AN ENHANCED CLUSTER HEAD SELECTION ALGORITHM FOR ROUTING IN MOBILE AD HOC NETWROK

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Dedicated To

My Family

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ABSTRACT

Mobile Ad hoc networks have become one of the most important kinds of network because of their simple construction, which does not require any pre-fixed infrastructure. Clustering is used to reduce connection load and eliminate the routing traffic that occurs during the discovery route process. The characteristics of MANET have led to many difficulties in partitioning the main networks to a cluster, selecting a node to be the cluster head, and choosing the most suitable route for sending data from a sender to a receiver. This thesis proposes an algorithm for increasing the stability of the cluster by selecting the most stable cluster head, maintaining the cluster structure with minimum maintenance overhead, and finding the best performance routing algorithm for use over MANET. This thesis proposes a cluster based routing protocol, the Enhanced Cluster Routing Protocol (ECRP), which uses a modified cluster formation algorithm to build the cluster structure and select one of the nodes to be the cluster head. The selection of the cluster head is made based on different parameters, which are: storage capacity, load distribution, accumulative time, available power, and node movement. The scale of each node is calculated according to these parameters and the node that contains the highest parameter values is chosen to be the cluster head, which is used to decide the route and the management process for all other nodes in the cluster. An algorithm for cluster maintenance is proposed that categorizes and recovers errors according to their type. The cluster maintenance stage ensures proper delivery when sending packets, which covers link failure, node movement, cluster head movement, ordinary nodes becoming the cluster head, two nodes needing to be the cluster head, and node shutdown. The routing discovery process is divided into two stages: intra-cluster routing discovery and inter-cluster routing discovery. Intra cluster routing is defined as routing within the same cluster. Inter-cluster routing corresponds to routing between two clusters using a *Global Positioning System* (GPS). A model for the Ad hoc network was simulated with various cluster scenarios. The effect of changes in movement (speed) and node density (number of nodes) on the performance of the proposed routing protocols was measured. The performance of ECRP algorithms was compared with other cluster based algorithms. The results show that the ECRP algorithms is more stable and effective than existing solutions as shown in the final trust scores for throughput, packet delivery ratio, end to end delay, number of dropped packets, and normalized control overhead. The simulation results show that the ECRP increases throughput and the packet delivery ratio. The end to end delay, the number of dropped packets, and normalized control overhead was reduced.The results presented in this thesis are significant in terms of making clustering algorithms acceptable to users and improving the performance of cluster formations, maintenance and routing algorithms over MANET. Results indicate that the ECRP can achieve at least a 5% to 10% improvement compared with other cluster based algorithms.

ABSTRAK

Penggugusan di dalam Mobile Ad Hoc Network (Manet) digunakan untuk mengurangkan beban sambungan dan menghapuskan trafik penghalaan rangkaian. Ciri-ciri Manet membawa kepada banyak masalah dalam pembahagian rangkaian ke dalam gugusan-gugusan seperti pemilihan Kepala Gugusan (CH) dan pemilihan laluan yang sesuai untuk menghantar dan menerima data. Kajian ini bertujuan untuk meningkatkan prestasi penggugusan dalam Manet, berdasarkan Protokol Penghalaan Gugusan yang Tertingkat (ECRP). Akibatnya, penggugusan di dalam Manet berdasarkan pembentukan algoritma ECRP telah direka untuk mengurangkan kekerapan perubahan kepala gugusan. Di samping itu, penggugusan di dalam Manet berdasarkan penyelenggaraan algoritma ECRP telah direka supaya bersesuaian dengan perubahan topologi. Tambahan pula, penggugusan di dalam Manet berdasarkan algoritma penghalaan ECRP telah dibangunkan untuk meningkatkan prestasi penghalaan di dalam Manet. Pembentukan algoritma ECRP telah direka berdasarkan parameter penting seperti kapasiti penyimpanan, pengagihan beban, masa terkumpul, kuasa boleh sedia, dan pergerakan nod. Kemudian, penyelenggaraan algoritma ECRP telah dibangunkan berdasarkan kesilapan kemayaan iaitu kegagalan pautan, pergerakan nod, pergerakan kepala gugusan, dua CHs dengan skala yang sama, dan penutupan nod. Algoritma penghalaan ECRP telah juga dibangunkan, berdasarkan kurangnya pergerakan nod dan jarak terdekat untuk menghantar dan menerima paket. Penemuan menunjukkan bahawa algoritma ECRP lebih stabil dan berkesan berbanding algoritma yang sedia ada seperti yang ditunjukkan dalam skor amanah akhir, dari segi daya pemprosesan, nisbah penghantaran paket, kelewatan hujung-ke-hujung, bilangan paket yang tercicir, dan kawalan overhed ternormal. Oleh itu, penemuan menunjukkan bahawa ECRP boleh mencapai 10% daripada peningkatan kestabilan, berbanding algoritma berasaskan penggugusan yang lain. Pembentukan gugusan ECRP, penyelenggaraan, dan algoritma penghalaan di dalam Manet menyumbang kepada peningkatan kestabilan rangkaian, mengurangkan beban penyelenggaraan, dan mengurangkan jumlah kehilangan paket. Hal ini sekaligus membuka lebih banyak peluang untuk rangkaian-rangkaian lain yang berskala besar dalam pelbagai persekitaran seperti ketenteraan, perubatan, dan kecemasan.

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LIST OF ABBREVIATIONS

ACK	Acknowledgment
ACO	Ant Colony Optimization
AODV	Ad hoc On-demand Distance Vector Routing
APOW	Available Power of each node
CBHRP	Cluster Based Hierarchical Routing Protocol
CBR	Continuous Bit Rate
CBRP	Cluster Based Routing Protocol
CH	Cluster Head
CMMD	Cluster Maintenance Based On Membership Degree
CROSS	Clustered Routing for Selfish Selection
DIS	Distance between particular nodes
DMAC	Dynamic Mobile Adaptive clustering
DP	Data Packet
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing
DSSS	Direct Sequence Spread Spectrum
DWCAIMP	Distribute A Weighted Clustering
ECCRP	Efficient Cluster Head Selection Algorithm
ECHSA	Efficient Cluster Selection Algorithm
ECRP	Enhanced Cluster Routing Protocol

ETSI	European Telecommunication Standards Institute
FHSS	Frequency Hopping Spread Spectrum
GPS	Global Positioning System
HDID	Highest Degree Approach
HFITF	High Frequency Intra Task Force
ICMS	Improved Cluster Maintenance Scheme
IEEE	Institute of Electrical and Electronics Engineers
IMS	Incremental Maintenance Clustering Scheme
ISM	Industrial Scientific and Medical
LAN	Local Area Network
LCC	Least Cluster heads Changes
LD	Load Distribution
LDID	Lowest ID Approach
LEACH	Low Energy Adaptive Clustering Hierarchy
LECBRP	Location Based Enhanced Routing Protocol
MAC	Medium Access Control
MaxTrans	Maximum value of Transmission range
MANET	Mobile Ad Hoc Network
MCGSR	Modified Cluster head- Gateway Switch Routing protocol
MIMO	Multiple Input Multiple Output
MOV	Movement of each node
NCO	Normalized Control Overhead
NS2	Network Simulator 2
OLSR	Optimized Link Status Routing
OTCL	Object Transcript Control Language

PDAs	Personal Digital Assistants
PDR	Packet Delivery Ratio
PS	Packet Size
RCA	Ring Clustering Algorithm
RREP	Route Reply
RREQ	Route Request
SC	Storage Capacity
SEEC	Signal and Energy Efficient Clustering
TCP	Transmission Control Protocol
TBWCA	Time-Based Weighted Clustering Algorithm
WLAN	Wireless Local Area Network
WCA	Weighted Clustering Approach

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW OF MOBILE AD HOC NETWORKS

Recently, the utilization of communication equipment that is personal, such as laptops, cellular phones, and personal digital devices, has grown significantly. This growth was accelerated by the reduction in price of these devices, supported by wireless interfaces. These wireless interfaces enable them to be connected to base stations available at different locations, such as railway stations, airports, hospitals and universities. These small, portable devices are simultaneously able to connect directly with each other without the need for any base station. Hence, a Mobile Ad Hoc Network (MANET) is created.

However, the connectivity between nodes in MANET is hampered by the movement of nodes, new node additions to the wireless network, and the node being shut down This has created a critical need for a self-regulated reliable network structure capable of being maintained under changing connectivity without requiring the support of a central manager. Additionally, the unlimited mobility of the nodes in MANET enables them to generate multiple routes. Consequently, precise routes with lower traffic can be established for these nodes. Towards this end, clustering has proved beneficial in reducing the complications of flat routing, since clustering significantly reduces the occurrence of the routing traffic through the flat routing process. Clusters partition MANET into small node groups; each group (cluster) comprising a cluster head node (CH), gateway, and normal (ordinary) nodes. Hence, the cluster head node is allowed to make routing decisions for a small number of hops, which in turn efficiently utilizes the available resources.

The MANET Network consists of several types of routing protocols: proactive, reactive and hybrid. The reactive routing protocol (AODV) creates a route only when it is required. In the proactive routing protocol (DSDV), there is advanced preparation of the route with the full information of the chosen routes presented in a table (Sangeetha *et al*., 2013). The hybrid routing protocol is a combination of AODV and DSDV protocols (Tsai *et al*., 2004).

1.2 CLUSTER MOBILE AD HOC NETWORKS

Conceptually, dividing the dynamic wireless network into a number of clusters (groups) was first suggested by several researchers who developed a self-organized, distributed algorithm to determine and maintain a linked structure despite the hop mobility and node failure. This algorithm is most appropriate for the High Frequency Intra Task Force communication network (HF ITF) which is a mobile and greatly dispersed general-purpose network offering a greater line of sight equal to the communication range for naval function units (ELOS: 50-1000km). In this case, the nodes are connected through radio waves with the HF band between (2-30MHz). HF ITF has been used together with various communication networks including battle information systems, advanced mobile phone technology and packet radio networks.

Efficiency of packet delivery is viewed as a significant goal of all MANET routing protocols and is highly significant in different kinds of application in wireless networks, for example intelligent agriculture monitoring systems, security management, and intelligent industrial sensor systems. It is possible to enhance these applications in wireless network systems by utilizing a communication model that is mobile, self-organized and offers an MANET approach. In this type of network, each node is deemed to be less costly and has adequate battery life in all possible communications. MANET comprises several mobile nodes with no distinction between a node that is normal and a router, because all nodes could be utilized for sending, receiving and forwarding packets (Lin & Gerla, 1997; Chunfeng, 2006).

Due to the mobility of the MANET nodes and the changes in network topology, the routing in this network is more complicated than in other networks. However, the traditional flat topology design is not efficient for networks with a great number of nodes since the control messages need to be transferred into all nodes in the network. Therefore, to solve the problem of packet routing, different approaches according to the hierarchical topology design for MANET are suggested.

In the hierarchical topology design, there is a division of the network into several clusters, each cluster comprising several nodes. Therefore, the control messages only pass through a specific cluster, which reduces the bandwidth overhead and the storage requirements for the network with a great number of nodes. Hence, clustering can be used to support large network scalability.

An appropriate routing method plays a significant role in the achievement of MANET because of its dynamic nature, which results in increasing the control overhead and bandwidth consumption in this type of network. The current MANET routing protocols can be classified into three groups: on-demand, table-driven and hybrid. In the table-driven protocol, all nodes are needed to preserve routing tables by sending periodic updates to check modifications in the network structure. A route is always available. This type of routing needs continuous updates, leading to the consumption of more network resources. Moreover, many of these routes may never be utilized due to topology changes and high node mobility. Therefore, this type of routing protocol is more appropriate for small-sized networks with minimum mobility.

There are several advantages when clustering in MANET is compared to traditional networks, because the former permits the best performance regarding the protocol in the Medium Access Control (MAC) layer by enhancing throughput, network delay, scalability and power usage. Additionally, it facilitates enhancement of network layer routing by minimizing the routing tables' size. It also reduces transmission overheads by updating the routing tables when topological changes take place, and facilitating the aggregate topology information as the size of a cluster is smaller than the size of the whole network. Hence, each node retains only a part (fraction) of the total amount of network routing information.

Despite these advantages, clustering still has many limitations, because the dynamic nature of MANETs hampers the cluster-based routing protocol from dividing a whole network into clusters and specifying the CH for each cluster. Additionally, clustering decreases connection and control overheads because of the pre-specified paths of communication through cluster heads. This is crucial for scalability of media access as well as routing protocols. Moreover, many mobile terminal(s) are regulated by a MANET utilizing a cluster topology. Forming and maintaining a cluster structure incurs extra cost in comparison with topology control without a cluster. Consequently, clustering has a number of side effects and disadvantages, which are summarized as maintenance problems. The rapid changes in wireless network topology involve a variety of mobile hops, resulting in an increase in the number of information messages exchanged until a critical point is reached. This information exchange consumes much network bandwidth and energy in mobile nodes (Chauhan *et al*., 2011).

Another limitation in clustering is the ripple effect of re-clustering that takes place if any internal events occur, such as the mobility or expiring of a mobile node. This may cause the re-election of a new cluster head, resulting in re-elections throughout the entire cluster structure and affecting the performance of higher-layer protocols through the multiplier impact of re-clustering (Subbaiah & Naidu, 2010). Another serious disadvantage of clustering in MANETs is the high power consumption of some nodes in comparison with other nodes within the same cluster. This is because a special node, like a gateway or a cluster head, is involved in managing and forwarding all the messages of the local cluster, which implies relatively high power consumption in comparison with ordinary nodes. The ultimate possibility is that nodes are shut down (Zhou *et al*., 2009).

1.3 RESEARCH MOTIVATION

The rapid increase of smaller and cheaper devices like mobile phones, PDAs and laptops and the growing need to exchange data between people within a short transmission range has led to the development of MANETs. The most important role of any network system is to transfer data from the source node to the destination efficiently and immediately. MANETs have many characteristic features, such as their dynamic nature, limited storage capacity, and restricted battery power. These features imply certain limitations on discovering and maintaining the routes of such a packet delivery and make the process of routing and resource management difficult. In this regard, numerous architectures have been proposed to perform this task, that may broadly be categorized into flat architecture and hierarchical architecture, depending on the node topology arrangement. In flat architecture, scalability is not sufficient to verify the expected aims of allowing the new nodes to enter and join the network and current nodes to leave the network. Regarding flat topology, the scalability worsens when the size of the network increases (Selvam & Palanisamy, 2011).

On the other hand, in the hierarchical type, all the specifications and details of the nodes are kept by groups of nodes in sets (clusters). Consequently, all the management and control packets have to be transferred within a specific number of nodes in the same cluster. Thus, the hierarchical structure can be used to minimize the bandwidth overhead and storage by using clustering, which is considered sufficiently scalable and efficient to overcome the problems of flat topology (Dana *et al*., 2008; Subbaiah & Naidu, 2010). The main purpose of clustering is to construct and maintain a specific cluster topology. It is divided into two stages: the cluster formation (construction) and the cluster maintenance. he former is used to build the main cluster structure and select the head of each cluster. The latter is used to maintain and update the cluster topology according to the network topology changes (Chung & Claypool, 2014).

Routing traffic between clusters is performed using a cluster head, which manages and keeps the routing information. This routing information results in reducing routing traffic which occurs during the routing process to provide an efficient clustering algorithm; it also makes the cluster structure as stable as possible in order to minimize resource utilization and enhance routing performance. Several studies have been conducted to obtain either a maximum cluster stability or a minimum dominant set in order to reduce the number of re-elections and re-affiliations by the mobile nodes. The principle of partitioning the nodes and routing packets differs in various algorithms by emphasizing different node parameters, such as mobility, connectivity, identification, remaining battery power, and sometimes a combination of multiple parameters. However, the re-election of the cluster head is considered a major challenge in MANET and has been studied in several algorithms. This provides a motivation for designing a scale-based clustering algorithm that can increase cluster stability as well as reduce the maintenance overhead. Hence, the routing performance is improved.

The main goal of this research is to improve the performance of the cluster routing protocol by selecting the most suitable node to be the head of the cluster, by suggesting a formation algorithm based on several system parameters. These parameters include storage capacity, load distribution, accumulated time, available power and the movement of the node. These parameters are used to calculate the scale of each node; the node with the greatest scale is selected to be the cluster head , which maximizes the stability of the cluster topology.

Additionally, an effective maintenance scheme has been suggested to improve the quality of the cluster routing protocol.

1.4 PROBLEM STATEMENT

Resource limitations in MANET are the main challenge facing the cluster-based routing protocol design because the node's mobility increases the control overhead, maximizes the bandwidth consumption and results in high end-to-end delay values (Bagwari *et al*., 2011b; Hamad, 2012; Hassan *et al*, 2014).

On the other hand, movement of the nodes can minimize the possibility of the existence of permanent cluster heads. Hence, the changes in cluster heads cause a loss of stored routing information that affects the whole routing protocol performance because of cluster topology instability (Yadav *et al*., 2010; Xie *et al*, 2013). Therefore, new cluster heads need to be elected appropriately to enhance the stability of the network topology and reduce the control overhead (Singh, 2014). Numerous algorithms, such as the Time-Based Weighted Clustering Algorithm (TBWCA) (Singh, 2014), Clustered Routing for Selfish Selection (CROSS) (Xie *et al*., 2014), and the Efficient Cluster Head Selection Algorithm (ECHSA) (Hussain *et al*., 2013), have been suggested for forming clusters and the election of cluster heads. The majority of these algorithms utilize a performance factor for the election of the cluster head, including identification number, connectivity, mobility, and distance between nodes. However, adopting one performance factor to assess a node's quality as a cluster head may degrade the network performance (Chauhan *et al*., 2011). Significant work has been demonstrated in this area, with some performance factors utilized to identify qualification of nodes as cluster heads without considering the control overhead of the whole network. Most of the proposed algorithms have focused on minimizing the instability from high-speed mobile hops by taking the comparative movement of a node and its neighbours into account, which then produces stable clustering (Singh *et al.*, 2014; Sampath *et al*, 2011). However, other important performance parameters, such as the available power accumulative time, limited storage capacity, movement, and the load distribution of the node that is elected as a cluster head, have not been considered.

The topology changes in MANET that are caused by node join, removal or failure should be considered in addressing the issue of link establishment or frequent link failure in order to provide robustness to face MANET's topology changes (Roy *et al.*, 2011; Pathak and Jain, 2015). Recovery of this process suggests cluster maintenance in such a way that the errors can be recovered with less effect on the cluster structure. Currently, the maintenance algorithms depend on the distance between the clusters that are available in the transmission range in order to reconstruct a new cluster, which means that the reconstruction of the new cluster will be increased as the distance between any two clusters increases (Yadaf *et al.*, 2010; Hassan *et al.*, 2014). This addresses the issue of re-clustering between two clusters in the same transmission range without taking into account the mobility of the nodes and the dynamic structure of the MANET.

Consequently, all MANET nodes are able to perform the sending, receiving and forwarding of packets. This implies that every node can have a role as a router in forwarding data and packets relayed through the network, possibly resulting in collisions for the wireless channel, retransmission problems and high delays (Hassan *et al*., 2014; Kanakala *et al*., 2014). This problem is aggravated by the number of nodes in the network.

Many algorithms have studied the cluster routing protocols and have provided a scalable routing algorithm that can improve the packet delivery ratio while minimizing the overhead (Hussain *et al*, 2013). However, although these algorithms can enhance the performance of the clustering routing protocol, selection of the cluster head is random, which raises a node concentration problem and offers poor reliability for data communication due to ignorance of the node communication range (Pandi and Palanisamy, 2012; Sharma *et al*., 2013). Additionally, the data communication overhead is significantly enhanced because of the construction of new clusters.

Thus, it is envisioned that an appropriate selection of a cluster head, adapting the frequent topology changes, and selecting the suitable route to pass the data from the sender to receiver based on Enhanced Cluster Routing Protocol (ECRP), would significantly enhance the performance of clustered MANETs.

1.5 RESEARCH QUESTIONS

The main research question is how to enhance the performance of cluster MANETs. The following sub-questions are posed:

i. How to minimize the cluster head change in MANETs?

ii. How to reconstruct and maintain topology changes in cluster MANETs?

iii. How to improve the performance of cluster routing in MANETs?

iv. How to evaluate the performance of the modal decomposition based on throughput, packet delivery ratio, end-to-end delay, number of dropped packets metrics performance in a simulation environment?

1.6 RESEARCH OBJECTIVES

The main objective of this research is to enhance the performance of cluster MANETs. In order to achieve this, the following sub-objectives are proposed:

i. To design a cluster MANET scheme based on the ECRP formation algorithm in order to minimize frequent cluster head changes, which will increase network stability.

ii. To develop a cluster construction scheme based on the ECRP maintenance algorithm in order to adapt the topology changes in MANETs.

iii. To develop a cluster routing scheme based on the ECRP routing algorithm in order to improve the routing performance of MANETs.

iv. To evaluate the performance of the modal decomposition based on throughput, packet delivery ratio, end-to-end delay, number of dropped packets metrics performance in a simulation environment.

1.7 RESEARCH SCOPE

The study analyzed the main problems pertaining to a clustering algorithm for MANETs, based on a cluster head selection strategy, and maintenance and routing algorithms. The research proposed a formation algorithm to construct and select the cluster head that depends on many parameters: storage capacity, load distribution, accumulated time, available battery power, and movement of each node. Cluster maintenance recovers from error, according to the type of topology change. The cluster routing algorithm depends on the location information system to reduce the network bandwidth overhead. All these algorithms were simulated and executed using NS2, and all the results were compared to existing cluster-based algorithms including Efficient Cluster Selection Algorithm (ECHSA), Incremental Maintenance Clustering Scheme algorithm (IMS), Efficient Cluster Head Selection Algorithm (ECHSA), Modified Cluster head-Gateway Switch Routing protocol (MCGSR) and Energy Efficient Coding Aware Cluster-based Routing Protocol (ECCRP). All these results were analyzed and explained in detail.

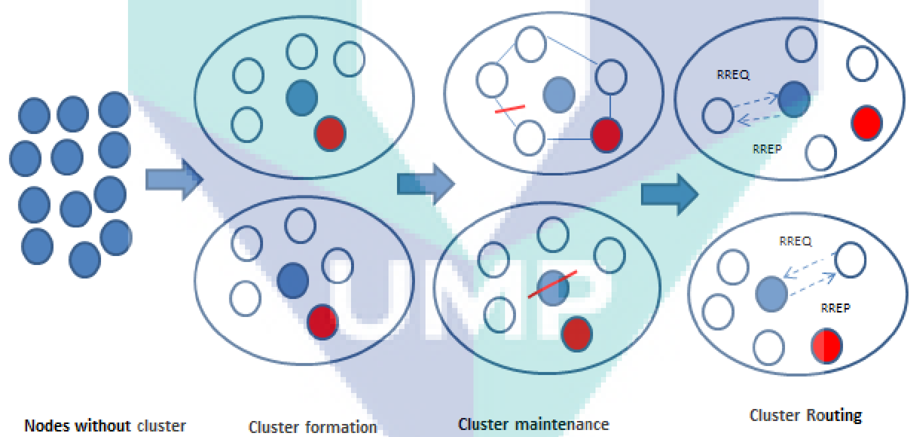

Figure 1.1 Cluster Mobile Ad Hoc Network

As shown in Figure 1.1, MANET was built using the proposed ECRP to form the cluster; maintain it by recovering from errors, depending on the type of topology changes; then establishing routing with least movement and minimum distance.

1.8 CONTRIBUTION OF THE RESEARCH

i. Minimization of MANETs frequent cluster head changes through designing cluster a new MANET based on the ECRP formation algorithm.

ii. Adaptation of MANET topology changes through the development of a cluster construction scheme based on the ECRP maintenance algorithm.

iii. Improvement of MANET routing performance through the development of the ECRP routing algorithm.

iv. Evaluation performance of the modal decomposition based on throughput, packet delivery ratio, end-to-end delay, number of dropped packets metrics performance in a simulation environment.

1.9 RESEARCH STEPS

i. Extensively surveying the literature to study the strengths and weaknesses of existing clustering algorithms. This motivates design of a new cluster MANET based on the ECRP formation algorithm to select an appropriate cluster head which minimizes the cluster head changes and improves time efficiency and resource saving.

ii. Developing a cluster construction scheme based on the ECRP maintenance algorithm to recover each link failure depending on its type. The visualization of the cluster errors is summarized as link failure, node movement and node shutdown.

iii. Developing a cluster routing scheme based on least movement and minimum distance parameters in order to improve the routing performance of MANETs.

iv. Verifying, validating and evaluating the performance of the modal decomposition based on throughput, packet delivery ratio, end-to-end delay, and number of dropped packets metrics performance in a simulation environment.

1.10 THESIS ORGANIZATION

The preparation of this thesis was designed to provide full details of the facts, computations, arguments and procedures to meet the primary objectives of the research. Hence the thesis is organized into six chapters as follows:

Chapter One provides a general overview of the research. It presents a compact introduction to the issues surrounding clustering in MANET. It covers the research background, motivation, problem, aim, objectives and scope.

Chapter Two discusses MANETs and their major features, benefits, issues, technologies, applications, routing strategies and categories of such routing. The concept of clustering is defined, and the benefits, stages, structural aspects, types of connection and major approaches introduced.

Chapter Three introduces and discusses a number of related studies.

Chapter Four contains a comprehensive explanation of the proposed clustering algorithms, with statistics, flowcharts and examples.

Chapter Five provides the simulation topology parameters and application of results, discussion, and comparison with current existing algorithms.

Chapter Six The conclusions of the current research are presented together with suggestions and recommendations for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Chapter two provides detailed explanations of the principles, architecture and categories of Ad Hoc Networks. It highlights the use of clustering in MANETs, definitions, main ideas, phases, advantages, importance, structures and types of connection. It presents a comprehensive review for the literature related to the research topic, that defines the general framework of this study. The review also provides background information from various related studies, compared with the current research. It presents an overview of cluster formation, maintenance and routing algorithms, focusing on their significance, advantages and drawbacks. For the formation stage, this chapter presents the important points associated with cluster head selection approaches, structures, goals, benefits, and restrictions, comparing the findings of existing studies. The maintenance stage and formation challenges for MANETs, that is their dynamic framework, routing, battery limits, link problems and congestion, are described. The routing stage and its two specific primary stages, routing techniques and types, are discussed in detail. Key routing techniques and their main types, distance vector routing, link state and source routing, are presented. The major concepts are explained and compared with the algorithms proposed in the following chapters.

2.2 MOBILE AD HOC NETWORKS (MANETs)

A Mobile Ad Hoc Network (MANET) is a group of any form of mobile nodes, such as smartphones, laptops or any PDA models, that communicate without requiring main management regulation from another node in an arbitrary mode. Therefore, their topology suffers from instability in the transfer and exchange of data, and the information in this type of network may be susceptible to loss and delay (Ilyas, 2003). However, their installation offers flexibility, and such equipment can be effectively used in military situations, disaster environments, sensor systems, commercial crisis systems and many other situations.

2.2.1 Mobile Ad Hoc Network Clustering

Wireless MANET comprises lots of nodes that work as routers. A MANET can be created dynamically with no infrastructure, although the clustering method considerably minimizes routing overheads and traffic (Jason *et al.*, 2009). The clustering approach in a MANET divides the entire network into small groups of nodes; each group comprises a cluster head, gateway nodes and ordinary nodes. Clustering can also be employed for the optimal use of available resources in large networks. Figure 2.1 represents all the nodes linked in the Ad Hoc system with no clustering involved, and Figure 2.2 the same network using clustering.

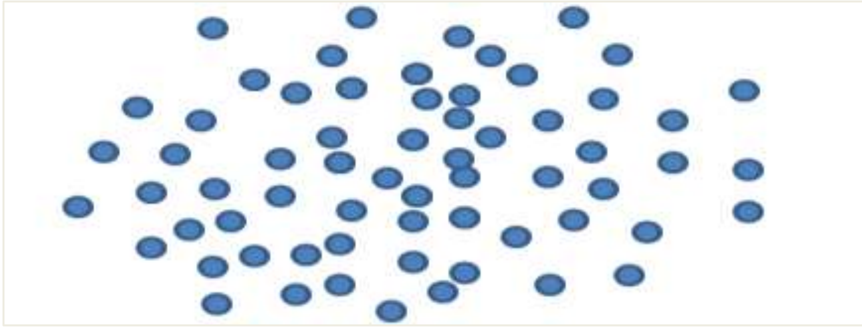

Figure 2.1: Wireless Ad Hoc Network without clustering

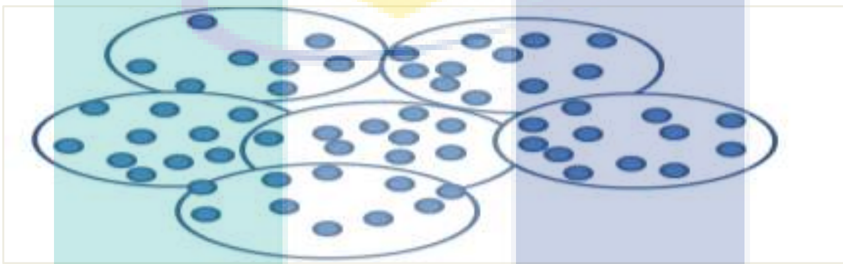

Figure 2.2: Wireless Ad Hoc Network using clustering

In MANET, the clusters are primarily categorized into overlapping and disjoint clusters (Anupama & Sathya Narayana, 2011), as illustrated in Figure 2.3. The main circle represents a cluster, and the small circles in the cluster represent the nodes of the wireless network. The vertices connecting the small circles stand for connections between the nodes.

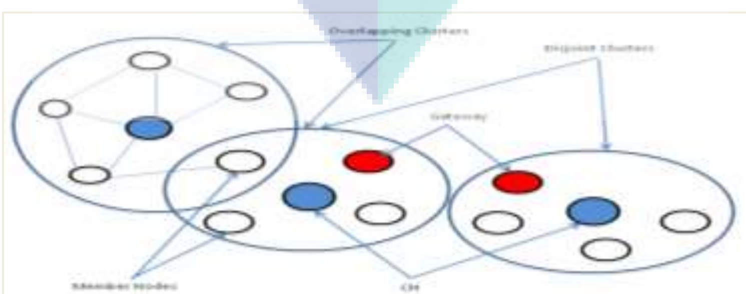

Figure 2.3: Overlapping and disjoint clusters

When the clusters are built, as indicated in Figure 2.4, the main node of each group is named the cluster head (CH); it manages the resources for all the hops in its group by finding an appropriate route to any hop in an identical cluster and allocating the inter- and intra-communication process. In the process of intra-interaction, each node may be connected to the others, so the data can be moved directly.The gateway node serves as an intermediary node for any interaction outside that group, which implies linking with other clusters. The selection process for the gateway is based on the position of the node; if it is found between two groups (clusters), it will probably be selected as a gateway node. The remaining nodes, which have direct links aided by the CH in the network, are called ordinary nodes, and may be selected as a gateway or a CH according to the system's needs.

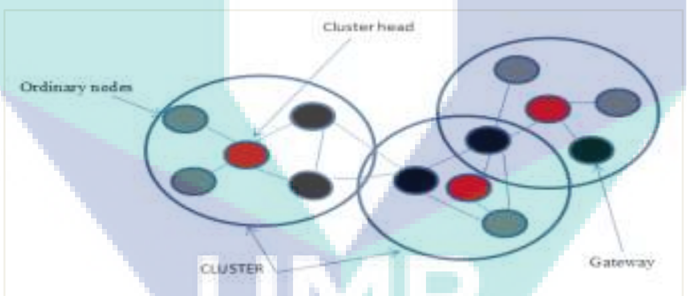

Figure 2.4: MANET clustering

The decision to select the CH depends on the specific algorithm. Any group must certainly be confirmed, utilizing the following properties to meet the requirements of MANET:

-Any node that is ordinary should be a neighbour to at least one CH.

-Any node that is ordinary should be a neighbour to the CH with the larger weight.

- CHs should not be neighbours to each other (Stefano, 1999).

2.2.2 Importance of clustering

In any interacting system, two main kinds of packet are passed through most of the nodes: information or control packets. The information packets are passed through numerous nodes until they are brought to a specific destination node, whereas the control packets are transmitted before the information. This transfer happens only from the source node toward the destination and does not need to move across any other nodes. The issue of a large amount of data being transferred emerges when the mobile nodes are continuously transported, together with topology changes, which result in periodical changes in the path status. This issue is addressed by employing the clustering approach because the data of the topology modifications and changes and routing tables' information will be transmitted via the various clusters. Nevertheless, the internal modifications and changes that take place within the group have to be internally retrieved; therefore, clustering can lessen the consumption of bandwidth, which is reflected positively in network performance (Bandyopadhyay & Coyle, 2003; Carlos *et al*., 2006).

The idea of clustering was proposed by several developers of mobile networks. It was noticed that after the wireless nodes were linked straight to the base section or to the access point, communication obstacles were eliminated by requiring only a single hop instead of being distributed by multiple hops (Chauhan *et al*., 2011). Many studies proposed to resolve the main issue in mobility by removing the base station and replacing it with a cluster head, and making the cluster head node perform all the base station tasks (Basagni *et al*., 1997).

A clustering algorithm could be employed to enhance scalability for the MANET and minimize the storage requirements, as the cluster head is likely to be used to transmit, receive, forward and keep the packets, and store the whole information about the gateways as well as other CHs in the network. This improves scalability and minimizes the consumption of bandwidth by reducing the number of nodes involved in transmitting the data (Ephremides, 2002).

A clustering framework may be employed for efficient power consumption since only nodes that can participate in the interaction and communication process will affect power consumption. The other nodes will maintain their battery power, so power consumption is reduced, using the other resources.

2.2.3 Cluster structures

Ad Hoc wireless nodes can be classified into two types: flat and hierarchical frameworks. In the flat framework (Figure 2.5) each node must forward the information to any or all the nodes in the same cluster, in practice working as a router. Hence, a great amount of flooded data is transported, requiring effective control to stop prevent the operation from having a negativeleffect on the network bandwidth. On the other hand, in the hierarchical structure, all the available nodes are specified to accomplish different operations. Any node can behave as a cluster head, an ordinary node, or a gateway. Therefore, it can transmit, receive and forward data, control interaction, and make a connection with other clusters, as indicated in Figure 2.6.

There are two main types of administration cluster, according to size: one-node and multi-node clusters. Regarding the first type, all wireless nodes which are available within the cluster are one node away from the CH, ensuring that each node is only two nodes away from every other node. In multi-node clusters, there is a limitation on the construction of the cluster; each node is at a specific distance from other nodes, as specified in building the cluster.

