node degree and residual energy.
- Two-hop cluster is formed with the maximum hop distance limited to one-hop at the initial stage of cluster construction and cluster head election. When the nodes in the transmission range of direct neighbors of CH joins the cluster multi-hop cluster is formed. At the maintenance stage the nodes join nearest cluster making the LWCRP scalable.
- Backup cluster head takes responsibility of network management up on:
    - remaining energy of cluster head becomes lower than the threshold level
    - cluster head moves and joins another cluster
- New CH is elected if backup cluster head moves or dies.
- Remaining energy is the defining factor in determining routing path. The path that has the highest remaining energy node combination is selected to forward packet.
- Nodes store the path to the other nodes found in the similar cluster.

CHAPTER FIVE

5 SIMULATION AND PERFORMANCE EVALUATION

5.1 Overview

The proposed protocol is simulated to evaluate the performance of the entire network by comparing our proposed protocol to existing works. The main objective of this study is reducing clustering overhead which minimizes energy consumption by designing light weigh cluster-based routing protocol for MANET. The proposed protocol reduces overhead by using minimum parameters for clustering and cluster head selection, avoids re-clustering by means of transferring cluster head responsibilities to backup cluster head upon cluster head movement or cluster head's low energy is encountered. It also maximizes the lifespan of member nodes of a network by sharing loads among nodes which is done during route discovery, choosing the route with highest combined remaining energy. The proposed solution's performance is evaluated after it was simulated in ns-3.35 using clustering overhead and cluster change performance evaluation metrics.

5.2 Simulation Environment

There are various simulation tools for simulating and testing MANET routing protocols.

5.2.1 NS-3

Network Simulator 3, or NS-3 is an open-source network simulation framework that provides a platform for modeling, simulating, and analyzing the behavior of computer networks. It is designed to enable researchers, developers, and network engineers to study various network protocols, architectures, and scenarios in a repeatable and controlled environment. NS-3 is written in C++ and can be extended and customized through programming.

Ns-3 was created specifically for scientific researches and educational applications. It is freely accessible for research and development under the terms of the GNU GPLv2 license.

The NS-3 project creates a user-friendly, and debug-friendly simulation core. The simulation workflow's requirements are met by NS-3 core, which handles everything from simulation configuration to trace collection and analysis. Both IP-based and non-IP-based network research is supported by the NS-3 simulation core. It is a robust network simulator and has enhanced simulation reliability. It makes use of real-time schedulers, which reduces the quantity of simulations-in-the-loop. Packets created by the NS-3 can be received on actual network devices. The simulation requirements of networking research are met by NS-3. (Naik.L et al., 2016).

NS-3 was selected because it supports MANET routing protocols along with mobility and Wi-Fi models. It supports basic network analysis and has great documentation. NetAnim is one of the additional tools that NS-3 can use. The simulation is visualized by NetAnim, making it possible to see how the nodes move and communicate (Skaggs-Schellenberg, 2020).

Advantages:

- ✧ **Specialized Network Simulation:** NS-3 is a dedicated network simulation framework that provides a comprehensive environment for modeling and simulating various network protocols, including MANET protocols.
- ✧ **Realistic Networking Models:** NS-3 enables to establish complex topologies, simulate realistic wireless channel behaviors, and incorporate detailed protocol behaviors, making it suitable for advanced network research.
- ✧ **Protocol Libraries:** NS-3 comes with built-in protocol libraries, making it easier to implement and test various MANET protocols without starting from scratch.
- ✧ **Open-Source Community:** NS-3 is open source, and its community actively contributes to its development and provides support. This community-driven nature can lead to quick updates and improvements.

While many features are available in simulation tools, not all of them provide good support for every feature of MANET simulation. The greatest option for the MANET is NS-3, which supports a broad variety of protocols across all layers (Salem et al., 2014).

5.3 Performance Evaluation

5.3.1 Performance Evaluation Metrics

Using performance evaluation metrics such as clustering overhead and number of cluster head changes, the suggested solution's performance is compared to the existing work. Our work's performance is contrasted with that of PB-WCA and NWBCA.

5.3.2 Simulation Setup

In a proposed solution 100 nodes are simulated in the area of 250x250m^2. The nodes move randomly with random way point mobility model. YansWifiPhy which is the default model for ad-hoc network in ns-3 and IEEE 802.11 standard was used at physical layer while ns3::AdhocWifiMac was used for MAC layer model. At transport layer UDP is employed. The nodes movement is paused at 5-25 seconds pause time to test the performance of our proposed solution in frequently changing topology as nodes can leave one cluster and join another cluster. The simulation was animated in NetANim which is a visualization tool of ns-3.35. The output of the simulation is exported to a ".csv" file for further analysis and visualization. The ".csv" file was used to compare and analyze simulation results, conduct statistical analysis, and generate graphs and charts to represent the performance of proposed solution. Random deployment of simulated nodes is shown in the following page figure 5.1.

The following table provides a summary of the simulation's parameters.

