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Scalability and Quality of Service in Mobile Ad Hoc Networks

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A hundred times everyday I remind myself that my inner and outer life are based on the labors of other men, living and dead, and that I must exert myself in order to give in the same measure as I have received and am still receiving. Albert Einstein

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Declaration

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Abstract

The recent rapid growth of cities, the evolution of wireless/mobile technologies and diverse demanding applications, the world is becoming more and more urban. Today, wireless and mobile networks as well multimedia applications play an essential challenging role within urban environment and they are take a considerable attention to improve and render the urban environment increasingly sustainable and livable. The main purpose of wireless and mobile networks is to share the fresh updated information collected around the urban environment between the stakeholders and the citizen constantly. However, it is very difficult to achieve this task in a complex, distributed, large (billions of heterogeneous connected devices) and diverse innovative demanding applications and services in urban environment. It is noteworthy that these demanding applications and services require constructing a wireless network that satisfies the scalability and quality of service (QoS) in this environment. In this dissertation we addressed two main issues in mobile ad hoc networks, namely: scalability and QoS. The scalability is defined as the ability of network to deal with large number of nodes and big network size, while QoS refers to the capability of a network to provide better service to selected network traffic especially a multimedia applications such as video streaming application that need a certain level of QoS over mobile ad hoc networks. The contributions of the dissertation to the addressed problem can be summarized as below:

First presenting an extensive study and analyze of existing clustering approaches for mobile ad hoc networks that recently appeared in literature, which we classify as: Identifier Neighbor based clustering, Topology based, Mobility based, Energy based, and Weight

based. We also include clustering definition, review existing clustering approaches, evaluate their performance and cost, discuss their advantages, disadvantages, features and suggest a best clustering approach. In addition, presenting some interesting virtual backbone based schemes with their performance evaluation. Both cluster-based and virtual based schemes, called: topology management schemes.

Second proposing a new efficient weight based clustering algorithm, which take into consideration the metrics: trust, density, Mobility and energy to choose locally the optimal cluster heads during cluster formation phase. In the proposed scheme, each cluster is supervised by its cluster head in order to ensure an acceptable level of security. It aims to improve the usage of scarce resources such as bandwidth, maintaining stable clusters structure with a lowest number of clusters formed, decreasing the total overhead during cluster formation and maintenance, maximizing lifespan of mobile nodes in the network and reduces energy consumption.

Third introducing an efficient k-hop scalability and QoS topology management scheme for large scale Mobile Ad Hoc Networks which is suitable for demanding application in urban environment. Such scheme, meets the scalability needs of urban environment as well the QoS of demanding applications like multimedia applications, by constructing a two hierarchical topology level based on trade-off between the clustering and virtual backbone mechanisms. To achieve and supports network scalability when network size increases (thousands of nodes) and satisfy the QoS of demanding applications, we propose in the first level, an efficient weight based clustering approach which considers a trade-off between the clustering metrics such as trust, density, mobility and energy, and QoS requirements like available bandwidth and link quality. In the second level, we based on connected dominating set algorithm to build a virtual backbone.

ملخص

النمو السريع للمدن، وتطور التقنيات اللاسلكية \ الجوال والتطبيقات التي تتطلب نوعية الخدمة، جعلت العالم اكثر واكثر تطورا و تحضرا. اليوم، الشبكات اللاسلكية و المحمول و كذا تطبيقات الوسائط المتعددة تلعب دورا أساسيا ضمن البيئة الحضرية، واصبحت تأخذ اهتماما كبيرا لتحسين هذه البيئة و جعلها على نحو متزايد بيئة حضرية مستدامة وملائمة للعيش. والغرض الرئيسي من هاته الشبكات اللاسلكية والمتنقلة هو تبادل المعلومات الجديدة التي يتم جمعها باستمرار بين أصحاب المصلحة والمواطن في هذه البئات الحضارية . لكن، من الصعب جدا تحقيق هذه المهمة في بيئة معقدة،نظام موزغ عشوائيا، والتي تحتوي على عدد كبير من الاجهزة غير متجانسة المتصلة، كذالك ظهور التطبيقات الذكية والخدمات المبتكرة في البيئة الحضرية . هذه التطبيقات والخدمات تتطلب بناء شبكة اللاسلكية التي تلبي قابلية التوسع -التدرجية- وجودة الخدمة (QoS) في هذه البيئات. في هذه الأطروحة عالجنا قضيتين رئيسيتين في شبكات اللاسلكية ، وهما: التدرجية (Scalability) وجودة الخدمة . التدرجية هي قدرة الشبكة على التعامل مع عدد كبير من العقد وحجم شبكة كبيرة يعني القدرة على النمو مع تزايد الاحتياجات، في حين جودة الخدمة هي قدرة شبكة على توفير خدمة أفضل لشبكة المرور وخاصة تطبيقات الوسائط المتعددة مثل تطبيق الفيديو التي تحتاج إلى مستوى معين من جودة الخدمة في الشبكات اللاسلكية. ويمكن إيجاز مساهمات أطروحة لمعالجة هاتين المشكلتين على النحو التالي:

اولا عمل دراسة شاملة على خوارزميات التجميع (Clustering) و virtual backbone في شبكات MANET التي ظهرت مؤخرا في الأدب (الاعمال الاخيرة).

ثانيا اقتراح خوارزمية جديدة فعالة على أساس المجموعات، التي تأخذ بعين الاعتبار المعايير: الثقة ، والكثافة ، والتنقل والطاقة لختيار رؤساء المجموعات الأمثل .

ثالثا اقتراح خوارزمية جديدة لإدارة طوبولوجيا لمعالجة مشاكل التدرجية وجودة الخدمة في شبكات اللاسلكية الكبيرة Large scale MANET.

Rèsumè

La croissance rapide des villes, l'èvolution des technologies sans fil / mobiles et les applications exigeantes, le monde devient de plus en plus urbain. Aujourd'hui, les rèseaux sans fil et mobiles ainsi des applications multimdias jouent un rôle stimulant essentiel au sein de l'environnement urbain et ils sont prendre une attention considèrable pour amèliorer et à rendre l'environnement urbain plus durable et vivable. Le but principal des rèseaux sans fil et mobiles est de partager en permanence les nouvelles informations recueillies autour de l'environnement urbain entre les parties prenantes et les citoyens. Cependant, il est très difficile de rèaliser cette tâche dans un system complexe, distribuè, de grande taille (des milliards de dispositifs hètèrogènes connectès) et diverses applications exigeantes innovants en milieu urbain. Il est noter que ces applications exigeants nècessitent la construction d'un rèseau sans fil qui rèpond l'èvolutivitè (scalability) et la qualitè de service (QoS) dans cet environnement. Dans cette thèse nous avons traitè deux principaux problèmes dans les rèseaux mobiles ad hoc, à savoir: èvolutivitè et la qualitè de service. L'èvolutivitè est dèfinie comme la capacitè du rèseau traiter un grand nombre de noeuds qui sont dèployès dans un grande taille du rèseau, et la qualitè de service se rèfère à la capacitè d'un rèseau pour offrir un certain niveau de QoS (bande passante èlevèe) pour les application exigeants, tel que: les application multimedia (video streaming). Les contributions de la thèse au problème traitè peuvent être rèsumèes comme suit:

Premier Un ètat-of-the-art approfondie sur les algorithmes de regroupement (clustering) et virtual backbone dans les rèseaux MANET qui a rècemment paru dans la littèrature.

Deuxième Proposer un nouvel algorithme efficace sur la base de clustering, qui prennent en considèration les paramètres: la confiance (T), la densitè (D), la mobilitè (M) et de l'ènergie (E) pour choisir localement les cluster heads optimales.

Troisième Proposer un nouvel algorithme de gestion de la topologie pour traite les problemes de lèvolutivitè et QoS dans les rèseaux MANET grande èchelle.

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Chapter 1

Introduction

1.1 Context and Problem Statement

In wired networks, the computers are connected by cables and characterized by their powers in terms of processing capacity and storage. In addition, such networks provide a stable bandwidth, good quality with high performance. In the early 90s, the consequent changes made in wireless networks has grown the interest of mobile computing. This last provides a flexible communication between mobile users and allows them to access to all available services independently than physical location and user mobility.

Wireless networks most commonly deployed today are based on fixed infrastructure, where the mobile user moves, and connect to each other through a fixed infrastructure. This type of networks known as "cellular networks". Furthermore, the connectivity between different mobile users are organized and centralized.

Nowadays, communicating mobile devices such as smart-phones, netbooks and tablets are expected to be mobile and be able to access the Internet services via high-speed communication links. These devices has a set of communication interfaces like 2G/3G cellular network, WIFI (e/b/g/n) and/or Bluetooth. Whatever the network interface is, the communications is managed by a infrastructure-based network (e.g Base station in Cellular network or AP in WIFI). Such communication scheme, generally ensures a high QoS whatever the type of applications (e.g. video streaming, web browsing..etc) with high performance (low end to end delay, high speed...).

However, infrastructure-based networks shows their limits in the mobile nature of current communications. Over the last 20 years, another class of communication, namely infrastructure-less wireless network known as Mobile Ad Hoc NETworks (MANETs)" has been extensively studied and which is a multi-hop self-structuring wireless networks. In such class, a set of mobile nodes can move and communicating wirelessly without the support of any centralized infrastructure. Each node in MANETs is free to move independently in any direction and will therefore change its links (wireless link) to other nodes frequently. So, nodes may join and leave the network at any time.

From a theoretical efficiency point of view, MANETs are more suitable to deal with today's ever changing network topologies. Indeed, as we know a mobile user keep moving through the time, this mobility changes in the localization of the network density and also the load distribution. As an example, let us consider a mall center, which are a very dense place during the weekends and a less number at night. In infrastructure-based network, the mall should be have a high number of centralized infrastructures to deal with big communications during weekends. At night however, these centralized infrastructures are nearly useless. But, in MANETs, does not require any centralized infrastructure and/or additional system to mange communications, where the topology is created by the mobile users them-self and it disappears if it is not useful anymore.

From amore practical point of view, MANETs is the optimal solution in term of cost and especially when infrastructure-based network are too costly, discredited and/or not suitable. Mobile users are frequently moved which always require a big network coverage areas. Using a fixed cell towers to extend the coverage area is very expensive, however, using MANETs is a good alternative to extend the actual covered area without any loss. In addition, MANETs can also be deployed as an substitute to replace a damaged infrastructure network in case of natural disaster. In summary, MANETs can be used in many fields like: military communications, smart cities, health-care and emergence applications ..etc due to its beneficial characteristics.

Despite these promising characteristics and high number of MANETs-based devices currently in use, MANETs is not widely used due to some technical limitations. Indeed, in last years, researchers in this area have been focused on solving problems related to energy efficiency, topology organization and/or security issues that arise in such distributed environments.

Due to the emergence of demanding applications and services like multimedia services, network topology management with QoS, resource management and data routing, have become a hot research topics in MANETs that have attracted a lot of interest. However, it is very difficult to guarantee an efficient network topology management with QoS requirements of multimedia services in large scale MANETs (e.g. urban environments). This is due to the complexity of the features of these networks, namely: network size, limited bandwidth, dynamic topology and limited power, unavailability of wireless links due to to the mobility of the nodes etc.

Structuring a network to achieve the scalability with QoS guarantee is an important task to simplify the data routing operation of multimedia services in large scale MANETs in urban environment. However, the topology changes unpredictably due to the nodes mobility. Also, maintaining the stability with low overhead in these kinds of networks is a challenging issue. In fact, the development of feasible schemes and protocols to manage large MANETs within urban environment is a very complex task.

Several topology management schemes have been proposed in MANETs. These schemes can be classified according to the network structure into two main categories: flat and hierarchical. Moreover, these schemes can be divided into QoS-based, multipath-based, query-based, etc. depending on the protocol main function and operation. In flat structure schemes, all network nodes have the same role. These nodes reach rapidly their limits when density and mobility of nodes increase. As a result, these solutions are inefficient to deploy large scale MANETs even though they are efficient for small network. The flat routing protocols show several limitations, when the number of nodes increases, such as: network overhead increase which leads to network saturation and the network becomes instable. Furthermore, the flat routing protocols do not take into account the QoS of demanding applications. For some applications such as multimedia services (e.g., video-conference, VoIP, Video on Demand, etc.), these routing schemes are not suitable especially if there is a need to guarantee certain requirements of quality of service It is important to adapt MANETs to support network with large number of nodes (scalability) and some acceptable level of QoS in order to efficiently deploy applications that are complex and require a lot of resources.

To overcome the limitations of flat routing protocols, the hierarchical structure has been proposed. Most of the hierarchical structure routing protocols are based on clustering schemes. Clustering is a well-known technique with special advantages related to scalability and efficient communication. The basic idea behind clustering consists in dividing the network mobile nodes into a set of clusters. Each cluster has a cluster head, ordinary nodes and gateways. The cluster head is responsible for coordinating the cluster activities. The election of the cluster heads may be based on one metric or combination of metrics such as: node ID, density, energy. A node is a candidate to be selected as gateway node if it can hear two or more cluster heads. The gateway node is used to relay the traffic among different clusters. To the best of our knowledge none of the proposed hierarchical routing structures support efficiently multimedia services in large scale MANETs (very large number of mobile nodes).

In this context, topology management with a high number of mobile nodes (scalability) and supporting QoS for multimedia applications issues are tackled in particular. Where, supporting scalability in large scale area e.g. urban environment as well satisfying the QoS requirements of demanding applications e.g. multimedia applications in large scale MANETs are the two main issues that are tackled in this thesis.

1.2 Motivation

MANETs is not relay on a specific device that play the role of coordinator or path messages from a source to a destination. In other word, no global coordinator which can organize the communications between network nodes. Hence, in MANETs the set of mobile nodes have to organize themselves in order to exchange data and avoid scalability issue that may occur when the size of network is growing. Clustering and virtual backbone approaches, are two main techniques that can help MANETs to support scalability and also ensure high QoS for demanding applications. The clustering approach aims to (1) divide the network into a set of clusters, (2) assign for each cluster a specific node called cluster head which is the manger of its subset (group of member nodes) and (3) communicate between clusters using getaway nodes. While, the virtual backbone approach select a subset of nodes from cluster heads and getaway nodes and/or communications channels and mimicking the infrastructure in the classical network paradigm. MANETs Clustering and virtual backbone however, are not deployed a specific dedicated devices but for regular network nodes which were selected to help relaying messages and avoid scalability and QoS issues.

This dissertation focuses on weight-based clustering approach to avoid scalability issues, while on dominating set based virtual backbones and their variants based on k-vertex-connectivity, m-vertex domination or l-level domination to ensure a high path quality (in term of QoS) between clusters for demanding applications, e.g. more specifically multimedia applications. We have chosen this Graph Theory formalism as it provides well defined notions that fits our requirements and can be adapted to various situations.