Figure 2.5: Nodes in flat structure

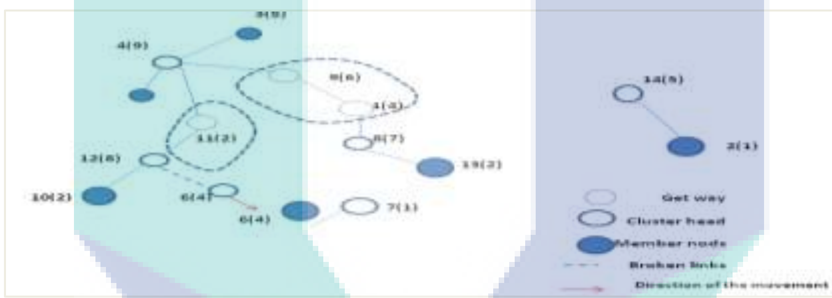

Figure 2.6: Nodes in hierarchical structure

Two algorithms can be utilized to build the cluster framework: connectivity-based and ID-based algorithms.

i) Connectivity-based algorithm: The structure of the cluster is ordered according to the level of connectivity of all the available nodes in the system. The node with the greatest number of close neighbours is selected to be the cluster head of the specific set. In this instance, if the number of neighbour nodes of a specific cluster head is reduced, its connectivity level will be reduced and a new node needs to be selected as cluster head of the set.

ii) ID-based algorithm: This algorithm is based on the identifier of the node. If a node has the lowest/highest ID in its set, it will be selected as the cluster head of the specific group (Ching *et al*., 1997).

2.3 FORMATION STAGE OF CLUSTERS

Several previous studies have suggested sub-dividing the entire network into small groups or clusters. The original idea has been modified and changed according to how it is distributed, determining the structure associated with the system regarding flexibility, movement, node failure and congestion. The real significance of an adaptable network without the necessity of overall management was recognized, meeting the requirement for a novel wireless channel with reduced congestion. Hence, numerous researchers suggested alternate designs for connecting clusters, in which the system is split into multiple sets (clusters) and various types of nodes need to be attached to each set. The cluster head for each set is directly linked to all its member nodes in order to resolve all the hop issues, utilizing the busy access technique (BTMA).

Various clustering algorithms were proposed, but from the constructional perspective they may be classified as cluster head-based and non-cluster head-based approaches (Felice, 2008). Cluster head-based approaches are determined by the selection of one of the cluster nodes to be the CH (i.e. the group front-runner), which is basically in charge of the management and routing operations of the other nodes (Shayeb *et al*., 2011). In contrast, the non-cluster head-based algorithm gives each node the freedom to decide which sets have actually to be accompanied, and exactly which group they have to leave, without depending on any involvement of the other nodes (Bagwari & Bisht, 2011a). The present study is based on the cluster head selection algorithm because many studies have shown that it is better than the non-cluster head selection alternative.

2.3.1 Main cluster head selection methods

Many clustering methods are used to construct the clusters and select one of the nodes as cluster head of a specific group. The CH is in charge of maintaining the routing data and arranging the system hops. Selecting the CH for a specific set in MANET is viewed as a challenging matter because of the dynamic topological changes involved. The CH is responsible for packet routing as well as administrating the activities of all a cluster's nodes (Garey & Johnson, 1979). Current approaches select the CH according either to the available identifiers of the system hops or based on the available location information of the nodes. As illustrated in Figure 2.7, the main methods for selecting the CH are the smallest identifier approach, the greatest identifier approach, the dynamic mobile adaptive clustering method, and the weighted clustering method. Each method has its its own characteristics and process for CH selection (Sampath *et al*, 2011).

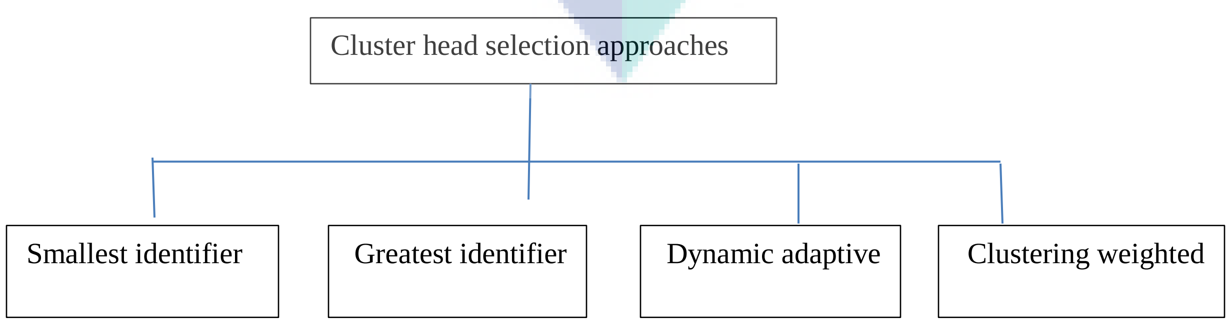

Figure 2.7: Main methods for cluster head selection

2.3.1.1 Smallest identifier method

The smallest identifier method for CH selection (LDID) is the most commonly used in Ad Hoc Network systems. The node with the lowest identifier in its set is chosen (Basu *et al*., 2001), arranging all connections and keeping all routes associated with the hops. As shown in Figure 2.8, the primary steps associated with the LDID process are as follows:

- All nodes have a unique identifier which is broadcast throughout the list of neighbouring nodes.

- Each node occasionally reviews the identifier of all neighbouring hops; if an ID is higher than the current node’s, this node is selected as ther cluster head.

-Any node with two neighbouring cluster heads as is selected to act as a gateway node, linking two separate clusters.

-Any node without the above characteristics acts as an ordinary node.

The essential features of the smallest identifier method are that any node needs to be connected to at least two others; therefore, this method is very simple to apply. As there is no overlapping clustering, only disjoint clustering can be applied. Moreover, any node can deliver just one message that is broadcast at the same time; therefore, connectivity in this algorithm is exceedingly restricted (Osama *et al*., 2006 ;Preetha & Chitra, 2014).

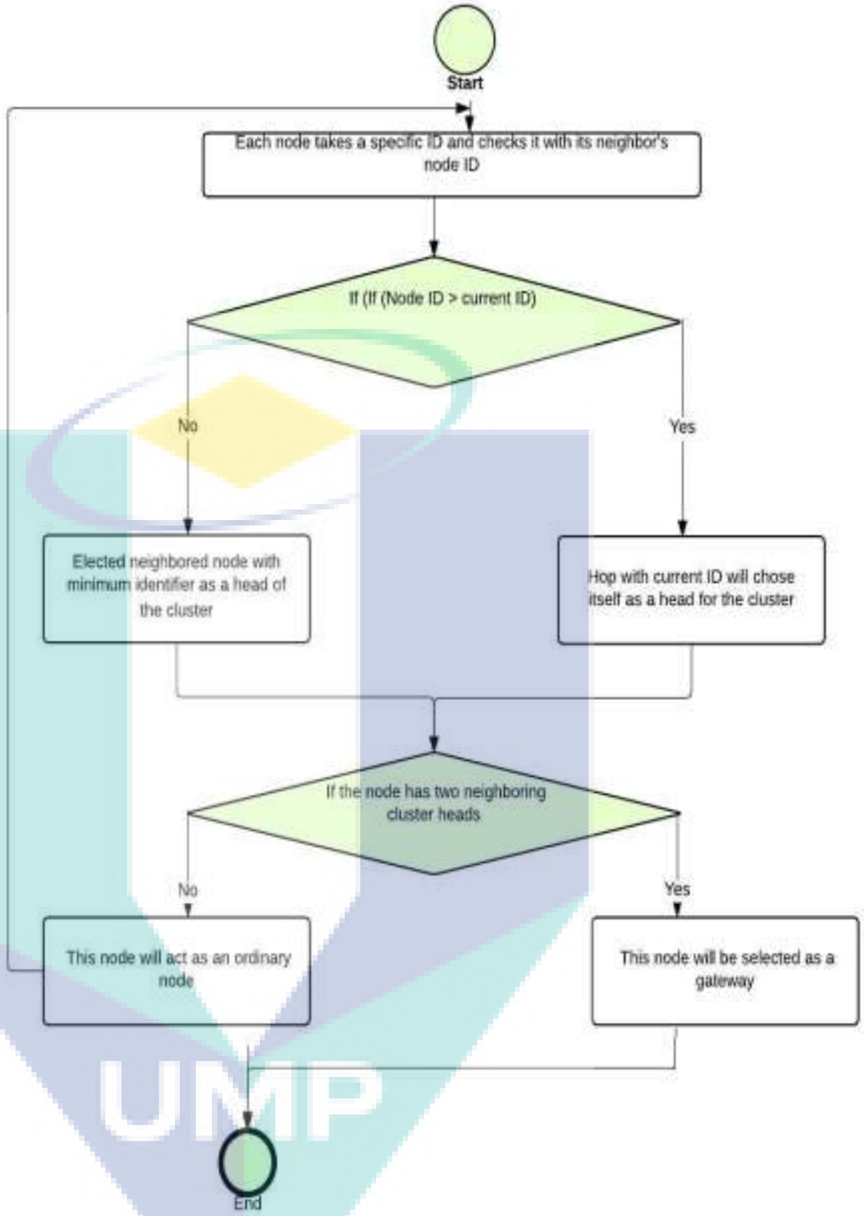

Figure 2.8: Steps of the smallest identifier method

2.3.1.2 Greatest identifier method

The greatest identifier method, proposed by Gerla (date) is also called the connectivity method of clustering. It is one of the oldest ones CH selection methods for MANETs. Again, there are three different kinds of node: cluster head, ordinary and gateway. The specific role of the CH is always to handle the routing and connection traffic associated with the nodes within that cluster. As shown in Figure 2.9, the primary steps of this method are as follows:

- All nodes have a unique identifier which is forwarded to all other nodes available in its transmission area.

-This identifier is broadcast throughout the list of its neighbouring nodes, and any node that receives it is listed as a neighbour of the sender.

- The node with the greatest number of neighbouring hops is selected as cluster head of the group. In the event of multi-hops that have the same number of neighbours, the node with the highest identifier is selected to act as cluster head.

The key characteristics associated with this method are as follows. This method has no restrictions on node density (size of cluster). Furthermore, unlimited changes of topology occur as a result of the great mobility of the nodes, which increases the chance of the cluster head congestion problem.

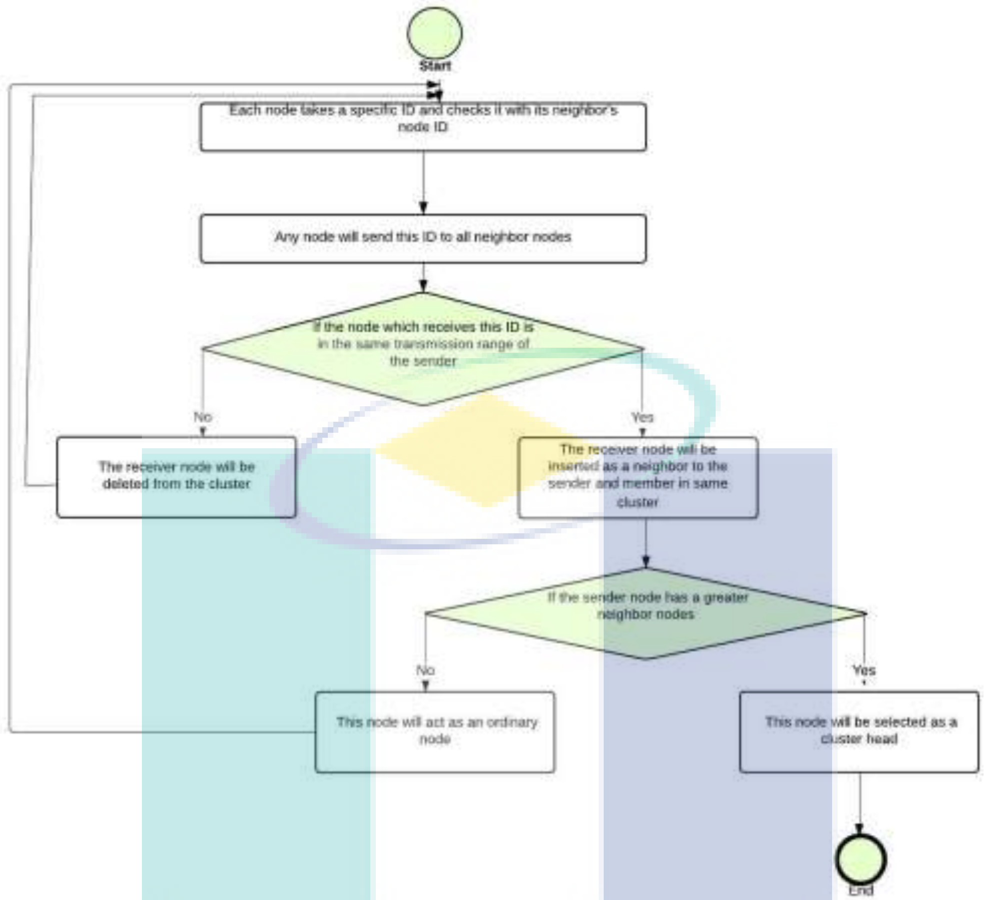

Figure 2.9: The greatest identifier method

2.3.1.3 Dynamic adaptive mobile clustering

This method is considered as an adjunct of the dynamic clustering algorithm which is utilized in the case of low mobility networks. It is preferable to the traditional dynamic algorithm because it can perform much faster (Basagni, 2012). A full description of this algorithm is shown in Figure 2.10, and the key steps associated with the process are as follows:

-Each node needs to be put into a particular cluster.

-Each node receives a particular identifier.

-The smallest and greatest identifier methods are likely to be used together, the former with regard to the assigned ID and the latter to select the highest ID according to the greatest number of neighbours.

-The sum weight of each node is calculated according to the least ID and the highest number of next-door neighbours.

- The maximum weight node broadcasts a message to all neighbouring hops to become the cluster head of the specific group.

-One other node with less weight will delay the waiting time for a cluster head message, which will choose which cluster is suitable for it to join. When nodes receive no message from the head of the cluster, they are not permitted to join any other cluster in the network.

The important characteristics associated with the dynamic method are as follows. This method can be viewed as inactive (passive method); hops expend power in both idle and sleeping modes. The maintenance overhead is minimized due to the passive feature which distinguishes this method (Chun, 2006).

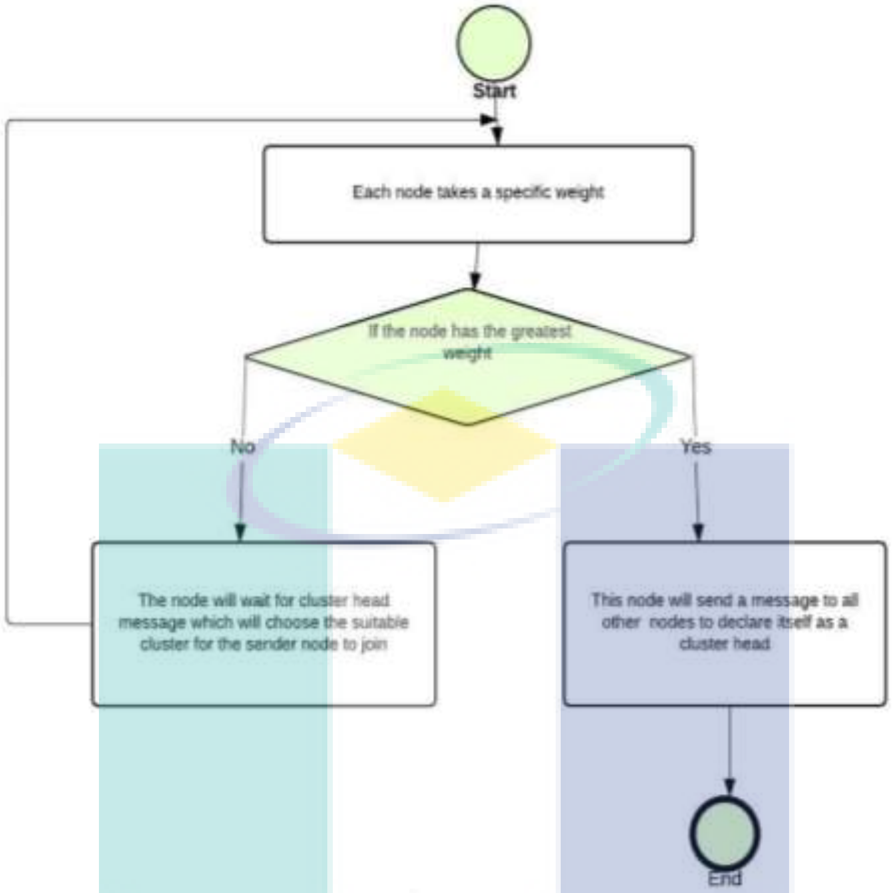

Figure 2.10: Dynamic adaptive clustering algorithm

2.3.1.4 Weighted method

This method takes into account many parameters, including transferring power and hop degree in calculating the weight of each node and selecting one of these nodes to be the cluster head of the group (Ratish *et al*., 2011). In this method, the size of the cluster must be identified by deciding on a specific threshold which is used to identify the permitted number of nodes in the cluster in order to ensure the work of the medium-access control layer (Aissa *et al*., 2013). The key steps in this method are explained below:

- For each node (m) in the network, find the degree based on Eq. (2.1):

$$D_{node} = /O(g)/ \sum_{node\,!=node}^{m} \{\text{distance } (g, g') < R\} \tag{2.1}$$

O(g) is the hop identifier

g and g' are two mobile nodes.

R is the range of transferring.

- Find the degree differences among all the nodes in the network using Eq. (2.2)

$$\Delta_{node} = \left| D_n - \beta \right| \tag{2.2}$$

β is the factor of errors (values are between zero and one)

- Find the degree's summation for all the network nodes by comparing the node with its neighbour, by Eq. (2.3)

$$D_{node} = \sum_{n}^{m} \{\text{distance } (g, g')\} \tag{2.3}$$

- Find the mobility mean of the network nodes, based on Eq. (2.4)

$$\text{Mobility} = \frac{1}{time} \sum_{t=1}^{T} \sqrt{\left(X_t - X_{t-1}\right)^2 + \left(Y_t - Y_{t-1}\right)^2} \tag{2.4}$$

-Find the total summation of distance for all nodes in the network, then calculate the weighting value of the mobile nodes by using Eq. (2.5)

$$\text{Weight} = a1 * \text{Degree}_n + a2\ \text{MOB}_n \tag{2.5}$$

Degree_n is summation of distance for all neighbours.

MOB is the mobility (average speed over time).

a1+ a2 are the coefficient and summation which = 1.

- The last step is to select the node with the least weight to be the head of the specific cluster (Mainak *et al*., 2002). The main steps in weighted clustering are presented in Figure 2.11.

The main features of this method are as follows: it is highly effective because it can provide the greatest framework for the medium-access control layer. Furthermore, the cluster head node consumes a great amount of power in sending, receiving and forwarding data (University of Florida, 2002)

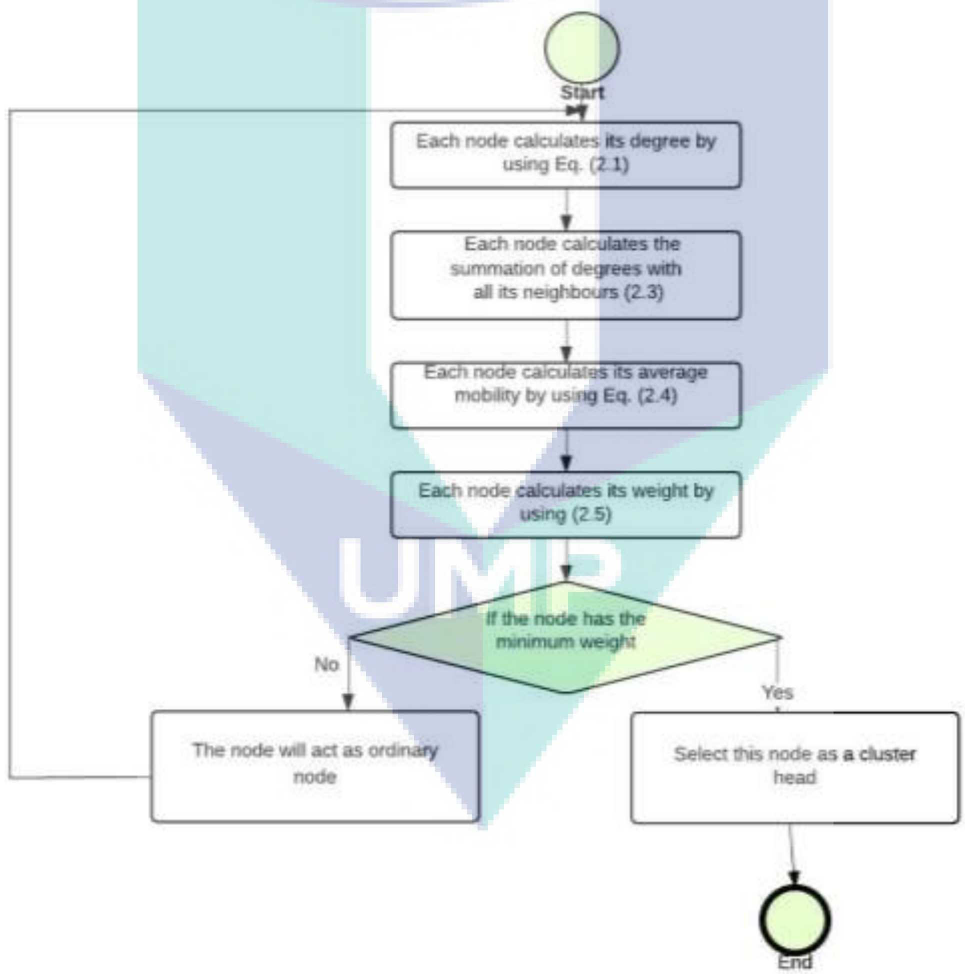

Figure 2.11: The weighted clustering main steps

2.4 Cluster head formation algorithms

Several algorithms have been proposed for selecting the CH, according to the consumption of power, node identifier, weights of individual nodes, etc. (Basagni *et al*., 2006). The advantages and limitations of algorithms for the clustering formation stage are explained below.

In 2011, Chauhan *et al*. presented and put into practice a distributed weighted based clustering algorithm for MANET to distribute a weighted clustering algorithm (DWCAIMP), which depends on gathering the weighting-based clustering algorithm with the distributed algorithm. The weight of each node is computed, employing the traditional three parameters: the number of the node's neighbours, transmission power, and the distance between nodes. First, each node is assigned a random ID value, which is broadcast to its neighbours and a neighbourhood table is built. This is followed by individual nodes: each node calculates its own weight on the basis of several factors, such as transmission power, the population of the node's neighbours and the distance between nodes. When a node finds its own weight, it is broadcast to its neighbours. When its weight is the greatest among its neighbors, the cluster head variable is set to 0. When an ordinary node receives a CH message, it checks all the nodes that sent CH messages.

The node with most weight assumes the status of CH for that hop. A wireless node transmits a specific message to the cluster members and informs them that the cluster head with a specific ID is chosen. This algorithm reduces the cluster head formation overhead and eliminates the control packet overhead, which improves performance and reduces the network's energy consumption. However, the cluster head selection mechanism in DWCAIMP is restricted to only a single neighbour node and does not consider multi-node neighbours. Therefore, DWCAIMP needs to be enlarged for the inclusion of k-hop or multi-hop neighbours. Thus, this study suggested adding some new parameters to the weight calculations of nodes to improve performance over that of DWCAIMP.

The efficient ant colony optimization algorithm (ACO) for cluster heads selection in MANETs depends on the optimization algorithm proposed by Sampath *et al.* (2011). This algorithm combines the four standard clustering algorithms described in section 2.3.1. It also uses an ant colony optimization algorithm to lower the number of clusters constructed in the network, The ants leave chemical material called pheromones on the path they pass through. When many ants pass along the same path, the pheromone will be increased. Hence, the more the pheromone, the greater the likelihood that a new ant will select the same path to obtain food.

The route selected by the ants is always the shortest route to the food. However, to apply this algorithm in cluster head selection, a cluster head is chosen according to the amount of the pheromone and the visibility value. The former is brought up to date in each time frame of the cluster, whereas the visibility value refers to the number of nodes in the cluster. Each time one hop is selected as the CH, the CH of the next cluster is chosen, depending on the pheromone and the visibility of its neighbours. This algorithm ceases only when all the hops in the MANET are preserved. A hop is reported to be preserved if it is chosen as a CH or it is located in the transfer range of one of the available cluster heads. The simulation results show that this algorithm can minimize the time of the cluster head selection process. ACO is similar to achieving the least dominating set for the topology graph, because the CH is one node away from its cluster members. However, ACO needs to be combined with other algorithms to solve the problem of multi-hop networking. Because the MANET consists of a number of hops that are arbitrarily moved, the highest number of movements results in the highest number of changes of cluster head. It also depends on measuring the number of clusters that are formed, to check the performance of its algorithms without taking into consideration the number of cluster head changes and the number of member changes, which increase as the movement of the member nodes increases.

Another efficient clustering formation mechanism is based on game theory, namely Clustered Routing for Selfish Selection (CROSS), designed by Xie *et al.* (2013). In this routing protocol, each node is considered as a player that enters a clustering game to participate in cluster head selection, where all individual nodes play a clustering game with their neighbours but only within communication range. In any case, one node can succeed in bidding for the position of CH in one district, thus attaining an optimal payoff. In the CROSS algorithm, any CH that is fortunate enough to vie for the physical media will immediately announce itself to be a real CH. When the announcement occurs, the other CHs will abandon their declaration to be real CHs, and they all return to the normal state. As a result, there is only one real CH in the neighbourhood, although several potential CHs have emerged. The simulation results verify that the CROSS mechanism shows better performance than the LEACH routing protocol (see section 2.6.4) in terms of energy consumption and end-to-end delay, and it can be used within a limited cluster space without considering the node parameters, such as the available power and the distance between nodes. The CROSS mechanism supposes that the maximum power level is large enough for every node to transfer packets to the destination node without taking into account how to adjust the node power level in order to adapt the power to a certain communication distance.

Singh *et al.* in 2014 presented a stable cluster heads selecting algorithm called Time-Based Weighted Clustering Algorithm (TBWCA), which uses a combination of the traditional weighted clustering algorithm and link expiration time computation. TBWCA calculates the weights prior to the clustering setup, and selects the node with the lowest weight to be the CH. The neighbours of CH are then not permitted to take part in the election process. It also uses Time to Link (TTL) to predict the duration of a wireless link between two mobile nodes and reflect the mobility of the nodes. The weight for each node is computed without involving the neighbours or clusters, but by using four parameters: transmission range, transmission rate, power consumed at the node, and the movement of the node. The TBWCA algorithm minimizes the instability resulting from the dynamic nature of the network by considering the relative movement of the node with its neighbours. It increases the stability of the network without considering speed or the velocity of the node because it makes the assumption that the direction and the speed of motion of the mobile nodes are not altered during the prediction interval. This is considered unsuitable for MANETs, which are characterized by unlimited mobility with different speeds.

Hussain *et al*. (2013) proposed a modified cluster head selection algorithm, namely the Efficient Cluster Head Selection Algorithm (ECHSA). ECHSA depends on computing intelligence capabilities to select the cluster head by using Bayes Estimator theorem, to measure and estimate the number of lost packets in the system and to select a more stable cluster head to increase the performance of the network. This algorithm also uses a 'black and white' list to identify the status of each node. It activates the active nodes and blacklists those that are not used in forwarding packets. Hence, the CH discovers the most suitable routes to send packets, and the network is restored through new routes. Additionally, ECHSA selects a new cluster head without disturbing the normal communication, and the additional resource utilization is reduced. The results and evaluation show that this algorithm is more effective than others, and it requires fewer resources for cluster head selection, which is reflected in the increased lifetime of the MANET. However, its main drawback is that it increases the control overhead of the network, which in turn increases the node energy consumption. It can be used with small-sized networks because as the number of nodes increases, the end-to-end delay will be increased accordingly. This is because the cluster head needs more time to categorize the nodes into active and non-active nodes.

Previous studies reported limitations that can be observed in these algorithms that need to be redressed. The limitations and the main issues that need to be addressed are illustrated in Table 2.1.

In DWCAIMP, the weight of each node depends on three parameters, the power of transmission, the number of neighbours of the hop, and the distance between nodes. Additionally, it is restricted to only one single neighbour node, and does not consider multi-node neighbours. As a result, DWCAIMP should be extended to involve k-hop or multi-hop neighbours. Some novel parameters also need to be included in computing the weight of the nodes to overcome the disadvantages of this algorithm and to achieve the highest performance from it without affecting the performance and the stability of the network.

The ACO algorithm can reduce the end-to-end delay time of the entire network since it is utilized to find the least controlled group for the structure graph, as the cluster head is one node away from its cluster members. However, if the number of hops is increased, it needs to construct another cluster to contain the new hops. This will increase the numbers of changes in cluster heads and in members as the movement of the member nodes increases. Since Ad Hoc Networks consist of a number of hops which are arbitrarily moved, the largest number of movements results in the highest number of cluster head changes.

The CROSS mechanism is implemented by assuming that the maximum power level is large enough for each node to transfer packets to the destination node without having to adjust the node power level for a certain communication distance. This makes it ineffective for the cluster head, which needs more power to complete its operations.

The TBWCA algorithm increases the stability of the network without considering the speed and the velocity of the node, because it supposes that the direction and the speed of motion of the mobile nodes are unchanged during the prediction interval. This is considered unsuitable for a MANET, that is characterized by unlimited mobility with different speeds.

All these limitations have been considered and addressed by suggesting an enhanced clustering formation algorithm to overcome them. The studies related to the formation algorithm are summarized in Table 2.1.

Table 2.1: Comparison of current formation clustering methods

Author	**Algorithm**	**Limitations**
Chauhan *et al*. (2011)	Distributed weighted clustering algorithm (DWCAIMP)	1-Used with only one single neighbour node, and cannot be used with multi-node neighbors. 2- Need to add more parameters to the weight algorithm in order to improve performance because it takes into account three parameters only: transmission power, number of neighbour nodes and distance.
Sampath *et al.* (2011)	Colony optimization algorithm (ACO)	1-It increases the number of cluster heads and cluster member election. 2- It depends on the number of constructed clusters to ensure the quality of the proposed algorithm without taking into account the number of CH changes and member changes, which are increased as the movement of the MANET nodes increases. 3- It needs to be combined with other algorithms to address the issue of multi-hop networks because the MANET consists of a number of hops, which are arbitrarily moved. Consequently, the highest number of movements results in the highest number of cluster head changes. 3- It depends on measuring the number of clusters, which are formed to check the performance of its algorithms without taking into account the numbers of CH and member changes, which are increased as the movement of the member nodes increases.
Xie *et al.* (2013)	Clustered routing for selfish selection (CROSS)	1-It can only be used within a limited cluster space without considering the node parameters, such as the available power and the distance between nodes. 2-It supposes that the maximum power level is large enough for every node to transfer packets to the destination node without taking into account how to adjust the node power level for a certain communication distance.
Hussain *et al.* (2013)	Efficient cluster head selection algorithm (ECHSA)	1-It increases the control overhead of the network, which increases the node energy consumption. 2-It can only be used with a small-sized network because as the density of nodes increases, the network delay will be increased accordingly, because the cluster head needs more time to categorize the nodes into active and non-active nodes.
Singh *et al.* (2014)	Time-based weighted clustering algorithm (TBWCA)	1-It increases the stability of the network without considering the speed and velocity of the node, because it assumes that the direction and the speed of motion of the mobile nodes are unchanged during the prediction interval. This is considered unsuitable for the MANET that is characterized by unlimited mobility with different speeds.

2.5 MAINTENANCE STAGE OF CLUSTERS

The essential objective of this stage is to retain the structure of the MANET cluster as much as possible. In one-node clusters, each hop communicates directly with the need for a cluster head. Hence, if one hop moves out of the transmission range of the other node, a failure of the link will occur, and the ordinary nodes must choose another cluster to join. This mechanism is called a re-election process, and results in the consumption of additional calculated costs and packet complications. As a result, algorithms need to be developed to reduce this challenge.

2.5.1 Dynamic structure

In a MANET environment, nodes have the ability to connect to other available nodes to effect transmissions directly and without requiring a pre-fixed infrastructure. However, other nodes are not available in transmissions that directly use a number of intermediate nodes to reach their location. All nodes that participate in the communication consist of a mobile Ad Hoc system in both of these situations. The limitations on the power of Ad Hoc systems with fewer protection parameters make the mobile random network vulnerable to attack and external intrusion. These intrusive threats can originate from any hop that is available within the transmission range of any node within the MANET topology. Additionally, the MANET mobile nodes cannot repel or resist many link attacks that can jeopardize the network. These attacks may consist of altering or damaging data, message replay, eavesdropping, damage details that are protected, interference, denial of service, etc. Consequently, MANET developers have to build a safer and more secure framework to manage this problem (Aarti & Tyangi, 2013; Srinivasa *et al.*, 2009).

2.5.1.1 Routing in MANETs

The nodes are moved in such a way as to change their place within a network. This leads to the creation of some routes which are unnecessary for the routing table, and increases the routing overhead. Additionally, the nature of MANETs results in regular changes to the topological system framework, and this makes the routing of the nodes more complex. These problems, combined with the crucial importance of the routing protocol in constructing communications between nodes, have made the routing procedure a popular focus in the MANET research field. Many routing protocols and MANET algorithms have been suggested, and their effectiveness has been discussed and analyzed by several researchers.

2.5.1.2 Link failure

MANET wireless links are invariably characterized by instability and flexibility. Consequently, they are more affected by loss of packets than are other networks, and probably the greatest number of challenges concern routing packets. When a link in a route is broken, the node that detects the break is supposed to be chosen to locally retain the broken link. After determining the route between the two communicating nodes (sender and destination), if any node in the route is shut down, the sender node will re-transmit an alert that the link is broken. It then keeps the problem by simply making a cache search to locate a fresh route to send the data toward the required location. If any route is held in the cache, it will move information to the sender node; otherwise, it will send a Route Error message to the transmitter to signify the link failure. The source node then deletes the entry regarding the shut-down node and attempts to locate a new route to send it to the appropriate destination (Papadimitratos & Haas, 2003; Shanthi & Sorna, 2013).