Table 5. 1 Parameters used in simulation

Simulation Setup	***Values***
Simulator software	NS-3.35
Simulation area	250x250m^2
Mobility model	RWP
Mobile nodes	100
Simulation Time	25-150s
Pause time	5-30s
Speed for mobile nodes	2–10 mps
Mobile node's transmission range	150 m
Connection Type	UDP
PHY	IEEE 802.11

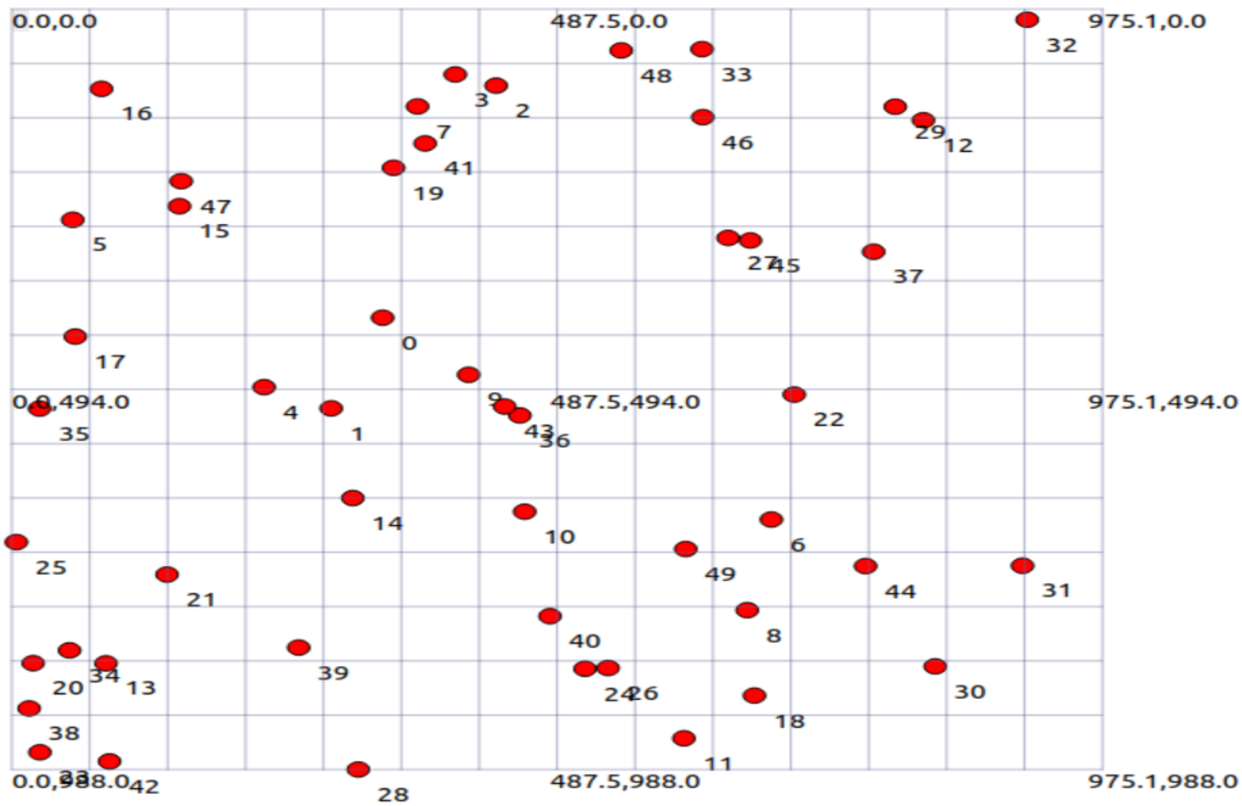

Figure 5.1 Node deployment in ns-3.35

5.4 Simulation Result

This section discusses the result of our simulation in 250x250m^2 area and compare the result of proposed solution LWCRP with existing works NWBCA and PB-WCA. Performance evaluation metrics like number of cluster head change and clustering overhead of LWCRP are analyzed with respect to existing works NWBCA and PB-WCA.

5.5 Analysis of Simulation Result

The result of simulation obtained from trace file is mapped to the existing NWBCA and PB-WCA protocols in terms of number of cluster head change at a given pause time, clustering overhead in the overall simulation time, cluster head changes at different node speed and clustering overhead at different mobile node speed. As stated in the graphs under sup-topics of this title, the result shows proposed solution has least number of cluster head change and least clustering overhead with respect to mobility of nodes at different speed. This indicates the energy consumption due to re-clustering and energy consumed due to clustering overhead is minimized by the proposed solution.

5.5.1 Number of Cluster Head Change Over Pause Time

Frequent cluster head change causes frequent re-clustering, increasing energy consumption due to communication overhead needed to re-clustering the network. The proposed solution minimized the number of cluster head changes at pause time of 5-30s. figure 5.2. shows the comparison of cluster head changes between existing protocols NWBCA, PB-WCA and proposed protocol LWCRP. From the result, initially cluster head change occurs slightly at higher number but as pause time increases the cluster head change becomes low.