Many contributions based on the same notions have been proposed for the last twenty years. Some of them are theoretical work. As a consequence, applying them on real devices is not realistic as they do not scale well. Moreover, such clustering schemes are not scalable when the network size increases to a very large number, and also can not satisfy a certain level of QoS for demanding applications like video streaming applications. In other hands, these contributions can be classified according to the network structure into two main classes: flat and hierarchical schemes. Flat structure protocols ensure a good routing scheme for best effort traffic. In contrast, for demanding applications like multimedia application are not suitable due to their limits to guarantee certain requirements of quality of service as well as they do not scale well (a few dozens of nodes). To overcome the limitations of flat routing protocols, the hierarchical structure has been proposed. However, based on our knowledge none of the proposed hierarchical-based schemes support the scalability efficiently and satisfy the QoS requirements of multimedia services in large scale MANETs. In other hand, several topology management schemes have been proposed, focusing on different metrics such as: node-id, node degree, energy, mobility and weight etc. to address the scalability issue in MANETs without taking into consideration the applications kinds (e.g.

QoS for demanding applications) and network size.

Although these solutions are providing insightful results they can still be enhanced according to some different views. First, we want to avoid the scalability issue by enabling network to support more than five thousands of nodes (Urban Environment applications:IoT). Second, to ensure a high QoS for multimedia applications (e.g. video streaming). As a consequence, we decided to propose topology management hierarchical QoS-based schemes for multimedia services and applications in large scale MANETs. The proposed schemes are based on the clustering and virtual backbone approaches. In summary, the main purpose of our topology management schemes are to support multimedia applications QoS requirements in dense MANETs.

1.3 Contributions

The dissertation contains the following contributions:

- An extensive state-of-the-art on the topology management techniques which are devided into: cluster-based and virtual backbone based. In cluster-based schemes, we distinguished and classified such algorithms based on their objectives and the manner of cluster heads election as: Identifier Neighbor based clustering, Topology based clustering, Mobility based clustering, Energy based clustering, and Weight based clustering. In addition, state-of-the-art on the scalability and QoS issues in MANETs. In other hand, we classified virtual backbone schemes based on the manner to find the optimal VB nodes (*e.g* DS nodes) subset. Finally, we performed an detailed comparison between various schemes in both cluster-based and virtual backbone based.

- Proposed a new topology management scheme based on clustering mechanism to solve scalability issue.

- Proposed a new hierarchical topology structuring QoS-based scheme in large scale MANETs such as urban environments with its demanding multimedia applications as a case study.

1.4 Dissertation Outline

The render of the dissertation is organized as follows:

Chapter 2 describes what ad hoc networks are and their characteristics and various applications. Then describes the classifications of the most popular routing protocols and their characteristics. The modeling of such networks is introduced at the end of the chapter.

Chapter 3 provides a state-of-the-art on topology management techniques in mobile Ad hoc networks (MANETs), our classification, their design goals, advantages and disadvantages and metrics for evaluating the performance of presented schemes.

Chapter 4 presents our new efficient weight based clustering algorithm that take into consideration the metrics: trust (T), density (D), Mobility (M) and energy (E) to choose locally the optimal cluster heads during cluster formation phase. In our proposed topology management scheme each cluster is supervised by its cluster head in order to ensure an acceptable level of security. It aims to improve the usage of scarce resources such as bandwidth, maintaining stable clusters structure with a lowest number of clusters formed, decreasing the total overhead during cluster formation and maintenance, maximizing lifespan of mobile nodes in the network and reduces energy consumption. The simulation results of the proposed clustering scheme for large-scale MANET is introduced at the end of the chapter.

Chapter 5 introduces our efficient k-hop scalability and QoS topology management scheme for large scale Mobile Ad Hoc Networks which is suitable for demanding application in urban environment. Our proposed scheme meets the scalability needs of urban environment as well the QoS of demanding applications like multimedia applications, by constructing a two hierarchical topology level based on trade-off between the clustering and virtual backbone mechanisms. After, the results of experimental evaluation of the proposed scheme is presented.

Chapter 6 summarizes the dissertation by presenting conclusions of the work. Next, future work and perspectives of the work are outlined.

Chapter 2

Mobile Ad hoc Networks

Abstract This chapter introduces all the prerequisite notions and definitions concerning wireless networks, more specifically mobile ad hoc networks (MANETs). In section 2.1, some useful information about radio spectrum used wireless network communication are presented. Section 2.2, summarizes the three main communications modes that are used in MANETs, namely: unicast, multicast and broadcast. In section 2.3 proposes a classification of mobile network communication (Infrastructure-based VS Infrastructureless-based) and some insights are provided concerning the term ad hoc and what researchers mean when applying it to communication networks. A IEEE 802.11 standard and its derived standard is presented in a second part. The last part of the MANETs presentation summarizes the major characteristics of this class of networks and their associated limitations are detailed. After, section 2.4, presents a small survey on existing routing protocols in MANETs, and their classification as well. To conclude this chapter, the section 2.5 provides various aspects concerning mobile ad hoc networks modeling. In the first part, MANETs communication graph static and dynamic graphs modeling are presented. Then, Wireless channel characteristics are presented in the second part.

2.1 Radio transmission in wireless networking

The radio transmission used in the wireless communication is based on the principle that the acceleration of an electron creates an electromagnetic field which in turn accelerates other electrons and so on [87].

In wireless environments, interference happens when two signals of the same or very similar frequencies bump into each other. To avoid such interferences, the radio/frequency spectrum is divided into several sections, named frequency bands, where each part is dedicated to a specific use.The limited size of the frequency spectrum consequently requires grouping a set of users in bands. For example, the band 25 MHz to 890 MHz is reserved for television and the upper 890 MHz band for cellular and satellite transmission [87].

Different parts of the radio spectrum are allocated for different radio transmission technologies and applications 2.1. In some cases, parts of the radio spectrum is sold or licensed to operators of private radio transmission services (for example, cellular telephone operators or broadcast television stations). Ranges of allocated frequencies are often referred to by their provisioned use (for example, cellular spectrum or television spectrum) [76].

2.2 Communication modes in mobile networks

Wireless communication is the data transfer between two or more nodes that are not connected by an electrical conductor.

The most common wireless technologies use radio. With radio waves distances can be short, such as a few meters for television or as far as thousands or even millions of kilometers for deep-space radio communications. It encompasses various types of fixed, mobile, and portable applications, including two-way radios, cellular telephones, personal digital assistants (PDAs), and wireless networking. Other examples of applications of radio wireless technology include GPS units, garage door openers, wireless computer mice, keyboards and headsets, headphones, radio receivers, satellite television, broadcast television and cordless telephones. While, less common methods of achieving wireless communications include the use of other electromagnetic wireless technologies, such as light, magnetic, or

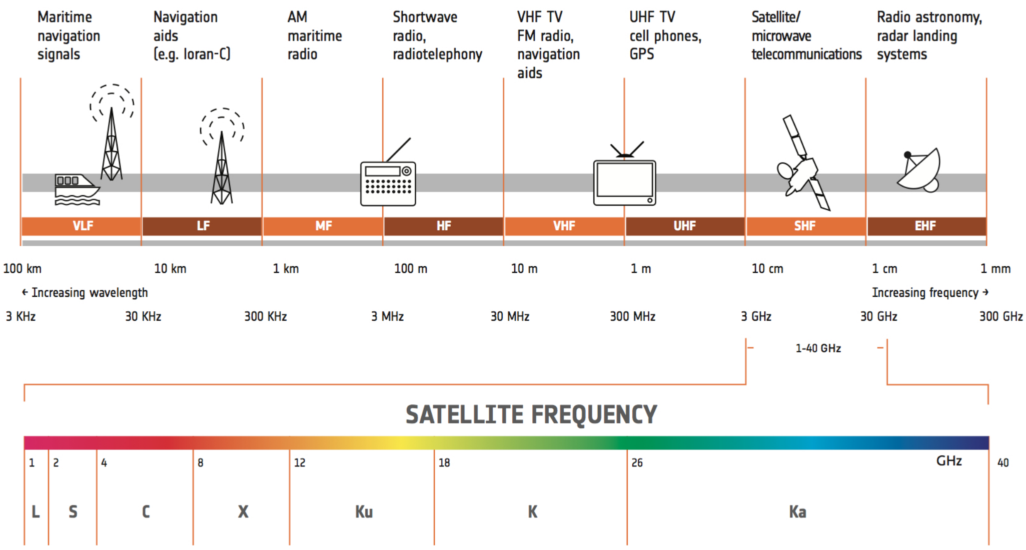


Figure 2.1: Radio Spectrum

electric fields or the use of sound [87].

Wireless networking is used to meet many requirements. Perhaps the most common use is to connect laptop users who travel from location to location. Another common use is for mobile networks that connect via satellite. Hence, the communication between mobile nodes in wireless networking consists of many modes, which are: point-to-point communication (Unicast), point-to-multipoint communication (Multicast), broadcasting.

2.3 Mobile networks categories

Today, the most usual type of wireless networks based on fixed infrastructure, typically consisting of several mobile nodes connected to each other through these infrastructures. This type of networks is called *cellular networks*. Consequently,

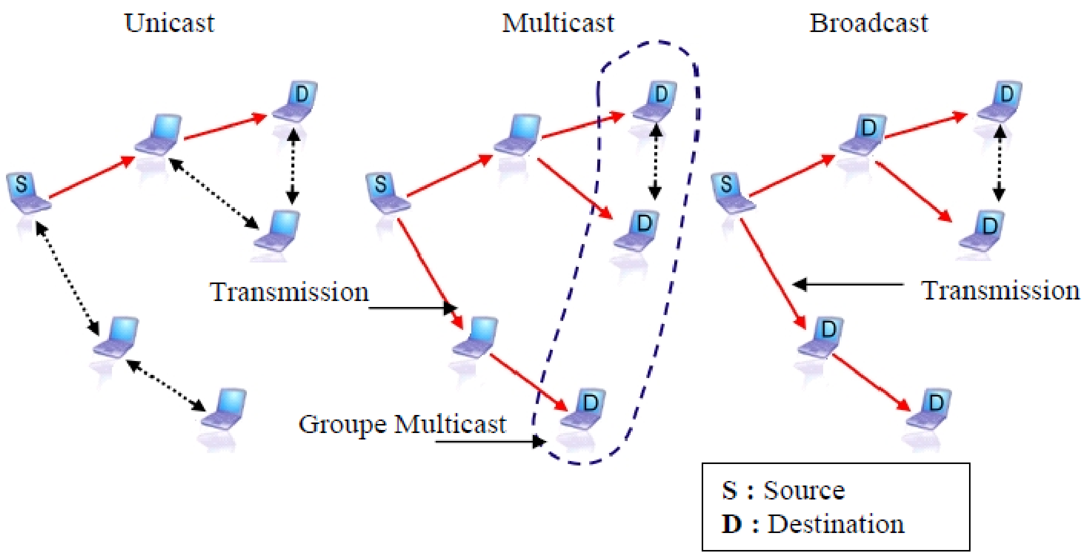


Figure 2.2: Mobile Communication Modes

connectivity between different network elements is centralized. On the other hand, *mobile ad hoc networks (MANETs)* are autonomous systems capable of self-organizing and self-configuring in multi-hop wireless networks without requiring any infrastructure support or centralized management for their operation. Each node in MANETs is free to move independently in any direction and will therefore change its links (wireless link) to other nodes frequently.

2.3.1 Infrastructure-based networks

A infrastructure-based networks or cellular network is a wireless communication network where the network is distributed over land areas called cells, each served by at least one fixed-location site, known as base station. This last provides the cell with the network coverage which can be used for transmission of voice, data and others. In a cellular network, each cell uses a different set of frequencies from neighboring cells, to avoid interference and provide guaranteed bandwidth within each cell [15].

Each cell is joined with neighbors cells which provide radio coverage over a wide geographic area. Such strategy enable a large number of mobile devices (e.g. mobile and smart-phones, pagers, etc.) to communicate via one or many fixed base stations with other mobile devices anywhere in the network.

Each base station defines a cell from which the mobile devices can transmit and receive data (e.g. voice, video and messages). While the set of base stations are interconnected through a wired communication network, generally reliable and high throughput. However, wireless connections between mobile devices have limited bandwidth that severely reduces the volume of information exchanged. In addition, a mobile device may be, at any given time, directly connected to only one base station. It can communicate with other sites around the station to which it is directly attached 2.3.

Cellular networks offer many features. First, more capacity than a single large transmitter, since the same frequency can be used for multiple links as long as they are in different cells. Second, Mobile devices use less power than with a single transmitter or satellite since the cell towers are closer. Finally, larger coverage area than a single terrestrial transmitter, since additional cell towers can be added indefinitely and are not limited by the horizon.