2.5.1.3 Congestion

In the Ad Hoc system, congestion occurs as a result of alterations in channel states, as TCP assumes that the loss of packets refers to congestion mistakes as opposed to connection failure errors. The sender node is informed of the congestion issue within the channel, and either reduces the packet transmission ratio or locates another path with lighter traffic. All the congestion control algorithms in MANETs have the ability to report to the original sender node about the congestion states, as they use the Transmission Control Protocol (TCP) inside their structure (Kumar *et al*., 2008).

2.5.2 Clustering Maintenance algorithms

Several studies hav eanalyzed and discussed the main issues of maintenance in clustering in MANET. Yadav *et al*. (2010) presented an effective clustering maintenance mechanism, the Incremental Maintenance Clustering-based Scheme (IMS) which aims at minimizing the number of CH changes and enhancing the stability of all clusters in the MANET. In IMS, the cluster construction mechanism depends on the lowest identifier clustering algorithm, where the hop with the smallest sequence number is selected as CH. In this algorithm, when two clusters heads are located within the same transmission range, CH re-election is delayed for a specific period of time until the maximum threshold is reduced. If both are still within each other's transmission range, the cluster head with the smallest identifier retains its role as CH, and the other one stops its operation as CH. IMS simulation results prove that this algorithm can reduce the number of CH re-election processes, thereby increasing the stability of the network. Additionally, they show that IMS is a better cluster maintenance mechanism than the LCC (Least Cluster heads Changes) and CBRP (Cluster Based Routing Protocol) maintenance schemes in terms of the number of changes in cluster heads and cluster members, and also in terms of of clustering overheads. This is due to avoiding unnecessary cluster head changes. However, the main drawback of the IMS algorithm is that it can only solve the problem of two cluster heads within the same transmission range. Hence, it is not efficient for use with unlimited movement nodes. Moreover, other problems such as link failure between nodes, movement of the nodes and shut down of the cluster head cannot be addressed by using this algorithm.

Moosavi and Rafsanjani (2011) proposed a new cluster maintenance algorithm, Cluster Maintenance based on Membership Degree (CMMD). In this algorithm, the CH checks the weight of each node, and removes a node if its weight is less than the specified threshold in its cluster. As a result, re-clustering of nodes which have no cluster to join occurs. The weight value of a node is obtained based on the cluster head energy and distance between hops and the cluster head. However, in CMMD, one node leaves its cluster and executes the re-election process if its weight in the cluster is less than the specified value. This method is appropriate for less mobile networks because re-clustering is done within the required time, as in a low mobility network, where re-clustering exclusion occurs as needed and only in the required time. This reduces energy consumption and increases the lifetime of the cluster. However, CMMD is a demand-driven algorithm because it is executed only on demand. This increases the lifetime and reduces the throughput, resulting in a high delay value. Additionally, CMMD is not suitable for high-mobility networks because the re-clustering operation is executed frequently, increasing energy consumption in the network.

Roy *et al*. (2012) proposed an enhanced cluster maintenance and formation algorithm, namely the Signal and Energy Efficient Clustering (SEEC) algorithm, to enhance MANET performance. This algorithm depends on the level of energy and the strength of the signal for all nodes in the MANET to increase the lifetime of the cluster head. It focuses on the maintenance and formation of clusters at little cost, using the resources of signal strength and battery power level of the node. It also deals with the energy-efficient communication issue by using network coding. Moreover, it is based on reduced flooding strategies to enhance the lifetime of the cluster head by gathering the algorithm network Coding Protocol (COPE) into a cluster-based routing protocol (CBRP) to further minimize the consumption of energy for the cluster head. This is considered the most important problem faced by the CBRP in reducing the lifetime of the cluster. The COPE protocol uses a network coding concept to reduce transmission times by aggregating the data at intermediate hops. The results of this research show that this algorithm extends the lifetime of the network and expends less power than other algorithms, because its main objective is to preserve the head node and reduce re-election of the cluster head. However, SEEC can increase the lifetime of the cluster head without considering the node mobility collision that results from packet aggregation. Additionally, it does not take into account the hidden nodes that expend the power of the entire network without real participation in any communication activity.

An enhanced cluster maintenance algorithm, Improved Cluster Maintenance Scheme (ICMS), was proposed by Pathak and Jain in 2015. ICMS takes into account two vital factors to calculate the weight of each node chosen to be the head of the cluster: node degree and bandwidth consumption. Additionally, when two clusters approach each other, they combine and form a single cluster. In this case, one of the two CHs must drop out from the role and the other will take over. Another approach of combining two clusters into one was suggested by the ICMS scheme. ICMS focuses on reducing the change of CH to improve performance, resulting in a more stable cluster, and reduces packet loss compared to that of the CBRP maintenance algorithm. Moreover, ICMS shows a high performance in terms of the number of cluster head and member changes, thus minimizing the chances of unnecessary cluster combination and reducing the control overhead message of the network. However, this algorithm is limited to small-sized networks with fewer than nine nodes, and the cluster size is limited to three nodes in order to minimize the number of candidate nodes that campaign to be cluster head.

According to the literature on maintenance, the limitations of the previous studies and the main issues that need improvement can be illustrated as shown below. The related studies that discussed maintenance algorithms, and their limitations, are summarized below and in Table 2.2.

IMS cannot handle the main cluster maintenance problems, which are link failure between nodes, movement of the nodes and shut down of the cluster head when has the problem of two cluster heads within the same transmission range. Thus, it is not efficient to be used with the unlimited node movement of MANET.

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CMMD is considered a good algorithm in terms of extending the lifetime of the node and reducing energy consumption. However, it is not suitable for high-mobility networks because the re-clustering operation is executed continuously, which increases energy consumption in the network. Additionally, its algorithm is demand-driven; this extends the lifetime, but it also reduces the throughput, resulting in a high end-to-end delay value.

The SEEC algorithm depends on the packet aggregation procedure. Although it can extend the lifetime of the cluster head, it does not consider the node mobility that results from packet aggregation. Nor does it take into account the hidden nodes that consume power throughout the entire network without real participation in any communication activity. All these limitations have been considered and an enhanced clustering maintenance algorithm proposed.

ICMS, suggested as an enhanced maintenance procedure for clustering in MANET, does have some advantages, like reducing the control overhead packets and minimizing unnecessary combinations. However, its disadvantages include being restricted to small-sized networks with fewer than nine nodes, and a cluster size limited to three nodes in order to minimize the number of candidate nodes seeking to be cluster head. This also reduces the speed of adaptation to topology changes.

Table 2.2: Comparison of maintenance clustering methods

Author	**Algorithm**	**limitations**
Yadav *et al.*(2011)	Incremental maintenance clustering scheme (IMS)	1-It can solve only the problem of two heads which are available in the same transmission area. Thus, it is not efficient for use with the unlimited movement of the MANET nodes. 2-It solves only the problem of link failure between two clusters within the same transmission range. Hence, other problems, such as link failure,

		movement of the nodes and shut down of the cluster head, cannot be recovered using this algorithm.
Moosavi and Rafsanjani (2011)	Cluster maintenance based on membership degree (CMMD)	1-It is not suitable for high-mobility networks because re-clustering is executed frequently, increasing energy consumption in the network. 2- It is a demand-driven algorithm. This extends the lifetime, but reduces throughput and results in a high end-to-end delay value.
Roy *et al*. (2012)	Signal and energy efficient clustering algorithm (SEEC)	1-It extends the lifetime of the cluster head without considering node mobility collision that results from packet aggregation. 2-It does not take into account the hidden nodes that consume network power without real participation in any communication activity.
Pathak and Jain (2015)	Improved cluster maintenance scheme (ICMS)	1-It is limited to small-sized networks with fewer than nine nodes, and the cluster size is limited to three nodes in order to minimize the number of candidate nodes seeking to be cluster head, which constrains the use of this algorithm to small networks with small cluster size.

2.6 ROUTING STAGE IN MANET

Routing, which directs information from the sender node to the destination node, is recognized as one of the most important aspects of MANET as its structure is distinguished by numerous changes. Each node can be used to send, receive and forward information. Hence, the routing should be selected to include the most appropriate path between nodes to forward packets to the particular destination node (Bhujade *et al*., 2014). As presented in Figure 2.12, the routing in Ad Hoc Network systems is categorized into two phases: routing techniques and routing category. Each stage is explained in more detail below.

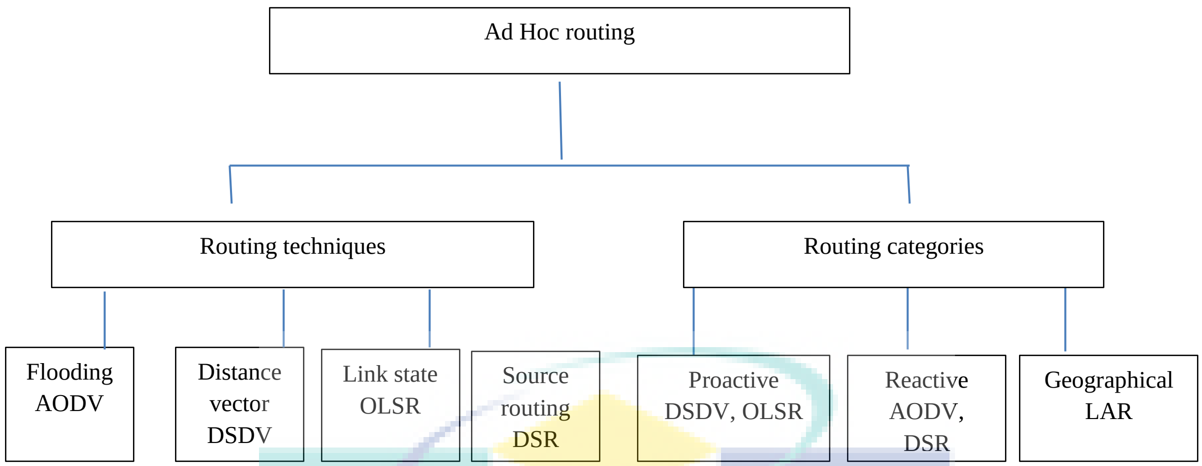


Figure 2.12: Ad Hoc routing

2.6.1 Routing techniques

Choice of the most appropriate path for forwarding packets depends on the routing technique. As indicated in Figure 2.13, the main techniques are flooding, distance vector, link state, and source routing.

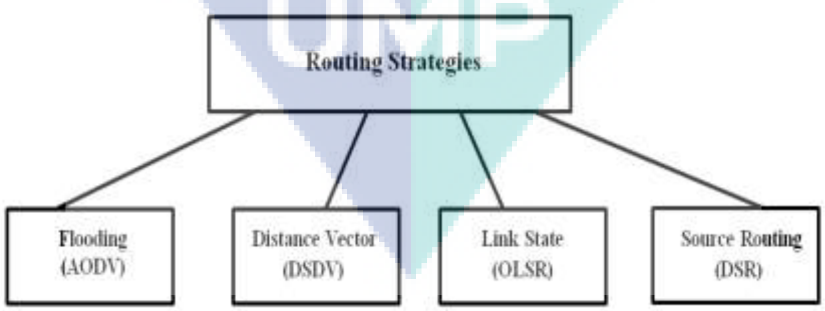


Figure 2.13: Routing techniques

2.6.1.1 Flooding

Flooding involves giving control data to all nodes that are available in the transmission area. The strategy is to allow the original node that transferred the data to transfer it to all its neighbour nodes. The node continues to transfers this information to any or all other neighbours until the data are brought to all the nodes in the system. However, this strategy can cause bandwidth overload (Perkins *et al*., 2003).

2.6.1.2 Distance Vector Routing

Distance vector routing depends on calculating the exact distance and direction to any link in the network. Direction means the hop that is next to the current one and also the exit user interface. Distance is a calculation of the route cost needed to reach a specific node. Using this technique, each node in the network is able to determine the distance to all other nodes in the network; these details are list in a special table, and occasionally broadcast to any or all nodes within the system. Destination Sequenced Distance Vector (DSDV) is an example of this routing technique (Boukerche, 2009), as clarified in Figure 2.14.

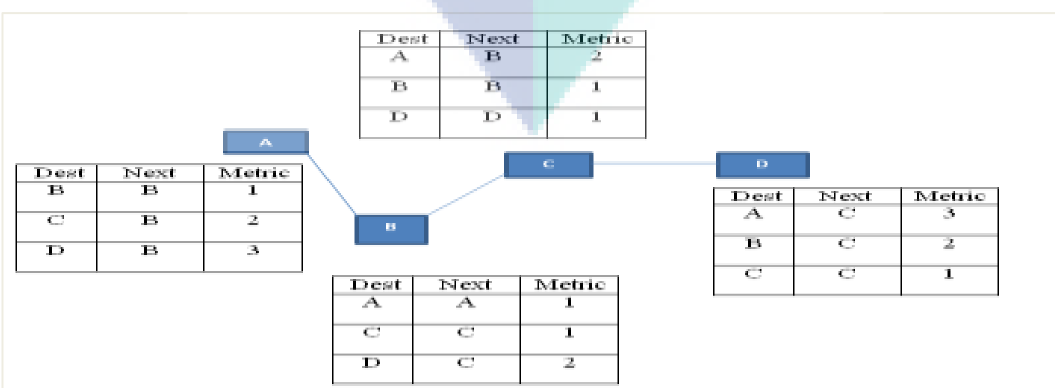


Figure 2.14: Distance vector routing technique

2.6.1.3 Link State Routing

The main concept of this routing technique is that each node develops a map of the connectivity of the network system, in the shape of a graph, to indicate the nodes that are connected.I Individual nodes then compute the optimal path, and rationalize it for each potential hop within the network. The groups of optimal paths constitute the routing table for the node. Each node stores an entire table of the network structure and the cost of each path, and sporadically disseminates this information to all other nodes. As a result, the routing information is updated and the sender chooses the route most suitable for sending its packets. Optimized Link Reputation Routing (OLSR) is an instance of this technique (Papadimitratos & Haas, 2003).

2.6.1.4 Source Routing

This is also referred to as path addressing. It gives permission to the transmitter of a packet to partially or entirely determine the path of the packet through the system. In comparison with non-source routing techniques, the routers in this system can specify the routes based on the packet's receiver. It indicates that each packet must support the whole information that is complete with the route. Hence, the routing decision selection takes place in the source node (sender node). Dynamic Source Routing (DSR) is a typical example of this technique (Larsson & Hedman, 1998; Sarkar *et al*., 2008).

2.6.2 Ad Hoc Routing Protocol Categories

In an Ad Hoc system, the routing process between nodes needs to be included under one of the following three categories, as explained in Figure 2.15.

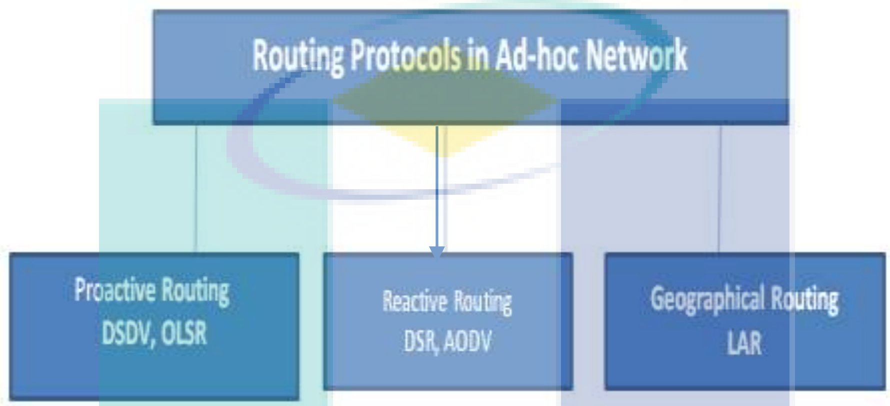


Figure 2.15: Routing protocol categories

2.6.2.1 Reactive Routing Protocols

In reactive routing, the route is made in accordance with a certain request, which means that the path is developed for the mobile nodes required to transmit packets to a particular node. There is no requirement for periodic upgrading of the routing information table; it has used the available information to interact between nodes. Route construction is typically carried out by transmitting a route request to all the nodes available in the network. When receiving this request, a node with a particular route will transmit a reply to the sender node.

Reactive protocols can be classified as source protocols and point-to-point protocols. In the former, each packet must include in its header the entire target address of the transmitter, destination and intermediate nodes. All intermediate hops use this target address to retransmit the packets to a given location, without having to update their routing table for each and every active path. Additionally, in this particular network type, the node does not need to periodically check out the available links and connections with the other nodes (Toh, 1996).

The disadvantage of source routing protocols is the inability to use them in a MANET system with many nodes. The main reason for this drawback is that, as soon as the size of the network is increased, the number of intermediate nodes will be also increase, and the likelihood of congestion and link failure also grows. Thus, it is not ideal for use in a large-scale network. Also, this type of routing protocol is unable to update its information based on network modifications, particularly when it handles Ad Hoc systems which are differentiated by highly mobile topology.

On the other hand, in the point-to-point routing protocol, each packet has the destination node address together with the address of the next node; therefore, the intermediate nodes transmit the packets according to the routing table. The major benefit of this type of routing protocol is that it is easy to construct, and has minimum delay and minimum network overload, as it does not send control routing packets periodically to all available hops in the network. However, its primary weakness is that most of the intermediate nodes should keep complete routing information on all the active routes. Dynamic Source Routing (DSR) and Ad

Hoc On demand Distance Vector Routing (AODV) are examples of the reactive routing protocol (Jiang, 1999).

2.6.2.2 Proactive Routing Protocols

The path is pre-constructed whether or not a particular routing request has been sent by a node. In this type of routing protocol, the routing data are sent to all other nodes in the network on an occasional basis. Each node available in the MANET system should contain the routing information packets, and this routing information should be updated based on the network structure modifications.

The routing information packets, which are to be brought up to date occasionally within the routing table, comprise the density of nodes required to connect to a particular destination node and the sequence number for all hops available in the route (Maghsoudlou, 2011). The primary benefit of this routing protocol type is its power to alter the routes based on the network topology modifications, and offering the least delay in data delivery (Patil, 2012).

The main disadvantages of proactive routing include the extensive use of bandwidth in the routing table which delivers routing information to any or all nodes available in the network. Destination Sequenced Distance Vector (DSDV) and Optimized Link State Routing (OLSR) are two typical examples of this protocol (Jurdak, 2007).

2.6.2.3 Geographical Routing Protocols

This is a valuable routing protocol for MANET due to its precision in specifying the route to the destination node. It depends on notification data received from the geographic location determined by the application. The details are sent in the shape of coordinates for the particular location,, information which can be obtained from any location determination system. The commonest location system employed could be the UPS (Universal Polar Stereographic) system.

This type of routing protocol is accepted as being significantly superior to Ad Hoc Networks, since it does not need to be periodically checked for topology modifications, and does not have to update routing or positioning information. The significance of the routers in this routing protocol is played down as the procedure of forwarding is based only on the information about the location (Maghsoudlou *et al*., 2011).

The primary benefit of this type of routing protocol is the short delay and minimum system overload. Additionally, fewer dropped packets and minimum routing data need to be transferred, as geographic routing can accurately establish the destination with less searching (Shivahare, 2012).

2.6.3 Ad Hoc Routing Protocols

There are many types of Ad Hoc routing protocols, but the most important are AODV, DSR, DSDV, OLSR and CBRP. These are explained in detail in the following sub-sections:

2.6.3.1 Ad Hoc On demand Distance Vector Routing (AODV)

AODV is an on-demand routing protocol; as the routes are constructed only when required, network traffic overheads are minimized. Additionally, AODV can effectively solve broken link problems (Wadbude and Richariya, 2012), as it permits multi-node routing between the system hops needed to construct an Ad Hoc Network. Moreover, it permits mobile nodes to find paths quickly to any destination nodes that exist in the specific communication area. In AODV, each node sends its neighbouring nodes a list of all other nodes available in the system; therefore, all nodes possess a routing table for all known nodes. If a hop in the transmission range loses contact, it can either maintain the path locally by giving a Route Request to locate another route to the destination node, or sends an error message which indicates that the destination node cannot be reached by this node. The major problem of this protocol is the count-to-infinity or loop problem (Ambhaikar *et al.*, 2012; Rajkumar & Duraisami, 2012).

2.6.3.2 Dynamic Source Routing (DSR)

DSR is a reactive on-demand routing protocol in which the number of hops that packets are required to move through is prepared and calculated in a packet header. Following the transmission of data, a comparison is made of the cache of routes in the nodes on this particular route. As shown in Figure 2.19, if the final result is accurate, the data are forwarded to a specific node; otherwise, the process of route discovery is repeated. This means that the origin node determines the whole route to be used to transfer a packet, not only to the next node. In other words, when the sender node has no route, it delivers a Route Request to any node that has a route towards the destination; the destination replies to the sender with a Route Reply. This reply contains the complete route which is delivered by sending the Route Request packet. The key benefits of DSR are its non-dependence on any apparatus used to decrease loops, and the route caching which is utilized to remove the overhead of route discovery. Nevertheless, DSR has drawbacks, such as collisions with neighbouring nodes. When the system topology is modified and the destination hop is inaccessible via the specified path, a mistake is announced and a new route needs to be developed, as shown in Figure 2.17 (Hac, 2003).

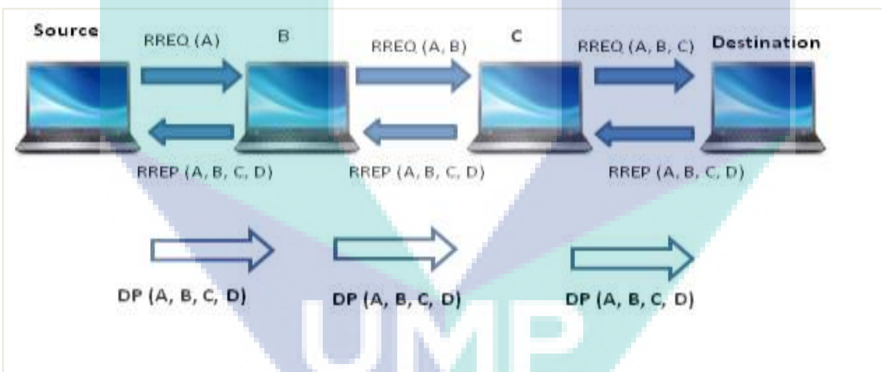


Figure 2.17: DSR route discovery

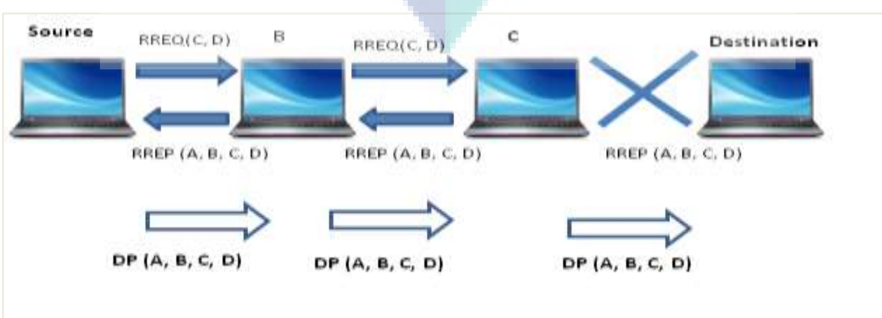


Figure 2.18: DSR route error

2.6.3.3 Destination Sequenced Distance Vector (DSDV)

DSDV is a table-driven routing protocol that uses a sequence number and adds it to the distance vector routing algorithm. It also preserves all periods that are changed during a network topology change. Each node occasionally sends its unique routing table updates, the essential link modifications and its particular sequence number to all other nodes. When two paths to a destination hop exist, sent by two different nodes, DSDV will select the one with the highest sequence number. If a similar number has been assigned to two paths, it will take the route with the smallest number of nodes. DSDV always minimizes the normalized control overhead by periodical updating and a set incremental time. Additionally, in this routing protocol, the paths are preserved by occasionally using switches made to the nodes routing table, and the settling time is utilized to decrease control overheads (Manoj *et al*., 2009). Moreover, DSDV retains only the best route rather than preserving all the multiple paths to all destination nodes in the network, reducing the total amount of information within the routing table. DSDV can be used to prevent traffic that results from extra incremental updates in the place of complete dump updates. The disadvantage of looping is that it is also lower in DSDV than in other protocols (Hac, 2003).

2.6.3.4 Optimized Link State Routing (OLSR)

OLSR is a proactive link state routing protocol, whose , main characteristic is its ability to utilize multipoint relays (Figure 2.16). These multipoint relays reduce the flooding messages broadcast to the community, by minimizing the repeated transmissions of the data. Each node within the MANET network selects a true number of neighbouring nodes which will retransmit its broadcast packets, thus minimizing repetitive data packets. The chosen neighbouring nodes are known as the multipoint relays of the node. Individual nodes select their multipoint relay groups. and each node must cover a maximum of two nodes away from it. On the other hand, neighbouring hops which are not available within the multipoint relay will also receive broadcast message packets, although they cannot retransmit. OLSR is a flat routing protocol; therefore, it requires no control to arrange its routing. Also, as it is essentially proactive, OLSR possesses the routing information to all nodes in the interaction area. It is suited to applications that do not involve long delays in transmitting data packets (Jacquet *et al.*, 2001). The working environment that gains most benefit from the OLSR protocol is a dense system, where communication is mostly between several nodes (Vijaya *et al.*, 2011).

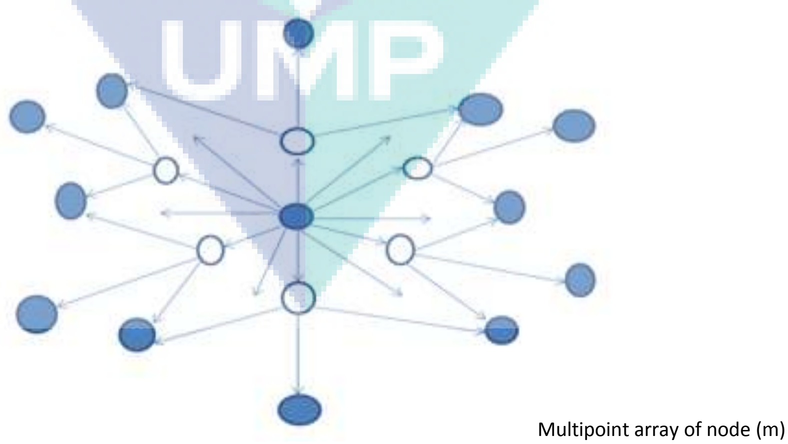


Figure 2.16: OLSR multi point relays

2.6.3.5 Cluster-based Routing Protocol (CBRP) :

This was introduced in 1999 by the theorist Jiang. The wireless nodes are separated into lots of individual and unconnected overlapping groups, where each group chooses one of its nodes to be CH in charge of the process of routing. The cluster heads are also capable of interacting with one another through gateway nodes (Rezaee & Yahamaee, 2009). A gateway is another kind of group node, which has two or more CHs similar to its neighbours. The CBRP clustering strategy divides the main network into small groups resulting in less traffic, because any route request has to pass through the cluster head but not the whole network (Reedy, 2014).

2.6.4 Clustering Routing Algorithms

This phase of clustering also has two main stages: route discovery and route maintenance. The discovery stage is utilized when the sender hop wants to send data and needs to find the appropriate path to reach the destination node. In the maintenance stage, the sender node specifies a path to the destination, but it can not reach it because of the frequent changes in the mobile topology, making the preserved route to the destination no longer attainable (Johnson *et al*., 2014).

A review of previous work related to designing cluster routing protocols follows. A multi-cluster-based head-gateway routing protocol for MANET was suggested by Bagwari, *et al*. (2011b) who studied the behaviour of MANETs using this model. The authors proposed an algorithm that distributed the outside clustering communication by using separate head-gateway couple nodes with appropriate routing protocols. Different MANET routing protocols are considered under this heading: AODV, DSR, OLSR and TORA. Additionally, the role of the couples among multi-cluster head-gateways within a cluster is considered. This aims to solve the problem of link breakage which results from selecting only one cluster head-gateway for each cluster, leading to isolating all cluster hops from communication with other clusters. It increases the number of cluster head-gateway pairs. Hence, if any pair of cluster head-gateways fails, it will not affect the communication of other cluster head-gateway pairs, due to the use of multi head-gateway couples. This increases the connectivity of the whole network.

In addition, as the number of arrival packets increases due to having multi head-gateway couples, the rate of serving also increases, resulting in the same usage rate as for the Ad Hoc Network. Consequently, it is concluded that when the number of head-gateway nodes increases, it will improve network connection by a factor equal to the number of couples. The simulation results of this study show that connection between the mobile hops can be increased by utilizing the enhanced routing protocol framework; the performance of the network is also improved. These improvements are achieved by using multi-cluster head-gateways pairs; when one head-gateway couple fails, another pair will be used instead. However, this approach minimizes the failure connectivity link, to be only in the direction toward a route where the failed couple nodes forward the data. Consequently, the achievement of routing in the MANET system is enhanced. This algorithm improves network performance without considering the high mobility of the nodes. Thus, it can be used with a minimum-speed network because movement in the network is increased, resulting in increasing the number of link breakages, and in turn increasing the number of cluster head-gateway pairs. Additionally, the cluster head-gateway nodes need more power and bandwidth to perform their operation, which results in higher resource utilization.

Rashed *et al*. (2011) suggested a hierarchical routing protocol, Cluster Based Hierarchical Routing Protocol (CBHRP), which is a modulated sample of the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. The particular concept behind the CBHRP design is the utilization of multiple cluster heads to aggregate the cluster information obtained from the receiving node. CBHRP is a two-layer protocol in which a number of clusters comprise the whole region. It presents head-set nodes instead of a single head,only one of which is active at any one time, while the remainder are in sleep mode. In this protocol, many states of a hop are found, such as passive associate, active, associate, candidate, and non-candidate status. It divides the MANET into a small number of clusters which include associate cluster heads and an active cluster head. The CH-set nodes are adopted to minimize the level of power consumption, increasing the lifetime of the whole network.

In the CBHRP model, the density of clusters and nodes is pre-specified as the network. The protocol process is categorized into two main stages, selection and packet transfer. At the beginning of the selection stage, a group of cluster heads is chosen randomly, which broadcast advertising of packets. Then, the network hops which receive the advertising packets will select their CHs depending on the strength of the received signal of the advertisement packets. After that, each hop sends acknowledgment packets to its CH. At each stage the CHs select a group of connected heads depending on the strength of the acknowledgment-transfer signal. The simulation results show that the CBHRP routing protocol expends less energy than LEACH routing, and reduces the time delay in data transfer. However, it increases the control overhead of the network because it needs to move between the several states of a node during its operation, reflected negatively in terms of packet delivery ratio and throughput of the network. Moreover, CBHRP pre-determines the number of clusters and nodes for the network, which increases the normalized controlled overhead of the whole network.

A location-based enhanced routing protocol, LECBRP for clustered MANETs, was proposed by Hamad *et al*. (2012). LECBRP employs local position information obtained by smart antennas for routing discovery and sends data according to the estimated paths. In the proposed routing protocol, each node estimates the location of its neighbouring nodes and stores the expected information in a position table. It also keeps the positions of non-neighboring hops. In addition, each head of cluster keeps a cluster neighbouring table with all the details of neighbouring cluster heads. Each node occasionally broadcasts a "Hello", which includes a location table and cluster neighbouring table. The cluster head depends on "Hello" information to discover the neighbouring cluster heads, reducing the control overhead of the whole network. However, the main limitation of this algorithm is that the CH divides the space of the network into four fixed areas to form a limited transmission range for the request area. This restricts this mechanism because the continuous changes of the MANET topology and the unlimited movement of the mobile nodes must be dynamically determined, and the space around the cluster head divided in order to be more resistant to MANET topology changes and node movement.

An enhanced cluster Ad Hoc routing protocol based on a number of sources and multicast characteristics to improve performance was suggested by Pandi and Palanisamy (2012). The traditional weighted cluster-based algorithm was basically changed for this purpose, and the weight of each hop was obtained by utilizing three factors: density of multicast member hops in one-node, density of multicast member nodes in one-node multi-hops, and density of multicast and cluster nodes within two neighbour-hops. The node with the largest weight is chosen as the head of the cluster and other nodes behave as cluster member nodes. The routing procedure of this algorithm depends on the CBRP routing procedure, in which the cluster head of the source node sends a request to the neighbouring clusters by using the nearest gateway nodes, and then broadcasts this message to the entire network. The results show that this new routing protocol generates a high packet delivery ratio, but with high normalized control overheads. This algorithm also increases the collision probability ratio because it sends a message to the entire network in order to find a path to the destination. This reduces link failure but increases the collision and end-to-end delay of the network.

Another effective cluster head routing protocol, Modified Cluster head Gateway Switch Routing (MCGSR), was presented by Sharma *et al*. (2013). MCGSR was suggested to improve the performance of the cluster routing protocol depending on gateway nodes. The main idea is that if any of the nodes needs to send packets to another node in another cluster, it can select gateway nodes to send the packets without needing to use the head of the other cluster. It divides the clustering routing into intra- and inter-routing. In intra-cluster routing, which is used to route packets within the same cluster, a proactive routing is applied by using the DSDV routing protocol that enables the CH to retain all the routing information of all the cluster members. In inter-cluster routing, the packet routing is made by using a reactive routing protocol represented by the AODV routing protocol. For DSDV, MCGSR adds three more fields (cluster head 1, cluster head 2 and flag) to its routing table; flag is used to indicate the type of node: (00) for ordinary node, (01) for the cluster head, and (10) for the gateway nodes. CH1 is the head of the first cluster and CH2 the head of the second cluster; for AODV, it adds two new fields, temporary source address and temporary destination address.

MCGSR proposes a routing algorithm that is a combination of the proactive and reactive routing protocols. If the node needs a route for a hop that exists within the same cluster, it depends on the DSDV protocol procedure to periodically update its routing table in order to share the routing information. The greatest number of nodes permitted in the routing table must be lower than or equal to 2. However, if the node needs to send data to any node outside its own cluster, it chooses a gateway by sending a Route Request (RREQ) following the route that was already created in the DSDV proactive process. As the RREQ packets traverse the path, the reverse route entry is constructed by each node in its reactive routing table and the hop account is increased by 1. After receiving the route request packet, each gateway node checks whether or not it has path details for the destination node . If it has the path details in its proactive routing table, it gives the temporary destination address and forwards the route request to the destination based on proactive routing information, and sends a new route for the destination node using Route Replay (RREP). This algorithm is active if the destination node is found in one attempt. However, if it is not found in one attempt, the sender node forwards the route request message to gateway nodes and the process continues until the destination node is found, thus increasing the power consumption and bandwidth overhead of the whole network. The proactive method that is used in intra-clustering can reduce the end-to-end delay in the network, but it increases the bandwidth consumption and normalized control overhead.