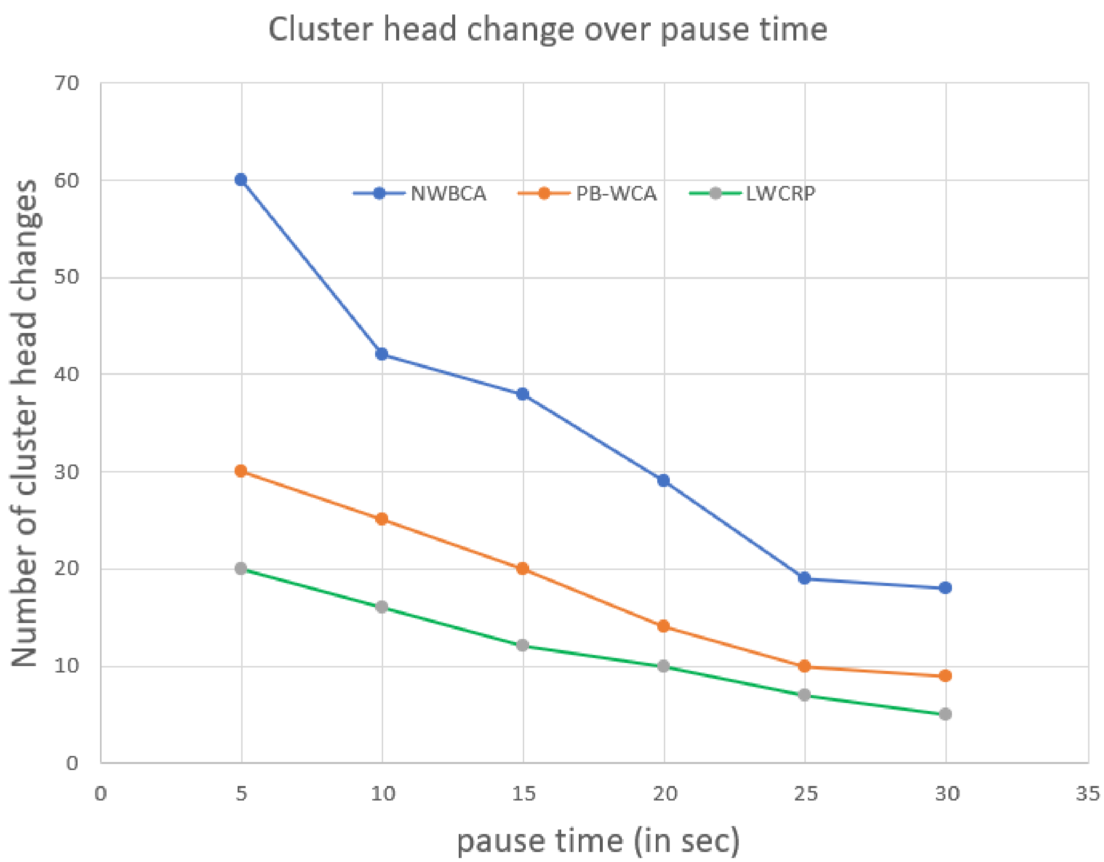

Figure 5.2 cluster head change over pause time

5.5.2 Number of Clustering Overhead Over Simulation Time

Here clustering overhead of proposed LWCRP over simulation time is discussed and compared to existing protocols NWBCA and PB-WCA. As shown in figure 5.3. the clustering overhead increases by few numbers as simulation time increases from the start of simulation time. Compared to existing work clustering overhead of LWCRP at the start of the simulation is higher than existing works, but it is reduced as the simulation time increased because control message exchange after cluster formation is less since re-clustering rarely occurs in the proposed solution. The overall clustering overhead is minimized compared to NWBCA and PB-WCA.

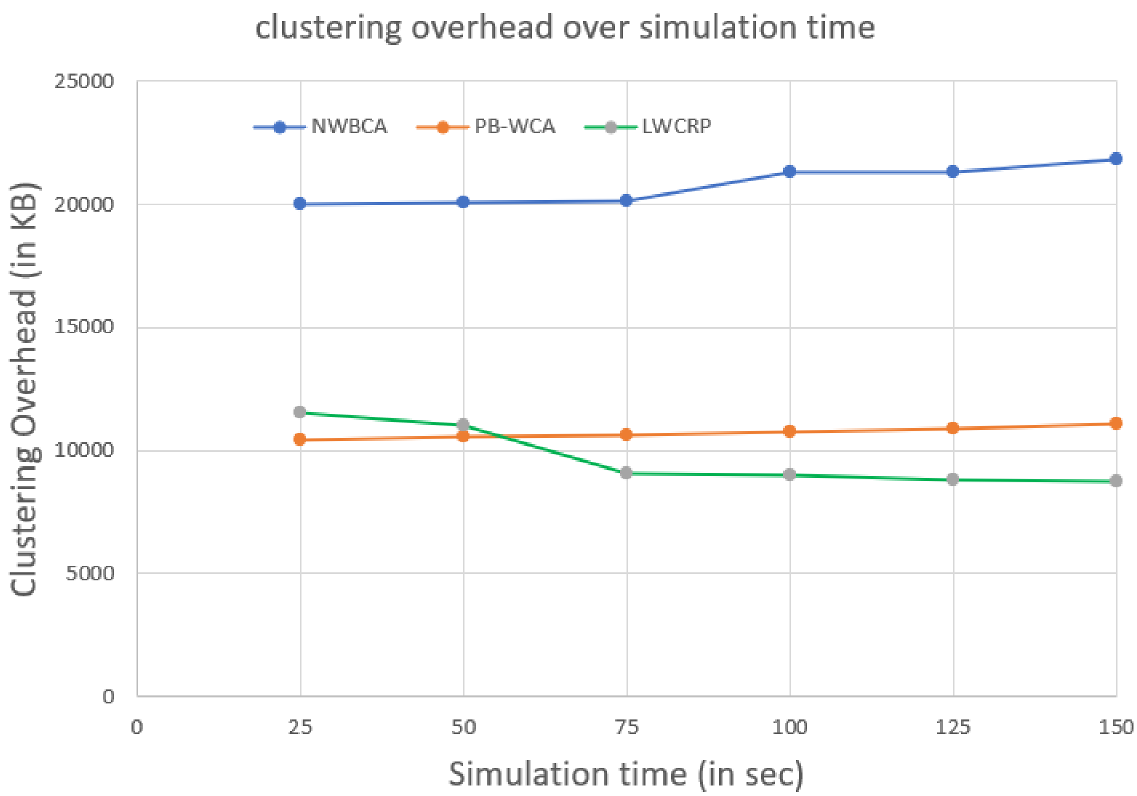

Figure 5.3 clustering overhead over simulation time

5.5.3 Number of Cluster Head Changes Against Mobile Node Speed

In a mobile ad hoc network, nodes can freely roam around and join or exit clusters. The cluster head change increases as mobile nodes get faster because nodes move among clusters at relatively higher speed which increases cluster head change. Compared to existing work our proposed LWCRP has better performance at reducing cluster head change when node speed is increased. Figure 5.4 shows cluster head change of existing works NWBCA and PB-WCA and proposed LWCRP.