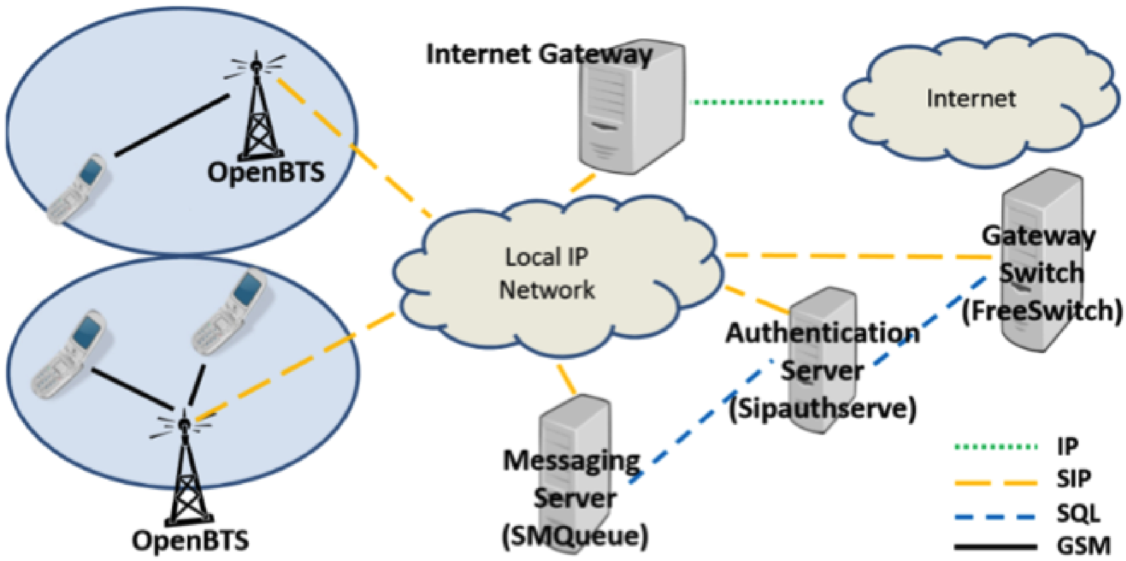


Figure 2.3: Architecture of Cellular Networks

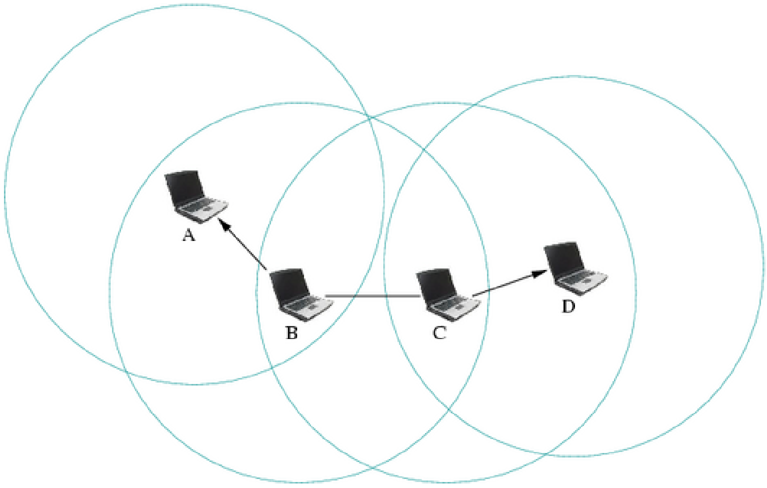


Figure 2.4: Mobile Ad hoc Networks (MANETs)

2.3.2 Mobile ad hoc networks

In infrastructure-less wireless networks known as Mobile Ad Hoc NETworks (MANETs), consisting of a set of autonomous mobile devices capable of self-organizing and self-configuring in multi-hop wireless networks 2.4, typically the set of mobile nodes communicate with each other to deliver data without the support of any network infrastructure (base station) or/and centralized management [60]. In MANETs, nodes move depending on the mobility model used and organize themselves arbitrarily. This means nodes may join and leave the network at any time 2.5. Due to the various benefits and the flexible characteristics, MANETs have gained great attention and has been utilized to model problems in various fields and application domains such smart cities, military communications, forest hazards, hostile environments, disaster management, health applications, and emergency services.

2.3.2.1 Definitions of mobile ad hoc networks

Before considering the technical aspects of ad hoc networking domain, let us start with some etymological definitions and background.

Definition 1 *(Cambridge Dictionary of American English)*
Ad Hoc for a particular purpose or need, especially for an immediate need

In the mid 16th century, the term ad hoc has been used in the Latin language, however nowadays is used by scientists to qualify a specific category of networks.

The most of wireless classical networks are characterized by a pre-existing infrastructure that coordinate and manage the communication between network devices. They are generally organized using hierarchical topology structures which are fixed through time (without any mobility of fixed stations). With the help of this centralized infrastructure, very distant devices can communicate without even knowing the exact path used for the transmissions. On the other hand, mobile ad hoc networks (MANETs) are autonomous systems capable of self-organizing and self-conguring in multi-hop wireless networks without requiring any infrastructure support or centralized management for their operation. Each node in MANETs is free to move independently in any direction and will therefore change its links (wireless link) to other nodes frequently. So, nodes may join and leave the network at any time.

Another definition of MANETs can be found in the IEEE 802.11 specification (Wi-Fi):

Definition 2 *(IEEE 802.11 specification)*
An ad hoc network is a network composed solely of stations within mutual communication range of each other via the wireless medium

This definition shows that a network can be modeled by a complete graph, where the vertices represents set of mobile devices, while edges are the links between these mobile devices. In which, all pairs of devices of the network can communicate with each other directly as they are in each other communication range. [85] in their definition add many additional characteristics of MANETs like multi-hop routing and dynamic nature of the network due to nodes mobility.

Definition 3 *(Stojmenovic et al)*
Wireless networks consist of static or mobile hosts (or nodes) that can communicate with each other over the wireless links without any static network interaction. Each mobile host has the capability to communicate directly with other mobile

hosts in its vicinity. They can also forward packets destined for other nodes.

Based on Stojmenovic definition, distant nodes (no direct communication between source and destination) communicate with each other using a intermediate node (relay nodes). These intermediate nodes are not dedicated to transmit data but are instead independent devices of the network and as such they may also be the source or the destination in another communication session.

Ensuring such mechanism of nodes cooperations requires that all nodes organize themselves. This organization defined by [36] as self-organization process.

Definition 4 *(Gerla et al)*
A mobile ad hoc network (mobile ad hoc network) is a collection of mobile nodes that dynamically self organize in a wireless network without using any pre-existing infrastructure.

Based on four previous definition by combining their major aspects, we can extract a general definition of Mobile Ad hoc Networks (MANETs).

Definition 5 *(General definition)*
An mobile ad hoc network 2.4 is a collection of interconnected wireless devices. Nodes can be mobile or static and they cannot rely on any pre-existing infrastructure to relay communication. As such, these networks are characterized by a self-organization process in order to support essential network services.

2.3.2.2 Wireless network standard

A. OSI model

OSI (Open Systems Interconnection) is reference model for how applications can communicate over a network. A reference model is a conceptual framework for understanding relationships. The purpose of the OSI reference model is to guide vendors and developers so the digital communication products and software programs they create will interoperate, and to facilitate clear comparisons among communications tools. Most vendors involved in telecommunications make an attempt to describe their products and services in relation to the OSI model. And although useful for guiding discussion and evaluation, OSI is rarely actually implemented, as few network products or standard tools keep all related functions

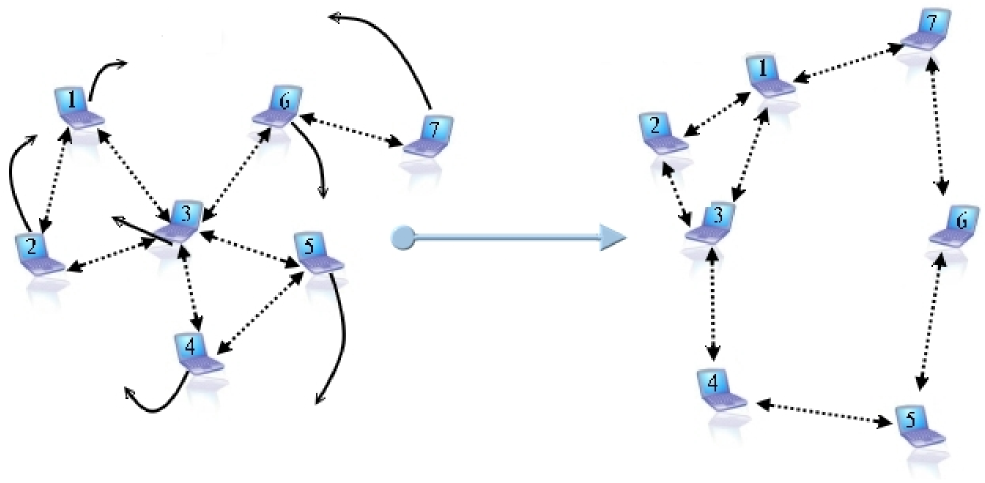


Figure 2.5: Dynamic Topology in Mobile Ad hoc Networks (MANETs)

together in well-defined layers as related to the model. The TCP/IP protocols, which define the Internet, do not map cleanly to the OSI model [70].

Developed by representatives of major computer and telecommunication companies beginning in 1983, OSI was originally intended to be a detailed specification of actual interfaces. Instead, the committee decided to establish a common reference model for which others could then develop detailed interfaces, which in turn could become standards. OSI was officially adopted as an international standard by the International Organization of Standards (ISO).

The OSI model takes the task of internetworking between devices and divides that up into what is referred to as a vertical stack that consists of seven layers.

1. *Physical layer*: This layer conveys the bit stream - electrical impulse, light or radio signal through the network at the electrical and mechanical level. It provides the hardware means of sending and receiving data on a carrier, including defining cables, cards and physical aspects. Fast Ethernet, RS232, and ATM are protocols with physical layer components.

2. *Data Link layer*: At this layer, data packets are encoded and decoded into bits. It furnishes transmission protocol knowledge and management and handles errors in the physical layer, flow control and frame synchronization. The data link layer is divided into two sub layers: The Media Access Control

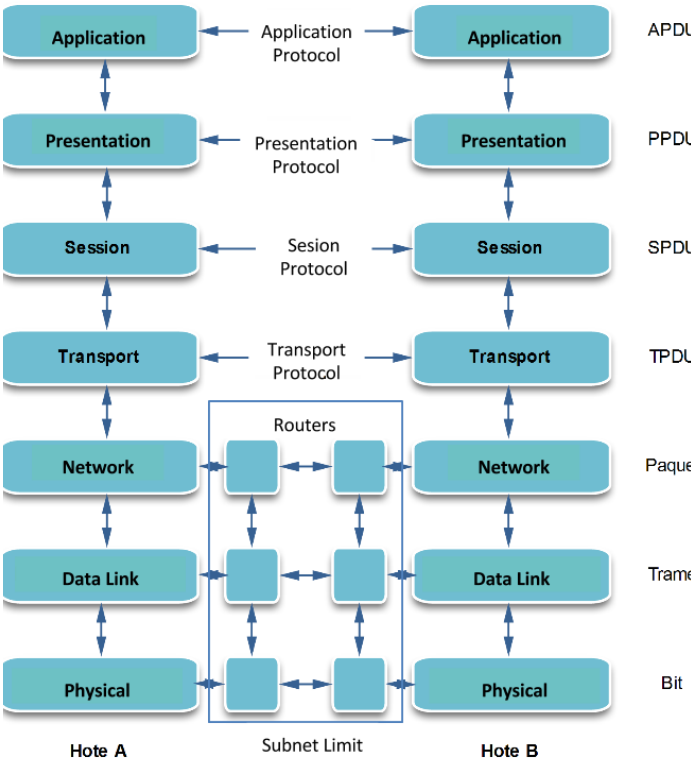


Figure 2.6: OSI Reference Model

(MAC) layer and the Logical Link Control (LLC) layer. The MAC sub layer controls how a computer on the network gains access to the data and permission to transmit it. The LLC layer controls frame synchronization, flow control and error checking.

3. *Network*: It provides switching and routing technologies, creating logical paths, known as virtual circuits, for transmitting data from node to node. Routing and forwarding are functions of this layer, as well as addressing, internetworking, error handling, congestion control and packet sequencing.

4. *Transport*: It provides transparent transfer of data between end systems, or hosts, and is responsible for end-to-end error recovery and flow control. It ensures complete data transfer.

5. *Session*: This layer establishes, manages and terminates connections be-

tween applications. The session layer sets up, coordinates, and terminates conversations, exchanges, and dialogues between the applications at each end. It deals with session and connection coordination.

6. *Presentation*: This layer provides independence from differences in data representation (e.g., encryption) by translating from application to network format, and vice versa. The presentation layer works to transform data into the form that the application layer can accept. This layer formats and encrypts data to be sent across a network, providing freedom from compatibility problems. It is sometimes called the syntax layer.

7. *Applications*: This layer supports application and end-user processes. Communication partners are identified, quality of service is identified, user authentication and privacy are considered, and any constraints on data syntax are identified. Everything at this layer is application-specific. This layer provides application services for file transfers, e-mail, and other network software services. Telnet and FTP are applications that exist entirely in the application level. Tiered application architectures are part of this layer.

B. Mobile ad hoc networks and OSI model

The OSI model was originally designed to meet the needs of wired networks, wireless networks have different characteristics than wired networks (mobility, signal quality, etc .). Despite these features, the transition to the wireless communication paradigm has kept the design principle layer of the OSI model. As all IEEE 802 standards, the 802.11 standard focuses on the first two layers, the physical layer and the data link layer as illustrated in Figure 2.7.

C. IEEE 802.11 standard

The base version of the standard was released in 1997, and has had subsequent amendments. The standard and amendments provide the basis for wireless network products using the WIFI brand. While each amendment is officially revoked when it is incorporated in the latest version of the standard, the corporate world tends to market to the revisions because they concisely denote capabilities of their products. As a result, in the market place, each revision tends to become its own

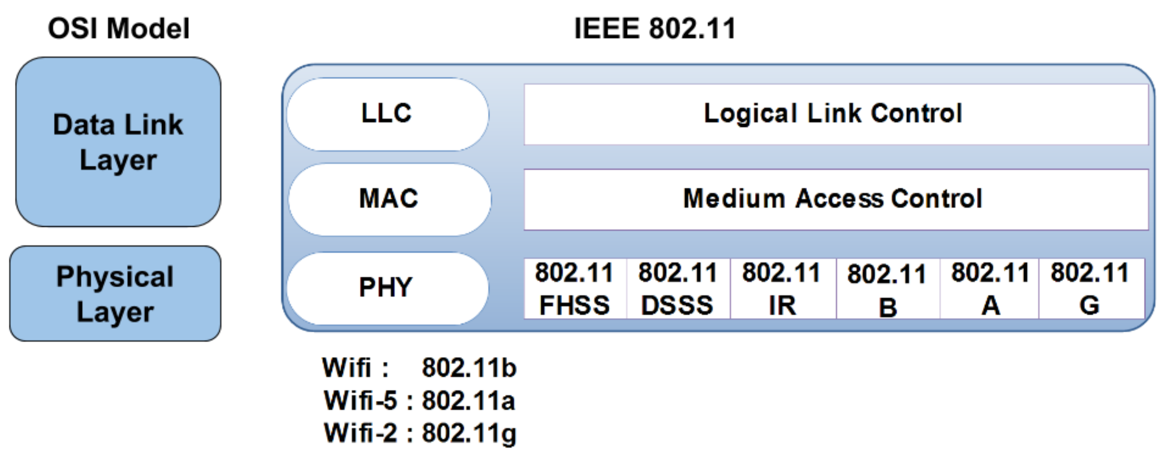


Figure 2.7: IEEE 802.11 and OSI Model

standard.IEEE 802.11 is a set of media access control (MAC) and physical layer (PHY) specifications for implementing wireless local area network (WLAN) computer communication in the 2.4, 3.6, 5, and 60 GHz frequency bands. They are created and maintained by the IEEE LAN/MAN Standards Committee (IEEE 802) [47]. In IEEE 802.11, the physical layer defines the modulation of radio waves and the characteristics of the signaling for the transmission of data, while the data link layer defines the interface between the bus of the machine and the physical layer, particularly it defines the access method to a shared medium and rules for communication between the different stations.

1. Physical Layer schemes

From the point of view of the physical layer, the 802.11 standard defines three non-interoperable techniques: IEEE 802.11 FHSS (Frequency Hopping Spread Spectrum) and IEEE 802.11 DSSS (Direct Sequence Spread Spectrum), which use both the radio medium at 2.4 GHz, IEEE 802.11 IR (InfraRed) and OFDM (Orthogonal Frequency Division Multiplexing) [47]. It provides three main functions. First, it provides an interface to exchange frames with the upper MAC layer for transmission and reception of data. Secondly, the PHY uses signal carrier and spread spectrum modulation to transmit data frames over the media. Thirdly, the PHY provides a carrier sense indication back to the MAC to verify activity on the media.