A new clustering algorithm, the Ring Clustering Algorithm (RCA), was presented by Hassan *et al*. (2014). It is a heuristic algorithm that groups mobile nodes in a network into rings. Each ring consists of three ring-nodes. The priority of a ring is determined according to a new parameter, the ring degree. RCA consists of three stages: ring formation, members joining, and node selection. In the first stage, each ring is constructed from three ring nodes. The ring is not constructed unless it has the highest precedence, which depends on the total-ring weight rather than the individual-node weight. The weight of a ring is the total number of neighbouring nodes of the three nodes. A node that cannot construct a ring joins with the closest ring as a member in the members-joining stage. In the node selection stage, the decision is made for a node to stay or leave the cluster. This algorithm can improve energy consumption and routing costs. However, the number of nodes for each ring is fixed (three only), and this number cannot be adapted in accordance with network size. RCA can also be used only with non-overlapping clusters, which constrains its use in MANETs, whose high mobility produces a great number of overlapping and non-overlapping clusters.

The Energy-efficient Coding-aware Cluster-based Routing Protocol (ECCRP) uses network coding in CH to minimize the number of re-transmissions. It was proposed and designed by Kanakala *et al*. (2014). ECCRP improved the queue arrangement process to further enhance the coding process. It takes input parameters, like nodes, mobility of nodes, initial energy of the nodes, and packets to be sent. In cluster formation, the lowest ID clustering algorithm is used to construct the cluster with fewest topology changes. The cluster head and gateway nodes are selected, depending on the available energy, to increase the lifetime of the whole MANET. ECCRP considers high-energy nodes as cluster heads. One way for power saving in MANETs is for all of member hops except gateways nodes to move to sleep mode when they are idle . In ECCRP, only gateway and cluster head nodes are active for any connection. In other words, the status of the network is always active to any connection. If a hop is idle for a second of time, it sends a packet to the head of the cluster to enter into the sleep mode. If this node receives an ACK from the cluster head, it goes into sleep mode to rest for seconds at a time. All nodes have an internal timer that resets when they are put into the sleep state. After a specific time, the hop wakes up automatically. Since the cluster heads and gateway are active all the time, delay is low in this algorithm. In ECCRP, an idle timer is defined as the calculation of the period that a node was in idle status, whereas the sleep timer represents the time that a node was in the sleep status. The simulation results prove that this algorithm can extend the lifetime and reduce the energy consumption of the whole network. However, the main limitation of this routing protocol is that it was implemented without considering node mobility, traffic, or the transmission range of the mobile node, which reduces its performance.

Based on the related studies on routing, the main observations and disadvantages in the existing protocols and the main issues needing improvement are illustrated below.

The Bagwari algorithm for routing, which is viewed as an efficient multi CH-gateway routing protocol, is used to solve the link breakage problem but only in the direction of a route, where the failed cluster head-gateway forwards the packets. This increases the reliability of routing but without considering the high mobility of the nodes; therefore, it can only be used with minimum-speed networks because as the movement of the network is increases, number of link breakages cluster head-gateway pairs increases. Not only does this result in increasing bandwidth consumption, but as the cluster head and gateway nodes increase, resource utilization will be increased as more power is needed to construct the pairs.

In the CBHRP routing protocol, the number of clusters and nodes for the network is pre-determined, which increases the normalized controlled overhead of the whole network. Additionally, the control overhead of the network is increased because it needs to move between the several states of a node during its operation; this is reflected negatively in terms of packet delivery ratio and throughput of the network.

Another study presented in the routing literature was the LECBRP routing protocol. The main limitation of this algorithm is that the CH divides the space of the network into four fixed areas in order to form a limited transmission range for the request area. This restricts the use of LECBRP, because the continuous changes of the MANET topology and the unlimited movement of the mobile nodes need to dynamically determine and divide the space around the cluster head in order to be more resistant to these changes.

In Pandi and Palanisamy's (2012) routing study, the limitation of increasing the overhead of the network was obvious because it sends a message to the entire network, including nodes outside the cluster, in order to find the path to the destination. This reduces link failure but increases the collision and end-to-end delay of the network.

The MCGSR algorithm has been presented as finding the most suitable route for the clustering nodes within the same cluster. Its first drawback is the proactive method used in intra-clustering to reduce end-to-end delay in the network; it also increases bandwidth consumption and normalized control overhead. However, MCGRS is good if the destination node is obtained at the first attempt; if this is not the case, the source forwards the route request message to a gateway and this loop continues until the destination node is found, increases the power consumption and bandwidth overhead of the whole network.

The RCA algorithm can be used only with non-overlapping clusters, which rules it out for MANETs.

The main limitation of the ECCRP routing algorithm is that it is implemented without considering node mobility, traffic, or the transmission range of the mobile node, which reduces its performance.

All these limitations have been considered and an enhanced clustering routing algorithm suggested to overcome these limitations. The previous studies on routing algorithms are summarized in Table 2.3.

Table 2.3: Comparison of current routing clustering methods

No.	**Author**	**Algorithm**	**Advantages**	**Limitations**
1.	Bagwari *et al.* (2011b)	Multi CH-gateway routing protocol	1- It increases the connectivity of the nodes.	1-This algorithm improves -the network performance without considering the high mobility

			2. It minimizes the failure of links to be only in the direction toward a route, where the failed CH-gateway forwards the packets. 3- It also increases the reliability of MANET routing protocols.	of the nodes; therefore, it can only be used with minimum speed networks, because increased movement of the network results in more link breakages, which increases the number of cluster head-gateway pairs and bandwidth consumption. 2- The cluster head and gateway nodes need more power and more bandwidth to perform their operation, which results in the highest resource utilization.
2.	Rashed *et al*. (2011)	Two-layer hierarchical routing protocol	1-It reduces battery power consumption. 2-It also reduces delay.	1-It increases the control overhead of the network, because it needs to move between the several states of a node during its operation, impacting negatively in terms of the ratio of packet delivery and throughput of the network. 2-It pre-determines the number of clusters and density of nodes for the network, which increases the normalized controlled overhead of the whole network.
3.	Hamad *et al*. (2012)	Location enhanced routing protocol (LECBRP)	1-It reduces the control overhead of the whole network. 2-It minimizes the time delay between nodes.	1-It is less resistant to the topological changes. 2-The CH divides the space of the network into four fixed areas in order to form a limited transmission range for the request area.
4.	Pandi and Palanisamy (2012)	Multiple sources and multicast cluster routing protocol	1- It increases the packet delivery ratio. 2- It reduces link failure	1- The maximum number of normalized control overheads is clear. 2- It also increases the collision probability ratio, because it sends a message to the entire network in order to get the path to the destination node, which reduces link failure, but increases collision and the delay.
5.	Sharma *et al*. (2013)	Modified cluster head-gateway switch routing protocol	It reduces end-to-end delay in the network.	1-It is good if the destination node is obtained at the first attempt. If not, the sender node forwards the route request

		(MCGSR)		packet to a gateway and this process continues until the destination node is found. This increases power consumption and the bandwidth overhead of the whole network. 2- It uses a proactive method in its intra-clustering that reduces the end-to-end delay in the network. However, it increases the bandwidth consumption and normalized control overhead, because of its periodic update requirements.
6.	Hassan *et al*. (2014)	Ring Clustering Algorithm (RCA)	1. It improves energy consumption. 2. It reduces the routing cost because of the usage of a fixed number of nodes (3) for each ring.	1- The number of nodes in each ring is fixed at three and cannot be adapted to the network size. 2- RCA can be used with non-overlapping clusters only. This constrains its usage in a MANET that is characterized by the highest mobility which produces a great number of overlapping and non-overlapping clusters.
7.	Kanakala *et al*. (2014)	Energy-efficient coding-aware cluster-based routing protocol (ECCRP)	1-It extends the existence of the network. 2-It reduces energy consumption.	1- The main limitation of this ECCRP is its implementation without considering node mobility, traffic, and transmission range of the mobile nodes, which reduces the performance routing.

2.7 SUMMARY

This chapter first presents the concept of MANETs and their unique features. Some of the primary MANET challenges, such as the dynamic framework, routing, battery pack limits, frequent failure of links, and congestion problems, are explained. The routing process in MANET is explained in detail and separated into two stages: routing strategies and routing category. Routing strategies comprise flooding, distance vector routing, link state, and source routing; and there are three classes of routing: proactive, reactive and geographic. For each one of these classes, one routing protocol was discussed in more detail: AODV, DSDV, DSR, OLSR, and CBRP.

A holistic view of clustering in MANET is provided, including benefits, importance, stages, structure and linking type. Finally, the major cluster head selection methods are described: the smallest and largest identifier methods, dynamic mobile clustering and weighted clustering. The full description and the main steps of these algorithms are given, with their advantages and disadvantages.

This chapter also presents the main phases of clustering, categorized as the formation, maintenance and routing phases. Some of the current related studies on clustering stages in MANETs are analyzed and compared, and with a full description of their main steps. The algorithms, their type, development, performance metrics and main advantages in ascending order are described, summarized in a table.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This research proposes an Enhanced Cluster Routing Protocol (ECRP) for use in MANETs. It employs an algorithm in a cluster formation to calculate the node scale, and an algorithm for cluster maintenance that categorizes and recovers errors according to type was developed.A further algorithm for routing packets was suggested, using the movement of nodes and distance to send data, and employing *Global Positioning System (GPS)* to acquire location data for individual nodes. This chapter presents the main approaches are used to implement the ECRP algorithms, using NS2. It also explains the validation and the verification of these algorithms.

3.2 RESEARCH APPROACH

This research comprehensively reviews the literature to explain the advantages and disadvantages of the currently available clustering algorithms. This leads to design of a cluster MANET based on ECRP formation algorithms, to select a cluster head which eliminates the cluster head changes and saves time and resources.

It also develops a cluster maintenance scheme based on the ECRP maintenance algorithm to solve the common link failure. Visualization of the link errors is summarized into link failure, node movement, cluster head movement, a member node that needs to be a cluster head, two cluster heads with the same scale, and node shutdown.

A cluster routing scheme is developed, based on least movement and minimum distance parameters for the routing performance of the MANET. Verifying, validating, and evaluating the performance of the modal decomposition based on throughput, packet delivery ratio, end-to-end delay, and number of dropped packets in a simulation environment are described. Figure 3.1 shows the main steps of the research.

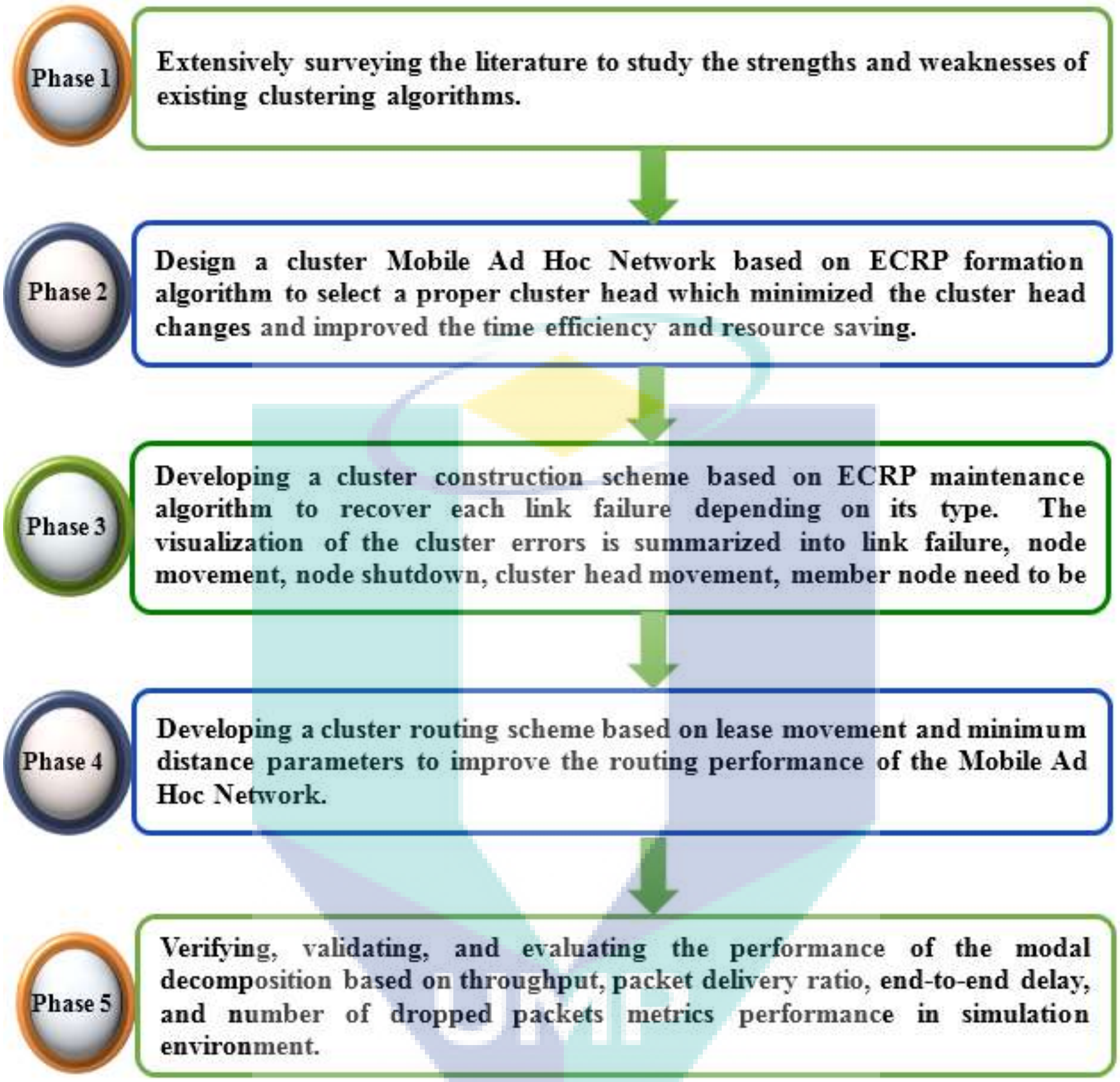


Figure 3.1: Research approach main phases

3.2.1 Literature Analysis

The initial stage of the ECRP is an extensive literature review, identifying indications and evidence that support the assumptions of the research, to formulate a realistic, achievable and worthwhile objective and research plan. The research plan involves the formulation of research problems, objectives, and the scope of the research. The criterion of this research in general and this stage in particular is to find the key points, strength, weakness and challenges associated with current clustering algorithms in Ad Hoc networks. Several processes are involved in the initial phase of clustering. First, finding the area of interest helps determine a viable and worthwhile research objective for the current ECRP algorithm. This is followed by a deep understanding of clustering algorithms in MANET in order to identify the current state of art and formulate appropriate research questions. The type of the research is defined with identifying the relevant contributions. Finally, the overall plan is formulated. Figure 3.2 summarizes the research clarification process, and shows the main research stages.

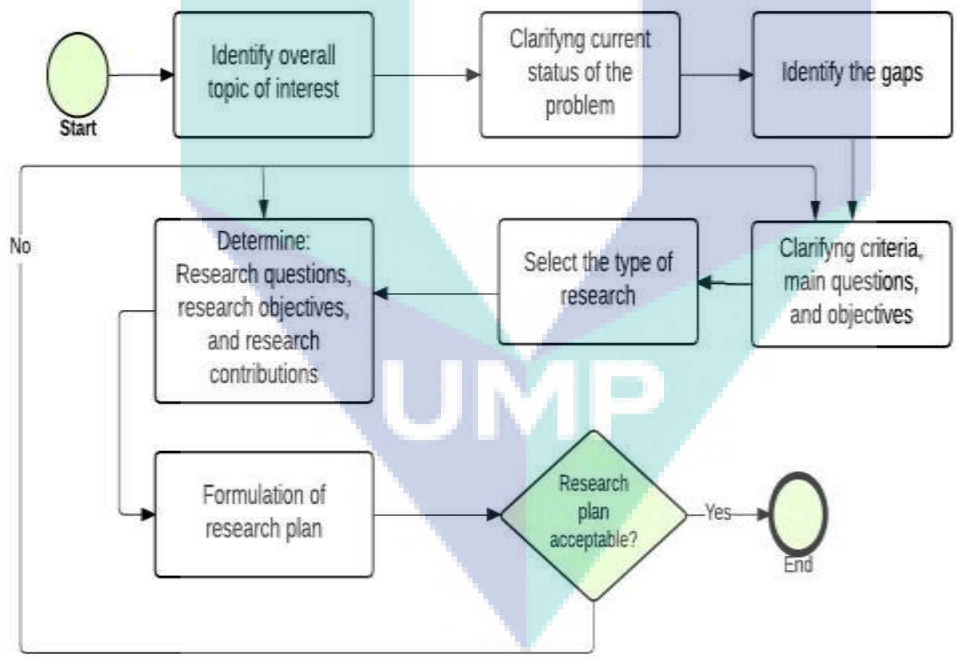


Figure 3.2: Steps of research analysis

3.2.2 Design ECRP Formation Algorithm

The main concept of the proposed algorithm involves modifying the weighted clustering algorithm, This algorithm uses three parameters to calculate the scale of each node: degree, mobility and the distance between nodes. These parameters are used to select the cluster head to enhance network performance. The literature review uncovered limitations in previous studies, discussed in detail in Section 2.6.1; an enhanced clustering formation algorithm was proposed to overcome these limitations. The difference between the standard weighted clustering algorithm and the proposed formation algorithm is that the latter takes into account other factors in order to increase the stability of the network and reduce the delay time of CH election, which in turn involves storage space, node distribution in the available area, accumulated time, available power, and node movement. The proposed formation algorithm is shown in Figure 3.3.

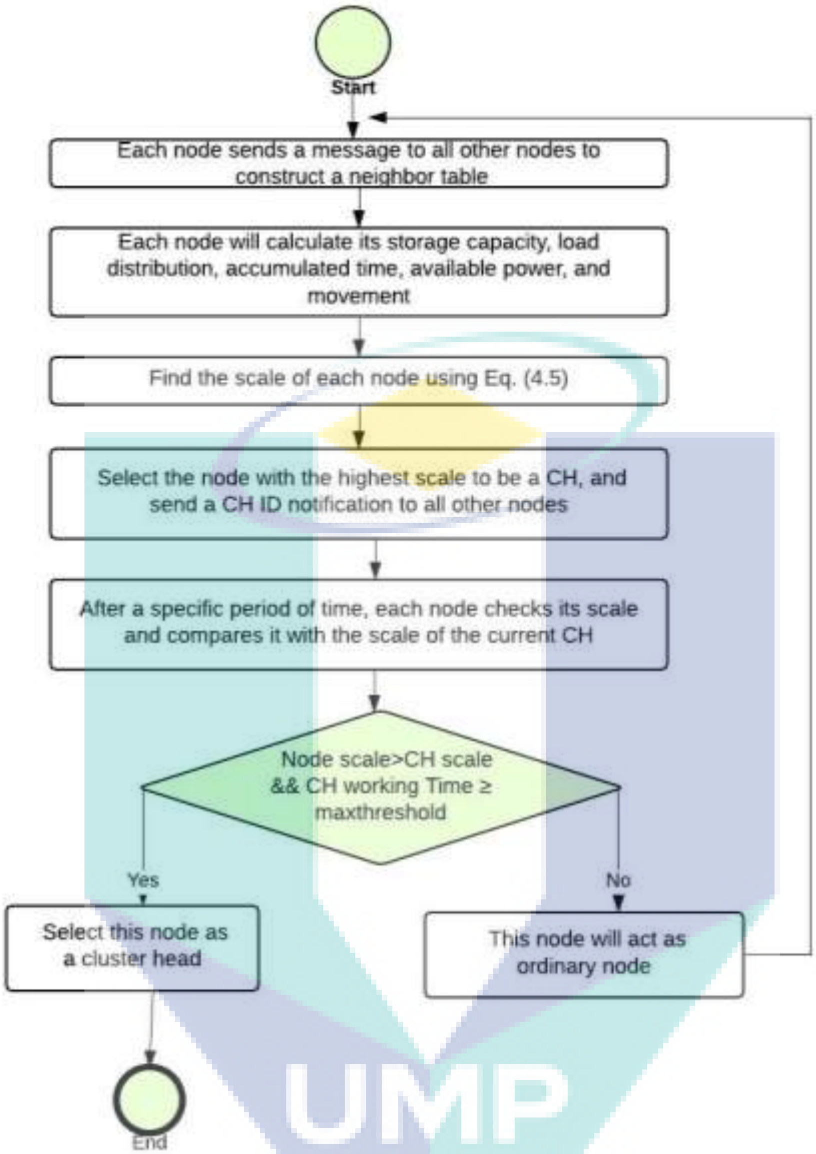


Figure 3.3: The ECRP formation algorithm

3.2.3 Develop ECRP Maintenance Algorithm

The maintenance stage of a cluster is initiated to ensure the correct delivery of packets, particularly in Ad Hoc networks which are characterized as having frequently changing topology. This dynamic is a result of the mobility of the nodes. The maintenance stage can be summarized in the following visualizations:

- Link failures
- Node movement
- CH movement
- A node that must be a CH
- Two CHs with the same scale
- Node shutdown.

3.2.4 Develop of ECRP Routing Algorithm

In the ECRP algorithm, routes are discovered based on their location as established by GPS, to reduce the burden of routing and management; this reflects positively on the performance of the entire network. In this study, two stages of cluster routing are considered. The first is intra-cluster routing, which is routing within the same cluster. The second is inter-cluster routing, which is routing between a pair of clusters.

3.2.4.1 ECRP Intra-cluster routing discovery

According to the ECRP intra-routing algorithm, all nodes know the locations of all other nodes in the same cluster. DSDV that is used for intra-routing is a proactive routing protocol. Each node periodically sends a routing table to all its neighbouring nodes. Hence, it can send data directly to the destination node. For example, if node 1 needs to send data to node 2, it must first check its neighbour table. If node 2 is located in this table, node 1 will send the data directly without needing to send a route request to the CH, as illustrated in Figure 3.4. Otherwise, it must send a route request to the CH to specify the exact destination route.

The CH contains the current CH ID. The source ID is the sender ID. The destination CH ID is equal to the CH ID, and the destination ID is the receiver ID. Since CH ID = destination CH ID, the source and destination should be available in the same cluster. The CH will check its members table to ensure that the destination is still a member og its cluster, before using multiple parameters to select the most suitable route. The selected route is characterized by the lowest movement and least distance.

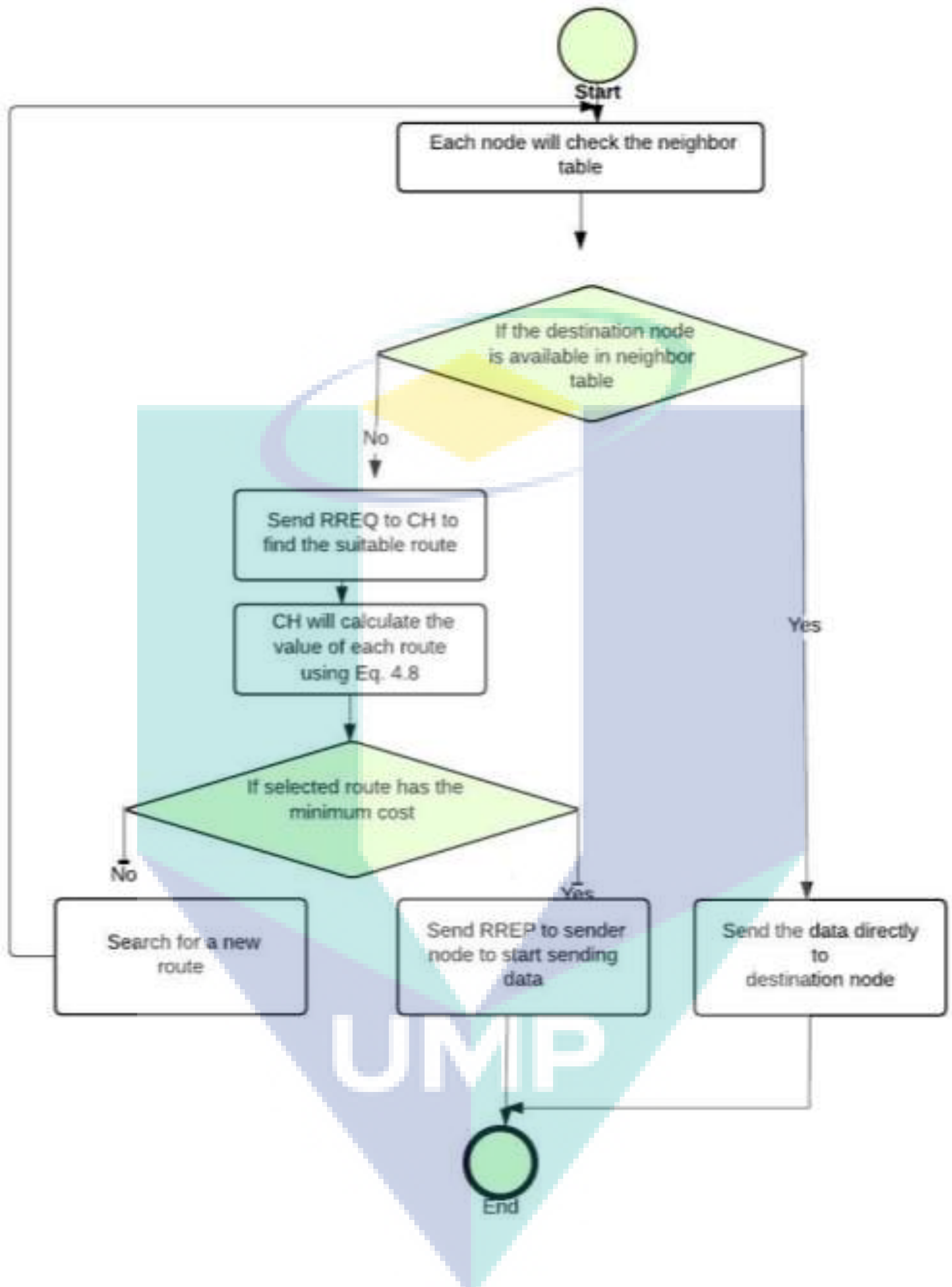


Figure 3.4: The ECRP intra-cluster routing algorithm

3.2.4.2 ECRP inter-cluster routing discovery

If any cluster intends to send data to other clusters, it must send a RREQ to the CH. The CH checks the cluster adjustment table, and then sends the request to the gateway node in its cluster to connect to other clusters. The RREP is derived from the receiver node, and contains the CH for the sender, the CH for the receiver, and the location of the receiver node, determined by GPS. If another gateway is available for the route, it is mentioned in the response. The proposed algorithm generates two scenarios. First, the CH forwards the RREQ sent by the sender node to its gateway, which then forwards the RREQ to the gateway of the second cluster. Finally, the RREQ is sent to the destination node, which sends a RREP to the sender on receipt of the request. Thus, this RREP contains information about its location. In summary, the sender sends the data to the gateway of its cluster. The gateway of this first cluster then forwards the data to the gateway of the second cluster. Finally, the data is sent to the specific destination node according to its GPS location information.

The second scenario occurs if the gateway of the second cluster cannot deliver the data to the destination node because the receiver node is within the cluster, but out of range. The gateway of the second cluster will send the RREQ to its CH, and the CH applies the aforementioned intra-cluster procedure to select a suitable route for sending data to the destination node. If the destination node is within the same cluster area, this process minimizes the number of errors and shortens the time. Figure 3.5 shows of all cases of the inter-cluster routing algorithm.

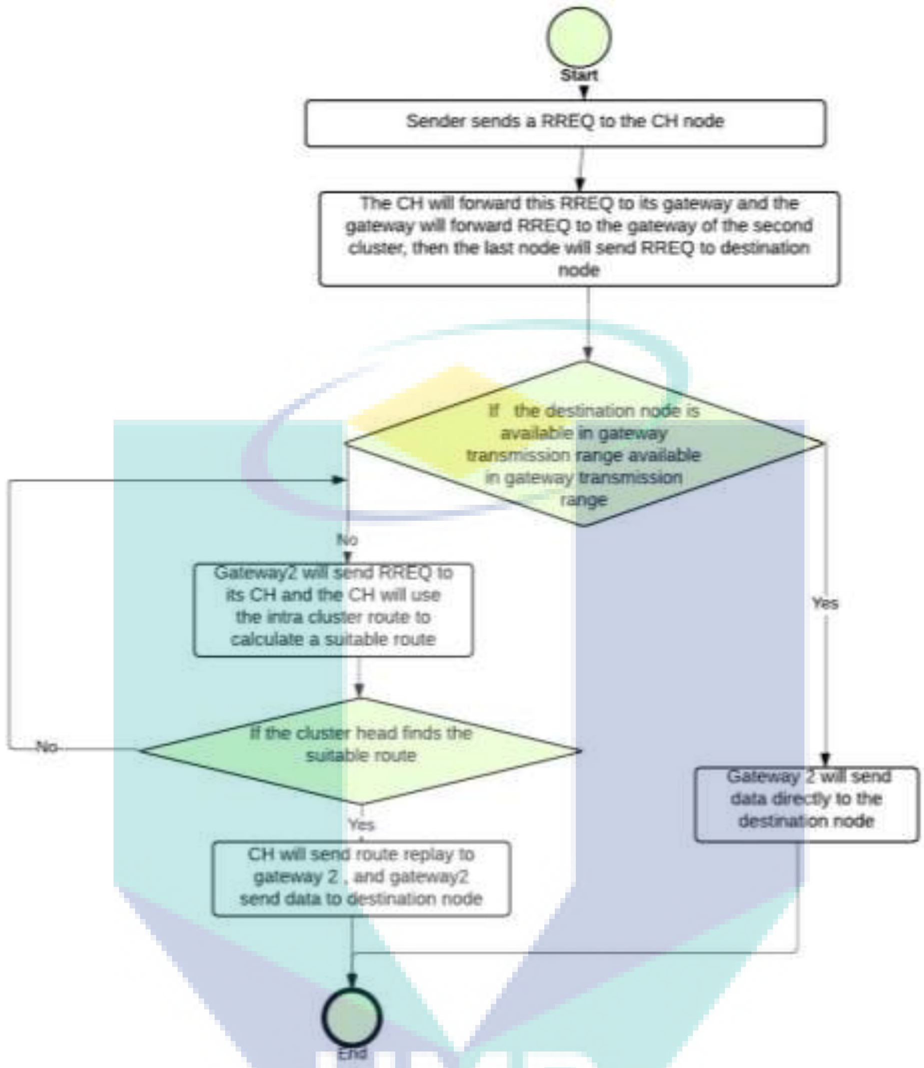


Figure 3.5: The ECRP inter-cluster routing algorithm

3.3 VALIDATION AND VERIFICATION

Verification of the proposed algorithm was done to ensure that it was programmed and implemented correctly, without containing any errors. The proposed algorithm was run with simple scenarios in order to be easily analyzed and the simulation results compared with the analysis. Then, these simple scenarios were made more complex to test the proposed algorithm.

The verification and validation of the proposed algorithm and its models are implemented in NS2 by comparing the results of the proposed algorithm with other cluster-based algorithm results obtained from NS2 simulation.

In addition, consistency tests were carried out to ensure that the proposed algorithm generated comparable results for input parameters that had the same effects. A script code was developed to trace the proceedings which occurred during the running time in order to check the implementation of the proposed algorithms. However, models for each of these algorithms had to be designed to accurately implement their functionality.

A number of standard techniques were used for verification and validation of the models. One major validation technique compared the proposed algorithm output with the expected results, and checked the tracing of the event for the algorithm execution to ensure that it was implemented properly. Thus, the verification and validation of the proposed model were made by comparing the results with other algorithms' obtained from actual simulation runs with more than 500 scenarios.

3.3.1 Verification of the proposed algorithms

Formal verification involves the approval or rejection of the correctness of the intended algorithms, which underlie a certain formal specification or property, by employing formal mathematical approaches. Formal verification can be beneficial in testing the correctness of systems like routing protocols, combinational circuits, digital circuits with internal memory, and software expressed as source code. This means that the formal verification can easily confirm whether or not the output of the model gives expected results. The formal verification of any system can be provided by designing a theorem that proves an abstract mathematical model of the system, by checking the proposed model and testing it to demonstrate if it satisfies the expected output or not, or by making an equivalence checking with a comparison between two different systems and models (Seligman *et al*., 2015).The verification and validation of the proposed model were applied by the theorem-proving method. Thus, the mathematical equations presented throughout Chapter 4 can be used as verification and validation for model implementation. The proposed model validation also applied the equivalence checking method, where the result is compared with the results of related works, and can be considered as two different models.

3.3.2 Validation of the proposed algorithms

To verify and validate the developed protocol, 500 scenarios were examined. In this respect, 5 metrics were tested, with 20 different experiments and various parameters for each metric. Scenario validation is one of the most important tasks for any wireless network. The scenarios were implemented and tested under a variety of parameters, including speed and node density (number of nodes) and testing a variety of metrics, including throughput, packet delivery ratio, average end-to-end delay, number of packets dropped, and normalized routing load. Different mobile Ad Hoc communications were used with correct initial placement of each device in the appropriate mobility model, where packets were generated and distributed through the network topology. Finally, the results of the above metrics were compared with those of other related algorithms.

3.4 PERFORMANCE METRICS

Various parameter metrics were utilized in comparing the effectiveness of the proposed routing protocols' performance with other routing protocols. Cluster protocol evaluation involves comparisons with various MANET routing protocols.

This study used five performance metrics: throughput, Packet Delivery Ratio (PDR), average end-to-end delay, number of dropped packets, and the normalized control overhead for protocols. These parameters were selected for their significance in evaluating any data communication network. All protocols need to be evaluated against these metrics to monitor their performance. Throughput demonstrates the success of a protocol's delivery over a particular time; the greater the throughput, the better the protocol performs. A high PDR indicates a highly successful packet delivery rate, indicating how efficient the proposed routing protocol is. Delay represents the minimum time for packet delivery. When few packets are dropped, this is an indication of an efficient routing protocol. Finally, less overhead shows that the proposed routing protocol can enhance quality without reducing the network bandwidth. The following metrics are employed to perform the evaluation:

3.4.1 **Throughput**

This is calculated by dividing the total amount of data delivered to the destination node by the time spent in receiving the final packet. A high throughput value indicates better performance for a given routing protocol (Eq. 3.1).

$$\text{Average throughput} = \frac{\sum Total\ NumberRecived\ Data * PS}{T} \tag{3.1}$$

- PS is packet size.