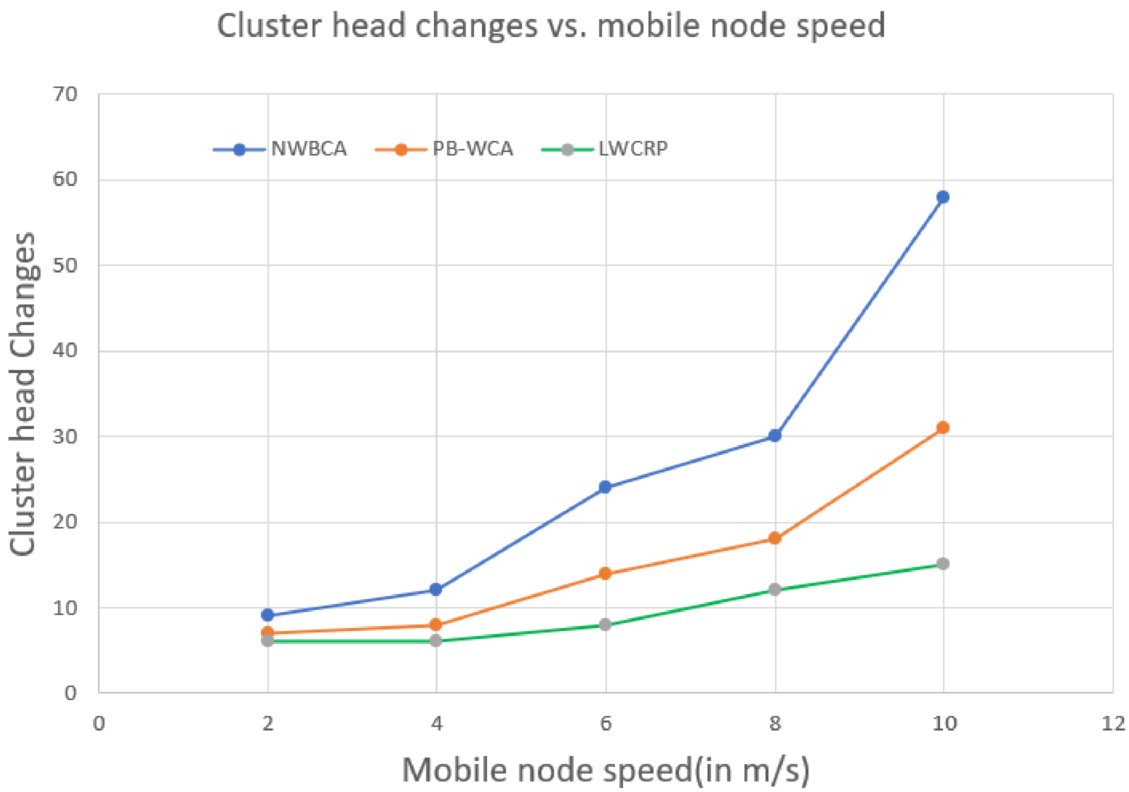

Figure 5.4 cluster head change vs mobile node speed

5.5.4 Number of Clustering Overhead Against Mobile Node Speed

Cluster head change management has crucial role in keeping topology stable and increasing network performance by reducing clustering overhead due to cluster maintenance. Cluster head change increases with the increased node speed in the network. At initial stages of simulation when nodes move at low speed the number of cluster head change is also low. Then, the clustering overhead slightly increases as nodes mobility at higher speed causes more network maintenance. From figure 5.5 it is clear that proposed LWCRP has good performance than existing protocols NWBCA and PB-WCA in reducing cluster head change when node speed is increased.