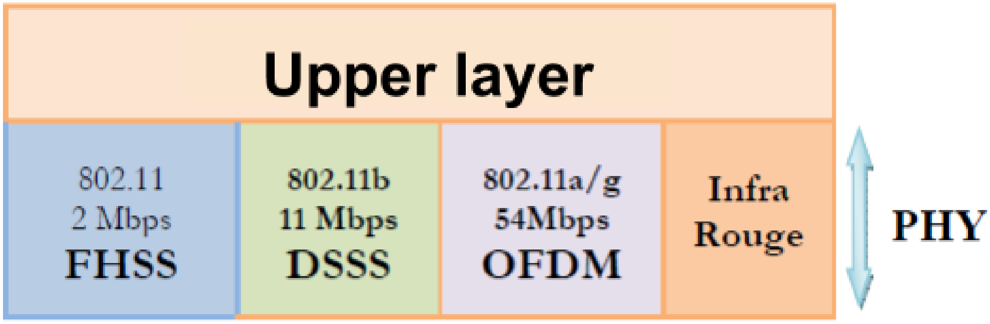


Figure 2.8: Physical Layer Schemes in Wireless Networking

- *FHSS*: is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both transmitter and receiver. It is used as a multiple access method in the frequency-hopping code division multiple access (FH-CDMA) scheme. FHSS is a wireless technology that spreads its signal over rapidly changing frequencies. Each available frequency band is divided into sub-frequencies. Signals rapidly change ("hop") among these in a pre-determined order. Interference at a specific frequency will only affect the signal during that short interval. FHSS can, however, cause interference with adjacent direct-sequence spread spectrum (DSSS) systems. A sub-type of FHSS used in Bluetooth wireless data transfer is adaptive frequency hopping spread spectrum (AFH).

- *DSSS*: is a spread spectrum technique whereby the original data signal is multiplied with a pseudo random noise spreading code. This spreading code has a higher chip rate (this the bitrate of the code), which results in a wide-band time continuous scrambled signal. DSSS significantly improves protection against interfering (or jamming) signals, especially narrow-band and makes the signal less noticeable. It also provides security of transmission if the code is not known to the public. These reasons make DSSS very popular by the military. In this technique, the 2.4 GHz band is divided into 14 sub-channels of 22MHz 2.9. This technique offers transmission rates from 5.5 to 11 Mbps. With the following advantages:

– Low spectral density of the transmitted signal, because the latter is broadband.

– High security, as the spreading code remains secret

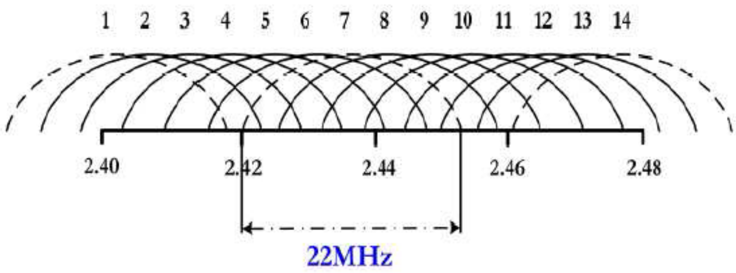


Figure 2.9: Direct Sequence Spread Spectrum (DSSS) Scheme

- *InfraRed*: it uses a light beam, this method is based on the use of the same frequencies as those used for optical fibers. Although infrared light has a wide bandwidth offering therefore relatively high data rates, the range of such communications is low. In contrast, the infrared can penetrate through the glass but not through opaque barriers, which represents an advantage in terms of security. However, as infrared networks are sensitive to light interference, the cutoff of the light beam involves the interruption of the transmission.

- *OFDM*: is a method of digital modulation in which a signal is split into several narrowband channels at different frequencies. The technology was first conceived in the 1960s and 1970s during research into minimizing interference among channels near each other in frequency. In some respects, OFDM is similar to conventional frequency-division multiplexing (FDM). The difference lies in the way in which the signals are modulated and demodulated. Priority is given to minimizing the interference, or crosstalk, among the channels and symbols comprising the data stream. Less importance is placed on perfecting individual channels.

2. Data Link Layer schemes

This layer sets up links across the physical network, putting packets into network frames. This layer has two sub-layers, the Logical Link Control Layer and the Media Access Control Layer.

The Data-Link layer ensures that an initial connection has been set up, divides output data into data frames, and handles the acknowledgments from a receiver that the data arrived successfully. It also ensures that incoming data has been received successfully by analyzing bit patterns at special places in the frames. The Data Link layer contains two sub-layers, the Logical Link Control Layer and the Media Access Control Layer.

1. *Logical Link Control layer (LLC layer):* The LLC layer is concerned with managing traffic (flow and error control) over the physical medium. The LLC layer also identifies a line protocol, such as SDLC, NetBIOS, or NetWare, and may also assign sequence numbers to frames and track acknowledgements.

2. *Media Access Control layer (MAC layer):* is concerned with sharing the physical connection to the network among several computers. Each computer has its own unique MAC address. Ethernet is an example of a protocol that works at the Media Access Control layer level. The IEEE 802.11 standard defines two access modes to the medium at the MAC level:

   - *Point Coordination Function (PCF):* can be used when the communications are managed by a fixed base station. It resides in a point coordinator also known as Access Point (AP), to coordinate the communication within the network. The AP waits for PIFS duration rather than DIFS duration to grasp the channel. PIFS is less than DIFS duration and hence the point coordinator always has the priority to access the channel.

- *Distributed Coordination Function (DCF):* can be used both for communications via a base station and for the mobile to mobile direct communications. This access method is used in the case of MANETs.

D. Medium access methods

In wireless networks, set of mobile devices suffer from access to the shared medium. To avoid this issue, many channel access techniques have been proposed 2.10. In the following, we present a set of these techniques in wireless networks.

Frequency Division Multiple Access (FDMA): is a channel access method used in multiple-access protocols as a channelization protocol. FDMA gives users an individual allocation of one or several frequency bands, or channels. It is particularly commonplace in satellite communication. FDMA, like other Multiple Access systems, coordinates access between multiple users. Specifically, it devises the frequency band allocated for wireless cellular telephone communication into 30 channels, each of which can carry a voice conversation or, with digital service, carry digital data. FDMA is a basic technology in the analog Advanced Mobile Phone Service (AMPS), the most widely-installed cellular phone system installed in North America. With FDMA, each channel can be assigned to only one user at a time. FDMA is also used in the Total Access Communication System (TACS).

Time Division Multiple Access (TDMA): It allows several users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each using its own time slot. This allows multiple stations to share the same transmission medium (e.g. radio frequency channel) while using only a part of its channel capacity. TDMA is used by Digital-American Mobile Phone Service (D-AMPS), Global System for Mobile communications (GSM), and Personal Digital Cellular (PDC). Each of these systems implements TDMA in somewhat different and potentially incompatible way.

Code Division Multiple Access (CDMA): CDMA allows multiple access, where many transmitters can send data simultaneously over a single communication channel. This allows several users to share a band of frequencies. To permit this without undue interference between the users, CDMA employs spread-spectrum technology and a special coding scheme (where each transmitter is assigned a code). it used as the access method in many mobile phone standards such as cdmaOne, CDMA2000 (3G), and WCDMA (LTE).

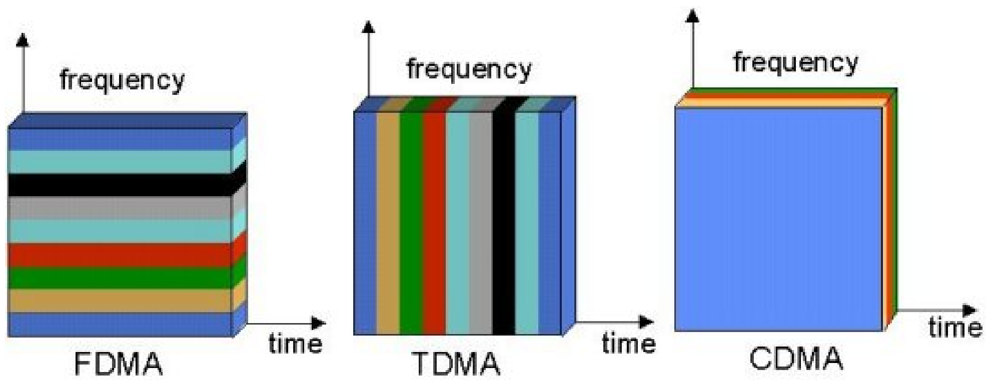


Figure 2.10: Channel access techniques: FDMA, TDMA and CDMA

Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA): is a technique for carrier transmission in 802.11 networks. It acts to prevent collisions before they happen by using a specific method known as collision avoidance (Collision Avoidance).

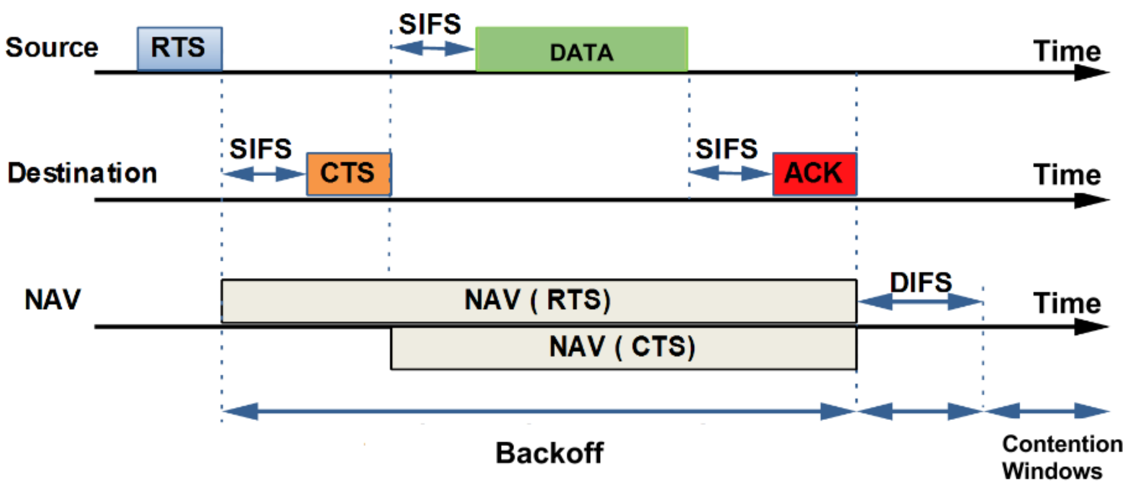


Figure 2.11: RTS/CTS Mechanism

In this technique, as soon as a node receives a packet that is to be sent, it checks to be sure the channel is clear (no other node is transmitting at the time). If the channel is clear, then the packet is sent. If the channel is not clear, the node waits for a randomly chosen period of time, and then checks again to see if the channel is clear. This period of time is called the backoff factor, and is counted down by a backoff counter. If the channel is clear when the backoff counter reaches zero, the node transmits the packet. If the channel is not clear when the backoff counter reaches zero, the backoff factor is set again, and the process is repeated. The backoff mechanism limits the risk of collision, but do not completely avoid. Due to this insufficient, IEEE 802.11 standard provides the use of the Request To Send (RTS) and Clear To Send (CTS) mechanism 2.11.

In RTS/CTS mechanism, a Request to Send (RTS) packet sent by the sender S, and a Clear to Send (CTS) packet sent by the intended receiver R. Thus alerting all nodes within range of the sender, receiver or both, to not transmit for the duration of the main transmission. Using this mechanism, IEEE 802.11 standard avoids the risk of collision. Thus, implementation of RTS/CTS helps to partially solve the hidden node and exposed stations problems illustrated 2.12 that is often found in wireless networking

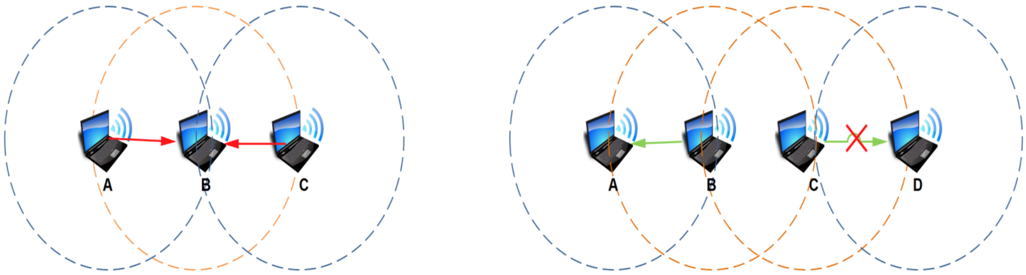


Figure 2.12: Hidden and Exposed Stations Issues

E. IEEE 802.11 standard derivations

IEEE 802.11 standard can be achieved a data rate from 1 to 2 Mbps. Revisions were made to the original standard in order to optimize data rate such as: IEEE

802.11(a,b,g) and/or improve the security. Other standards are oriented towards improving the quality of service (QoS) like 802.11e. Table 2.1 shows the main derived standards from the IEEE 802.11 standard and their characteristics.

2.3.2.3 Characteristics of mobile ad hoc networks

Mobile ad hoc networks is mainly characterized by:

- **Limited bandwidth**: One of the primary characteristics of wireless networks is the use of a shared communication medium. Such sharing behavior reduces the amount of bandwidth reserver for each device.

- **Wireless communication**: Network nodes communicate with each other using wireless communications channels which are generally less reliable than wired paths. Indeed, wireless channels can be affected by various factors like obstacles between the source and the destination, collision, interferences and also atmospheric conditions. In addition, the density of nodes may greatly impact the available bandwidth due to the shared capacity nature.

- **Energy constraints**: The mobile hosts are powered by independent power sources such as batteries or other consumable sources. The energy parameter must be taken into account in any control made by the system. As a consequence, one of the main design objective is energy efficiency in order to increase the network lifetime (Definition 6).

Definition 6 *(Network lifetime)*
The network lifetime is the span from the deployment from the instant the network is considered nonfunctional. When a network should be considered nonfunctional is, however, application specific. Table 2.2 the power required by a wireless transceiver during transmit/receive packets and idle. In addition, the transceiver consumes much more power to transmit or receive messages than when being idle. Hence, for more energy efficient; the design of protocols for ad hoc networks should reduce the number of messages.