-T is the receiving time of the final packet in the destination node.

3.4.2 Packet delivery ratio

PDR is the ratio of the received packets to packets sent in a network. It is computed by dividing the number of successfully delivered packets by the number of packets dispatched by the sender node. Multiplying this number by 100 provides the percentage. This parameter is a reflection of the successful sending of data, employing the routing protocol (Aggarwal *et al*., 2011); see Eq. 3.2.

$$\text{PDR} = \frac{\sum \text{Number of received packets}}{\sum \text{Number of sent packets}} \qquad 3.2$$

3.4.2 **End-to-end delay**

This is the average time taken in transferring data from the sender node to the destination node. A minimal end-to-end delay indicates the routing protocol's satisfactory performance. This parameter is calculated by dividing the sum of the differences between the sending and receiving processes of the same packet by the total number of the delivered packets (Eq.3.3).

$$\text{End-to-end delay} = d_{t+} d_{p+} d_{m+} d_q \qquad (3.3)$$

- d_t is the transmission delay (time needed to keep and forward packets; equal to packet length (bit)/ bandwidth (bps)).

- d_p is the propagation delay (the delay of the wireless channel propagation; equal to the length of the wireless link/speed of propagation).

- d_m is the process delay (the time needed to find a suitable link before transmission).

- d_q is the queue delay (waiting time in the queue based on the congestion of the channel) (Jiao *et al.*, 2014).

3.4.4 Number of dropped packets

On reaching a network layer, a packet is sent to the destination node if the route has been correctly identified. However, when this does not happen, the packet is buffered while the correct route to the destination node is identified. Consequently, if the buffer is full, the packet is dropped.

3.4.5 Normalized Control Overhead

This is arrived at by dividing the total number of packets transmitted under protocol control by the total number of delivered data packets with respect to time (Surayati *et al.*, 2009), as shown in Eq. 3.4.

$$\text{NCO}= \frac{\sum \text{Number of control packets}}{\sum \text{Number of delivered packets}} \qquad (3.4)$$

3.5 SUMMARY

This study proposes algorithms to improve the performance of Ad Hoc networks through clustering (formation, maintenance and routing) algorithms for the MANET. The formation algorithm finds the scale of each node, and the node with the highest scale is used as the head of the cluster, which is responsible for the entire management, administration and routing process in the specific network. The maintenance algorithm deals with connection problems occurring during the cluster formation stage. The errors in the network are categorized according to type: link failure, node movement, cluster head movement, a node that needs to be a cluster head, two cluster heads with the same scale, and node shutdown. Finally, a routing algorithm was divided into intra- and inter-routing, to select routes with the least movement of nodes and the shortest distance to send the data.

CHAPTER 4

DESIGNING AND MODELING CLUSTER FORMATION, MAINTENANCE, AND ROUTING ALGORITHMS

4.1 INTRODUCTION

This chapter proposes an Enhanced Cluster Routing Protocol (ECRP) for use in MANET. It employs, first, an algorithm in a cluster formation to compute the node scale, which chooses a cluster head in line with the parameters, such as size of the available storage, load sharing, incremental time, available power, and the movement of each node. Second, an algorithm for cluster maintenance that categorizes and recovers errors according to type was developed. Third, an algorithm for routing the packets was proposed, using the movement of nodes and distance between them to select the most stable route to send data; this algorithm employs *GPS* to acquire location data for individual nodes. The process of route discovery is split into intra-cluster and inter-cluster routing.

This chapter presents the procedure used to implement the ECRP algorithms using NS2. It also explains the primary parameters that are altered in the Ad Hoc channel, the design assumptions made by ECRP, the definition of the proposed clustering algorithms used for cluster formation, cluster maintenance and procedures, and routing algorithms and assumptions. The headers and packets required to find the route to the destination are also described. An operational example is presented at the end of each algorithm.

4.2 ECRP DESIGN ASSUMPTIONS

The ECRP algorithm is designed with the following assumptions:

i) The Hello packet, which is broadcast by each node, can be received by all the available nodes in the specific cluster within a specific period of time.

ii) The maximum number of the nodes in each cluster is 8.

iii) GPS is used to obtain node coordinates in the network.

iv) Two stages of cluster routing are considered. Intra-cluster routing is routing within the same cluster, implemented in ECRP as a proactive protocol that depends on information that is sent periodically between nodes. Second, inter-cluster routing takes place between two clusters; it is a reactive protocol, which determines the best route only when required.

v) All the Ad Hoc network nodes are able to transmit from one location to a destination location randomly; however, the highest threshold value of the transmission range of all nodes, denoted by MaxTrans, is 300 M. It is defined as an argument in the program code. This value administers and minimizes link failure errors, and constrains the network topology. At the beginning of the simulation, this value is equal for all network nodes.

4.3 ECRP CLUSTER FORMATION ALGORITHM

The concept behind this algorithm is modification of the original weighted clustering algorithm (see Section 3.2). The original weighted clustering algorithm utilized three parameters to find the scale of each node: degree of nodes, mobility, and the distance between nodes. All three parameters are used in choosing the head of the cluster, to contribute to improving the network performance. The review of related studies showed some limitations, which were discussed in detail in Section 2.6.1. These limitations need to be overcome, which was done by using an enhanced clustering formation algorithm. The difference between the original weighted clustering algorithm and the proposed formation algorithm is that the former considers other factors to increase the stability of the network and reduce the time delay in CH election, which involves storage space, node distribution in the available area, accumulated time, available power, and node movement. The proposed formation algorithm is shown in Algorithm 4.1. Its main steps are as follows:

Step 1: Each node sends a "Hello" message to all other nodes to inform them of its existence.

Step 2: The CH is selected by determining the node with the highest scale. This step applies only to nodes that has not been previously selected as a CH. The scale is calculated according to the following parameters:

1) The storage capacity (*SC*) of the node is calculated by considering the memory capacity of each node, which is equal to the percentage of the remaining memory over full memory capacity.

2) The load distribution (*LD)* is used to estimate the remaining number of nodes that can still be handled by each node. It is computed using Eq. (4.1):

$$LD = \left| N_i - CS \right| \tag{4.1}$$

N_i is the number of neighbouring nodes.
CS is the cluster size.
LD assesses the number of nodes that can be covered by the cluster.

3) The active period of the node is represented by *T*, which reflects the summation of the active periods spent by the nodes in sending and receiving packets. If this value is high, it means that this node is more active than the others, and can cover more cluster nodes, which enhances the stability of the entire cluster. The *T* value is calculated using Eq. (4.2).

$$\mathrm{T} = \left| \sum_{k=1}^{N} (T_{R1} - T_{R2}) \right| \tag{4.2}$$

N is the number of neighbouring nodes.
T_{R1} is the received time of the first packet from the specific node.
T_{R2} is the received time of the last packet from the same node.

4) The remaining energy of each node is referred to as APOW (available power) and can be calculated by subtracting the consumed energy of the node from the initial energy of the same node to network b. APOW is expressed as shown in Eq. (4.3)

$$\text{Consumed energy} = P * T$$
$$\text{APOW} = \text{initial power} - \text{consumed power} \quad (4.3)$$

P is the power utilized for sending / receiving a single packet.

T is the time taken to send / receive a single packet.

APOW is the total available power.

5) The movement of each node, which is denoted as MOV, is used to calculate the movement of the node with respect to the other neighbouring nodes. In the standard Weighted Cluster Algorithm (WCA), the movement is calculated from the difference between the new and old coordinates of the nodes divided by a specific time. In this research, movement is calculated as a function of the "Hello" message power. Since the "Hello" message is sent periodically from the neighbouring nodes to all other nodes in a cluster, the receiving node will compare the power of two consecutive "Hello" messages from the same node using Eq. (4.4). The node with a small movement value will have smaller power differences, which means that the ratio between new P_N and old P_N must be as small as possible to increase the stability of the cluster.

By considering node *n* and node *m* as neighbouring nodes, node *m* receives a "Hello" message. The last node will calculate the power of the received message. After a specific period of time, it will receive another "Hello" message from the same neighbouring node and will calculate the relative MOV for node *n* by using Eq. (4.4):

$$\text{MOV} = \frac{1}{(t2-t1)}(\,|\sqrt{(x2-x1)^2+(y2-y1)^2}) \quad (4.4)$$

(x1, y1) the coordinates of node1at time t1 (x2, y2) the coordinates of node2 at time t2

6) The combined scale of each node is calculated based on the parameters for each node in the cluster, using Eq. (4.5):

$$S = a_1 SC + a_2 LD + a_3 T + a_4 APOW - a_5 MOV \quad (4.5)$$

SC is the storage capacity.
LD is the load distribution.
T is the accumulative time.
APOW is the available power in the node.
MOV is the movement of the node.
a_1, a_2, a_3, a_4 and a_5 are the coefficients for scale calculation.

The sum of these coefficients is equal to 1, and the important factors are the assigned values. The coefficients of the following study are as follows: APOW=0.30, T= 0.25, MOV= 0.20, SC=0.15, and LD=0.10.

Step 3: The node with the greatest scale is selected as the CH. This node sends a message to all other nodes to inform them that it has been selected as a CH node.

Step 4: Each node periodically sends a message to all other nodes in the cluster. This message contains the node ID, request type, scale, and working period.

- Request type: "CH" indicates that the sender is the CH; "WCH" indicates that the sender wants to be the CH and will send requests to the current CH to compare its scale with the new CH. For "E", the sender asks the current CH to cease its operation because it has a higher scale than the current CH.

-Scale: The weight of the node.

- Working period: This is the period of time for which the CH operates. If it has a high value, it must be replaced with a new CH because its scale is reduced over time.

All nodes in the cluster will calculate their node scale (S) and broadcast this value to all nodes in the cluster. Any node that needs to be the CH sends a WCH (want to be the cluster head) request to all other nodes in the cluster, and waits for a specific period of time. Then it will receive a response from the current CH that contains the CH scale and the working period. If the scale of the current CH is greater than the node which needs to be CH, and its working period is shorter than Threshold 1, the sender node behaves as an ordinary node.

After a specific period of time, WCH sender repeats the request. The current CH checks if its scale is greater than that of the current CH, and if the working time of the current CH is long, the new CH will be declared as the CH of the cluster. The new CH sends a message that contains the node ID, CH message, scale, and 0. This exchange of CHs reduces the overhead of the entire network and distributes the burden among all available nodes. This distribution is reflected positively in routing protocol performance.

Step 5: If the two nodes are of the same scale, one of them is chosen as the CH, and the other one is utilized as a gateway to connect to external clusters.

(1) Begin {

(2) Each node sends "Hello" message to all other nodes in its transmission range.

(3) Each node establishes its neighbour list.

(4) For (int i=1; i < period of time; i++)

(5) { For (int j=1; j< number of nodes; j++)

(6) Calculate its storage capacity;

load distribution using Eq. (4.1);

Accumulated time using Eq. (4.2);

Available power, using Eq. (4.3);

And movement for each node using Eq. (4.4).}

(7) Find the scale of each node by using (4.5).

(8) *Each node broadcasts its scale, and the node with the highest scale will send WCH message to the current CH.*

(9) *The cluster head will compare its scale with the scale of the node that sent the request.*

(10) *Initial node scale =0*

(11) *If node (j) scale > node (i) scale {*

cluster head=node (j);

Cout>>"node(j) is the cluster head of all nodes";}

(11) *Else {Cluster Head=node (i);*

(12) *Cout>>"node (i) is the cluster head of all nodes";*

(13) *End }*

Algorithm 4.1: ECRP cluster formation algorithm

All nodes calculate their own scales, and this information is sent as a specific message to all neighbouring nodes. This message contains the selection method of the node as the CH**.**

The network topology shown in Figure (4.1) shows a network of 10 nodes to explain the proposed formation algorithm. The large and small circles are used to represent the cluster and nodes, respectively. If node 1 needs to form its own cluster using the proposed cluster formation algorithm, it will send a “Hello” message to all other nodes available within its specific transmission range, and then each node will build its neighbour table, represented in Table 4.1; it consists of four nodes.

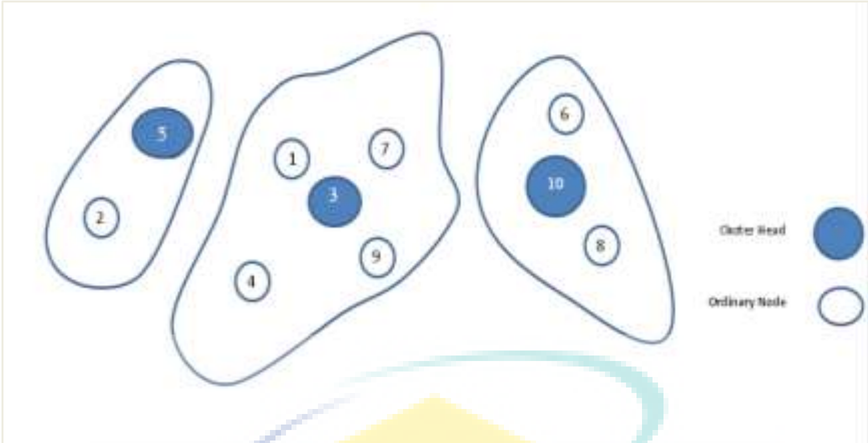


Figure 4.1: ECRP cluster formation scenario

Table 4.1: The neighbour table for node (1)

Neighbour node ID
3
4
7
9

Thus, cluster 1 is constructed with cluster size 5 and contains the nodes 1, 3, 4, 7, 9. The head of this cluster is selected according to step (2) in the algorithm. The scale is calculated as follows:

- For node (1),

if (SC=0.75, LD= 4, T=140, APOW=450, MOV=3),

the scale will be = (0.15*0.75+0.10*4+ 0.25*140 + 0.30*450 - 0.20*3) = 169.91

- For node (3),

if (SC=0.70, LD= 3, T=120, APOW=400, MOV=3),

the scale will be = (0.15*0.70 + 0.10*3 + 0.25*120 + 400* 0.30 - 0.20*3) = 160.90

- For node (4),

if (SC=0.70, LD= 3, T=120, APOW=400, MOV=3),

the scale will be = (0.15*0.70 + 0.10*3 + 0.25*120 +0.30 * 400 - 0.20*3) = 157.05.

- For node (7),

if (SC=0.15, LD= 5, T=100, APOW=150, MOV=3),

the scale will be = (0.15*0.15 + 0.10*5 + 0.25*100 + 0.30*150-0.20*3) =69.92.

-For node (9),

if (SC=0.25, LD= 2, T=100, APOW=250, MOV=1),

the scale will be = (0.15*0.25 + 0.10*2 + 0.25*100 + 0.30*250 - 0.20*1) =100.03.

Thus, the node with the highest scale is selected to be the cluster head: in this example, node 1, (169.91); and it will advertise itself as a cluster head by sending a CH message to all other nodes, containing the following:

Cluster head ID	Request Type
4	CH

Then the neighbour table for each node will be updated to contain the neighbour node IP and the CH for each cluster. For example, the node 1 neighbour table is shown as Table 4.2.

Table 4.2: The CH table for each node

Neighbor node ID	Cluster head ID
3	4
4	4
5	2
7	4
9	4

If Node 3 needs to advertise itself as a cluster head, it will send a WCH to the current CH using the following request format:

Node ID	Request Type
3	WCH

The current CH, which is node 4, will check its scale and working time and compare these two values with node 3's scale and working time. If the scale of node 3 is greater than node 4's, its working time is smaller. Node 4 will end its operation and node 3 will declare itself as the CH of the cluster by sending the following message:

Node ID	Request Type
3	CH

Otherwise, node 4 will continue its work as CH for the specific cluster. The scale calculation for each node is presented in Table 4.3.

The validation of this algorithm is given in Section 5.6.

Cluster size	LD	SC in (GB)	T in (msec)	APOW In (J)	MOV in (m/sec)	Scale	CH
3(N_1, N_2, N_3)	(1,2,2)	(0.5,2,1)	(80,70,120)	(200,150,250)	6,3,2	81.37,63.6, 105.15	N_3
5(N_1, N_2, N_3, N_4, N_5)	(2,3,4,3, 2)	(0.75, 2, 4,1.5, 1.2)	(90,110,140, 80,65)	(150,250,500, 450,180)	2,4,2,5, 6	67.71,81.40, 178.90,156.52, 71.83	N_3
7(N_1, N_2, N_3, N_4, N_5 N_6, N_7)	(6,4,3,2,5,2,3)	(5,0.25,2,4,1, 1.5,2)	(120,60,50,60, 100,25, 90)	(300,150,200,175,140,120,230)	3,5,4,6, 7,8,2	121.95,61.25, 74.10,68.60, 64.05,44.22, 92.5	N_1
9(N_1, N_2, N_3, N_4, N_5 N_6, N_7, N_8, N_9)	(2,5,6,4,3,6,2,5,7)	(1.6,0.5,1,2,3, 5,1.3,1.5,6)	(40,100,50,120,20,40,50,60, 140)	(250,150,100,240,260,140,100,240,300)	3,2,2,3, 4,2,2,5, 1	86.04, 65.97,43.65, 78.30,89.85, 53.19, 43.29,88.12, 126.80	N_9

Table 4.3: Scale calculation for ECRP

4.4 ECRP MAINTENANCE ALGORITHM

The maintenance stage of a cluster ensures correct delivery of the packets in Ad Hoc networks characterized by a frequently changing topology. This dynamic is a result of the movement of the nodes. The maintenance stage can be summarized by the following visualizations: link failures, node movement, cluster head movement, a node that must be a CH, two CHs with the same scale, node shutdown).

4.4.1 Link failure

In the proposed algorithm, cluster link failures can be categorized into two types. As displayed in Figure 4.2, the first type affects the cluster structure. For example, two nodes *m* and *n* are related to one cluster and send a message to inform the CH when the link between them is damaged. The CH then updates its link table. If these two nodes are under its control and within its range, it requests only those nodes to update their link information. If the nodes are out of range, the CH asks them to construct a new, separate cluster and determine a new CH as proposed by the CH selection algorithm. The node with the greater scale value declares itself as CH. The second type of link failure (Figure 4.3) does not influence the cluster structure between two clusters. The two nodes inform the CH of the failure through a message. They also update their link information.

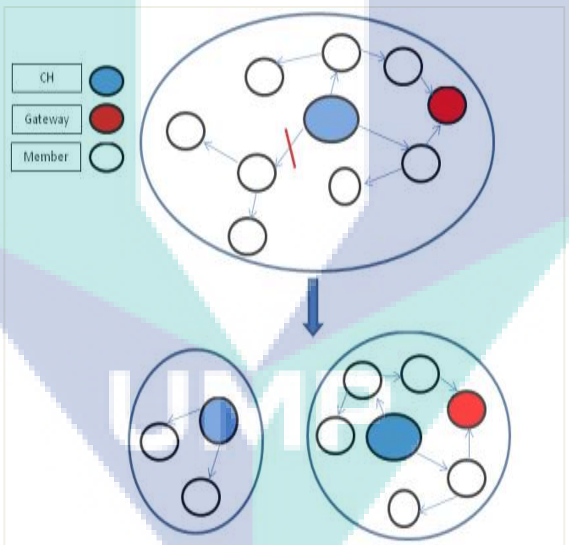


Figure 4.2: Link failure within the same cluster

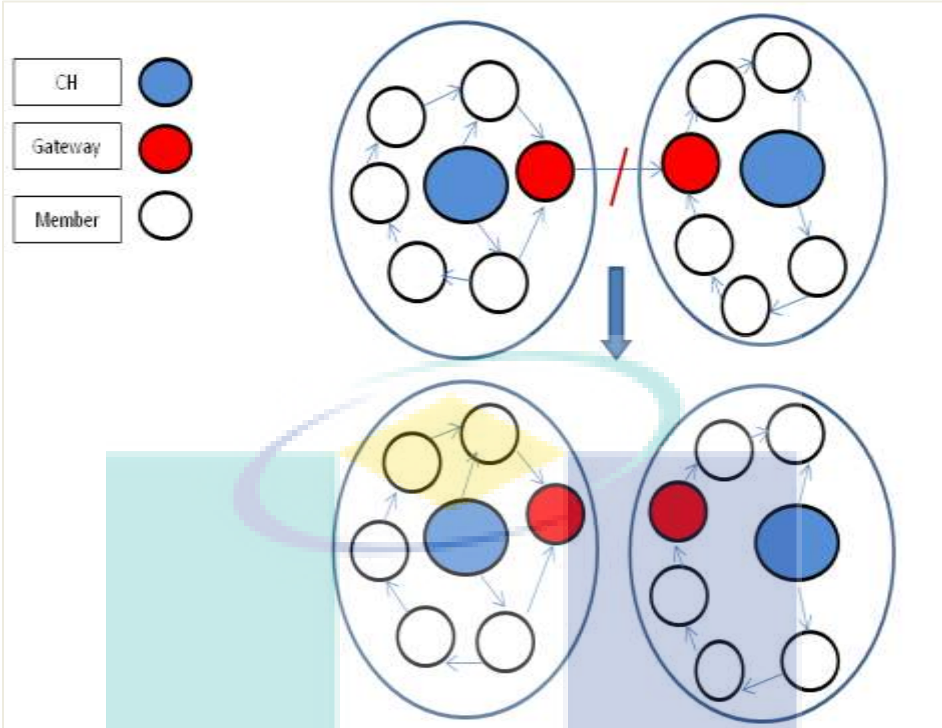


Figure 4.3: Link failure between cluster 1 and cluster 2

4.4.2 Node movement

In the ECRP algorithm, as shown in Algorithm 4.2, when a node travels from one cluster to another, it sends a message to all the nodes in the new cluster. This message contains important information regarding the node, including its ID, message type, location and scale. The current CH checks the maximum permitted number of nodes. If the cluster has not reached its maximum number of members, then the CH sends a positive acknowledgement to the new node. The new node responds with an appended message to declare its entrance into the new cluster. The CH updates its member table and sends this message to all available nodes in its cluster. If the cluster has reached the maximum permitted number of members, then the CH sends a negative acknowledgement to the new node. The new node must then search for a new CH.

The main difference between this algorithm and the weighting clustering algorithm are that if a node with low mobility and high score moves and joins another cluster, this node will be directly selected to be the CH of the cluster with no need to re-calculate the CH value, but it only checks the APOW. If its power is greater than the maximum power threshold, it declares itself as CH. Another difference is that if an ordinary node moves to another cluster, there is no need for re-clustering in the original cluster, but it needs to update the neighbour table for the cluster members. However, this is in contrast to the traditional cluster algorithm that needs to re-form all the clusters, not only cluster changes. This reduces the time and control overhead of the network. Figure 4.5 illustrates the procedures of the proposed criteria.

(1) Begin
(2) {
(3) The node that needs to join the cluster sends Join request to the CH.
(4) The CH will check the number of the available nodes in its cluster {
(5) If (available members in cluster <maximum permitted number of nodes){
(6) Cluster head will accept the node request.
(7) Update the member table.
(8) Broadcast the new updated member table.
(9) Else
(10) {
(11) Cluster head will reject the (Join) request.
(12) The node that sent the request will search for another cluster.
(13) }
(14) End

Algorithm 4.2: The node movement procedure

4.4.3 CH shutdown

In the ECRP maintenance algorithm, the cluster node with the highest scale is selected as CH, and the second highest scale as a gateway. Thus, when the CH is shut down or moves away, the other node will be notified because each CH periodically sends (live) messages to confirm its existence. In this case, the gateway will directly declare itself as the CH and send CH request packets to all other nodes to update their CH ID without a need for recalculation. This reduces the overhead and re-clustering processes and increases the stability of the cluster. In a weighted clustering algorithm, if the CH does not send (live) messages, all its members will join the closest CH. They send join message to this new CH to request becoming a member of its cluster. If the CH responds with a positive acknowledgment, the nodes become its members. The CH then sends an update message to all its nodes, and vice versa.

4.4.4 Nodes that must be a CH

If one of the mobile Ad Hoc network's ordinary nodes needs to be a CH, its scale must be checked according to the ECRP algorithm. If the scale of this node is greater than that of the current CH and if the working period of the current CH is long, the node declares itself as a cluster head. Otherwise, it remains as an ordinary node.

4.4.5 Two CHs with the same scale

If there are two CHs within the transmission range of each other, the CH selection will use a specific criterion to deal with this situation, as shown in Figure 4.5. If two CHs receive the Hello message from each other, they are within the same transmission range. CH1 will check its member table; if there is more than one gateway, it will change its state to an ordinary node, otherwise, it will check its scale. If its scale is greater than the current gateway, it will directly declare itself as the gateway of the cluster, because if the CH shuts down or moves, this gateway will be used as the CH to reduce re-clustering. This operation can be done by changing the CH ID to a new CH ID, without a need for more overhead.

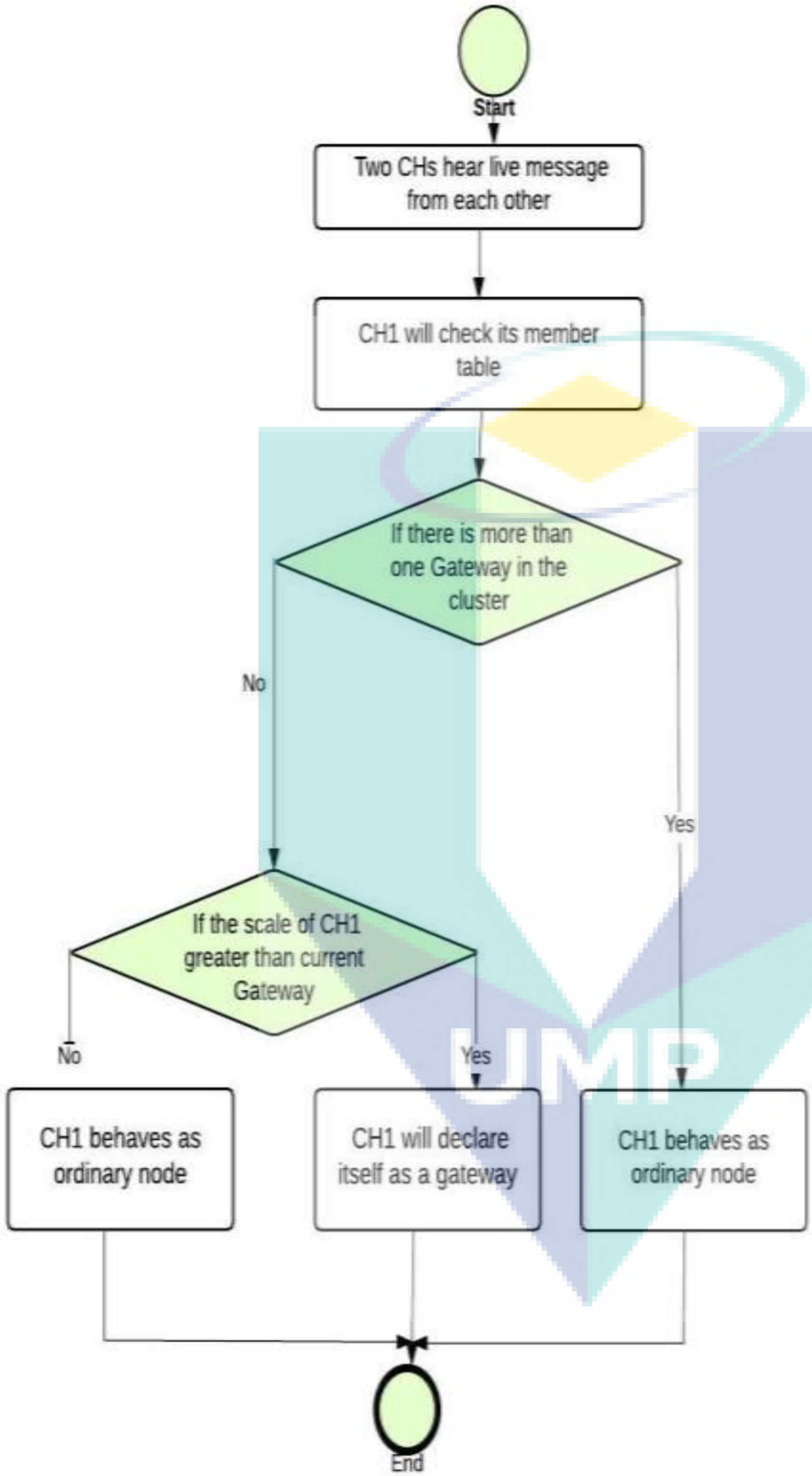


Figure 4.5: ECRP maintenance algorithm for two CHs in the same transmission range

4.4.6 Node shutdown

If no node sends a message to a CH after a specific time, the message is either out of the current cluster range or the node has shut down. Therefore, the CH deletes all the information on this node, updates its member table, and then sends this information to all other nodes on its list.

The network topology shown in Figure 4.6. illustrates a network consisting of ten nodes. The large and small circles represent the cluster and nodes, respectively. It is assumed that node 3 needs to travel from its own cluster (cluster 1) to a new cluster (cluster 2).

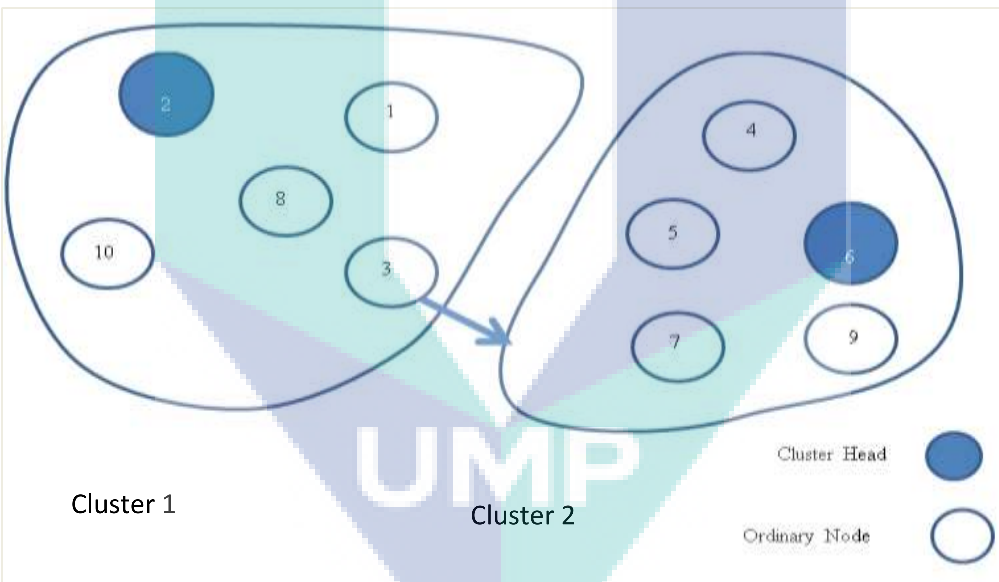


Figure 4.6: Maintenance scenario

Following the ECRP maintenance algorithm, it sends a Join request to node 6, the cluster head of cluster 2, as follows:

Node ID	**Request Type**	**Current CH**	**Scale**
3	Join	2	46

Node 6 will check its maximum number of members. If the maximum number is < 6, it will accept the request and send an update message to all its members to insert node 3 into the member table. The new member table will be as follows:

Node ID	Request Type	Cluster members
6	Update	4,5,6,7,9,3

The validation of this algorithm is demonstrated in Section 5.7.

4.5 ECRP ROUTING ALGORITHM

In the ECRP algorithm, routes are discovered according to the location of the data which are obtained through GPS, in order to minimize the load of management of the routing, which reflects strongly on the performance of the whole Ad Hoc network. In this study, two stages of cluster routing are taken into account: intra-cluster and inter-cluster routing.

4.5.1 ECRP Intra-cluster routing discovery

Based on the intra-routing algorithm for the ECRP, all nodes within the same cluster know each other's location. The DSDV routing protocol is used for intra-routing. DSDV is a proactive routing protocol, so each hop periodically sends a routing table to all its neighbouring nodes. Consequently, it can send data to the destination node directly. For example, if node 1 needs to send data to node 2, it must first check its neighbouring table. If node 2 is located in this table, node 1 will send the data directly with no need to send a route request to the CH, as illustrated in Figure 4.7. Otherwise, it must send a route request to the CH to specify the exact destination route, as shown in Table 4.4.

Table 4.4: Intra-route request to the CH

Packet type (Route-Request)	**Flags**
CH ID	Specify the CH ID of the sender
Source ID	Specify the sender ID
Destination CH ID	Specify the CH ID of the receiver
Destination ID	Specify the receiver ID

The CH contains the current CH ID. Source ID is the sender ID. Destination CH ID is equal to CH ID, and destination ID is the receiver ID. Since CH ID = destination CH ID, the source and destination should be available in the same cluster. The CH checks its members table to ensure that the destination is still a member of its cluster before using multiple parameters to select the most suitable route, as clarified in Figure 4.8.