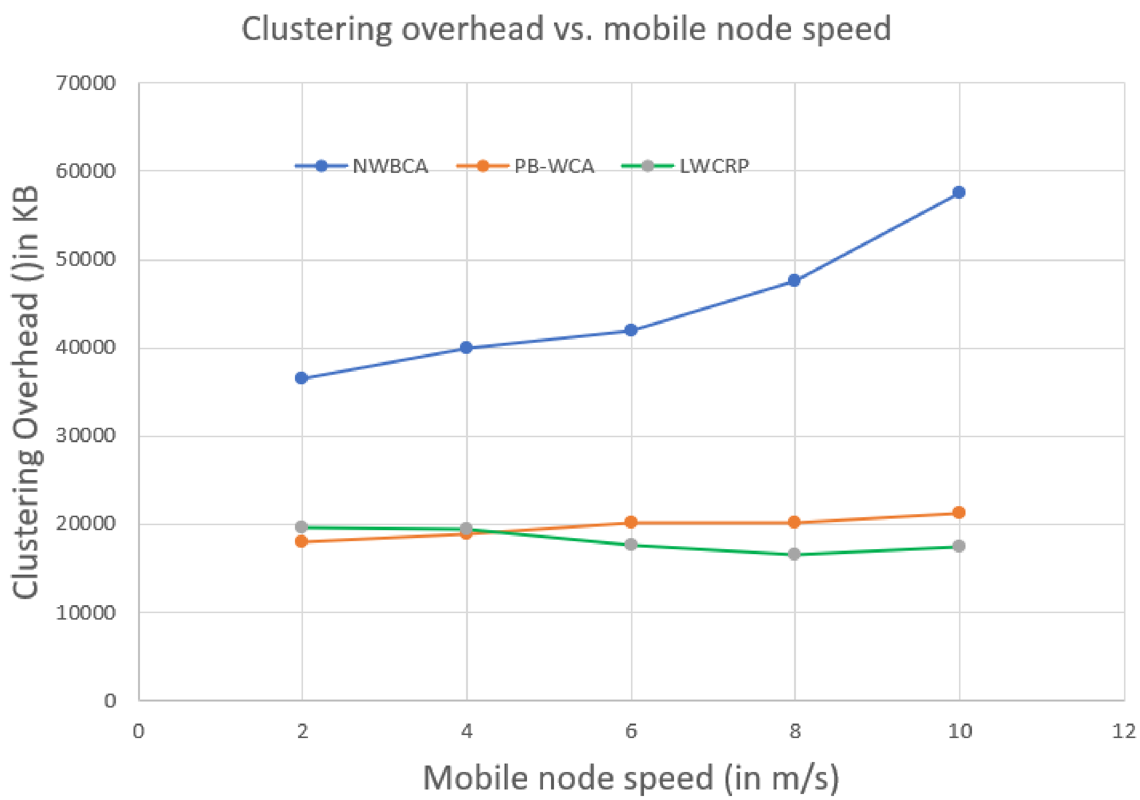

Figure 5.5 clustering overhead vs mobile node speed

5.6 Result Evaluation

The result obtained from the trace file of simulation of 100 nodes for 150s in 250x250m^2 area is compared to existing works in terms of evaluation metrics and discussed in the above graphs. As the results show the proposed LWCRP showed improvement in both evaluation metrics: clustering overhead and CH change than NWBCA and PB-WCA. The proposed LWCRP's performance is assessed in different parameters. These evaluation parameters are the amount of clustering overhead throughout the simulation time, clustering overhead at different mobility speed of nodes, CH change at different pause time and CH change at different mobility of nodes. The figure 5.6 shows clustering overhead of proposed LWCRP compared to existing works throughout simulation time. Clustering overhead in kb. i.e the message exchange among nodes in the process of selecting CH and forming cluster at different instance of time in the overall simulation time.

Table 5. 2 Clustering overhead over simulation time

Protocols	Simulation time (in second)						
	25	50	75	100	125	150	Clustering overhead (in KB)
NWBCA	20010	20100	20150	21306	21337	21860	
PB-WCA	10405	10555	10623	10757	10873	11054	
LWCRP	**11536**	**11051**	**9090**	**9008**	**8798**	**8764**	

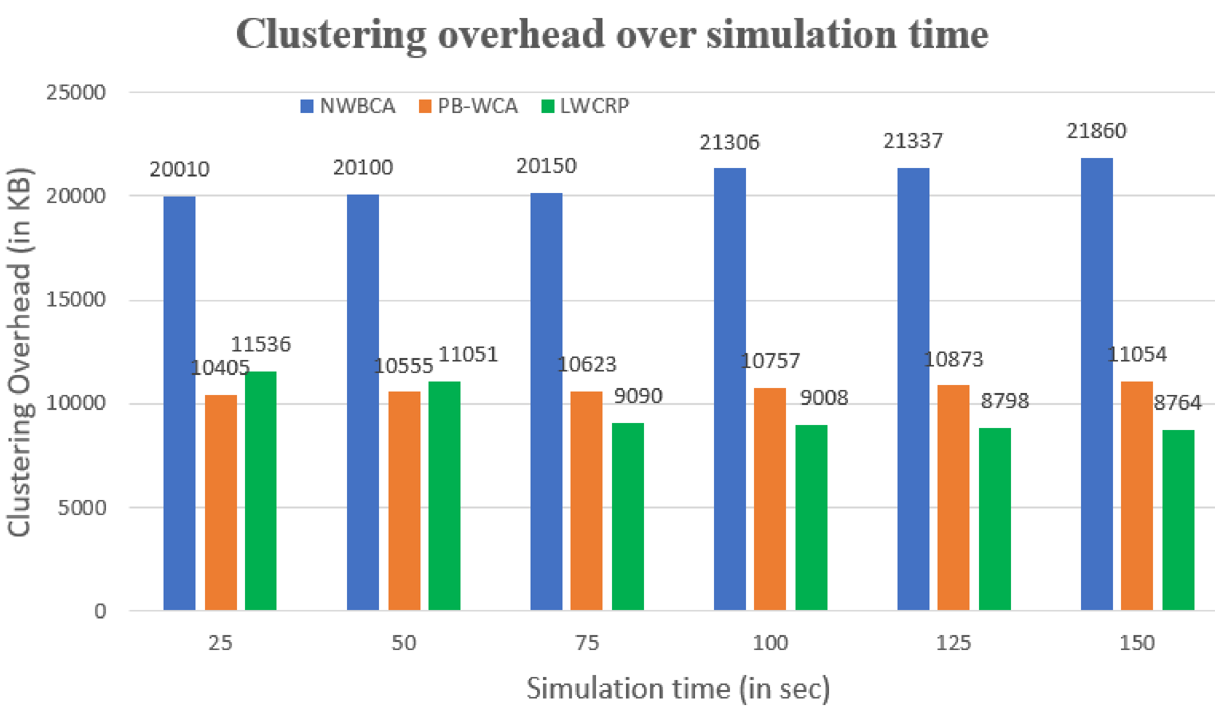

Figure 5.6 Clustering overhead over simulation time

The proposed LWCRP imposed less clustering overhead than both existing works when mobility is increased. The figure 5.7 shows the evaluation of proposed LWCRP to existing works with regard to clustering overhead at different mobility speed of nodes. It shows how increased speed of nodes affect the CH selection and cluster formation. When the nodes moving speed increases, the nodes leave one cluster and join another cluster or form new cluster. forming new cluster involves extra message exchange which increases overhead. The figure shows message exchange among nodes when mobility of nodes is increased.