Table 2.1: Derived standards and their characteristics

Standard	Characteristics
802.11	Standardization Date: 1997 Frequency Band: 2.4GHz Data Rate: theoretical: 2Mbps, real: $<$ 1Mbps Range: 100 m
802.11a	Standardization Date: 1999 Frequency Band: 5GHz Data Rate: theoretical: 54Mbps, real: 30Mbps Range: 50 m, Specificity: 8 radio channels
802.11b	Standardization Date: 1999 Frequency Band: 2.4GHz Data Rate: theoretical: 11Mbps, real: 6Mbps Range: 100 m, Specificity: 3 radio channels
802.11e	Improving quality of service (MAC level) for audio and video support.
802.11f	Interoperability between access points
802.11g	Standardization Date: 2003 Frequency Band: 2.4GHz Data Rate: theoretical: 54Mbps, real: 30Mbps
802.11h	802.11a adaptation to European standards electromagnetic radiation.
802.11i	Improving security of transmissions in frequency bands 2.4GHz and 5GHz.
802.11n	Standardization Date: 2006 Data Rate: theoretical: 500Mbps Adapting MIMO technology
802.11q	Provides improvements in the field of radio resources measurement
802.11r	Standardization Date: 2008 Improving VoIP Performance

Table 2.2: Transceiver Power Consumption: CISCO IEEE 802.11 a/b/g wireless card

Standard	Power Idle (mA) Power	Power Tx (mA)	Power Rx (mA)
802.11a	203	554	318
802.11b	203	539	327
802.11g	203	530	282

- **Limited physical security**: Mobile Ad Hoc networks are more affected by the security setting than traditional wired networks. This is justified by the physical constraints and limitations that make the control of the transferred data should be minimized.

- **Resource-constrained computation**: MANETs devices are generally limited in term of computation. As such, protocols and applications designed for these types have to attain efficiency requirements with the few available resources.

- **Dynamic topology**: Mobile devices of the network move using an arbitrary manner. Consequently, the network topology may change at unpredictable moments, rapid and random.

- **Scalability**: In MANETs the size of network (number of nodes) is generally less (a few hundred of nodes). So, protocols designed for such networks should be able to cope with very different topologies and try to achieve a high performance when network size increase (Definition 7). This requirement is even more difficult to obtain if we consider the energy conservation and the resource-constrained computation characteristics that we previously detailed.

  Definition 7 *(Network scalability)*
  Scalability is a desirable property of a system, a network, or a process, which indicates its ability to either handle growing amounts of work in a graceful manner or to be readily enlarged.

Hence, a good MANETs scheme must support the scalability when network size increase.

2.4 Routing protocols in MANETs

To better understand the strategies used in the design of mobile ad hoc networks protocols. This section describes some notions about routing protocols within

MANETs and presents the principles of best-known routing protocols in mobile ad hoc networks.

Definition 7 *(Routing)*
Routing is the process of moving packets across a network from one host to a another. It is usually performed by dedicated devices called routers..

2.4.1 MANETs routing protocols classification

In mobile ad hoc networks, to ensure the delivery of a packet from the source to the destination, each node must run a routing protocol and maintain its routing tables in memory. Routing protocols can be classified into the three main classes: reactive, proactive, and hybrid 2.13.

Nowadays, there are around one hundred routing protocols, many standardized by the IETF (Internet Engineering Task Force) and others still at the stage of Internet-Draft. This section gives, for each category, an overview of the most important ones.

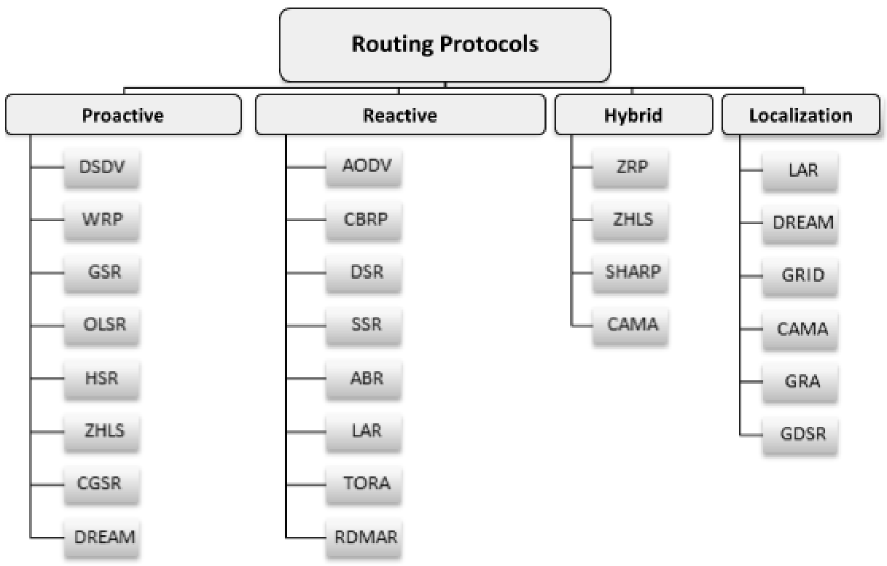


Figure 2.13: Classification of MANETs Routing Protocols

These routing protocols 2.13 can be classified based on three criteria [44]: the type of control information delivery, the topology structure and localization-based (e.g use GPS to identify the location of each node in order to simplify the routing process).

2.4.1.1 Reactive protocols

Mobile ad hoc networks reactive protocols, namely: on-demand protocol, topology information is given only when needed. If a network node wants to know the rout to a specific destination node, first, it broadcasts a rout request demand packet. When such packet reach the final destination, it replies by sending a rout reply packet to the source of rout request. Route request and replay mechanism gives a reduced average control traffic, with bursts of messages when packets need being routed, and an additional delay due to the fact that the route is not immediately available.

- *Dynamic Source Routing (DSR)* [50] is a routing protocol that use a source routing mechanism, which means the source puts the complete route in the packet header. Such mechanism avoids path loops. To send data, a source node broadcast a Route Request to its neighbors and awaits the replay; any receiving node adds its address to the Route Request and retransmits the packet to their neighbors. Once the packet has reached its final destination node, the latter reverses the route and sends the Route Reply packet. This is possible if the MAC protocol permits bidirectional communications; otherwise, the destination node performs another route discovery back to the originator. Every node maintains also a route cache, which avoids doing a route discovery for already known routes. A mechanism of route maintenance allows the originator node to be alerted about link breaks in the route.

- *Ad hoc On-demand Distance Vector routing (AODV)* [72] is a distance vector routing protocol, i.e. routes are advertised as a vector of direction and distance. It uses sequence numbers for control messages to avoid the Bellman-Ford "counting to infinity" problem and routing loops. Before date transfer, a source node broadcasts a Route REQuest packet (RREQ). The RREQ is relayed by receiving nodes until it reaches the destination or an intermediate node with a fresh route (i.e. a route with an associated sequence number equal or greater than that of the RREQ) to destination. Afterward, this node after generates a Route REPlay (RREP) packet and sends back to the originator of the RREQ. In addition, AODV protocol uses a specific Route ERRor (RERR) packets to notify nodes about link breaks.

2.4.1.2 Proactive protocols

In other hand, proactive protocols (named also periodic or table driven protocols) are required to exchange the topology control messages periodically. Nodes receiving such messages periodically update their routing table. Therefore, control traffic is more dense but constant, and routes are instantly available. However, the drawbacks of this type of protocol is the cost of maintaining topology information and routing even when there is no need and no data traffic. This eventually generates a continuous bandwidth consumption.

Two main methods are used in this class : the link state and distance vector. In link state protocol [59] every node constructs a map of the connectivity to the network, in the form of a graph, showing which nodes are connected to which other nodes. Each node then independently calculates the next best logical path from it to every possible destination in the network. The collection of best paths will then form the node's routing table. In contrast, a distance vector routing protocol [26] requires that each node inform its neighbors of topology changes periodically. It uses the BellmanFord algorithm to calculate the paths between source/destination pair. Distance vector routing protocols have less computational complexity and message overhead compared to link state routing protocols.

- *Destination-Sequenced Distance-Vector routing (DSDV)* [61, 73] is a distance vector routing protocol also, which requires each node to send its routing table to its neighbors. Route information contains a route sequence number, the destinations address, the destinations distance in hops, and the sequence number of the information received regarding the destination as stamped by the destination itself.

- *Optimized Link State Routing (OLSR)* [22] is a link-state proactive routing protocol optimized for MANETs. It uses Hello and Topology Control (TC) messages to discover and disseminate link state control packets to network nodes. Using Hello messages each node discovers 2-hop neighbor information and elects a set of multipoint relays (MPRs). MPRs makes OLSR unique from other link state routing protocols. Individual nodes use the topology information to compute next hop paths regard to all nodes in the network utilising shortest hop forwarding paths.

- *Topology dissemination Based on Reverse-Path Forwarding (TBRPF)* [68] is a proactive link state routing protocol, each node constructs a source tree using partial topology information stored in its topology table. The tree provides paths to all reachable nodes and is computed using a modified Dijkstra algorithm. In this protocol, periodically each node broadcast part of its tree with its neighbors while it uses differential Hello messages to report changes in neighbors status and neighbors discovery as well.

- *Fisheye State Routing (FSR)* [71, 38] is a link state protocol that support scalability when network size increase. Each node broadcasts link state information of a destination to its neighbors, with a frequency inversely proportional to the destination distance in hops. Therefore, every node has a precise knowledge of its local neighborhood while knowledge of distant nodes is less precise (hence the name Fisheye). This makes the routing of a packet accurate near the source and the destination. FSR is proficient in handling large networks.

- *Wireless Routing Protocol (WRP)* [65] is a protocol that propose a new path-finding algorithm in order to reduce network loops. In WRP, each node broadcasts its routing tables to its direct neighbors, by communicating the distance and second-to-last hop to each destination. Nodes send an acknowledgment upon reception of update routes. Each nodes maintain a distance table, a routing table, a link-cost table, and a message retransmission list.

2.4.1.3 Hybrid protocols

Hybrid protocol is a trade-off between reactive and proactive protocols. Usually, it divides the network nodes into a set of small groups, and a node employs a proactive protocol for routing inside its near neighborhood group (intra-group) and a reactive protocol for routing outside this group (inter-group).

- *Zone Routing Protocol (ZRP)* [43] is a hybrid routing protocols, where it defines for every node a range in term of number of hops inside which packets are routed using a proactive routing protocol. Routes for nodes outside the transmission range are discovered using a reactive routing protocol. The working mode of ZRP is specified locally by IARP (IntrAzone Routing Protocol) [42], and for inter zone routing by IERP (IntErzone Routing Protocol).

- *Cluster Based Routing Protocol (CBRP)* [48] it uses the cluster-based algorithm to divide the network into overlapping or disjoint node clusters, each cluster being 2-hops in diameter. For every cluster, the cluster head node has the duty of exchanging route discovery messages with other cluster heads. A proactive routing protocol is used inside every cluster, while inter-cluster routes are discovered reactively via route requests.

2.5 Mobile ad hoc networks modeling

This section provides a set of modeling aspects related to network communication graph and wireless communication link in mobile ad hoc networks.

2.5.1 Network communication graph

A network topology in mobile ad hoc networks can be presented as a graph, depending on the nature of wireless links, the set of nodes represent by graph vertices while graph edges represent the links between these node. Firstly, we provides definitions and notion to model MANETs as a static graphs and then provides some insights how to deal with mobile nodes (dynamic graphs) in the second part.

2.5.1.1 MANETs static graphs

In order to model the MANETs communication as a static graph, we based on two aspects, namely: network and transmission range. Such aspects are presented in detail in [79]. Moreover, most of MANETs communication static graph modeling use the Unit Disk Graphs [21].

Network A network NT is defined by a set of N nodes that deployed in a specific area R. Where R defined as $R = [0, l]^i$ with l represents the side of cube and $i = 1, 2, 3$ is the dimensional of the cube. The position of node v in the area R is defined by its location function $LO : N \to R$ that maps each node $v \in N$ to its physical location *LO(v)*.

Definition 8 *(Network)*
A network NT is a couple NT = (N,LO) composed of a set of nodes N and a location function LO associating each node of $v \to N$ *to its physical location.*

Transmission range In graph theory, the set of MANETs nodes can be presented by a vertex set, while the links are defined by the set of directed edges. Such edges ensure communications between a vertex set thanks to transmission range of each node. In MANETs every mobile node v is characterized by its transmission range, which defined as "*the maximum distance that allows the node to receive and send packet correctly*". As the area R is a i-dimensional space with $i = 1, 2, 3$, the maximum distance subject to its transmission range t_r that node$v$ can be reached defined as follow:

- ▷ If i = 1, the maximum range that node v can be reached is of length $2t_r$.
- ▷ If i = 2, the maximum range is circle of radius t_r and centered at LO(v).
- ▷ If i = 3, the maximum range is a sphere of radius t_r and centered at LO(v).

Definition 9 *(Transmission range)*
A transmission range t_r *for a network NT is a function that assigns to every node*

$n \in N$ a value $t_r(v) \in [0, t_{rmax}]$ representing its transmission range. Parameter t_{rmax} is called the maximum transmission range.

In MANETs the node transmission range is defined based on a particular propagation model [84]. Any transmission range t_r has a maximum range that can be reached $t_r \in [0, t_{rmax}]$ and it is uniquely associated to with a transmit power $p \in [0, P_{max}]$.

Definition 10 *(MANETs Communication graph G(N,E))*
A communication graph $G = (N,E)$ is a directed graph composed of a set of vertices, which representing the communication nodes, and directed edges, that representing the available directional communication channel between network nodes. N is the set of nodes of a given network $NT = (N,LO)$. A directed edge (u, v) $\in E$ if and only if $t_r(u) \geq \delta(LO(u), LO(v)$, with $\delta(LO(u), LO(v)$ the euclidean distance between nodes u and v.

Unit disk graph The edges in definition 10 is a directional links, where it is not the case in wireless links which require a bidirectional links. To address this issue, a very well-know subclass of communication graphs have been proposed by [45] called the Unit Disk Graphs (UDG). In graph theory point of view, unit disk graph is a graph builds by a collection of equal-radius nodes circles, where these nodes circles are connected by one edge 2.14. In such graphs, an homogeneous and standardized transmission range is assumed, i.e. all wireless nodes are characterized by a transmission range of value 1. As a matter of fact, an edge between two nodes u and v exists if and only if the Euclidean distance between these two nodes is less or equal to 12.14. Figure 2.14 represents a simple unite disk graph with two nodes A and B. And their circles represents the transmission range of each node. Furthermore, Figure 2.15 shows a geometric representation of maximum number of independent neighbors problem in unit disk graph. Such problem is NP-hard to determine whether a graph can be represented as a unit disk graph. However, there are many other graph optimization problems like graph coloring, maximum independent set and minimum dominating set which can be approximated efficiently by using the geometric structure of these graphs.

Definition 11 *(Unit disk graph)*
A Unit Disk Graph G = (N,E) is a graph formed from a collection of equal-radius circles, in which two circles are connected by an edge if one circle contains the center of the other circle.