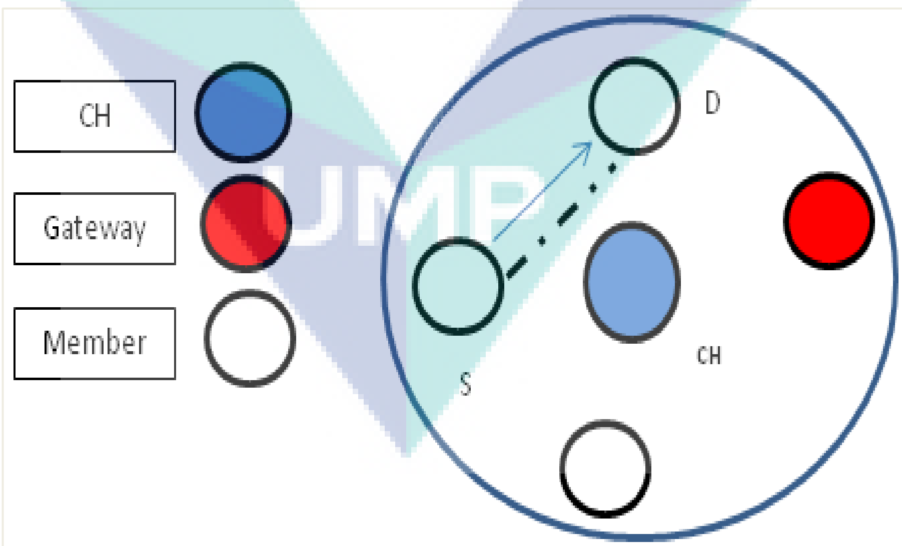


Figure 4.7: Intra-cluster routing if the destination information is available in the sender neighbour table

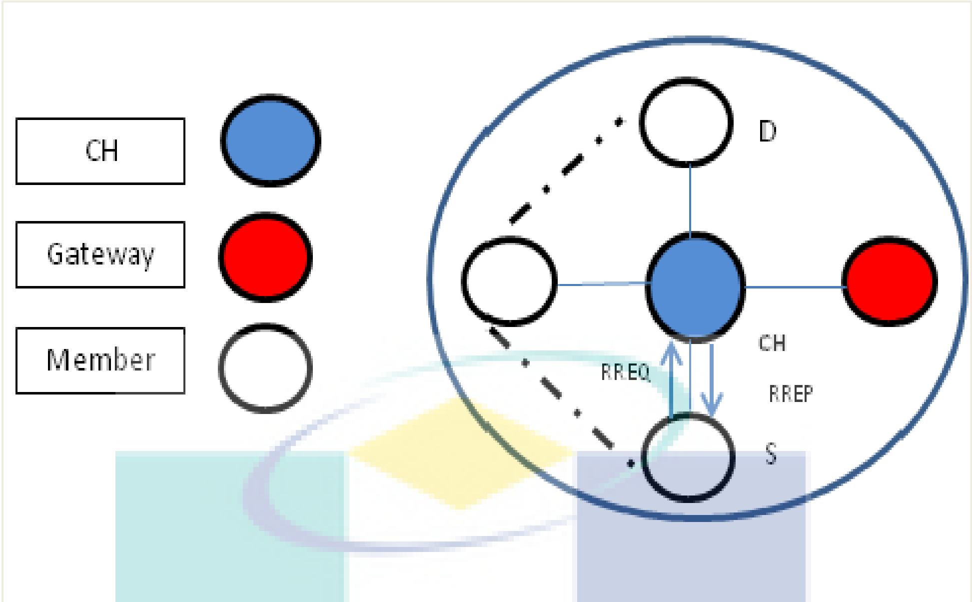


Figure 4.8: Intra-cluster routing if the destination information is not available in the sender neighbour table

The selected route is characterized by the following properties:

1) The majority of the nodes in the selected route should be as stable as possible to limit link failure. This condition is achieved by calculating the movement of each node in the route using Eq. (4.6):

$$MOV=\frac{1}{(t2-t1)}\left(\left|\sqrt{(x2-x1)^2+(y2-y1)^2}\right|\right) \quad (4.6)$$

- (x1, y1) are the coordinates of node 1 at time t1.
- (x2, y2) are the coordinates of node 2 at time t2.

2) The selected route must contain nodes that are at an average distance from the sender to the receiver, which is calculated using Eq. (4.7):

$$\text{Average D} = \left(\left| \sqrt{(x2 - x1)^2 (y2 - y1)^2} \right| \right) \text{ N} \quad / \qquad (4.7)$$

- (x1, y1) are the coordinates of node 1.

-(x2, y2) are the coordinates of node 2.

- N is the number of nodes.

3) CH calculates the cost of the route using Eq. (4.8):

$$\text{Route cost} = a*\text{MOV} + b * \text{Average D} \qquad (4.8)$$

- a & b are the coefficients with a sum equal to 1.

As shown in Table 4.5, when the CH finds a route with a lower scale, it sends a Route-Replay to the sender node, consisting of current CH ID, ID of the sender, the sequence of the route (specific nodes), destination ID (ID of destination), and the flags that contain the packet type:

Table 4.5: Intra-route reply to the CH

Packet type (Route-Replay)	**Flags**
CH ID	Specify the CH ID of the sender
Source ID	Specify the sender node ID
Route sequence	Contains the sequence of the route
Destination CH ID	Specify the CH ID of the receiver
Destination ID	Specify the receiver node ID

The network

topology shown in Figure 4.9 is used to explain the proposed intra-routing algorithm. The network consists of seven nodes. The large and small circles represent the cluster and nodes, respectively. Each discontinuous coloured arrow represents an independent route.

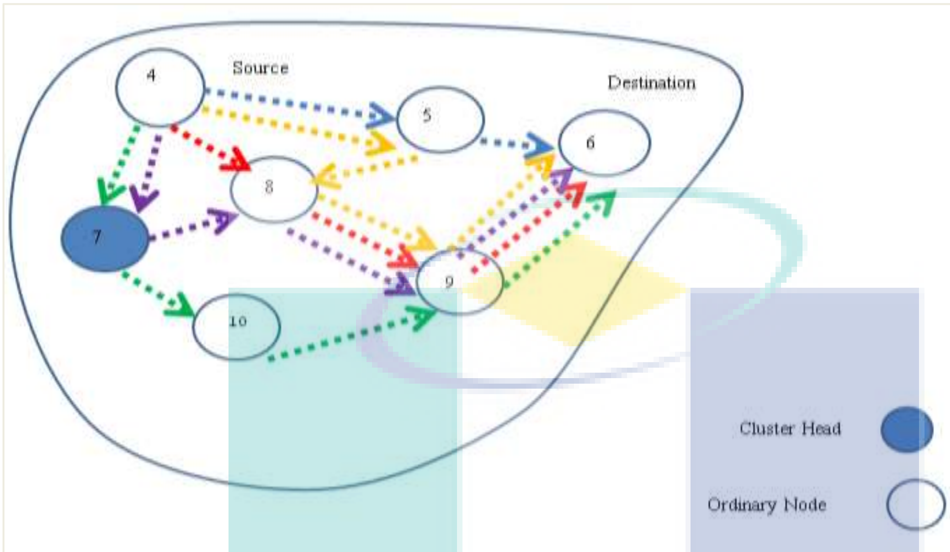


Figure 4.9: ECRP intra-routing scenario

Figure 4.9 assumes that node 4 needs to send data to node 6, located in the same cluster. Node 7 is the CH of the cluster; therefore, node 4 checks its neighbour table. Since the destination node, node 6, is not available in the neighbour table or in the cache routes, it sends a route request to node 7. The route-request table is shown in Table 4.6.

Table 4.6: ECRP intra-route-request before scale calculation

Packet type (Route-Request)	**Flags**
CH ID	7
Source	4
Destination CH ID	7
Destination ID	6

Node 7 calculates the route cost of each available route to the destination and selects the lowest to send back to the sender; therefore, the route sequence (4, 8, 9, 6) will be selected as the best route to send data from node 4 to node 6.

As shown in Table 4.7, if the movement of nodes (4,5,6,7,8,9,10) = (15,10,15,10,5,13,3) m/sec, and the average distance between each node and its neighbour nodes = (10,20,10,10,5,2,30), then

- The route cost for (4,5,6) route will be = (0.5* 15+0.5*10) +(0.5*10+ 0.5*20) + (0.5*15+0.5*10)=40
- The route cost for (4,8,9,6) route will be = (0.5*15+0.5*10) + (0.5*5+ 0.5*5) + (0.5* 13+ 0.5*2) + (0.5*15+0.5*10) =39.
- The route cost for (4,7,10,9,6) route will be = (0.5*15+0.5*10) + (0.5*10+ 0.5*10) + (0.5*3+0.5*30) + (0.5* 13+ 0.5*2) + (0.5*15+0.5*10) =59.
- The route cost for (4,7,8,9,6) route will be = (0.5*15+0.5*10) + (0.5*10+ 0.5*10) + (0.5*5+ 0.5*5) + (0.5* 13+ 0.5*2) + (0.5*15+0.5*10) = 47.5.
- The route cost for (4,7,8,9,6) route will be = (0.5*15+0.5*10) + (0.5*10+ 0.5*10) + (0.5*5+ 0.5*5) + (0.5* 13+ 0.5*2) + (0.5*15+0.5*10) = 47.5.
- The route cost for (4,5,8,9,6) route will be = (0.5*15+0.5*10) + (0.5*10+ 0.5*20) + (0.5*5+ 0.5*5) + (0.5* 13+ 0.5*2) + (0.5*15+0.5*10) = 52.5.

Table 4.7: ECRP route scale calculation

Source ID	Destination ID	Route sequence	Route state	Route cost
4	6	4,5,6	Valid	40
4	6	4,8,9,6	Valid	39
4	6	4,7,10,9,6	Valid	59
4	6	4,7,8,9,6	Valid	47.5
4	6	4,5,8,9,6	Valid	52.5

As shown in Table 4.8, CH will send the following Route-Reply to node 4:

Table 4.8: ECRP intra-route reply after scale calculation

Packet type (Route-Reply)	Flags
CH ID	7
Source ID	4
Route sequence ID	4, 8, 9, 6
Destination CH ID	7
Destination ID	6

Node 4 will use the route with the lowest cost to send its data to the destination, node 6, that is route sequence 4, 8, 9, 6; this route is the lowest, 39. A full description is given in Algorithm 4.3.

(1) Begin {

(2) Each node will check the neighbour table.

(3) If the destination node is available in neighbour table.

(4) Send the data directly to the destination node.

(5) Else.

(6) {Send RREQ to cluster head to find the suitable route.

(7) Custer head will calculate the value of each route using Eq. 4.8.

(8) If (the selected route has the minimum cost),

(9) This route will be used to send data.

(10) CH Sends RREP to sender node to start in sending data.

(11) Else.

(12) Searching for the new route}.

(13) End.

Algorithm 4.3: Procedures for intra-cluster routing discovery

4.5.2 ECRP inter-cluster routing discovery

If any cluster needs to send data to other clusters, it must send a RREQ to the cluster head. The cluster head checks the cluster neighbour table and sends the request to its gateway node to make a connection to other clusters. The RREP is derived from the receiver node and contains the CH for the sender, the CH for the receiver, and the location of the receiver node, which is determined by GPS. If another gateway is available for the route, it is given in the response.

The proposed algorithm produces two scenarios. In the first, shown in Figure 4.10, the CH forwards the RREQ sent by the sender node to its gateway, which forwards the RREQ to the gateway of the second cluster. Finally, the RREQ is sent to the destination node, which sends a RREP to the sender on receiving this request. This RREP contains information regarding its location. In summary, the sender sends the data to the gateway of its cluster, which forwards it to the gateway of the second cluster. Finally, the data is sent to the specific destination node according to its GPS location information.

The second scenario, as shown in Figure 4.11, occurs if the gateway of the second cluster cannot deliver the data to the destination node because the receiver node, although within the cluster, is out of range. The gateway of the second cluster sends the RREQ to its CH, and the CH applies the intra-cluster procedure to select a suitable route for sending data to the destination node. If the destination node is within the same cluster area, this process minimizes the number of errors and shortens the time. Algorithm 4.4 is a full description for all cases of the inter-cluster routing algorithm.

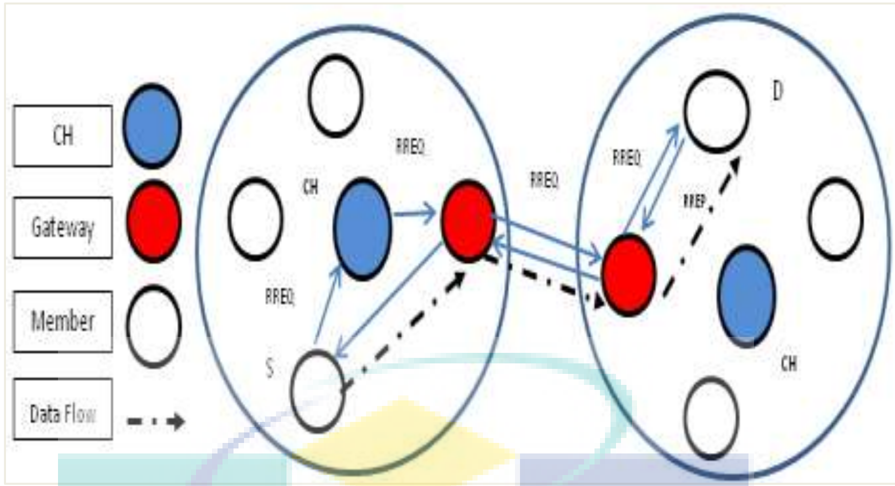


Figure 4.10: First scenario of the inter-cluster discovery algorithm

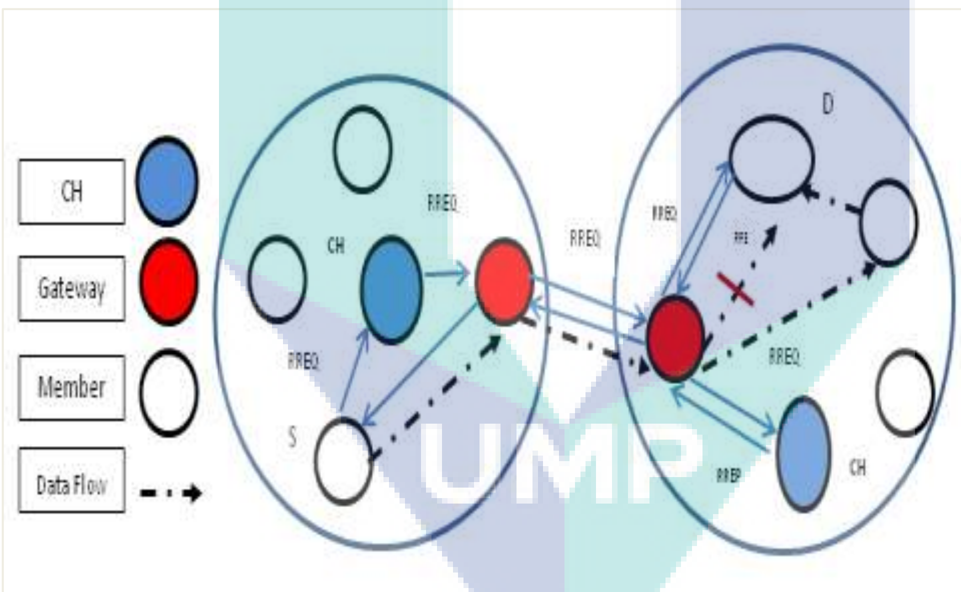


Figure 4.11: Second scenario of the inter-cluster discovery algorithm

To explain the proposed inter-routing algorithm, the network topology is demonstrated in Figure 4.12. The network consists of 12 nodes. The large and small circles represent the cluster and nodes, respectively. Each discontinuous colored arrow represents a route request, and the continuous arrows represent the travelling data.

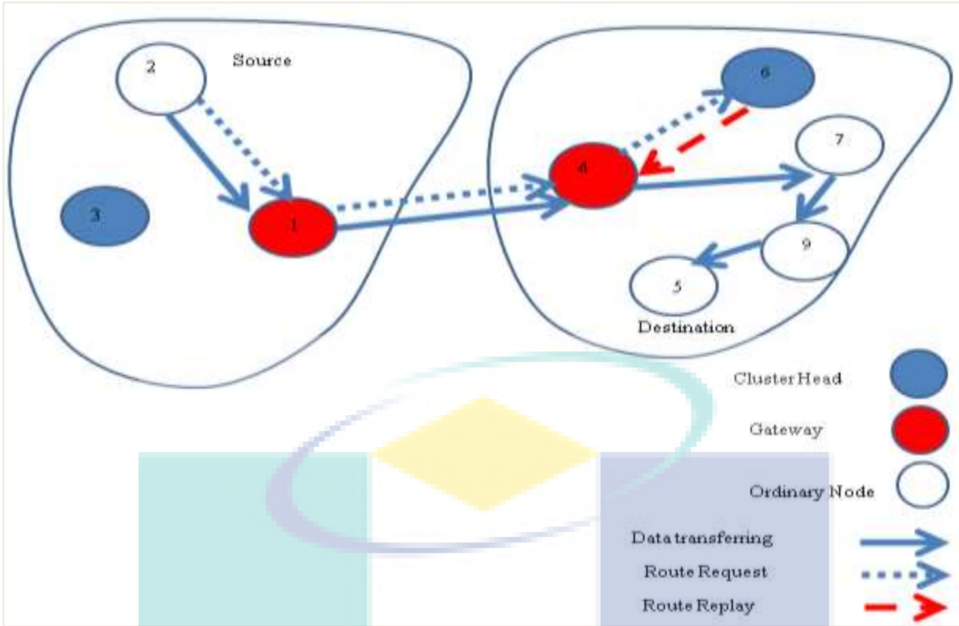


Figure 4.12: ECRP inter-routing algorithm scenario

Figure 4.12 assumes that node 2 needs to send data to node 5, located in a different cluster. Node 3 and 1 are the CH and gateway of cluster 1, respectively, and nodes 6 and 4 of cluster 2. Node 2 sende the Route Request to its CH (node 3), as shown in Table 4.9.

Table 4.9: Inter-Route Request

Packet type (Route-Request)	Flags
CH ID	3
Source ID	2
Route sequence	-
Destination CH ID	6
Destination ID	5

Since the destination node (node 5) is not available in its cluster, the request is sent to node 4 (gateway of cluster 2) and the last node checks that the available nodes are within its transmission range. If node 5 is not in transmission range, it forwards the request to node 6 (CH of cluster (2)). The CH selects the appropriate route according to its scale and sends a route reply to the gateway to send the data; therefore, the final result is that node 2 sends data to node 1 (gateway of cluster 1). The last node sends the data to node 4 (gateway of cluster 2) and, after receiving the appropriate route from the CH, node 4 sends it to node 5, as shown in Table 4.10.

Table 4.10: Inter-Route Reply

Packet type (Route-Reply)	**Flags**
CH ID	6
Source ID	4
Route sequence	4,7,9,5
Destination CH ID	6
Destination ID	5

A full description is given in Algorithm 4.4.

(1) Begin {Sender node sends RREQ to the CH in the same cluster.
(2)The CH will forward this RREQ to its gateway, then the gateway will forward RREQ to the gateway of the second cluster, then the last node will send RREQ to the destination node.
(3) If the destination node is available in gateway transmission range,
(4) The sender will send data to gateway1, then gateway 2 will send it to the destination node.
(5)Else.
(6) The gateway 2 will send another RREQ to its CH and CH will use the intra cluster route algorithm to calculate the suitable route.

(7) If the CH finds the suitable route,

(8)Gateway 2 sends data using the determined route to the destination node.

(9)Else

(11)Gateway 2 will send another route request} End.

Algorithm 4.4: The inter-cluster discovery procedure

4.8 SUMMARY

In this chapter, enhanced algorithms for clustering formation, maintenance and routing for Ad Hoc networks were proposed and used in the ECRP routing protocol. The ECRP formation algorithm calculates the scale of each node and selects the node with the highest scale to be the CH. The ECRP maintenance algorithm depends on structure visualization to recover each error. ECRP routing is categorized into intra- and inter-routing to send packets from the sender to the destination. The main objective of these algorithms is to enhance the stability of clusters and improve the quality of the routing process.

CHAPTER 5

ANALYSIS OF SIMULATION AND RESULTS

CHAPTER 4

METHODOLOGY

4.1 INTRODUCTION

This chapter proposes an Enhanced Cluster Routing Protocol (ECRP) used in MANET. It employs an algorithm in a cluster formation to compute the node scale, which chooses a cluster head in line with the parameters which are size of available storage, load sharing, incremental time, available power, and the movement of each node. An algorithm for cluster maintenance that categorizes and recovers errors according to type was developed. Furthermore, an algorithm for routing the packets was proposed, using the movement of nodes and distance between nodes to select the more stable route to send data, and it employs *Global Positioning System (GPS)* to acquire location data for individual nodes. The process of route discovery is split into intra cluster routing discovery and inter cluster routing discovery.

This chapter presents the procedure used to implement the ECRP algorithms using NS2. It also explains the primary parameters that are altered in the Ad hoc channel, the suggested design assumptions that are made by ECRP, the definition of the proposed clustering algorithms used for cluster formation, cluster maintenance, and its procedures, and routing algorithms and its assumptions. The required headers and packets used to find the route to the destination are also described. An operational example is presented at the end of each algorithm.

4.2 ECRP DESIGN ASSUMPTIONS

The ECRP algorithm is designed with the following assumptions:

vi) The hello packet, which is broadcasted by each node, can be received by all the available nodes in the specific cluster within a specific period of time.

vii) The maximum number of the nodes in each cluster is 8.

viii) A global positioning system (GPS) is used to obtain node coordinates in the network.

ix) Two stages of cluster routing were considered. The first is intra cluster routing, which is described as routing within the same cluster. The ECRP intra cluster routing is a proactive protocol that depends on information that is sent periodically between nodes. The second is inter cluster routing, which is routing between two clusters. The ECRP inter cluster routing is a reactive protocol, which determines the proper route only when required.

x) All the Ad hoc network nodes are able to transmit from one location to a destination location randomly; however the highest threshold value of the transmission range of all nodes, denoted by MaxTrans, must be equal to (300 M). It is defined as an argument in a program code. This value administrates and minimizes link failure errors, and constrains the network topology. At the start of the simulation, this value is equal for all network nodes.

4.3 ECRP CLUSTER FORMATION ALGORITHM

The main concept of the proposed algorithm involves modifying the weighted clustering algorithm (which was explained in detail in Chapter 3, Section 3.2). The weighted clustering algorithm uses three parameters to calculate the scale of each node, which are: degree of nodes, mobility, and the distance between nodes. These parameters are used to select the cluster head to enhance network performance. From the literature review it was found that there were limitations in previous studies that need to be improved (all of these limitations were discussed in detail in Section 2.6.1) and were solved using an enhanced clustering formation algorithm. The difference between the standard weighted clustering algorithm and the proposed formation algorithm is that the proposed algorithm takes into account other factors to increase the stability of the network and reduce the delay time of CH election which involves: storage space, node distribution in the available area, accumulated time, available power, and node movement. The proposed formation algorithm is shown in Algorithm 4.1 and Figure 4.1. The main steps in the proposed cluster formation algorithm are as follows:

Step 1: Each node sends a “hello” message to all other nodes to inform them of its existence.

Step 2: The CH is selected by determining the node with the highest scale. This step is applicable only to the node that has not been previously selected as a CH. The scale is calculated according to the following parameters:

7) The storage capacity (*SC*) of the node is calculated by considering the memory capacity of each node which is equal to a percentage of the remaining memory over full memory capacity.

8) The Load Distribution (*LD)* is used to estimate the remaining number of nodes that can still be handled by each node. LD is computed using Eq. (4.1):

$$LD = \left| N_i - CS \right| \tag{4.1}$$

where:

N_i is the number of neighboring nodes.

CS is the cluster size.

LD assesses the number of nodes that can be covered by the cluster.

9) Active period of the node is represented by *T*, which reflects the summation of the active periods spent by the nodes in sending and receiving packets. If this value is high, it means that this node is more active than the other nodes, and it can cover more cluster nodes, which enhances the stability of the entire cluster. The *T* value is calculated using Eq. (4.2).

$$\mathrm{T} = \left| \sum_{k=1}^{N} (T_{R1} - T_{R2}) \right| \tag{4.2}$$

where:

N is the number of neighboring nodes.

T_{R1} is the received time of the first packet from the specific node.

T_{R2} is the received time of the last packet from the same node.

10) The remaining energy of each node is referred to as APOW and can be calculated by subtracting the consumed energy of the node from the initial energy of the same node to network b. APOW is expressed as shown in Eq.(4.3)

$$\text{consumed energy} = \mathrm{P} * \mathrm{T}$$
$$\text{APOW} = \text{initial power} - \text{consumed power} \tag{4.3}$$

where:

P the power utilized for sending / receiving single packet

T sending / receiving time for a single packet

APOW is the total available power

11) The movement of each node, which is denoted as MOV, is used to calculate the movement of the node with respect to the other neighboring nodes. In standard weighted Cluster Algorithm (WCA), movement is calculated based on the difference between the new and

old coordinates of the nodes divided by a specific time. In this thesis, movement is calculated as a function of power, depending on “Hello” message power. Since the “Hello” message is sent periodically from neighbor nodes to all other nodes in a cluster, the receiving node will compare the power of two consecutive “Hello” messages from the same node using Eq. (4.4). Then the node with a small movement value will have smaller power differences, which means that the ratio between new P_N and old P_N must be as small as possible to increase the stability of the cluster.

Considering node (N) and node (M) as neighbor nodes, and node (M) receives a “Hello” message. The last node will calculate the power of the received message. After a specific period of time, it will receive another “Hello” message from the same neighbor node and will calculate the relative MOV for node (N) by using Eq. (4.4):

$$MOV=\frac{1}{(t2-t1)}\left(\left|\sqrt{(x2-x1)^2+(y2-y1)^2}\right|\right) \qquad (4.4)$$

where:

(x1, y1) the coordinates of node1at time t1

(x2, y2) the coordinates of node2 at time t2

12) The combined scale of each node is calculated based on the afore-mentioned parameters for each node in the cluster using Eq. (4.5):

$$S = a_1 SC + a_2\, LD + a_3\, T + a_4\, APOW - a_5 MOV \qquad (4.5)$$

where:

SC is the storage capacity

LD is the load distribution

T is the accumulative time

APOW is the available power in the node

Mov is the movement of the node

a_1, a_2, a_3, a_4 and a_5 are the coefficients for scale calculation.

The summation of these coefficients is equal to 1, and important factors are assigned values. The coefficients of the following study are as follows: APOW=0.30, T= 0.25, MOV= 0.20, SC=0.15, LD=0.10.

Step 3: The node with the greatest scale is selected as the CH. This node sends a message to all other nodes to inform them that it has been selected as a CH node.

Step 4: Each node periodically sends a message to all other nodes in the cluster. This message contains the following: node ID, request type, scale, and working period.
where:

- Request type: "CH" indicates that the sender is the CH; "WCH" indicates that the sender wants to be the CH and will send requests to the current CH to compare its scale with the new CH. For "E" the sender asks the current CH to cease its operation because it has higher scale than the current CH.

-Scale: The weight of the node.

- Working period: This is the period of time for which the CH operates. If it has a high value, then it must be replaced with a new CH because its scale is reduced by time.

All nodes in the cluster will calculate its node scale (S) and broadcast this value to all nodes in the cluster. Any node that needs to be the CH will send a WCH (want to be the cluster head) request to all other nodes in the cluster, and wait for a specific period of time. Then it will receive a response from the current CH that contains the CH scale and the working period. If the scale of the current CH is greater than that node which needs to be CH, and its working period is shorter than Threshold 1, then the sender node behaves as an ordinary node.

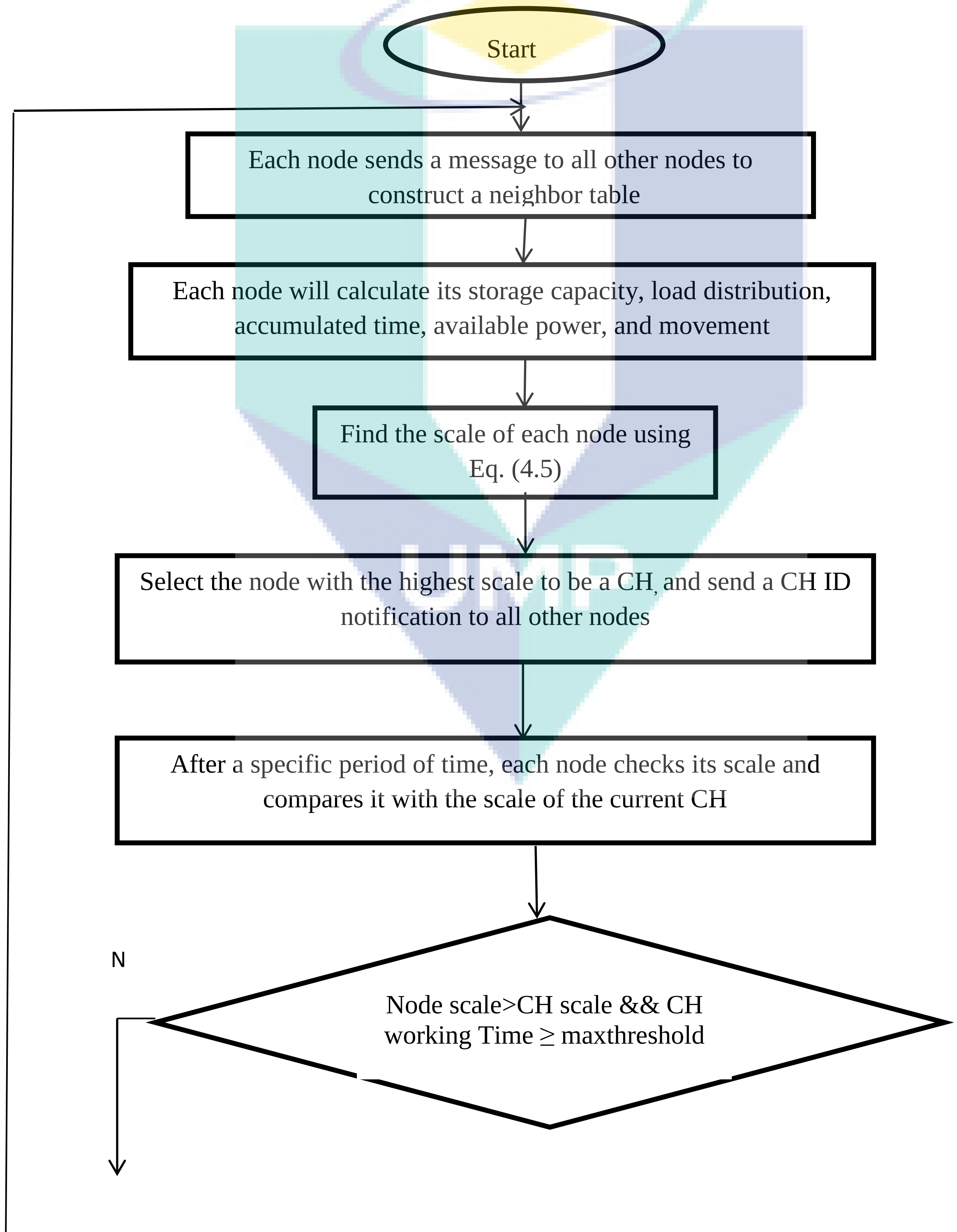
After a specific period of time, WCH sender repeats the request. The current CH will check if its scale is greater than that of the current CH, and if the working time of the current CH is long, then the new CH will be declared the CH of the cluster. The new CH sends a message that contains the following: node ID, CH message, scale, and 0. This exchange of CHs reduces the overhead of the entire network and distributes the burden among all available nodes. This distribution is reflected positively in routing protocol performance.

Step 5: If the two nodes are of the same scale, then one of them is chosen as the CH. The other one is utilized as a gateway to connect to external clusters.

```
(12)    Begin {
(13)    Each node sends  "Hello"  message to all other nodes in its transmission range
(14)    Each node establishes its neighbor list
(15)    For ( int  i=1; i < period of time; i++)
(16)                {       For ( int  j=1; j< number of nodes; j++)
(17)    calculate its storage capacity;
  load distribution using Eq. (4.1);
                  Accumulated time using Eq. (4.2);
                   Available power, using Eq. (4.3);
                   And movement for each node using Eq. (4.4). }

(18)    Find the scale of each node  by using (4.5)
(19)    Each node broadcasts  it's scale, the node with the highest scale will send WCH
     message to the current CH
(20)    The cluster head will compare its scale with the scale of  the node that
     sent the request.
(21)    initial node scale =0
(22)    If  node (j) scale  > node (i) scale{
                    cluster head=node (j);
                    Cout>>"node(j) is the cluster head of all nodes";}
 (11) Else {Cluster Head=node (i);
 (12) Cout>>"node (i) is the cluster head of all nodes";
(13)End    }
```

Algorithm 4.1:ECRP cluster formation algorithm



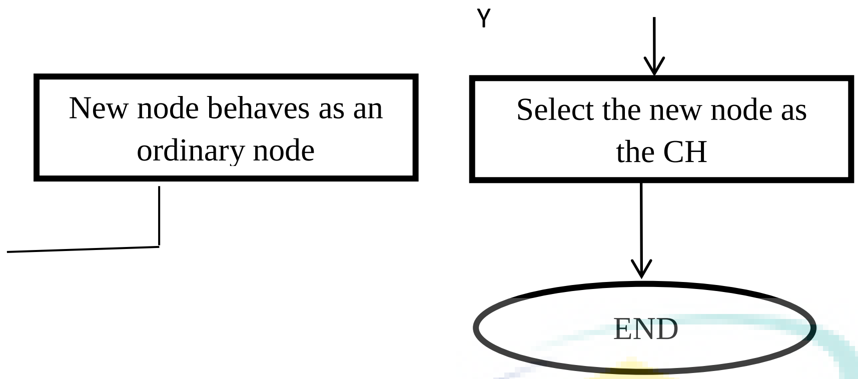


Figure 4.1: ECRP cluster formation algorithm

All nodes calculate their scales, and this information is sent as a specific message to all neighbor nodes. This message contains the selection method of the node as the CH**.**

Consider the network topology shown in Figure (4.2). A network that consists of 10 nodes is used to explain the proposed formation algorithm. The big circles and small circles are used to represent the cluster and nodes, respectively. Assuming that node 1 will need to form its own cluster using the proposed cluster formation algorithm, it will send a "Hello" message to all other nodes available in its specific transmission range and then each node will build its neighbor table, which is represented as the following:

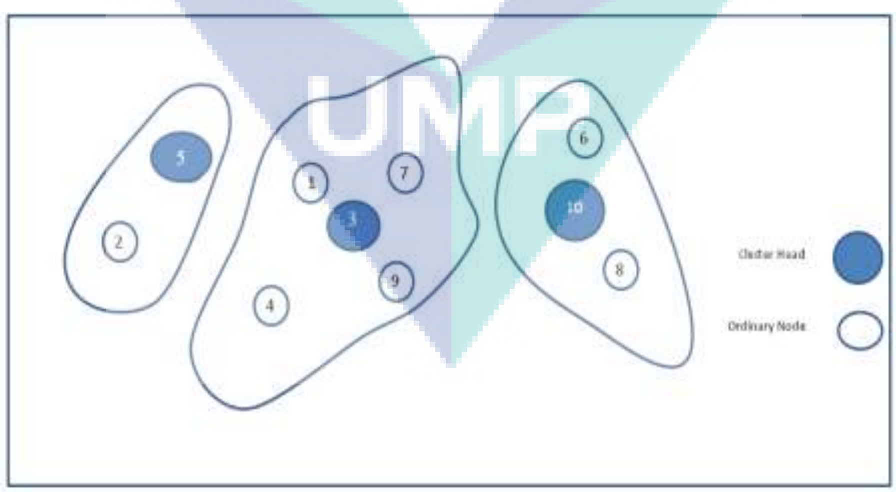


Figure 4.2: ECRP cluster formation scenario

The neighbor table for node 1 is shown in Table 4.1 and consists of 4 nodes.