Table 5. 3 Clustering overhead vs mobile node speed

Protocols	Mobile node speed (in m/s)					
	2	4	6	8	10	Clustering overhead (in KB)
NWBCA	36503	40020	42011	47561	57478	
PB-WCA	18045	18867	20104	20152	21254	
LWCRP	**19597**	**19368**	**17687**	**16543**	**17420**	

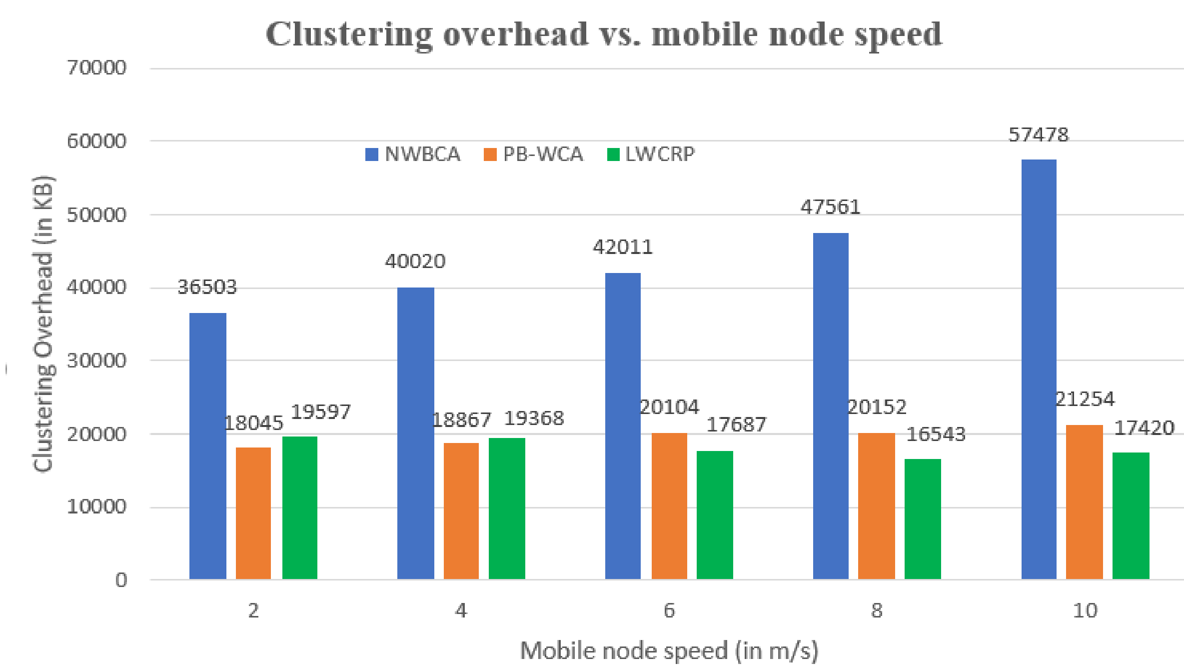

Figure 5.7 Clustering overhead vs mobile node speed

Another evaluation metric used to compare the proposed work to existing works is CH change. At different pause time the CH occurred in the network by proposed work and existing works was evaluated. The performance of the proposed work is better than existing works. Figure 5.8 shows the evaluation result of proposed work against existing works.

Table 5. 4 Cluster head change over pause time

Protocols	Pause time						
	5	10	15	20	25	30	Number of CH change
NWBCA	60	42	38	29	19	18	
PB-WCA	30	25	20	14	10	9	
LWCRP	**20**	**16**	**12**	**10**	**7**	**5**	