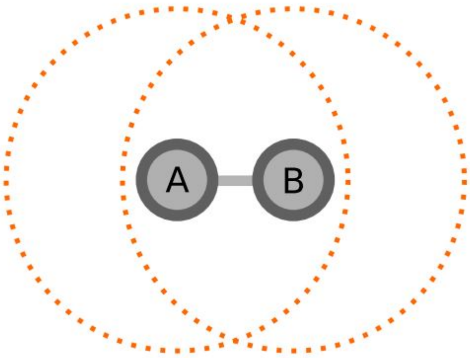


Figure 2.14: Simple Unit Disk Graph with Two Nodes.

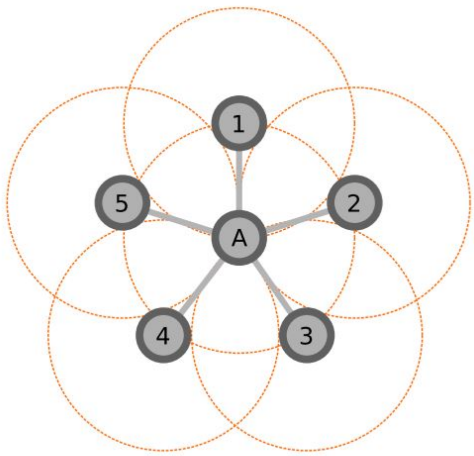


Figure 2.15: UDG Maximum Number of Independent Neighbors Problem.

2.5.1.2 MANETs Dynamic graphs

In MANETs, nodes move depending on the mobility model used and organize themselves arbitrarily. This means nodes may join and leave the network at any time. Such nodes mobility leads to topology changes through time continuously. The topology changes represent a big problem in the communication graph model which need to process. Firstly, we present the necessary modification to adapt the static communication graph model to dynamic topology changes (Dynamic communication graph model). Secondly, we provides various idea to handle dynamic graphs issue.

Communication graph model adaptation Based on [74]. Nodes mobility can be easily addressed using a modified location function LO , and , so, the node v location can be defined as $LO_{dyn} : N \times T \rightarrow R$, hence, for each node $v \in N$ and any time $t \in T$, LO_{dyn} monitor any changes in the position of node v at time t in area R.

Definition 12 *(Dynamic network)*
A dynamic network NT_{dyn} is a sequence of static network at different time t. Moreover, NT_t at a time t is a couple $NT_t = (N_t, LO_{dyn})$ composed of the set of vertices at time t and a location function LO_{dyn} providing the position of any node $v \in N_t$ at any time t.

Where N_t in the set of considered nodes at time t in area R.

In addition, the topology control in MANETs are mainly based on modifying the transmission range of nodes periodically in order to preserve some graph properties like nodes connectivity, number of hops, etc. As a consequence, a dynamic transmission range is defined as: $t_{rdyn} : N_t \times T \rightarrow [0, t_{rmax}]$. A dynamic communication graph is defined as follow:

Definition 13 *(MANETs Dynamic communication graph)*
Given a network $NT_t = (N_t, LO_{dyn})$ at time t and a dynamic transmission range t_{rdyn}, a dynamic communication graph is a sequence of static communication graphs for different values of time t. A static communication graph at time t is defined as $G_t = (N_t, E_t)$. An edge (u, v) at time t exists in Et if and only if $t_{rt}(u) \geq \delta(LO_{dyn}(u, t), LO_{dyn}(v, t))$.

2.5.2 MANETs wireless communication link

Typically, nodes in MANETs communicate with each other through wireless links, and, so, MANETs wireless link is an important part of MANETs modeling. A radio link (wireless link) is established between the source node and the destination node if and only if the received power P_r by the destination is above a defined sensitivity threshold λ. P_r value depends on two factors, namely: transmission power of source node P_t and path loss PL between source node and destination node.

$$P_r = \frac{P_t}{PL(source, destination)} \tag{2.1}$$

The main issue in MANETs wireless link modeling is the path loss PT modeling. This is due to the fact that path loss model represents an important parameter in the simulator as it has a big impact on both simulation time and quality of simulation results. Each simulator based on path loss to determine the quality of communication between two nodes, thus, results of single simulation can differ depending on the path loss model used. Furthermore, the path loss model requires a heavy computation, where path loss calculation will be periodically. As a results, the simulation results will increase accordingly. Many physical phenomenon need to take into account during path loss model like:

- ▷ Scattering, when many small obstacles are between source and destination (e.g. tree leaves).
- ▷ Reflection, when the radio signal hits the surface of large objects compared to its wavelength (e.g. the radio signals can be reflected by walls and buildings).
- ▷ Diffraction, when the radio signal encounters very sharp edges.

Many propagation models have been proposed and integrated in wireless network simulators, namely: the free space propagation model, log-distance path model and two-ray ground model.

- ▷ *The free space propagation model* proposed by [34], in which the received power falloff is proportional to the square of the distance. Line-of-sight has to be clear and only the direct path between the transmitter and the receiver is taken into account.

$$P_d = \frac{P_t G_t R_t \lambda^2}{(4\pi)^2 d^2 L} \tag{2.2}$$

where P_t is the transmitted signal power. G_t and G_r are the antenna gains of the transmitter and the receiver respectively. $L(L \geq 1)$ is the system loss, and λ is the wavelength. It is common to select $G_t = G_r = 1$ and $L = 1$ in ns simulations.

▷ *The two-ray ground model* [78], a single line-of-sight path between two mobile nodes is seldom the only means of propation. The two-ray ground reflection model considers both the direct path and a ground reflection path. It is shown that this model gives more accurate prediction at a long distance than the free space model. The received power at distance d is predicted by

$$P_r(d) = \frac{P_t G_t G_r {h_t}^2 {h_r}^2}{d^4 L} \tag{2.3}$$

where h_t and h_r are the heights of the transmit and receive antennas respectively

▷ *The log-distance path model* presented in [78], is a generalization of the two previous approaches. It is based on a exponent α that depends on the environmental conditions.

2.6 Recap of key points

- The radio transmission used in the wireless communication is based on the principle that the acceleration of an electron creates an electromagnetic field which in turn accelerates other electrons and so on [87].
- Wireless communication is the data transfer (via radio) between two or more nodes that are not connected by an electrical conductor.
- There are two main mobile network classes, namely: infrastructure-based

like cellular networks and infrastructureless-based like mobile ad hoc networks. The Infrastructured wireless networks is based on fixed infrastructures called base stations, typically consisting of a set of mobile nodes connected to each other through wireless links via these base stations. In contrast, in Mobile Ad Hoc NETworks (MANETs), consisting of a set of autonomous mobile devices capable of self-organizing and self-conguring in multi-hop wireless networks, typically the set of mobile nodes communicate with each other to deliver data without the support of any network infrastructure (base station) or/and centralized management. In MANETs, nodes move depending on the mobility model used and organize themselves arbitrarily. This means nodes may join and leave the network at any time.

- Routing represents the process of transfer messages across a network from one node to a another. MANETs Routing protocols can be classified into the three main categories: reactive, proactive, and hybrid.

- Modeling mobile ad hoc networks is a wide domain composed of the wireless channel, the communication graph and the mobility models.

Chapter 3

Topology Management Schemes In Mobile Networks

Abstract This chapter presents an extensive stat-of-art on both clustering algorithms and virtual backbone in mobile ad hoc networks. The clustering algorithms allow to structure the network by dividing network nodes into groups of entities called clusters while virtual backbone is constructed by a small subset of specific nodes that cover all network nodes. Such approaches aims to give the network a hierarchical structure. The main purpose of topology management is to improve resource management and network performance parameters like routing delay, bandwidth consumption and throughput. This chapter is organized as follows: clustering definition, algorithm of cluster head selection, the design goals of clustering algorithms, the advantages and disadvantages of corresponding clustering schemes and metrics for evaluating the performance of presented clustering schemes are presented in section 3.1. Section 3.2 proposes a study and analyze some of existing clustering approaches in MANETs that the most important and the best known in the literature. These approaches classified into two types of clustering algorithms: One-hop and K-hop clustering schemes. Well known Virtual backbone-based schemes are presented in section 3.3. To conclude this chapter, the section 3.4 provides a comparison of both cluster-based and virtual backbone based schemes.

3.1 Clustering schemes in MANETs

3.1.1 Clustering definition

The process that divides the network into interconnected substructures, called clusters. Each cluster has a particular node called cluster head (CH) that elected as cluster head according a specific metric or a combination of metrics like identity, degree, mobility, weight, density, etc. The cluster head as coordinator within the substructure. Each CH acts as a temporary base station within cluster and communicates with other CHs [83, 41]. A cluster is therefore composed of cluster head, gateways and members nodes 3.1.

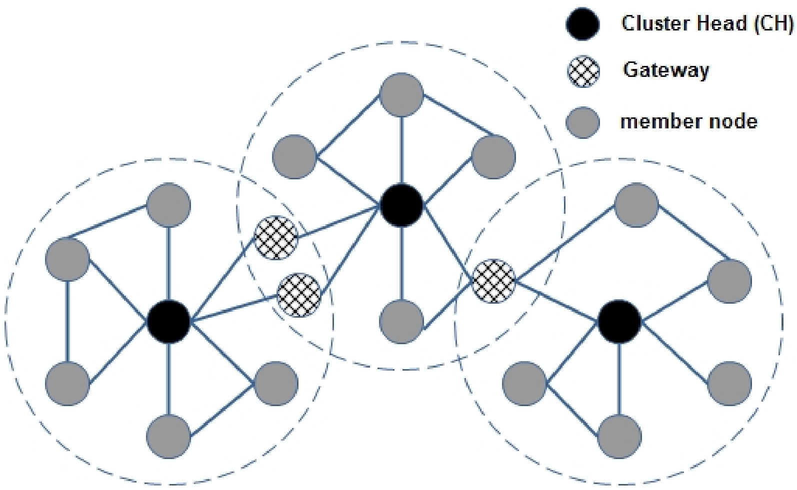


Figure 3.1: Clusters Structure

- *Cluster Head (CH)*: it is the leader of the cluster which has additional functions such as: channel access, routing, calculation of the routes for longer-distance messages, resources allocation, forwarding inter-cluster packets and power control etc.
- *Gateway*: is a node that has links inter-cluster and can therefore access to neighboring clusters and forward data between them.
- *Member Node (Ordinary nodes)*: is a node that is neither a CH nor gateway node. Each node belongs exclusively to a cluster independently of its

neighbors that might reside in a different cluster

3.1.2 Algorithms of cluster head election in MANETs

There are several algorithms that introduced by literature for cluster heads election in mobile ad hoc networks [88] which are listed as follows: Lowest-ID, Highest- Degree, Distributed Clustering Algorithm, Weighted Clustering Algorithm (WCA) and Distributed Weighted Clustering Algorithm (DWCA) [17].

3.1.2.1 Lowest-ID (LID)

It is the first algorithm for cluster heads election proposed [29]. In the first step, assigning a unique ID to each node in the network and each node in the networks broadcasting its ID to all the neighbor nodes. The IDs compared and the node having the lowest ID is elected as a cluster head, while its single hop neighbors become the cluster members. Thus, the IDs of the neighbors of the cluster head will be higher than that of the cluster head. This algorithm having several issues such as: the number of cluster heads that elected may become undesirably high, the packet delivery delay may become excessive, battery drainage, the selection of cluster heads has to be frequently updated causes by high nodes mobility etc.

3.1.2.2 Highest-Degree (HD)

The highest degree algorithm [37] uses location information for cluster formation. Each node is aware of the number of its neighbor nodes that broadcasts between the neighborhoods nodes. The node that has maximum number of neighbors the highest degree is elected as cluster head. If the degree of neighbor nodes is the same, the lowest-ID node becomes the cluster head. Then the one hop neighbor nodes of the cluster head become ordinary members of the cluster. In this algorithm the number of cluster heads is relatively low compared with lowest ID algorithm. Furthermore, it also reduces the packet delivery delay. However, the re-affiliation count of nodes is being high when the node mobility increases.

3.1.2.3 Distributed Clustering Algorithm (DCA)

It represents an enhancement of lowest-ID algorithm and it uses node ID for the selection of cluster heads [10]. In cluster formation step each cluster elect its cluster head from its neighboring nodes that having the lowest ID. This algorithm have a many advantage compared with lowest ID algorithm, every node can determine its cluster and only one cluster, and transmits only one message which may be impose a good control trafc load, it inherits the drawbacks of the Lowest-ID algorithm. In fact, the cluster heads number becomes very expensive and there are no optimizations on the network parameters such as throughput and power control.

3.1.2.4 Weighted Clustering Algorithm (WCA)

In WCA [16] the cluster head elects based on the combined metrics that called parameters like the transmission power, node degree, mobility and battery power of mobile nodes etc. The weighted clustering algorithm selects a cluster head according to the weight parameters value of each node. The parameters are taken into account in order to calculate a weight factor W for every node v is defined as:

$$W_v = w_1 \times Fact_1 + w_2 \times Fact_2 + w_3 \times Fact_3 + \cdots + w_n \times Fact_n. \qquad (3.1)$$

Where, the node with the minimum weight W_v is selected as a cluster head and wi , $i = 1...n$ are weighting factors. Although WCA has proved better performance than all the previous algorithms, it lacks a drawback in knowing the weights of all the nodes before starting the clustering process and in draining the CHs rapidly. As a result, WCA has increased the overheads in the network. The cluster maintenance procedure is invoked, when a node moves to a region which is not covered by the cluster head, throughout the whole network.

3.1.2.5 Distributed Weighted Clustering Algorithm (DWCA)

DWCA [20] is an enhanced version of WCA to achieve distributed clustering set up and to extend lifetime span of the system. This algorithm consists of the clustering formation and clustering maintenance phases. DWCA chooses locally optimal cluster heads and incorporates power management at the cluster heads. This algorithm differs from WCA in which it localizes configuration and reconfiguration of clusters and poses restriction on the power requirement on the cluster heads. This algorithm provides better performance than WCA in terms of the number of re- affiliations of CHs, end-to-end throughput and delay, total overheads during the clustering phases, and the minimum lifespan of nodes.

Some other cluster heads election algorithms have been given in: Distributed Mobility Adaptive Clustering Algorithm (DMAC) [10] and Distributed Score Based Clustering Algorithm (DSBCA) [2].

3.1.3 Advantages of clustering approach

Clustering is a hopeful solution for large scale MANETs. The principle of clustering is to organize the network into a hierarchical structure. This hierarchical structure has several advantages like:

- Optimize the resources management and bandwidth by minimizing the amount of information exchanged in order to keep the routing tables, and it saves energy in MANETs.
- Optimize the diffusion of information in order to provide good network performance. The idea is to allow some nodes to relay the information.
- Facilitate the reuse of resources for improve the ability of the system [49].
- The whole of cluster heads and gateways can form a virtual backbone (dorsal) for routing inter cluster. Thus, the generation and dissemination of routing information can be limited to this set of nodes, which avoids the frequent broadcasts of routing information that can overload the network and degrade performance [53].
- The hierarchical structure shows the network smaller and more stable in the eyes of each node [95].
- It helps to improve routing at the network layer by reducing the routing tables size.