Table 4.1: The neighbor table for node (1)

Neighbor node ID
3
4
7
9

Thus, cluster 1 is constructed with cluster size (5) and contains the nodes (1, 3, 4, 7, 9). The head of this cluster is selected according to step (2) in the proposed formation algorithm. The scale is calculated as the following:

- For node (1):

If the (SC=0.75, LD= 4, T=140, APOW=450, MOV=3)

The scale will be = (0.15*0.75+0.10*4+ 0.25*140 + 0.30*450 - 0.20*3) = 169.91

- For node (3):

If the (SC=0.70, LD= 3, T=120, APOW=400, MOV=3)

The scale will be = (0.15*0.70 + 0.10*3 + 0.25*120 + 400* 0.30 - 0.20*3) = 160.90

- For node (4):

If the (SC=0.70, LD= 3, T=120, APOW=400, MOV=3)

The scale will be = (0.15*0.70 + 0.10*3 + 0.25*120 +0.30 * 400 - 0.20*3) = 157.05

- For node (7):

If the (SC=0.15, LD= 5, T=100, APOW=150, MOV=3)

The scale will be = (0.15*0.15 + 0.10*5 + 0.25*100 + 0.30*150-0.20*3) =69.92

-For node (9):

If the (SC=0.25, LD= 2, T=100, APOW=250, MOV=1)

The scale will be = (0.15*0.25 + 0.10*2 + 0.25*100 + 0.30*250 - 0.20*1) =100.03

Thus, the node with the highest scale will be selected to be the cluster head. In this example, the CH will be node 4 because it has the highest scale among all the cluster nodes (169.91), and node 4 will advertise itself as a cluster head by sending a CH) message to all other nodes that contain the following:

Cluster head ID	**Request Type**
4	CH

Then the neighbor table for each node will be updated to contain the neighbor node IP and the CH for each cluster. For example, node 1 neighbor table is shown in Table (4.2):

Table 4.2: The CH table for each node

Neighbor node ID	**Cluster head ID**
3	4
4	4
5	2
7	4
9	4

If node 3 needs to advertise itself as a cluster head, it will send a WCH to the current CH using the following request format:

Node ID	**Request Type**
3	WCH

The current CH (which is Node 4) will check its scale and working time and compare these two values with Node 3) scale and working time. If the scale of Node 3 is greater than Node 4 , its working time is smaller, Node 4 will end its operation and Node 3 will declare itself as the CH of the cluster by sending the following message:

Node ID	**Request Type**
3	CH

Otherwise, Node (4) will continue its work as a CH for the specific cluster. The scale calculation for each node is presented in Table 4.3

Cluster size	**LD**	**SC in (GB)**	**T in (msec)**	**APOW In (J)**	**MOV in**	**Scale**	**CH**

The validation of this algorithm is verified in Chapter 5, (Section 5.6).

Table 4.3: Scale calculation by using ECRP

					(m/sec)		
3(N_1, N_2, N_3)	(1,2,2)	(0.5,2,1)	(80,70,120)	(200,150,250)	6,3,2	81.37,63.6, 105.15	N_3
5(N_1, N_2, N_3, N_4, N_5)	(2,3,4,3,2)	(0.75, 2, 4,1.5, 1.2)	(90,110,140, 80,65)	(150,250,500, 450,180)	2,4,2,5, 6	67.71,81.40, 178.90,156.52, 71.83	N_3
7(N_1, N_2, N_3, N_4, N_5 N_6, N_7)	(6,4,3,2,5 ,2,3)	(5,0.25,2,4,1, 1.5,2)	(120,60,50,60, 100,25, 90)	(300,150,200,17 5,140,120,230)	3,5,4,6, 7,8,2	121.95,61.25, 74.10,68.60, 64.05,44.22, 92.5	N_1
9(N_1, N_2, N_3, N_4, N_5 N_6, N_7, N_8, N_9)	(2,5,6,4,3 ,6,2,5,7)	(1.6,0.5,1,2,3, 5,1.3,1.5,6)	(40,100,50,12 0,20,40,50,60, 140)	(250,150,100,24 0,260,140,100,2 40,300)	3,2,2,3, 4,2,2,5, 1	86.04, 65.97,43.65, 78.30,89.85, 53.19, 43.29,88.12, 126.80	N_9

4.4 ECRP MAINTENANCE ALGORITHM

The maintenance stage of a cluster is initiated to ensure the correct delivery of the sending packets, especially given that Ad hoc networks are characterized by a frequently changing topology. This dynamics is a result of the mobility of the nodes. The maintenance stage can be summarized into the following visualizations:

- Link failures
- Node movement
- CH movement
- A node that must be a CH
- Two CHs with the same scale
- Node shutdown

4.4.1 Link failure

In the proposed algorithm, cluster link failures can be categorized into two types. As displayed in Figure 4.3, the first type affects the cluster structure. For example, two nodes *m* and *n* are related to one cluster and send a message to inform the CH when the link between them is damaged. The CH then updates its link table. If these two nodes are under its control and are within its range, it requests only those nodes to update their link information. If the nodes are out of its range, the CH asks them to construct a new, separate cluster and determine a new CH as proposed by the CH selection algorithm. The node with the greater scale value declares itself as a CH.

The second type of link failure does not influence the cluster structure between two clusters. As exhibited in Figure 4.4, the two nodes merely inform the CH regarding the failure through a message. They also update their link information.

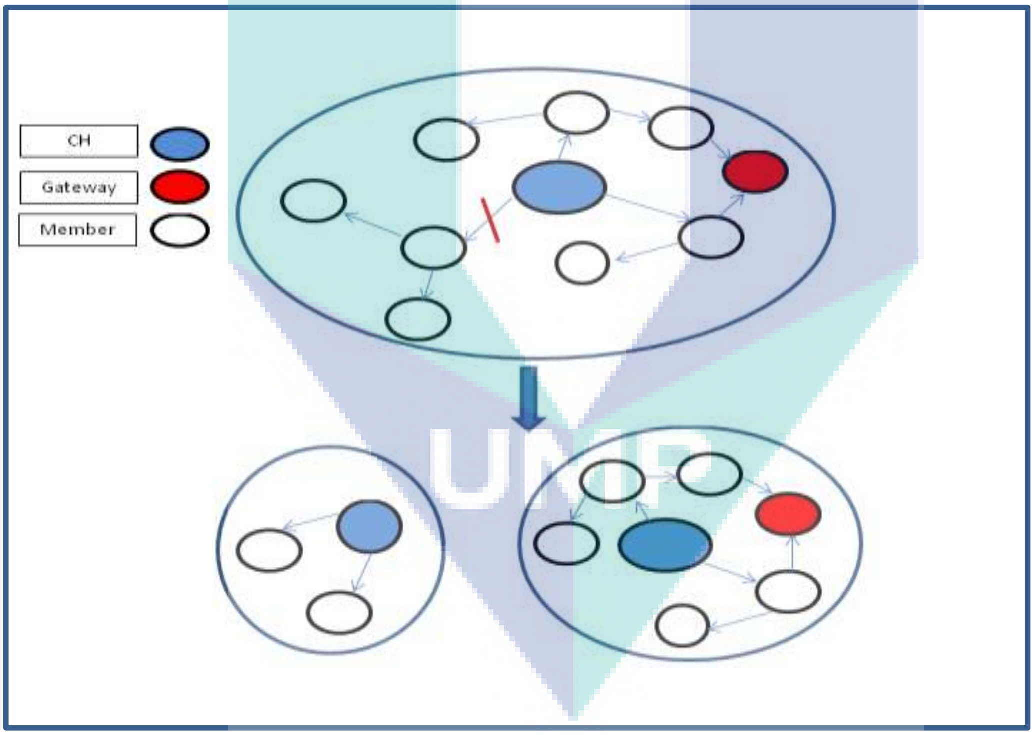


Figure 4.3: Link failure within the same Cluster

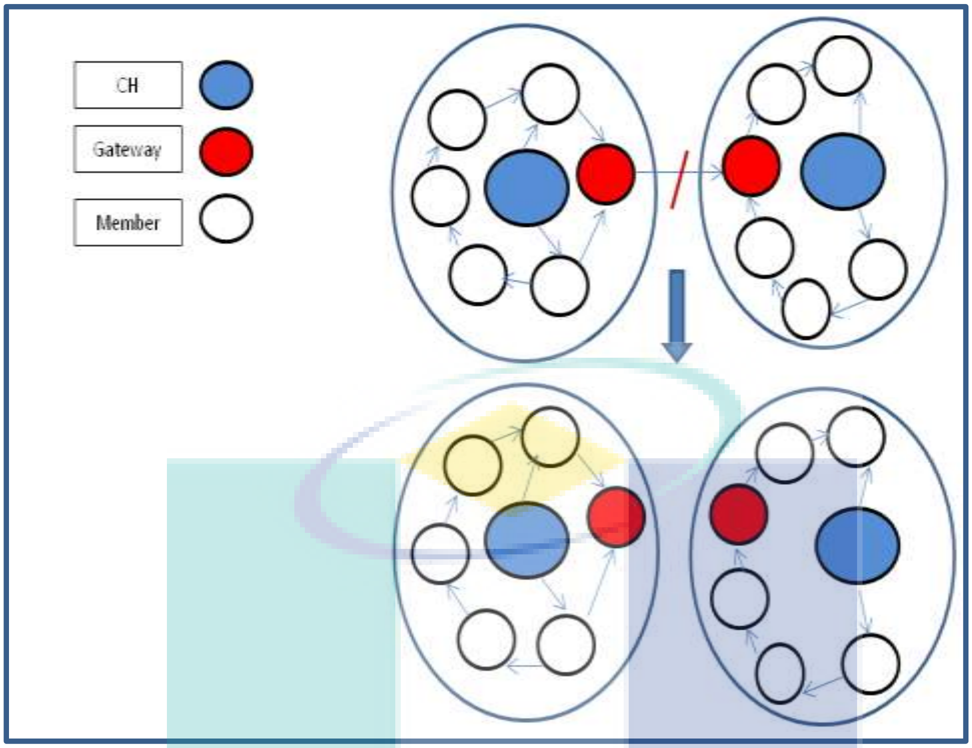


Figure 4.4: Link failure between cluster1 and cluster2

4.4.2 Node movement

In the ECRP algorithm, as shown in algorithm 4.2 and Figure 4.5, when a node travels from one cluster to another, it sends a message to all of the nodes in the new cluster. This message contains important information regarding the node, including its ID, message type, location, and scale. The current CH checks the maximum permitted number of nodes. If the cluster has not reached the maximum number of members, then the CH sends a positive acknowledgement to the new node. The new node responds with an appended message to declare its entrance into the new cluster. The CH updates its member table and sends this message to all available nodes in its cluster. If the cluster has reached the maximum permitted number of members, then the CH sends a negative acknowledgement to the new node. The new node must then search for a new CH.

The main differences between this algorithm and the weighting clustering algorithm are that if a node with low mobility and high score moves and joins another cluster, this node will be directly selected to be the CH of the cluster without needing to re-calculate the CH value but it only checks the APOW, and if its power is greater than the maximum power threshold, it declares itself as a CH. Another difference is that if an ordinary node moves to another cluster, there is no need for re-clustering in the original cluster, but it needs to update the neighbor table for the cluster members. This is in contrast to the traditional cluster algorithm that needs to re-cluster all of the clusters, not only cluster changes. This reduces the time and control overhead of the network. Figure 4.5 illustrates the procedures of the proposed criteria.

```
Begin
{
The node that needs to join the cluster sends Join request to the CH
The CH will check the number of the available nodes in its cluster{
If  (available members in cluster <maximum permitted number of nodes){
Cluster head will accept the node request
Update the member table
Broadcast the new updated member table
  Else
 {
Cluster head will reject the (Join) request
The node that sent the request will search for another cluster
 }
End
```

Algorithm 4.2: The procedure of node movement algorithm

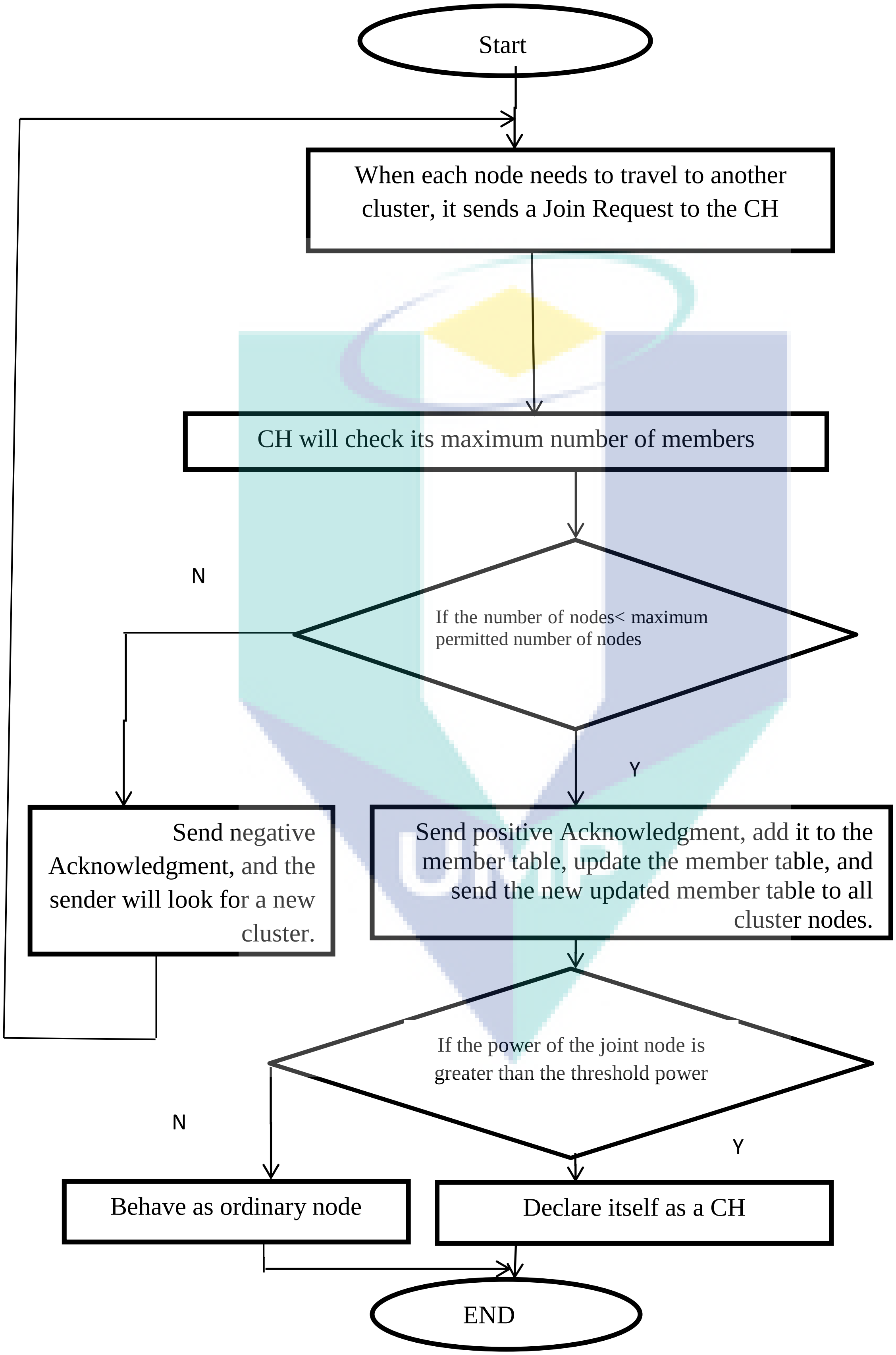

Start
When each node needs to travel to another cluster, it sends a Join Request to the CH
CH will check its maximum number of members
If the number of nodes< maximum permitted number of nodes
N
Y
Send negative Acknowledgment, and the sender will look for a new cluster.
Send positive Acknowledgment, add it to the member table, update the member table, and send the new updated member table to all cluster nodes.
If the power of the joint node is greater than the threshold power
N
Y
Behave as ordinary node
Declare itself as a CH
END

Figure 4.5: ECRP node movement algorithm

4.4.3 CH shutdown

In the ECRP maintenance algorithm, the cluster nodes with the highest scale are selected as a CH, and the second highest scale will be selected as a gateway. Thus, when the CH is shut down or moves away, the other node will be notified because each CH periodically sends (live) messages to prove its existence. In this case, the gateway will directly declare itself as the CH and send CH request packets to all other nodes to update their CH ID without a need for recalculation, which reduces the overhead and re-clustering processes and increases the stability of the cluster. In a weighted clustering algorithm, if the CH does not send (live) messages, all of its members will join the closest CH. They send join message to this new CH to request to be a member of its cluster. If the CH responds with a positive acknowledgement, then the nodes become its members. The CH then sends an update message to all of its nodes, and vice versa.

4.4.4 Nodes that must be a CH

If one of the mobile Ad hoc network ordinary nodes needs to be a CH, then its scale must be checked according to the ECRP algorithm. If its scale of this node is greater than that of the current CH and if the working period of the current CH is long, then the node declares itself as a cluster head. Otherwise, it behaves as an ordinary node.

4.4.5 Two CHs with the same scale

If there are two CHs within the transmission range of each other, the CH selection will uses specific criterion to deal with this situation, as shown in Figure 4.6 . If there are two CHs receiving the hello message from each other, it means that the two CHs are within the same transmission range. CH1 will check its member table; if there is more than one gateway, then it will change its state to an ordinary node, otherwise it will check its scale. If its scale is greater than the current gateway, it will directly declare itself as the gateway of the cluster, because if the CH shutdowns or moves, this gateway will be used as the CH to reduce re-clustering. This operation can be done by changing the CH ID into a new CH ID, without needing more overhead.

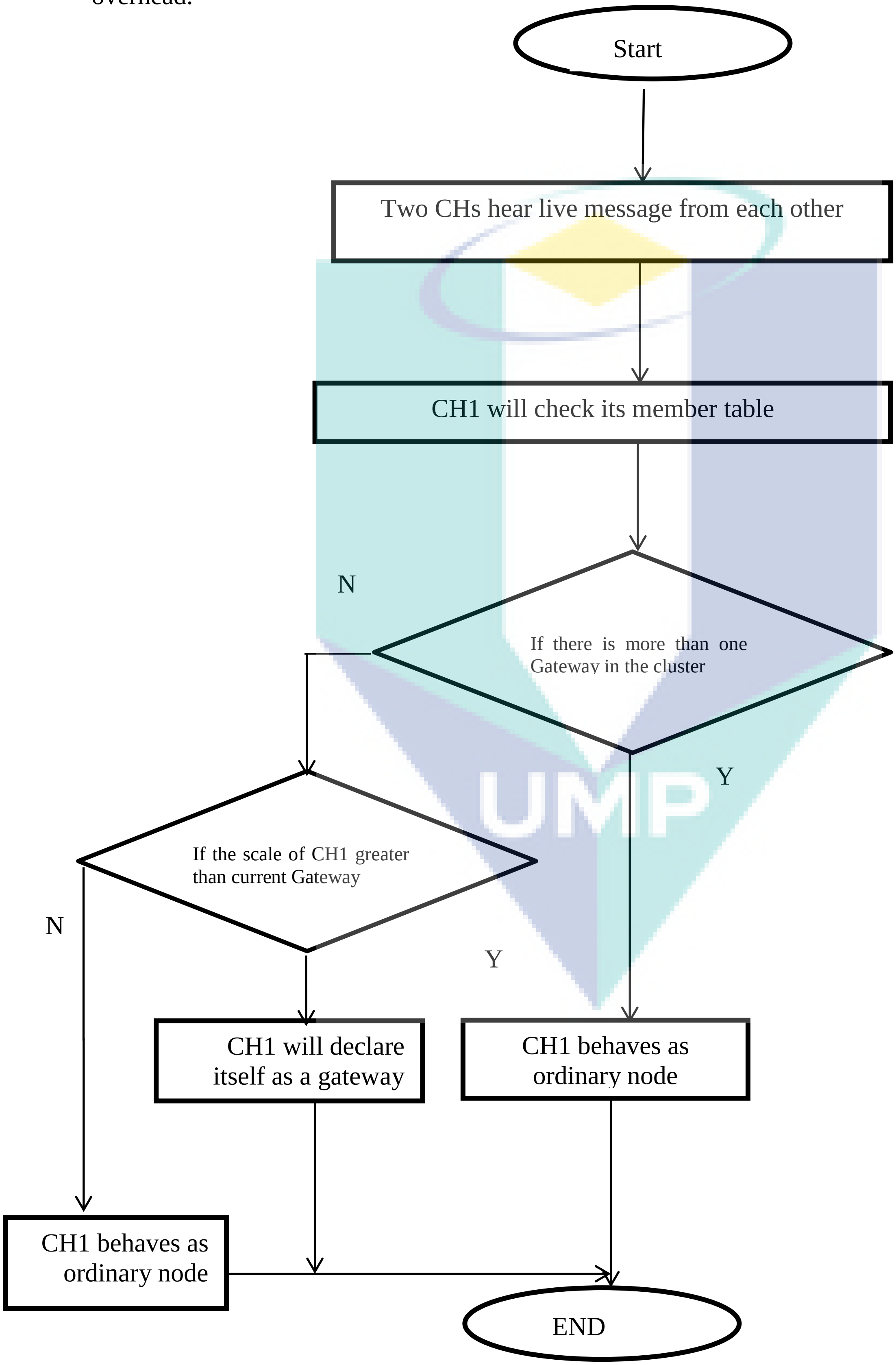


Figure 4.6: ECRP maintenance algorithm if two CHs are in the same transmission range

4.4.6 Node shutdown

If no node sends a message to a CH after a specific time, then the message is either out of the current cluster range or the node has shut down. Therefore, the CH deletes all of the information on this node and updates its member table, following which it sends this information to all other nodes in its list.

Consider the network topology shown in Figure 4.7. The network consists of 10) nodes. The big circles and small circles are used to represent the cluster and nodes, respectively. Assume that Node 3 needs to travel from its own cluster (cluster 1) to a new cluster (cluster 2).

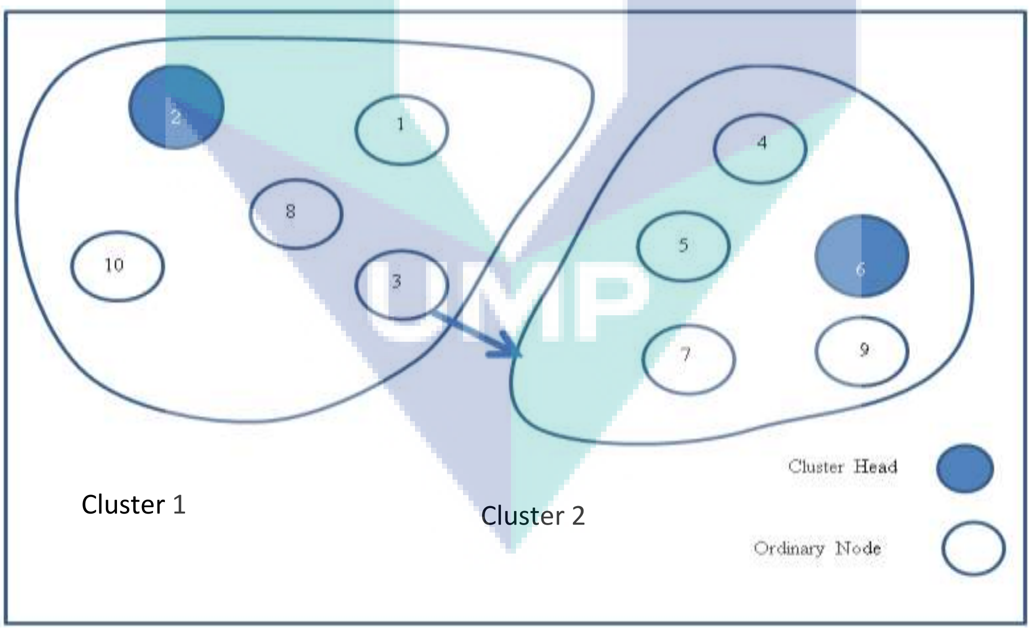


Figure 4.7: Maintenance scenario

Using the ECRP maintenance algorithm, it will send a Join request to Node 6 which is the cluster head of cluster 2, as the following:

Node ID	Request Type	Current CH	Scale
3	Join	2	46

Node 6) will check its maximum number of members. If the maximum number is < 6, it will accept its request and send an update message to all its members to insert Node 3 into the member table, so the new member table will be the following:

Node ID	Request Type	Cluster members
6	Update	4,5,6,7,9,3

The validation of this algorithm is found in Chapter 5, Section 5.7 .

4.5 ECRP ROUTING ALGORITHM

In the ECRP algorithm, routes are discovered based on where the information is located through the Global Positioning System (GPS) to reduce the burden of routing and management, which reflects positively on the performance of the entire network. In this study, two stages of cluster routing are considered. The first is intra cluster routing, which is described as routing within the same cluster. The second is the inter cluster routing, which is routing between a pair of clusters.

4.5.1 ECRP Intra cluster routing discovery

According to the ECRP intra routing algorithm, all nodes know the locations of all other nodes in the same cluster. DSDV is used for intra routing. DSDV is a proactive routing protocol, so each node periodically sends a routing table to all its neighboring nodes so it can send the data directly to the destination node. For example: if node 1 needs to send data to node 2, it must first check its neighbor table. If node 2 is located in this table, then node 1will send the data directly without needing to send a route request to the CH, as illustrated in Figure 4.8. Otherwise, it must send a route request to the CH to specify the exact destination route, as shown in Table (4.4), which consists of the following fields:

Table 4.4: Intra route request to the CH

Packet type (Route- Request)	**Flags**
CH ID	Specify the CH ID of the sender
Source ID	Specify the sender ID
Destination CH ID	Specify the CH ID of the receiver
Destination ID	Specify the receiver ID

The CH contains the current CH ID, Source ID is the sender ID, destination CH ID is equal to CH ID , and Destination ID is the receiver ID. Since the CH ID = Destination CH ID, the source and destination should be available in the same cluster and the CH will check its members table to ensure that the destination is still a member in its cluster before using multiple parameters to select the most suitable route as indicated in Figure 4.9.

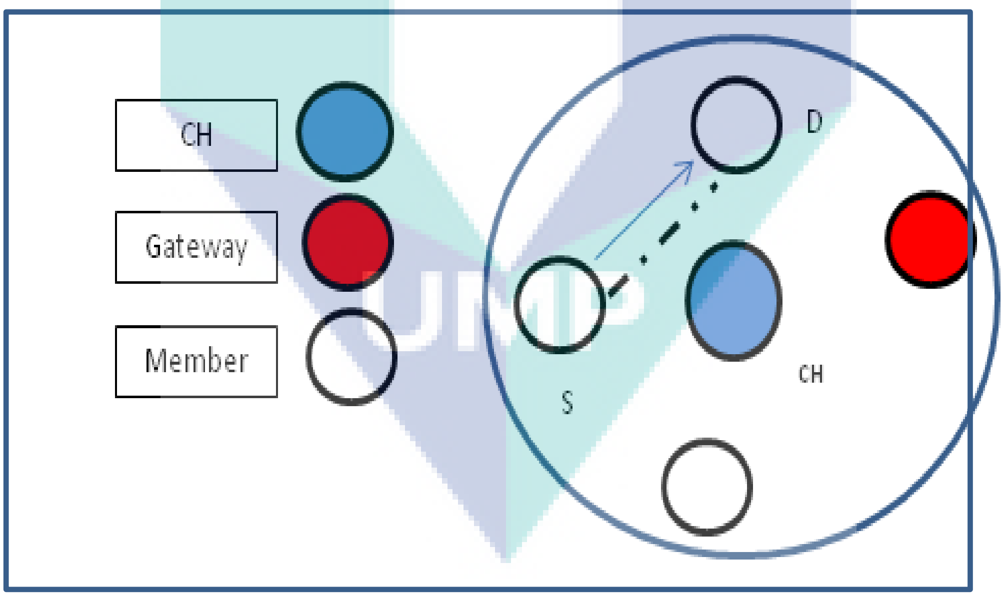


Figure 4.8: The intra clustering routing if the destination information is available in the sender neighbor table

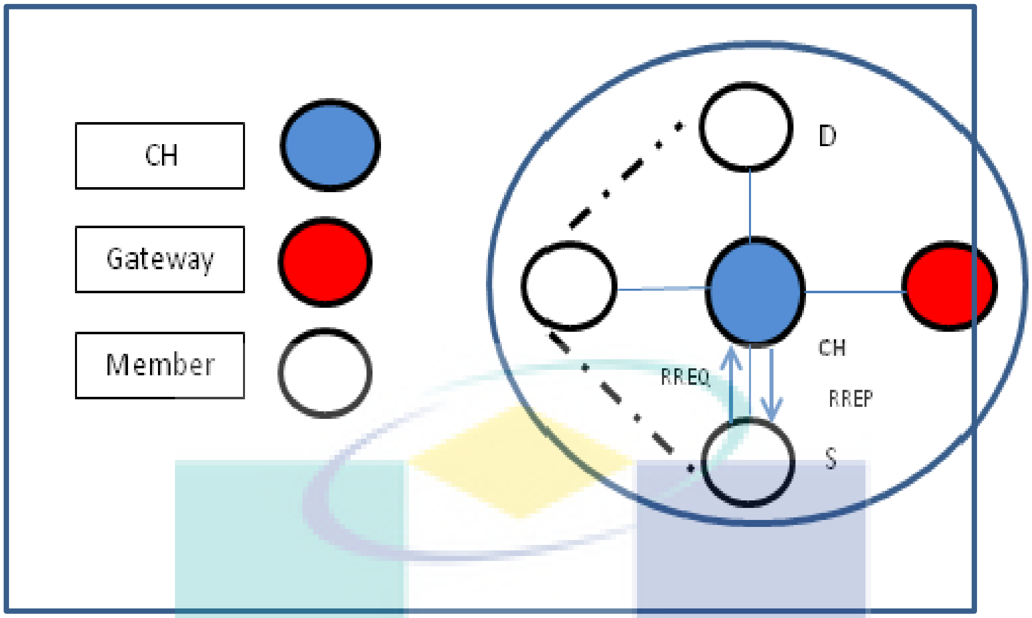


Figure 4.9: The intra clustering routing if the destination information is not available in the sender neighbor table

The selected route is characterized by the following properties:

3) The majority of the nodes in the selected route should be as stable as possible to limit link failure. This condition is achieved by calculating the movement of each node in the route using Eq.(4.6):

$$MOV=\frac{1}{(t2-t1)}\left(\left|\sqrt{(x2-x1)^2+(y2-y1)^2}\right|\right) \quad (4.6)$$

where

- (x1, y1) are the coordinates of node 1 at time t1
- (x2, y2) are the coordinates of node 2 at time t2

2) The selected route must contain the nodes that are at an average distance from the sender to the receiver, which is calculated using Eq. (4.7):

$$Average\ D=\left(\left|\sqrt{(x2-x1)^2(y2-y1)^2}\right|\right)\ N \quad / \quad (4.7)$$

where

- (x1, y1) are the coordinates of node1

-(x2, y2) are the coordinates of node2

- N is the number of nodes

3) CH will calculate the route cost of the route using Eq. (4.8) as follows:

$$\text{Route cost} = a*MOV + b * \text{Average D} \tag{4.8}$$

where:

- a & b are the coefficients with a sum equal to one

As shown in Table 4.5, when the CH finds a route with less scale, it sends a Route-Replay to the sender node that consists of current CH ID, ID of the sender, the sequence of the route (specific nodes), destination ID (ID of destination), and the flags that contain the packet type:

Table 4.5: Intra route replay to the CH

Packet type (Route- Replay)	**Flags**
CH ID	Specify the CH ID of the sender
Source ID	Specify the sender node ID
Route sequence	Contains the sequence of the route
Destination CH ID	Specify the CH ID of the receiver
Destination ID	Specify the receiver node ID

The network topology shown in Figure 4.10 is used to explain the proposed intra algorithm. The network consists of 7 nodes. The big circles and small circles are used to represent the cluster and nodes, respectively. Each discontinuous colored arrow represents an independent route.

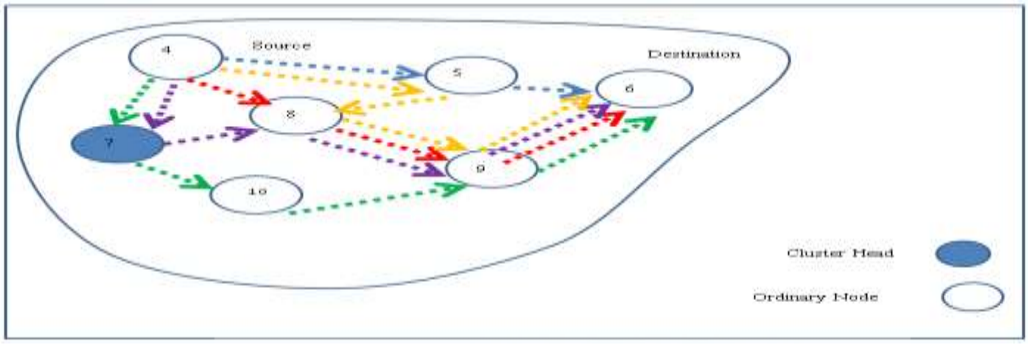


Figure 4.10: ECRP intra routing scenario

Assume that Node 4 needs to send data to Node 6 that is located in the same cluster. Node 7 is the CH of the cluster, so Node 4 will check its neighbor table. Since the destination node, Node 6 is not available in the neighbor table and is not available in the cache routes, it sends route request to Node 7. The Route-request table is as shown in Table 4.6 and consists of the following fields:

Table 4.6: ECRP intra Route-request before scale calculation

Packet type (Route- Request)	**Flags**
CH ID	7
Source	4
Destination CH ID	7
Destination ID	6

Node 7 will calculate the route cost of each available route to the destination and select the lowest cost route to send back to the sender so that the route sequence (4, 8, 9, 6) will be selected as the best route to send data from Node 4 to Node 6.