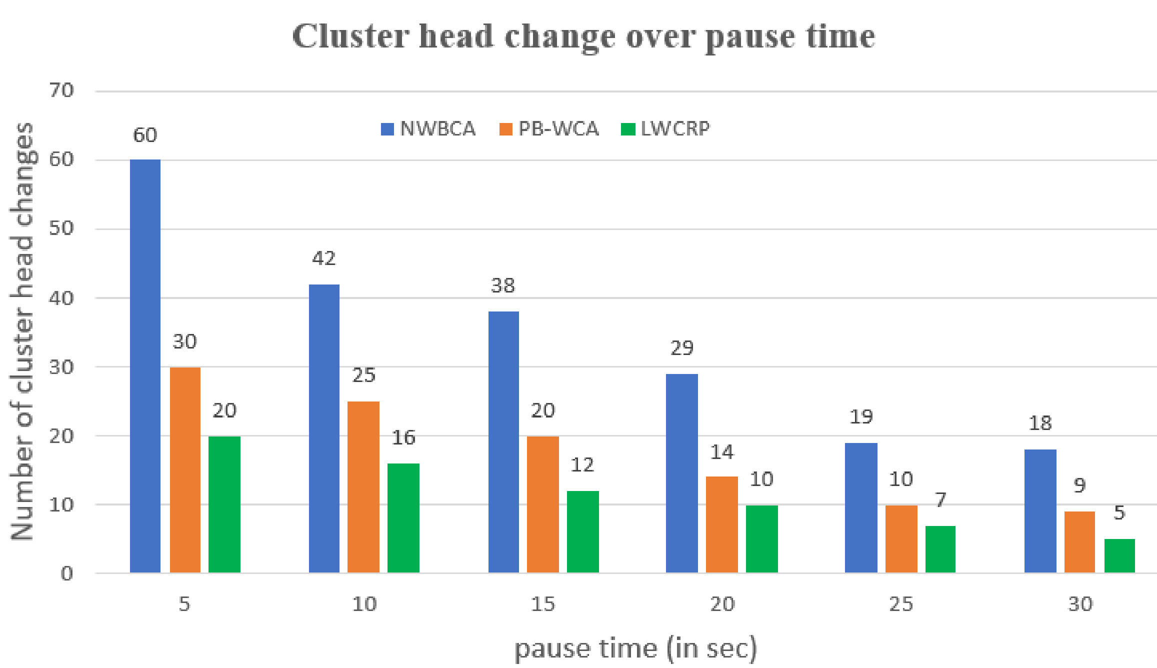

Figure 5.8 Cluster head change over pause time

The CH change of the proposed work and existing works was also evaluated at different node speed. Again, the proposed LWCRP outperforms existing works in reducing CH change when mobility is increased. The evaluation result is depicted in figure 5.9.

Table 5. 5 Cluster head change vs mobile node speed

Protocols	Mobile node speed (in m/s)					
	2	4	6	8	10	Number of CH change
NWBCA	9	12	24	30	58	
PB-WCA	7	8	14	18	31	
LWCRP	**6**	**6**	**8**	**12**	**15**	

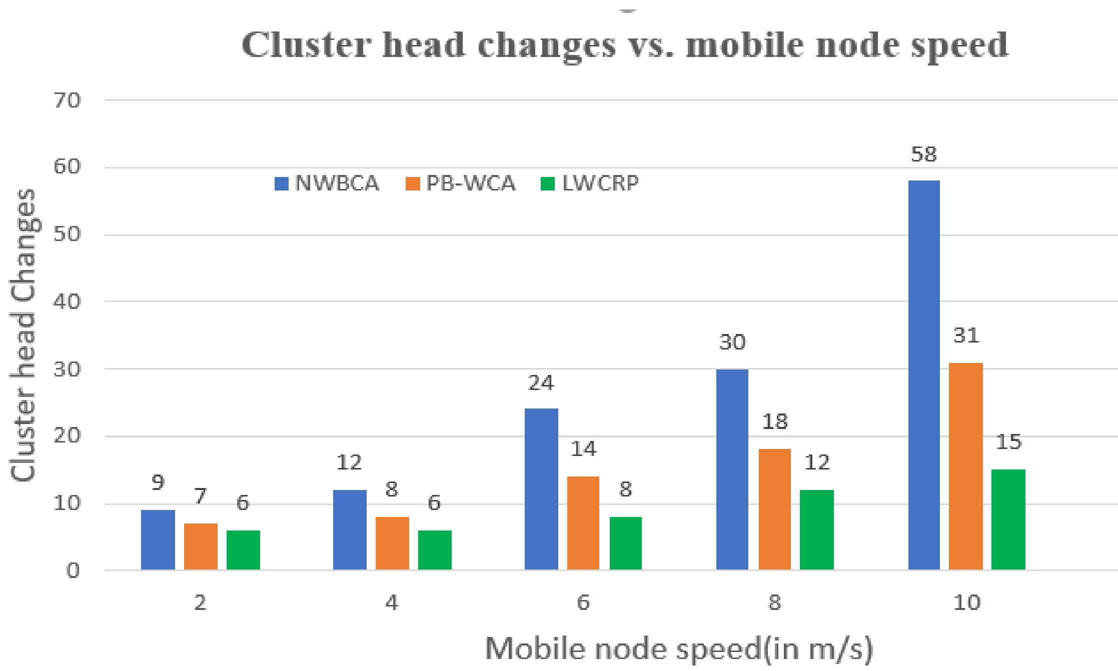

Figure 5.9 Cluster head change vs mobile node speed

5.7 Discussion

The primary objective of this thesis was to reduce overall consumption of energy of a MANET network by reducing the amount of computation made during clustering and reducing the number of cluster head change in the network. The proposed LWCRP showed better performance at achieving these objectives; reducing number of cluster head change and reducing the clustering overhead.

The research questions listed in Section 1.4 of Chapter 1 of this thesis were addressed based on simulation result and performance metrics.

RQ1. How to form cluster and select cluster-head with minimum overhead?

In cluster-based routing protocols, cluster formation and cluster head selection procedure pose a significant overhead which has an adverse effect on the performance of the network. Reduced clustering overhead yields less computation and less message exchange among nodes during cluster formation. The proposed LWCRP uses only two parameters in the process of computing weight to divide network into clusters and selecting CH for each cluster which reduces clustering overhead and improved performance of existing work.

RQ2. How to reduce number of cluster head change?

Cluster head change disrupts network stability and causes re-clustering. The re-clustering causes extra message exchange to the network which consumes resources like energy and bandwidth, degrading the overall network performance. Therefore, reducing the number of cluster head change improve the network performance. The proposed LWCRP achieves this aim by reducing the CH death by sharing the responsibility of packet transmission to other member nodes of the cluster. The nodes forward the packet toward destination through the path with a combination of nodes with highest remaining energy.