- The local changes caused by node mobility do not affect the whole network, but only part. Thus, the information processed and stored by each node is reduced.

3.1.4 Issues and clustering approach cost

The Clustering has the advantage to be an attractive alternative to address the problems of scalability and several problems as we have seen in section 3.1.3, such as reducing communication and control overheads due to pre-determined paths of communication through cluster heads and ensure a good security infrastructure. However, this technique has drawbacks and issues that related to the highly nodes mobility in MANETs that makes it difficult for the clustering schemes to divide a mobile network into clusters and determination of cluster heads for each cluster. In fact, clusters formation and maintenance structure demand additional cost compared to the flat network. The analysis of clustering cost can evaluate its effectiveness and its scalability. They are as follows:

- The maintenance of the clusters structure required control messages that exchange periodically between mobile nodes in the network; this control messages exchange provides an additional load on the network. As the number of control messages increases with the number of nodes in a dense and large network, control messages exchange will draw significant part of the limited resources in terms of bandwidth (consumes a lot of network bandwidth), processing time and energy in mobile nodes. The control messages will compete jointly with the data traffic to access to the channel and overloading the network. Under such conditions, applications of the upper layers cannot function properly [19, 69].

- The ripple effect of re-clustering is seen in some proposals of clustering and can significantly affect the performance of upper layer protocols. This purpose consists to trigger the reconstruction of the entire clusters structure (re- clustering) if a certain event occurs locally such as movement or leaving, or the death of a mobile node and, as results it may lead to the re-election of a new cluster head. This effect will take place when a new or single cluster head re-election affects the structure of several clusters and triggers a chain of re- election of cluster heads on the whole network [93].

- Clusters formation is a process of collecting information and decision making role for each node in the whole network. The duration of this phase measured in number of laps remains an important metric and represents a considerable cost in a clustering algorithm. Some proposals assume that nodes stay static during the cluster formation phase. Thus, more this phase is longer more time is where nodes are not mobile is long. For most clustering schemas, cluster formation phase can be executed in parallel on the entire network which makes the convergence of cluster formation faster. But in these schemas, nodes do not take the same time for making their role. In addition, for clustering schemas where the decision of a node is based on the broadcast decisions in its neighborhood, sometimes nodes wait indefinitely in large and dense networks, in other hand some nodes consume more power (energy) when compared to others nodes of the same cluster like a cluster head or a cluster gateway that manage and forward all messages of the local cluster, their power consumption will be high compared to ordinary nodes. It may cause untimely shutdown of nodes [25, 82].

3.1.5 Performance metrics

The large number of clusters and the frequent cluster heads change leads to many drawbacks like route invalidation, frequent occurrence of re-affiliation, produce additional overhead etc. that engender rebuilding of the whole network causing instability of network topology. A good clustering scheme, achieve scalability in presence of large networks and high mobility, minimize the communication overheads, decreasing the energy consumptions, reduces the cluster head formation, reduces the re-affiliation caused by high speed moving nodes, ensure a good stability of the network topology by producing a stable clusters, and improve the usage of scarce resources such as bandwidth and energy.

Given the multitude and diversity of clustering algorithms proposed is not a trivial task to evaluate various clustering protocols, it is difficult to find good metrics for evaluating the performance of clustering schemes. Based on the work

[93, 33]. We deduced the groups of following metrics:

- *Total overhead*: Overhead incurred during the network operation time.
- *Message complexity per topology change*: The number of messages exchanged between the nodes to accomplish valid cluster reorganization after a change in the network topology.
- *Average cluster size*: The average number of nodes catered by the cluster head.
- *Average number of clusters* : The average number of clusters formed in the network.
- *Total distance to cluster heads*: The number of hops between nodes and cluster heads.
- *Average cluster head lifetime*: The average time period for a mobile node to act as a cluster head.
- *Average cluster membership lifetime*: The average time period for a mobile node associated with its corresponding cluster head
- *Average number of cluster head changes*: The average number of cluster head change.
- *Number of dominant set updates*: A set of cluster heads is called a dominant set, if all the nodes in the network are either in the set or neighbors of nodes in the set. It gets updated when a node can no longer be a neighbor of any of the existing cluster heads
- *Number of re-affiliations*: The re-affiliation count is incremented when a node gets dissociated from its cluster head and gets associated as a member of another cluster within the current dominant set.
- *Time complexity per topology change*: The time taken to accomplish valid cluster reorganization after a change in the network topology.

- *Cluster stability*: Maintaining a stable structure during network topology changes.
- *Variance cluster head lifetime* : The time variance during which a node plays the role of cluster head.

3.2 Classification of cluster-based schemes in mobile ad hoc networks

In this section, we present and analyze the main algorithms proposed in last research papers published for clusters construction in MANETs. There are several solutions to organize a network into clusters. Every clustering algorithm consists of two mechanisms, cluster formation and cluster maintenance. In cluster formation, cluster heads are elected among the nodes to form the hierarchical network. These clusters are identified by their cluster head. The cluster maintenance phase comes into picture when there is the node movement that produces the topology change. So, it needs to do re-affiliations of new cluster head in the cluster. Much of these clustering approaches build One-Hop clusters where each node is one hop from its cluster head. Other algorithms generate K-Hop clusters where each node is more K hop from its cluster head. The different algorithms differ on the selection criterion of cluster heads, that is to say the metric. This metric can be a specific metric such as the node ID, the degree, the mobility, energy etc. or a combination of metrics.

We distinguished and classify this algorithms based on their objectives and the manner of cluster heads election as: Identifier Neighbor based clustering, Topology based clustering, Mobility based clustering, Energy based clustering, and Weight based clustering.

- ☐ *Identifier Neighbor based clustering*
  In this category, a unique ID is assigned to each node and each node in the whole network knows the ID of its neighbors. The cluster head is chosen following some certain rules such as the lowest ID, highest ID, etc.

- ☐ *Topology based clustering*
  In the topology based clustering, the cluster head is chosen following some metric. This metric computed from the network topology like node connectivity also called a node degree.

- ☐ *Mobility based clustering*
  The mobility is an important characteristic in MANETs, and is the main factor affecting topology change that cause frequent re-clustering and route invalidation. Mobility based clustering take the mobility metric into account in cluster formation in order to form a stable cluster structure by grouping mobile nodes with similar speed into the same cluster.

- ☐ *Energy based clustering*
  The node battery power is an important constraint since it corresponds directly to operational lifetime, hence the energy limitation poses a severe challenge for network performance. In the clustering algorithms a CH bears special tasks compared with member nodes such as routing that may cause excessive CH energy consumption. Energy based clustering take the energy metric into account in cluster formation in order to balance the energy consumption among mobile nodes to avoid node failure.

- ☐ *Weight based clustering*
  Weight based clustering use of a combined weight metric that takes a several metrics into account like transmission power, node degree, distance difference, mobility and battery power of mobile nodes etc. for cluster formation. This clustering scheme can effectively and dynamically adapt itself with the ever changing topology of MANETs. One advantage of this approach is that it can flexibly adjust the weighting factors for each metric to adjust to different scenarios.

3.2.1 One-hop clustering schemes

3.2.1.1 Identifier neighbor based clustering

There are many one-hop clustering schemes. In [29] proposed early clustering algorithms for ad hoc networks, which called LCA (Linked Cluster Algorithm). In LCA each node declared as cluster head or not based on its ID and its neighbors IDs. In cluster formation, initially, all nodes have a member node state, periodically each node in the whole network broadcasts the list of neighbor nodes and their ID including itself. Subsequently, node that has the lowest ID is selected as cluster head. In this way, the IDs of the neighbors of the cluster head will be always higher than that of their cluster head. A node which can hear two or more cluster heads is a gateway. Otherwise, a node is a member node. The process repeats until every node belongs to at least one cluster and has its own cluster head. At the end of cluster formation process each node in the network must have one of the following stats: CH node, member node, getaway node. The LCA algorithm constructed overlapping clusters and non-overlapping clusters in the same time 3.2. This algorithm considers only the nodes with the lowest ID which are selected arbitrarily without taking into account other metrics for CH election process. Since the node IDs do not change with time, nodes with a small ID are more likely to be selected as cluster head. Thus, if these cluster heads keep their status as cluster head for a long time as the result they quickly consume their energy.

In LCA the cluster maintenance is costly since the mobility of one node can lead to the complete structure reconstruction. In [18] proposed Least Cluster Change (LCC), these improved versions of LCA algorithm which adds a maintenance step to minimize the cost of re-clustering. The LCC algorithm divided into two phases: cluster formation and cluster maintenance. The cluster formation is the same as that in LCA, i.e. the nodes with the lowest ID in their neighborhood are elected as cluster head. The reconstruction of clusters only in the following two cases:

- If two cluster heads are neighbors, then one of the two will give up the role of cluster head according to lowest-ID or highest connectivity.

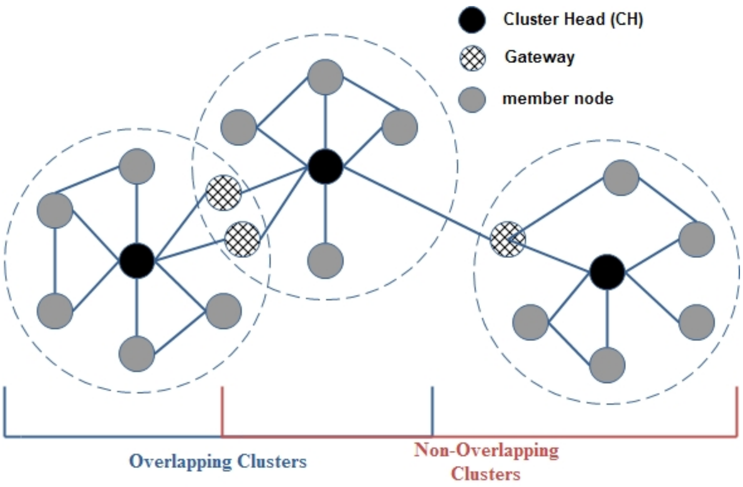


Figure 3.2: Cluster Formation in Linked Cluster Algorithm.

- If a node not cluster head (non-CH) moves outside the clusters formed and not join to an existing cluster (moves out its cluster and does not enter into any existing cluster in the whole network) then it will become cluster head and form a new cluster.

LCC significantly improves the stability of clusters. So a not CH node when leave a cluster and go to other cluster then the re-election of cluster head in the cluster will not occur even if the node has the ability to be cluster head. But this algorithm has some disadvantages e.g. the cost of re-clustering is still a bit expensive, in the second case of clusters reconstruction, cluster structure reconstruction invoked when a single nodes movement and once this happens, the large communication overhead for clustering generate that overload the network.

In [58] proposed Adaptive Clustering Algorithm (ACA) for MANETs. In this algorithm the cluster head state uses only in cluster formation step. Once the clusters formed, the concept of cluster head disappears and the cluster nodes play the same role in the network. The authors motivation is that cluster heads can become bottlenecks and spend their resources faster than other nodes. This algorithm uses the same metric as the LCA algorithm (the lowest ID) for the CH selection and formed non-overlapping clusters. In cluster formation 3.3, each node maintains a set K which contains initially IDs of all its one-hop neighbors.

Indeed, if a node u has the lowest ID in K, than this node must broadcast its state (CH, member, unspecified) to all its neighbors. Upon receiving the status of a node u, the neighbors of u remove it from their set K. If u is cluster head, neighbors attaching to him if they were not members of any cluster or the CH which they were attached have an ID higher than u. The process continues until the set K of each node is empty. In cluster maintenance, each node must know its two-hop neighbors. As a result, he knows if the members of its cluster are two-hop to him. If the distance between two nodes in the same cluster becomes three hops, than cluster maintenance invoked. Therefore, to maintain the cluster two steps are required:

- Check if there is any member of my cluster has moved out of my locality.
- If Step 1 is successful, decide whether I should change cluster or remove the nodes not in my locality from my cluster.

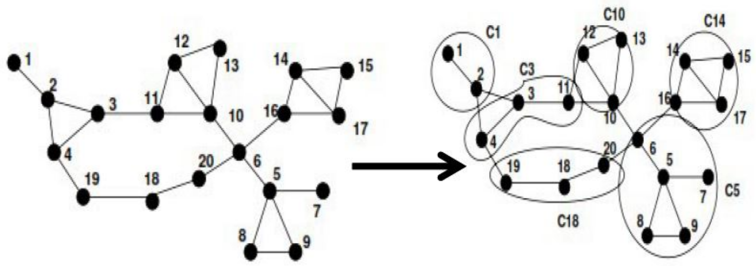


Figure 3.3: Cluster Formation in Adaptive Clustering Algorithm.

In [32] presented a self-stabilizing clustering algorithm for ad hoc networks. In this algorithm the node that has the highest ID among all its neighbors is elected as cluster head. The proposed algorithm satisfies the two following properties:

- Every node in the network must belong to a single cluster in order to form non-overlapping clusters.
- All nodes of a given cluster are at a distance at most one of their cluster head.

In cluster formation 3.4, all nodes exchange the HELLO packets periodically between each node and build their neighbors lists based on the received HELLO packets from other nodes. These HELLO messages are also used by each node to announce its presence. If a node does not receive a HELLO message from one of its neighbor during a period, it considers that this neighbor has disappeared. At the end of this period, each node will compare the neighbors IDs and looking for the highest ID neighbor within the same cluster. The node with the highest ID is elected as cluster head. The cluster head inform its neighbors of its status by broadcast a HELLO message. At the reception of this HELLO message which contains a CH status, all neighbors become member nodes. When a node remains within the transmission range of two cluster heads it becomes a gateway. At the end of the process each node must have one of the following statuses: cluster head, gateway or member node. In this algorithm, the cluster maintenance invoked in the following three cases: when new node appears, when a node disappears and when a node moves. Where two cluster heads become neighbors, the node with the lowest ID give up its role as CH and becomes a member node after it sends a HELLO message to their neighbors to inform them of its new status. Otherwise it conserves the cluster head status.

The self-stabilizing clustering algorithm based only on local knowledge, every node has only need to know only the list of its neighbors. This allows reducing the bandwidth consumption and avoiding the broadcast or multicast. In addition, this algorithm used a unique message in cluster construction process and its automatically adapts to topological changes. However, this scheme formed a number of clusters that relatively high in the whole network and the lowest ID metric for CH election keep the nodes CH status as cluster head for a long time as the result they quickly consume their energy.