As shown in Table 4.7, if the movement of nodes (4,5,6,7,8,9,10) = (15,10,15,10,5,13,3) m/sec, and the average distance between each node with its neighbor nodes =(10,20,10,10,5,2,30) :

- The route cost for (4,5,6) route will be=(0.5* 15+0.5*10)+(0.5*10+ 0.5*20)+(0.5*15+0.5*10)=40
- The route cost for (4,8,9,6) route will be=(0.5*15+0.5*10)+(0.5*5+ 0.5*5)+(0.5* 13+ 0.5*2) + (0.5*15+0.5*10)=39

- The route cost for (4,7,10,9,6) route will be=(0.5*15+0.5*10)+(0.5*10+ 0.5*10)+ (0.5*3+0.5*30) + (0.5* 13+ 0.5*2) + (0.5*15+0.5*10)=59
- The route cost for (4,7,8,9,6) route will be=(0.5*15+0.5*10)+(0.5*10+ 0.5*10)+ +(0.5*5+ 0.5*5)+(0.5* 13+ 0.5*2)+ (0.5*15+0.5*10)=47.5
- The route cost for (4,7,8,9,6) route will be=(0.5*15+0.5*10)+(0.5*10+ 0.5*10)+)+(0.5*5+ 0.5*5)+(0.5* 13+ 0.5*2)+ (0.5*15+0.5*10)=47.5
- The route cost for (4,5,8,9,6) route will be=(0.5*15+0.5*10)+(0.5*10+ 0.5*20)+ +(0.5*5+ 0.5*5)+(0.5* 13+ 0.5*2)+ (0.5*15+0.5*10)=52.5

Table 4.7: ECRP Route scale calculation

Source ID	Destination ID	Route sequence	Route state	Route cost
4	6	4,5,6	Valid	40
4	6	4,8,9,6	Valid	39
4	6	4,7,10,9,6	Valid	59
4	6	4,7,8,9,6	Valid	47.5
4	6	4,5,8,9,6	Valid	52.5

As shown in Table 4.8 ,CH will send the following Route-Replay to Node 4 :

Table 4.8: ECRP intra Route-replay after scale calculation

Packet type (Route- Replay)	Flags
CH ID	7
Source ID	4
Route sequence ID	4. 8. 9. 6
Destination CH ID	7
Destination ID	6

Node 4 will use the route with the lowest cost to send its data to the destination, Node 6, with the route sequence 4, 8, 9, 6 because the cost for this route is the lowest and is equal to 39 . The full description of this algorithm is shown in algorithm 4.3 and Figure 4.11.

(1) Begin {

(2) Each node will check the neighbor table

(3) If the destination node is available in neighbor table

(4)Send the data directly to the destination node

(5)Else

(6) {Send RREQ to cluster head to find the suitable route

(7) Custer head will calculate the value of each route using Eq. 4.8

(8) If (the selected route has the minimum cost)

(9)This route will be used to send data

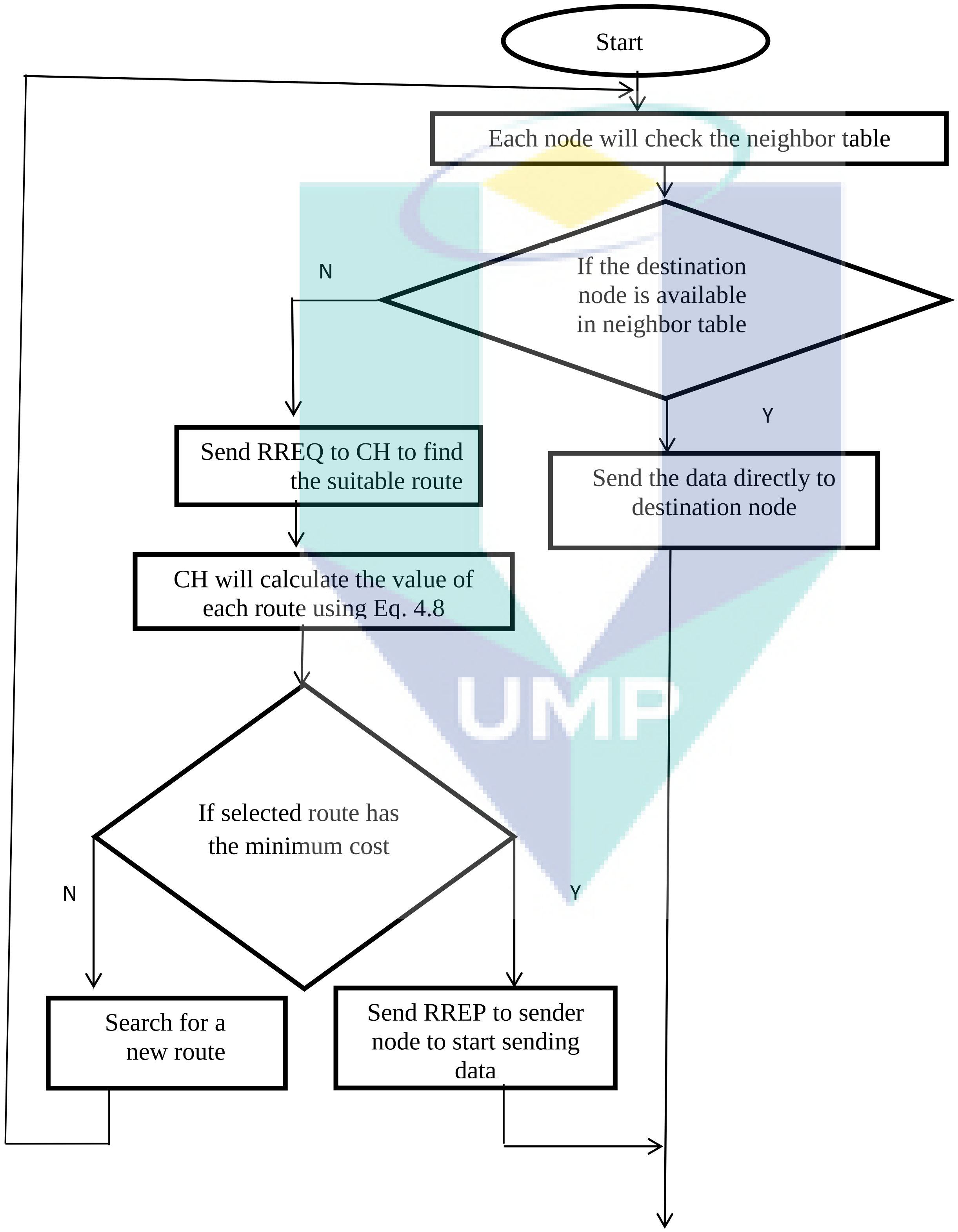
(10) CH Send RREP to sender node to start in sending data

(11) Else

(12) Searching for the new route}

(13)End

Algorithm 4.3: The procedures Intra cluster routing discovery



Start
Each node will check the neighbor table
If the destination node is available in neighbor table
N
Y
Send RREQ to CH to find the suitable route
Send the data directly to destination node
CH will calculate the value of each route using Eq. 4.8
If selected route has the minimum cost
N
Y
Search for a new route
Send RREP to sender node to start sending data

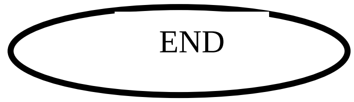


Figure 4.11: Intra cluster routing discovery algorithm

4.5.2 ECRP Inter cluster routing discovery

If any cluster intends to send data to other clusters, it must send a RREQ to the CH. The CH checks the cluster adjusting table and then sends this request to the gateway node in its cluster to connect to other clusters. The RREP is derived from the receiver node and it contains the CH for the sender, the CH for the receiver, and the location of the receiver node, which is determined by GPS. If another gateway is available for the route, it is mentioned in the response. The proposed algorithm (as presented in Figure 4.12 and Figure 4.13) generates two scenarios: In the first scenario (as shown in Figure 4.12), the CH forwards the RREQ sent by the sender node to its gateway, which then forwards the RREQ to the gateway of the second cluster. Finally, the RREQ is sent to the destination node, which on receipt of this request sends a RREP to the sender. This RREP contains information regarding its location. In summary, the sender sends the data to the gateway of its cluster. The gateway of this first cluster then forwards the data to the gateway of the second cluster. Finally, the data is sent to the specific destination node according to its GPS location information.

The second scenario (as shown in Figure 4.13) occurs if the gateway of the second cluster cannot deliver the data to the destination node because the receiver node is within the cluster but is out of range. The gateway of the second cluster will send the RREQ to its CH, and the CH applies the aforementioned intra cluster procedure to select a suitable route for sending data to the destination node. If destination node is within the same cluster area, this process minimizes the number of errors and shortens the time. Algorithm 4.4 and Figure 4.15 show a full description for all cases of the inter cluster routing algorithm.

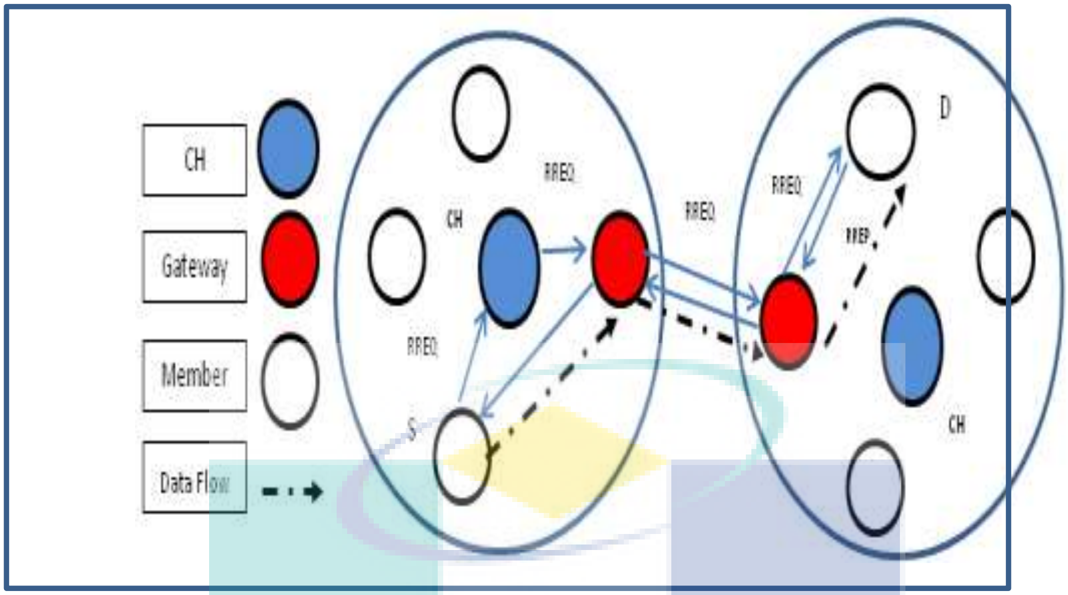


Figure 4.12: First scenario of the inter cluster discovery algorithm

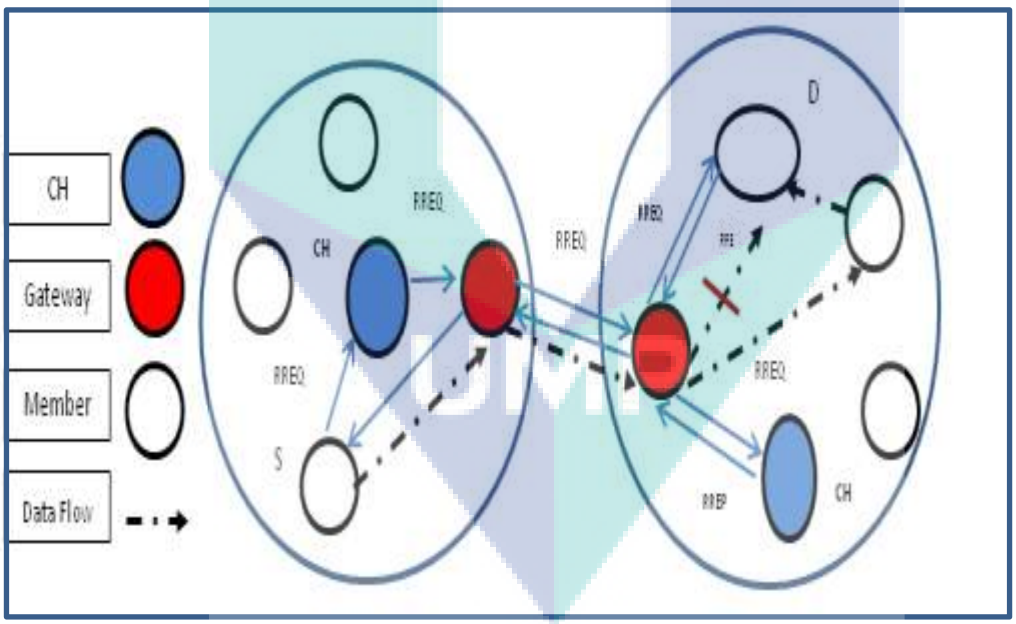


Figure 4.13: Second scenario of the inter cluster discovery algorithm

To explain the proposed intra algorithm, consider the network topology shown in Figure 4.14. The network consists of 12 nodes. The big circles and small circles are used to represent the cluster and nodes, respectively. Each discontinuous colored arrow represents a route request, and the continuous arrows represents the traveling data.

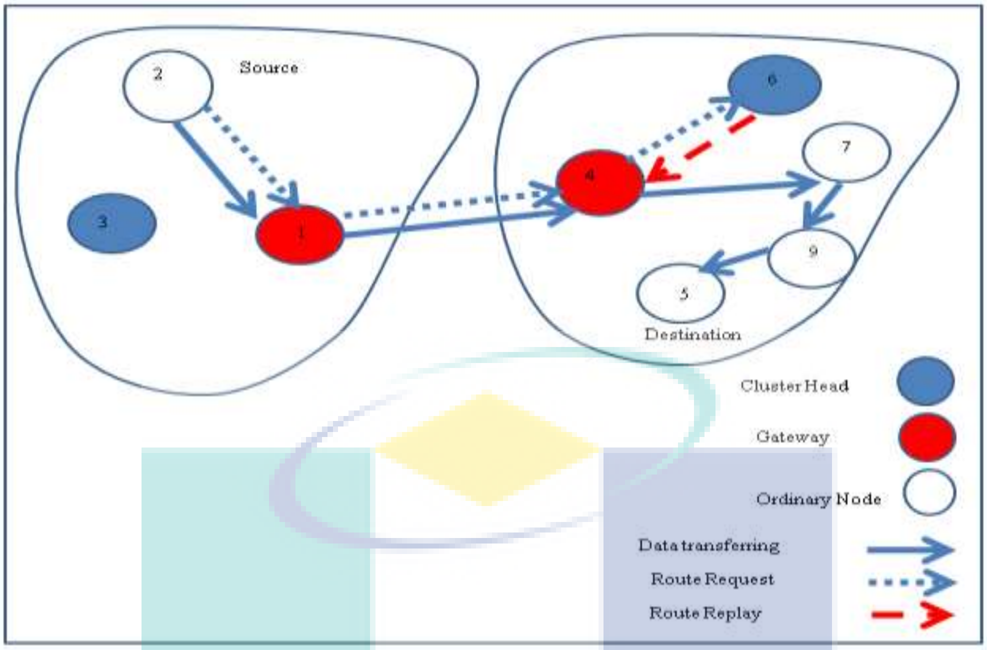


Figure 4.14: ECRP inter routing algorithm scenario

Assume that Node 2 needs to send data to Node 5 and both of them are located in two different clusters. Node 3 and Node 1 are the CH and the Gateway of the cluster 1 respectively. Node 6 and Node 4 are the CH and the Gateway of cluster 2 respectively. Node 2 will send the Route Request to its CH (Node 3), as shown in Table 4.9 :

Table 4.9: Inter Route Request

Packet type (Route- Request)	**Flags**
CH ID	3
Source ID	2
Route sequence	-
Destination CH ID	6
Destination ID	5

Since the destination node (Node 5) is not available in its cluster, this request will be sent to Node 4 (Gateway of cluster 2) and the last node will check the nodes available in its transmission range. If it does not find Node 5 in its transmission range, it will forward the request to Node 6 (CH of Cluster (2)). The CH will select the appropriate route according to its scale and sent a route replay to the gateway to send the data so that the final result is that Node 2 will send data to Node 1 (Gateway of cluster 1). Then the last node will send data to Node 4 (Gateway of cluster 2) and, after receiving the appropriate route from the CH, Node 4 will send the data to Node 5 as shown in Table 4.10 :

Table 4.10: Inter Route Replay

Packet type (Route- Reply)	**Flags**
CH ID	6
Source ID	4
Route sequence	4,7,9,5
Destination CH ID	6
Destination ID	5

The full description of this algorithm is shown in algorithm 4.4 and Figure 4.15. The validation of this algorithm is shown in Chapter 5, Section 5.8 .

(10) Begin {Sender node sends RREQ to the CH in the same cluster
(11) The CH will forward this RREQ to its gateway, then the gateway will forward RREQ to the gateway of the second cluster, then the last node will send RREQ to the destination node.
(12) If the destination node is available in gateway transmission range
(13) sender will send data to gateway1, then gateway 2 will send it to destination node
(14) Else
(15) The gateway 2 will send another RREQ to its CH and CH will use the intra cluster route algorithm to calculate the suitable route
(16) If the CH finds the suitable route
(17) Gateway 2 sends data using the determined route to the destination node
(18) Else
(11)Gateway 2 will send another route request} End

Algorithm 4.4: The procedure of the inter cluster discovery algorithm

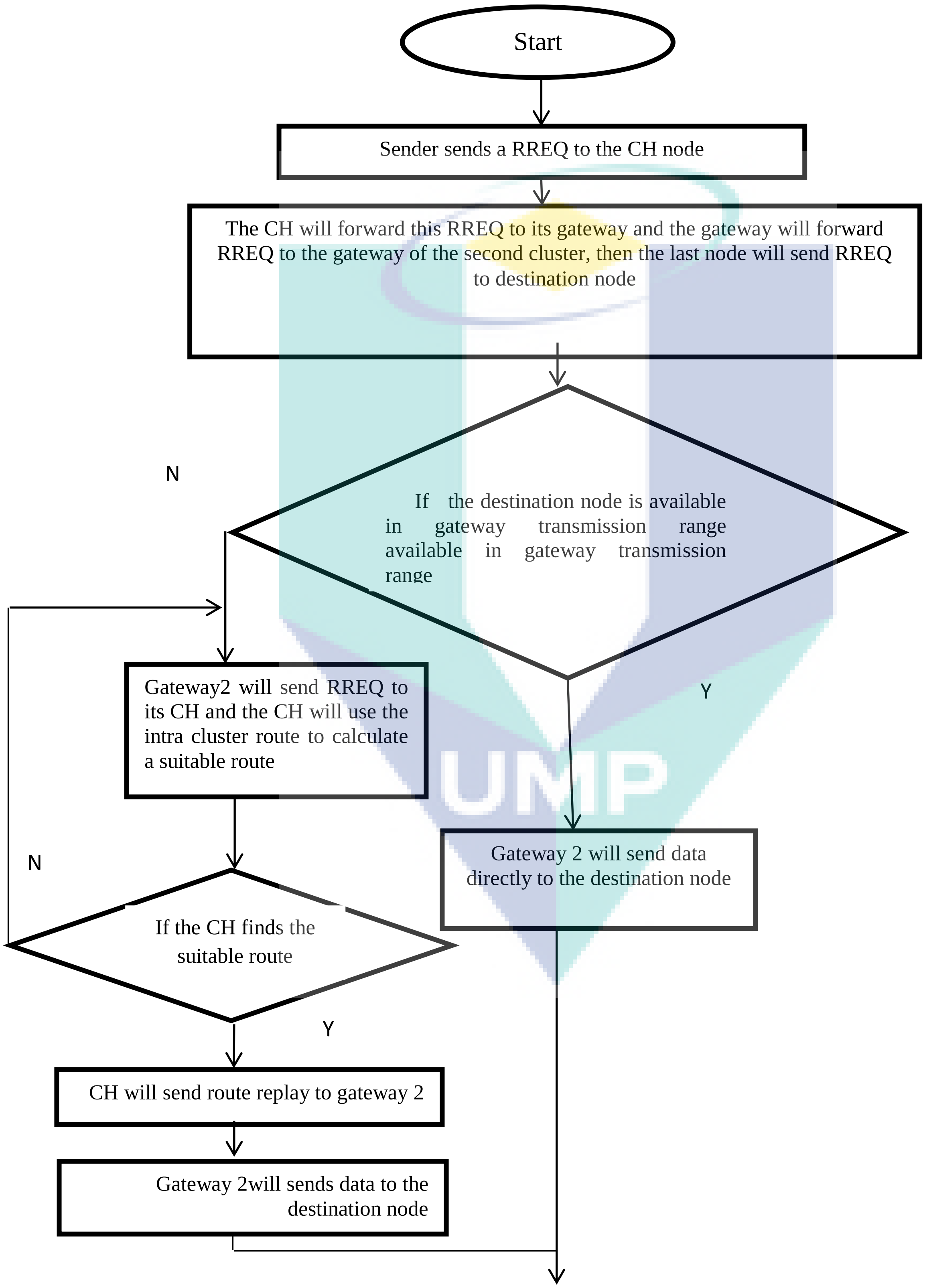

Start
Sender sends a RREQ to the CH node
The CH will forward this RREQ to its gateway and the gateway will forward RREQ to the gateway of the second cluster, then the last node will send RREQ to destination node
If the destination node is available in gateway transmission range available in gateway transmission range
N
Y
Gateway2 will send RREQ to its CH and the CH will use the intra cluster route to calculate a suitable route
Gateway 2 will send data directly to the destination node
N
If the CH finds the suitable route
Y
CH will send route replay to gateway 2
Gateway 2will sends data to the destination node

Figure 4.15: The ECRP inter cluster discovery algorithm

4.6 PERFORMANCE METRICS

For the purpose of comparing the proposed routing protocols performance with other routing protocols in for effectiveness, various parameter metrics were utilized. Cluster protocol evaluation involves comparisons with various MANET routing protocols.

This study used five performance metrics: throughput, Packet Delivery Ratio (PDR), average end-to-end delay, the number of dropped packets, and the normalized control overhead for protocols evaluation. These parameters were selected for their significance in evaluating any data communication network. All protocols need to be evaluated against these metrics to monitor their performance. Throughput demonstrates the success of a protocol's deliveries for a particular time and therefore the larger the throughput the better the protocol performs. . A high PDR indicates a highly successful packet delivery rate, which shows how efficient the proposed routing protocol is. Delay represents the minimum time for packets delivery. When few packets are dropped it is an indication of a very efficient routing protocol and less overhead proves that the proposed routing protocol has the ability to enhance the quality without reducing network bandwidth. The following metrics are employed to perform the evaluation:

i) Throughput: is calculated by dividing the total amount of data delivered to the destination node by the time spent in receiving the final packet. A high throughput value indicates better performance for a given routing protocol. Eq. 4.9 is employed to achieve this parameter:

$$\text{Average throughput} = \frac{\sum Total\ NumberRecived\ Data * PS}{T} \qquad (4.9)$$

where:

PS is packet size.-

-T is the receipt time of the final packets in the destination node.

ii) PDR: is the ratio of received packets to sent packets in a network. PDR is computed by dividing the number of successfully delivered packets by the number of packets dispatched by the sender node. Multiplying this number by 100 provides the percentage. This parameter is a reflection of the successful sending of data employing the routing protocol (Aggarwal et al., 2011), and it is obtained Eq. 4.10:

$$\text{PDR} = \frac{\sum \text{Number of received packets}}{\sum \text{Number of sent packets}} \qquad (4.10)$$

iii)End-to-end delay: is the average delay time incurred in transferring data from sender node to destination node. A minimal end-to-end delay indicates the routing protocol's satisfactory performance. This parameter is calculated by dividing the sum of the differences between the sending and receiving processes of the same packet by the total number of delivered packets. This metric can be computed with Eq. 4.11

$$\text{End-to-end delay} = d_{t+} d_{p+} d_{m+} d_q \qquad (4.11)$$

where:

- d_t is the transmission delay (time needed to keep and forward packets and which is equal to packet length (bit)/ bandwidth (bps)).

- d_{pr} is the propagation delay (that reflects the delay of the wireless channel propagation and which is equal to length of the wireless link/speed of propagation .

- d_m is the process delay (the time needed to find the suitable link before transmission).

- d_q is the queue delay (waiting time in the queue based on the congestion of the channel) (Jiao et al., 2014).

iv) Number of dropped packets: On reaching a network layer a packet is sent to the destination node if the route has been correctly identified, but if not, the packet is buffered while the correct route to the destination node is identified. However, if the buffer is full, then the packet is dropped.

v)Normalized Control Overhead: This is arrived at by dividing the total number of packets transmitted under protocol control by the total number of delivered data packets with respect to time (Surayati et al., 2009), as shown in Eq. 4.12 :

$$NCO= \frac{\sum \text{Number of control packets}}{\sum \text{Number of delivered packets}} \tag{4.12}$$

4.7 VALIDATION AND VERIFICATION OF THE PROPOSED ALGORITHM

4.7.1 proposed Algorithms Validation

The verification and validation of the proposed algorithm and its models are implemented in NS2 by comparing the results of the proposed algorithm with other cluster-based algorithm results obtained from NS2 simulation. Verification of the proposed algorithm was done to ensure that it was programmed and implemented correctly without containing any errors. The proposed algorithm was run with simple scenarios in order to be easily analyzed and the simulation results could be compared with the analysis. Then these simple scenarios were made more complex to test the proposed algorithm.

In addition, consistency tests were carried out to ensure that the proposed algorithm generated comparable results for input parameters that had the same effects. Furthermore, a script code was developed to trace the proceedings which occurred during the running time, in order to check the implementation of the proposed algorithms. However, models for each one of the proposed algorithms had to be designed properly in the way that they could accurately implement the functionality of these algorithms.

A number of standard techniques were used for verification and validation of the models. One major validation technique compared the proposed algorithm output with the expected results, and checked the tracing of the event for the algorithm execution to ensure that it was implemented properly. Thus, the verification and validation of the proposed model were made by comparing the results to other algorithm results, which were obtained from actual simulation runs with more than 500 scenarios.

4.7.2 Scenario Validation of the proposed algorithms

To verify and validate the developed protocol, 500 scenarios were examined. In this respect, 5 metrics were tested, with each metric making 20 different experiments and various parameters. Scenario validation is one of the most important and essential tasks for any wireless network. The implementation scenarios were implemented and tested under a variety of parameters including speed and node density (number of nodes) and testing the variety of metrics, including throughput, packet delivery ratio, average end-to-end delay, number of packets dropped, and normalized routing load. Moreover, different mobile Ad hoc communications were used with correct initial placement of each device with appropriate mobility model where packets were generated and distributed in the network topology Area. Finally, the results of the above metrics were compared to the other related work algorithms results.

4.7.3 Formal Verification

Formal verification involves the approval or rejection of the correctness of intended algorithms underlying a system regarding a certain formal specification or property, employing formal mathematicl approaches, Formal verification can be beneficial in verifying the correctness of systems like: routing protocols, combinational circuits, digital circuits with internal memory, and software expressed as source code. This means that the formal verification can easily confirm whether the output of the model gives expected results or not. The formal verification of any system can be provided by: making a theorem proving an abstract mathematical model of the system, checking the proposed model and testing it to see if it satisfies the expected output or not, or by making an equivalence checking with a comparison between two different systems and models (Seligman et al., 2015). However, the proposed model verification and validation were applied by theorem proving method. Thus, the mathematical equations that are presented throughout Chapter 4 can be used as verification and validation for model implementation. In addition, proposed model validation also applied the equivalence checking method, where the result is compared to related works results, which can be considered as two different models.

4.8 SUMMARY

In this chapter, enhanced algorithms for clustering formation, maintenance, and routing for Ad hoc networks were proposed and used in ECRP routing protocol. The ECRP formation algorithm is used to calculate the scale of each node, and select the node with the highest scale to be the CH of the cluster. The ECRP maintenance algorithm depends on structure visualization to recover each error, and ECRP routing is categorized into intra and inter routing to send the packets from the sender to destination. The main objective of these algorithms is to enhance the stability of clusters and improve the quality of the routing process.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1 INTRODUCTION

This research aimed at improving Ad Hoc network performance by proposing cluster-based algorithms for cluster formation, maintenance and routing. This chapter summarizes the thesis, as follows: Section 6.1 introduces chapter. Section 6.2 presents the conclusions of the research, from applying the Enhanced Cluster-based Routing Protocol (ECRP). Section 6.3 presents the contributions of the research and Section 6.4 its limitations. Future work is suggested in Section 6.5.

6.2 SUMMARY OF THE RESEARCH

This research focused on the design of a cluster head-based protocol, with enhanced algorithms for all phases: formation and maintenance of clusters, and routing. The proposed algorithms are dependent on partitioning the topology of the network into several clusters according to several cluster-formation parameters. A pair of protocol agents was required, one maintaining the proactive routing within the cluster, and the other the inter-cluster routes. The design was simulated in three scenarios, and comparisons made with other cluster-based algorithms. The scenarios were used to analyze the impact of the various factors (e.g. node speeds and number of nodes) on how the clustering algorithm performs, regarding average throughput, ratio of packet delivery, end-to-end delay, total packets dropped and normalized control overheads. The concluding remarks follow.

DSDV is the most appropriate routing protocol for Ad Hoc networks; clusters are not required, since DSDV provides the maximal performance parameters at all speeds. It also shows the best throughput value regardless of any increase in the number of nodes. Its end-to-end delay is invariably minimal, regardless of the number of nodes. With DSDV, it is possible to enhance performance from 10 to 20%, which is considered significant with respect to routing protocol quality.

Strategically, however, clustering is ideal in increasing the performance of Ad Hoc networks, with its routing protocol showing optimal performance. For instance, when the DSDV, CBRP and LEACH routing protocols are compared, CBRP and LEACH outperform DSDV for quality, clearly indicating how important clustering is in making Ad Hoc networks more efficient. CBRP is the ultimate cluster-based routing protocol, outperforming others in average throughput, PDR, end-to-end delay, packets dropped, and normalized control overhead.

Shadowing propagation is regarded as the best wireless propagation model. It performs than the free space and Two Ray ground models by 13 to 1 %, as it can improve how MANET performs by increasing throughput values and PDR, shortening end-to-end delay, and reducing the rate of dropped packets and normalized control overhead.

The ECRP algorithms perform better with regard to average throughput compared to all other routing protocols, by as much as 100 Kbps. This is primarily due to the fact that in the formation algorithm, the calculated weights of each hop can be used to identify the high-quality nodes in the network and select one of them as the CH of the whole cluster, increasing the stability of the cluster. The highest throughput in maintenance is related to the minimum amount of re-clustering, given the highest number of stable nodes and cluster heads. The major cause of the elevated throughput value in routing algorithms is the utilization of GPS by the ECRP routing algorithms to establish the site of individual nodes, improving the precision of the sites and route discovery. This significantly simplifies the route maintenance operation that is required whenever a route fails.

ECRP algorithms provide the maximum PDR value, in comparison with the other routing protocols. PDR performance is enhanced by approximately 4% the suggested algorithms raise the total quantum of delivered packets relative to the quantum of transmitted packets. In ECRP formation, the node with least movement is selected to be the CH of that cluster, which increases the stability and increases the proportion of delivered packets. It also reduces the opportunity for CH failure, as indicated by the overall increased stability of the clusters. In ECRP routing, the route with the least distance and mobility in sending packets is selected, addressing the problem of congestion.

The end-to-end delay achieved for all instances of speeds and number of nodes in all ECRP algorithms is reduced in comparison with the others by more than about 110 msec. In the formation algorithm, the minimum value is produced because of its criteria in transition between CHs, which makes the cluster head re-affiliation as low as possible. Maintenance has a minimum end-to-end delay, using a special criterion that recovers every error, based on type, and is shown in the efficiently performing routing protocol. The low end-to-end values in ECRP routing algorithms result from strategic selection of the appropriate routes. In the case of a destination node being in the same cluster, there is direct transmission of the data, eliminating the need to transmit it to the CH of the cluster.

In the case of dropped packets, the ECRP algorithms reduce the rate by 5 to 15%. In cluster formation, the CH with a high storage capacity is selected. In the routing discovery strategy, the route is shortest to the destination, and this lowers the link failure ratio and limits the extent of buffer issues.

As noted in various situations, CRP algorithms reduce normalized control overheads by 10 to 30%. In comparison, all earlier algorithms experienced a greater control overhead during the cluster formation stage, resulting in their overall performance being degraded.

Finally, the routing protocol disseminates this overhead throughout the cluster phases, using routing discovery when the route is not available in the routing table or the destination is in another cluster, which decreases the routing overhead information.

6.3 CONTRIBUTIONS OF THE RESEARCH

v. Minimization of MANET frequent cluster head changes by design of a cluster network based on the ECRP formation algorithm.

vi. Adaptation of MANET topology changes through the development of a cluster construction scheme based on the ECRP maintenance algorithm.

vii. Improvement of MANET routing performance through development of the ECRP routing algorithm.

viii. Evaluation performance of the modal decomposition based on throughput, packet delivery ratio, end-to-end delay and number of dropped packets metrics in a simulation environment.

6.4 LIMITATIONS OF THE RESEARCH

Despite the careful selection of supporting methods and guidelines from other studies, some of their limitations have been carried over into this work. First, the findings of this research cannot be generalized to different topologies. Secondly, it cannot be applied with non-cluster head clustering algorithms. Finally, this research needs to be applied in the real environment in order to measure the performance of the Ad Hoc Network.

6.5 FUTURE WORK

The algorithms proposed in this research could be developed by future researchers, as summarized below.

- Other clustering routing algorithms could be utilized on the basis of non-CH algorithms, and comparisons could be carried out between the CH-based ECRP algorithm and new protocols with non-CH algorithms.

- A potential area of research could be the investigation and analysis of the suggested cluster's behaviour in congestion, in cluster head failures, and when the system itself fails.

- The feasibility of using dynamic cluster head selection, lowest ID, highest ID, etc. to improve the performance of routing protocols and to obtain a higher performance could be investigated.

- Selecting the cluster head weight parameters by an artificial intelligence algorithm, such as PSO (Practical Swarm Optimization) or fuzzy logic, which reduces the overhead and increases the throughput and packet delivery ratio, could be studied.

- The cluster security problems using the ECRP algorithms could also examined, and an appropriate way to solve them suggested.

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1- Khalaf O.I., Sulaiman N., 2015. Effect of node density and FEC packet size on video quality over heterogeneous networks. *International journal of scientific research and development*.(ISI *journal* /Thomson Reuters).

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2- Khalaf O.I., Sulaiman N., 2015. Effect of node density and FEC packet size on video quality over heterogeneous networks. International conference on science, technology and management (ICSTM 2015)

3- Sulaiman N., Khalaf O.I. , 2014.Effect of using different QoS parameters in performance of AODV, DSR, DSDV AND OLSR routing protocols in MANET. *International conference on advances in computing and information technology*.

AWARDS

1- **Gold Medal**: an enhanced routing procedure and error correction algorithm for improving video transmission over wireless network , **CITREX 2015**, university Malaysia Pahang, Malaysia, April 2015 .

2- **Silver Medal**: improving video calls quality for MANET. CITREX 2015, University Malaysia Pahang, Malaysia, April 2014