5.8 Summary

MANET's performance is highly affected by routing protocol employed in the network. Simplifying network management is achieved by partitioning the network into clusters, which are collections of nodes. Cluster formation and cluster head selection are critical to the protocol's performance in the cluster-based MANET routing scheme. Computations made during cluster formation and cluster head selection as well as message exchange during the process consumes the energy of the nodes. Minimizing the computation and message exchange reduces energy consumption which results in increased lifetime of the nodes. Reducing cluster head change occurred due to node death keeps the network in the stable state and improves the performance of the network. The proposed LWCRP showed better performance than existing protocols NWBCA and PB-WCA in reducing clustering overhead and cluster head change caused by cluster head node's early death due to extra packet forwarding load imposed on the cluster head by sharing the load to other member nodes. The proposed LWCRP computes weight of nodes from residual energy and node degree parameters. The node with the highest weight become cluster head and one-hop cluster is formed. Then nodes in the transmission range of neighbor nodes of cluster head node joins cluster. The backup cluster head is then elected and takes responsibility of cluster management if cluster head reaches minimum threshold or moved to another cluster. Clustering overhead of LWCRP is minimum as only two parameters (node degree and residual energy) are used to compute weight. To minimize energy consumption and early death of cluster head, packet forwarding responsibility is shared to other member nodes. Nodes know how to reach other nodes in the cluster and can directly send the message to each other without the knowledge of CH. So, CH load is minimized which means energy consumption of CH is reduced preventing early death of CH. As a result, CH change due to CH death is minimized, keeping the network stable and enhancing network performance. The backup cluster head serves as CH in case CH's energy falls below the defined threshold or CH is moved to another cluster. This avoids re-clustering and maintains network stability with minimum message exchange reducing the overhead required for cluster maintenance. From the simulation result we can conclude that LWCRP imposed minimum clustering and maintenance overhead and reduced the CH change in the network. As a result, the overall network performance is improved compared to existing works NWBCA and PB-WCA.

CHAPTER SIX

6 CONCLUSIONS AND FUTURE WORKS

6.1 Conclusions

This research addressed two problems affecting the performance of MANET's cluster-based routing protocols. The problems are clustering overhead and cluster head change which degrades network performance. The energy consumed due to clustering overhead and energy consumption for re-clustering unnecessarily wastes resource which is supposed to be used for the communication among nodes in the MANET network. In this thesis we proposed LWCRP which forms cluster with minimum clustering overhead and reduces maintenance cost by employing backup CH. Besides, the proposed LWCRP maintains the network stability by preventing early death of CH due to energy drain by sharing the task of CH to other member nodes. Keeping the CH alive for a longer time keeps the network stable which poses minimum number of CH change in the network. The minimum clustering and maintenance overhead and minimum CH change reduces energy consumption and enhances the overall network performance. In this context the proposed LWCRP outperforms the existing PB-WCA as well as NWBCA.

We used ns-3.35 to implement our proposed LWCRP protocol and evaluated its performance using performance evaluation metrics cluster overhead and cluster head change in different context. It's seen from simulation result that the proposed protocol performed better performance in both reducing clustering and maintenance overhead as well as cluster head change.

6.2 Contributions

This study plays significant role in reducing energy consumption of MANET nodes and increasing network lifetime. In MANET's cluster-based routing protocols energy is not only consumed for communication purpose, but also for network management. Substantial amount of energy is consumed during cluster formation, CH election and cluster maintenance. This study reduces energy consumption in two ways. The first one is by reducing overhead occurred due to computations made during clustering and CH election by calculating weight from only residual energy of nodes and node degree. The second way is by avoiding re-clustering of the network due to CH death by reducing the burden of CH.

Selecting reliable route and improving scalability are also important contributions of this research.

6.3 Future Works

The proposed protocol’s main objective is reducing energy consumption of the MANET network and increasing the network lifetime. Even if we achieved our purpose yet there are points worth improvement in the future work. The proposed LWCRP constructs route by combining the nodes with the highest remaining energy without considering delay. In the future work a route selection process will consider both energy and distance. i.e reliable route with nodes having enough remaining energy and minimum distance will be used for data transmission. Adding security mechanism to our protocol is other issue to be addressed in the future.

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APPENDIX

Appendix A. NS-3.35 code to calculate weight for cluster formation.

```
//weight calculation
std::vector<double> weights(nodes.GetN());
for (uint32_t i = 0; i < nodes.GetN(); ++i)
{
Ptr<Node> node = nodes.Get (i);
Ptr<EnergySource> source = node->GetObject<EnergySourceContainer> ()->Get (0);
double res_energy = source->GetRemainingEnergy(); // Get the residual energy
double range = 50.0;  // Communication range of the node
std::vector<double> num_neighbors(nodes.GetN(), 0);  // Initialize vector to hold the number of neighbors per node

for (uint32_t i = 0; i < nodes.GetN(); ++i)
 {
  Ptr<Node> node1 = nodes.Get (i);
  Ptr<ConstantPositionMobilityModel> mob1 = node1->GetObject<ConstantPositionMobilityModel>();

  for (uint32_t j = 0; j < nodes.GetN(); ++j)
    {
    if (i == j) continue;

     Ptr<Node> node2 = nodes.Get (j);
     Ptr<ConstantPositionMobilityModel> mob2 = node2->GetObject<ConstantPositionMobilityModel>();

     double distance = mob1->GetDistanceFrom(mob2);

     if(distance <= range)
      {
       num_neighbors[i]++;
      }
    }

 }
```

Appendix B. NS-3.35 code to set and get weight for cluster formation.

```
/*
* set and get weight for cluster formation
*/
//set weight
void SetWeight(double weight)
{
  lwcrp_weight = weght;
}
//get weight
double GetWeight()const
{
  return lwcrp_weight;
}
```

Appendix C. NS-3.35 code to set and get weight for route selection.

```
/*
* set and get route weight
*/
//set route

void SetRoute(double path_weight)
{
  lw_path_weight = path_weight
}

//get route weight

double GetRoute()const
{
  return lw_path_weight
}
```