3.2.1.2 Topology based clustering

High Connectivity Clustering (HCC) proposed by [37]. This algorithm is based on the degree of connectivity (number of neighbors node) to construct clusters, selects the node having the highest number of neighbors as cluster head. In cluster formation, initially, all nodes are not covered. Each node broadcasts the list of

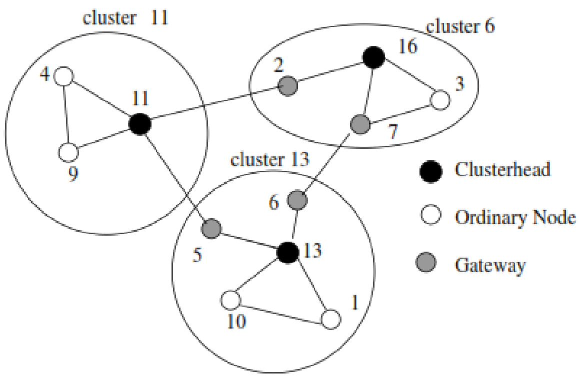


Figure 3.4: Cluster Formation in Self-stabilizing Clustering Algorithm.

nodes that can detect. If two nodes have the same degree of connectivity, then the node with the lowest ID becomes cluster head. Nodes belonging to several clusters play the role of gateway. HCC generates a limited number of clusters because it favors nodes with highest degree as CHs. In mobile environment, this algorithm produces cluster heads which are not likely to play their role as cluster heads for a long time because their degree change very frequently unlike the lowest ID algorithm where nodes with lowest ID keep their status as cluster head for a long time. However, the re-affiliation count of CHs is high due to node movement and the metric chosen for CH election. In addition, the degree of nodes increases, it gives less throughput because resources which are available to cluster head are shared between all its neighbors. So, CH becomes a bottleneck. Like LCA, this algorithm builds at the same time overlapping and non-overlapping clusters.

The clustering algorithms generate two types of clusters as the following overlapping and non-overlapping clusters. In overlapping clusters, a node can belong to several clusters. The disadvantage of schemes with overlapping clusters is that the re-affiliation of a mobile node of a cluster to another causes the restructuring of involved clusters and in some cases the restructuring of the whole network. To address this problem, schemes with non-overlapping clusters have been proposed in order to each node belongs to a single cluster. This allows limiting the cluster maintenance step at a single cluster in the re-affiliation of a node in a cluster to another.

In [92] proposed 3-hop Between Adjacent Cluster-heads (3hBAC). 3hBAC forms a 1-hop non-overlapping clusters structure with three hops between neighboring cluster heads by the introduction of a new node status, named cluster guest. Cluster guest is a mobile node that cannot directly connect to any cluster head, but can access some cluster with the help of a cluster member. It also defines a priority in the nodes declaration through an attribute called Head Priority (HP), HP can be one of the following values: set, declined, unset to indicate whether a node can serve as a cluster head or not. Initially all mobile nodes have an attribute HP fixed at the value UNSET. In cluster formation 3.5, each mobile node can get the information of its neighbors by HELLO message exchanges between them, including Node ID, Node Degree and Node Status. The nodes having the highest degrees declared as CHs and change its HP value to SET and its one hop neighbors attach it as members nodes (changes HP values to declined). The neighbor nodes of these members nodes and cannot directly connect to any cluster head declared as cluster guest. After the completion of the first cluster, the cluster formation can be performed in parallel in the network. For cluster maintenance, 3hBAC used the same procedure of cluster maintenance in the LCC algorithm. This algorithm keeps the adjacent cluster heads at least two-hops away. So:

- When two cluster heads move into the reach range of each other, one is required to give up its cluster head role, the cluster head with lowest degree give up its status and becomes a member node.
- When a non-cluster head mobile node moves out of the transmission range of all existing cluster heads, if it can still communicate with any member node in any cluster, it joins that cluster as a cluster guest.
- A merge function invoked to merge some cluster into a neighbor cluster. When a cluster head updates its member table, it will check whether its members connect with other cluster heads. And when it finds out that. all of its members can directly connect with some other clusters besides itself or can attach to other cluster heads as cluster guests, it give up its cluster head role, and that cluster head joins a neighboring cluster as a cluster guest.

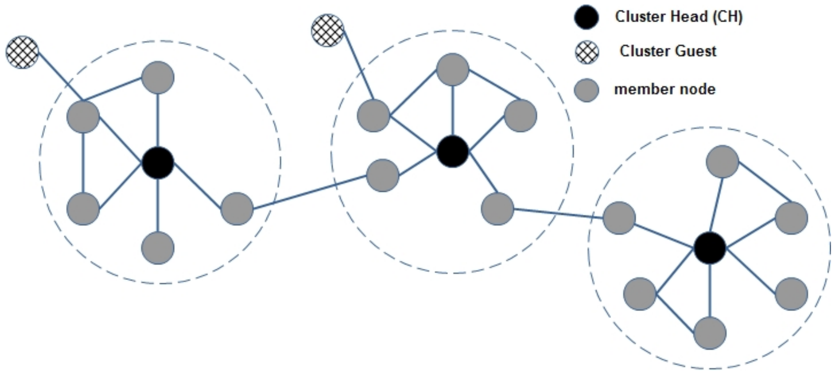


Figure 3.5: Cluster Formation in 3hBAC.

This algorithm reduces the number of CHs in the whole network (3-hop between the adjacent CHs), CHs and members nodes keep its status longer time and the merge function can eliminate some unnecessary clusters. However, this algorithm requires that each node maintains two tables: a neighbor table and member table that contain all member nodes of the network. This can be costly in terms of memory and exchanged messages.

In [40] proposed a new clustering algorithm in MANETs that named α-Stability Structure Clustering (α-SSCA). α-SSCA proceeded in three phases. The first phase consists to collect the information (such as neighbor nodes detection) necessary for CHs election by exchange HELLO message between neighbor nodes. The second phase consists to CHs election and clusters formation, this algorithm uses a score function as a metric for CHs election. This score function represents the number of neighbors which are not yet decided their states in the structure of clusters. The node that has the highest score in its neighboring is elected as cluster head. This metric is used to move away the CHs each other. Each node can take one of the following states: CH, member node, not-decided. Initially all nodes are in the not-decided state. As time progresses, each node tries to attach the cluster structure by taking one of the two final states CH or member 3.6. Finally, the final phase maintains the cluster structure changes in the network topology due to node movements. In α-SSCA the clusters maintenance phase is inspired from the LCC algorithm. It aims to improve the stability of the cluster structure. Two differences are detected between the LCC and α-SSCA.

The first is the metric used to elects cluster heads nodes. LCC uses the degree of nodes while α-SSCA uses the number of neighbors that not yet decided. The second difference is that α-SSCA more relaxed the condition for which a cluster head give up its role of cluster head when two cluster heads move into the reach range of each other. Indeed, the topology changes that may occur in the network can be divided into two elementary events: A mobile node can detect the presence of a new neighbor node or it can detect the loss of link with a neighbor exists. When one of these events occurs, the α-SSCA puts conditions for invoke the cluster maintenance process. This algorithm increase moderately the number of clusters with the aim of improving the topology stability of the clusters generated, and reduces the explicit information (overheads) introduced by the clustering algorithm.

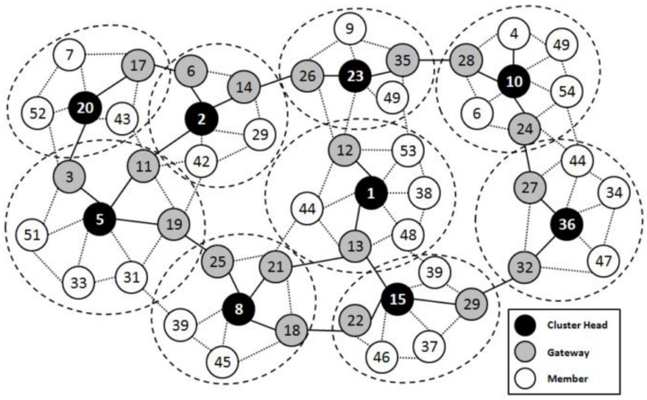


Figure 3.6: Cluster Formation in α-SSCA.

3.2.1.3 Mobility based clustering

In [11] proposed Lowest Relative Mobility Clustering Algorithm (MOBIC). This algorithm also based on the LCA algorithm but involves another metric [1] 3.7 which is the relative mobility of nodes as a criterion in the cluster head selection. The idea is to allow less mobile (low speed) nodes to play the role of cluster heads

[1] In Cluster formation, the authors propose an aggregate local mobility metric such that mobile nodes with low speed relative to their neighbors have the chance to become cluster heads

because they provide more stability. The relative mobility of a node represents the power levels ratio of successive transmissions received by a node from its neighbors. So the node having the lowest mobility in its neighborhood keeps a more stable neighborhood over the time and will be a good candidate to become cluster head. In cluster formation, all nodes broadcast HELLO messages periodically. Each node measures the received power levels of two successive HELLO messages exchange from every neighbor, and then calculates the pairwise relative mobility metrics using 3.2. Before sending the next broadcast packet to its neighbors, a node computes the aggregate relative mobility metric M using 3.3.

$$M_Y^{rel}(X) = 10log_{10}\frac{R_X Pr_{X\to Y}^{new}}{R_X Pr_{X\to Y}^{old}} \quad (3.2)$$

$$M_Y = var_0\Big(M_Y^{rel}(X_1), M_Y^{rel}(X_2), ..., M_Y^{rel}(X_m)\Big) = \Big[(M_Y^{rel})^2\Big] \quad (3.3)$$

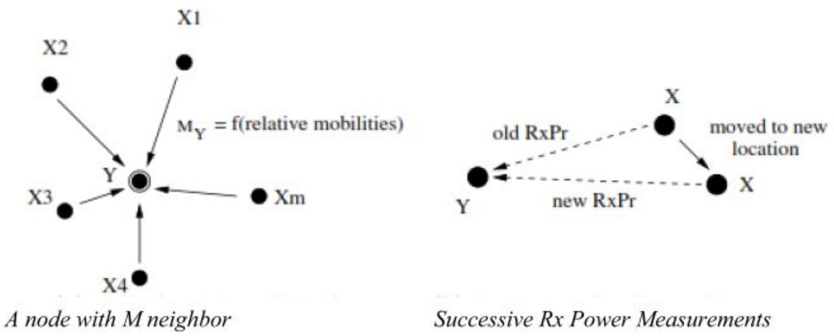


Figure 3.7: Aggregate Local Mobility Calculation.

After, every node broadcasts periodically its own mobility metric M (initialized to 0 at the beginning of operations) in a Hello message to its 1-hop neighbors. At receives the aggregate mobility values from its neighboring nodes, and then compares its own mobility value with those of its neighbors. The node that has the lowest value of M (aggregate relative mobility) amongst all its neighbors is elected as cluster head, otherwise it declares itself to be member node. If a node is a neighbor of two cluster heads, then it becomes a gateway node. If two neighboring nodes in a Cluster Undecided state have the same value of M, MOBIC resort to comparison of IDs and follow the Lowest-ID algorithm. MOBIC uses the same clusters maintenance procedure that LCC algorithm [18] but the authors adding an additional rule to minimize the cost of clusters maintenance, in which named CCI, is used to avoid unnecessary cluster head relinquishing. If two CHs are neighbors longer than the CCI time period, then one of the two will give up its cluster head status (the node that have the lowest mobility metric). Otherwise, they both keep the cluster head status. This mechanism reduces the CHs change by avoiding clusters maintenance once two cluster heads are in the same neighborhood. However, the limitations of LCC algorithm are not completely eliminated. In addition, MOBIC requires that nodes must be able to estimate the signal level with their neighbors to calculate the relative mobility.

In [52] presented a novel clustering algorithm, which guarantees longer lifetime of the clustering structure. The main idea in this algorithm is to estimate the future mobility of mobile nodes so as to select CHs that will exhibit the lowest estimated mobility in comparison to the other nodes. The mobility estimation of each node based on the stability of its neighborhood. For estimating the future node mobility, the authors used provably good information theoretic techniques, which allow on-line learning of a reliable probabilistic model for the existing node mobility. Then, by combining the mobility prediction scheme proposed in the algorithm with the highest degree clustering technique, the authors proposed a distributed algorithm that builds a small and stable virtual backbone over the whole network. This clustering algorithm ensuring good cluster formations that are highly resistant to node mobility, remain neighbors for sufficiently long time in each cluster. In cluster formation, each node u broadcasts the message CLUSTERHEAD(u) to its neighbors, when u has the highest weight among its neighbors, thus declaring its decision of being CH. Otherwise, u waits for the decision of all nodes having larger weight than its own weight and then it decides its own role (CH or member node). In cluster maintenance, this algorithm eliminates the problem of frequent CH changes that caused by node mobility, by allowing a node to become a CH or to affiliate with a new cluster without starting a re-clustering phase. In addition, this method does not suffer from the chain reaction effect [58] where local changes in cluster head roles may propagate over the network, and in case of re-clustering, the size of the affected area is effectively controlled.

In [66] proposed a mobility prediction-based clustering (MPBC) scheme for MANETs with high mobility nodes, where a node may change the associated cluster head several times during the lifetime of its connection. The basic information in MPBC is the relative speeds estimation for each node in the whole network. The Doppler shifts associated with periodically exchanged HELLO packets between neighboring nodes and a serial of mobility-based clustering strategies are used to estimate their relative speeds. MPBC divided into two stages: initial clustering stage and a cluster maintaining stage. In initial clustering stage, all nodes broadcast the HELLO packets periodically and build their neighbors lists based on the received HELLO packets from other nodes. When the network is rst established, all nodes are in the initial state, and the initial clustering is performed. The process can be described as follows:

- Each node estimates the relative speed of two successive HELLO message exchange from every neighbor and creates an entry for the corresponding neighbor in its neighbor list. The relative speed is updated each time when a new HELLO packet in received from the corresponding neighbor.
- Each node calculates its effective average relative speed based on the estimated relative speeds to the nodes in its neighbor list. After, every node broadcasts periodically its effective average relative speed included in the next HELLO packet to its neighbors. The effective average relative speed is updated based on the latest neighbor list and relative speed information.
- At receiving of the effective average relative speed values from its neighbors. Each node compares them with its own effective average relative speed. Nodes with lowest effective average relative speed in their own neighborhoods are selected as CHs. After, each CH broadcasts a CH announcement to its neighbor.
- If node u receives the CH announcements from one CH, it joins the CH. If node u receives the CH announcements from multiple CHs, it selects the CH that can provide it with the longest stay time.

In the cluster maintaining stage, the authors used the prediction-based methods to solve the problems caused by relative node movements, including the cases when a node is about to move out of the coverage area of its current CH, two CHs move into the reach range of each other, one is required to give up its CH role, and a CH is not qualified to keep serving its members. These approaches extending the connection lifetime and providing more stable clusters and guarantees the basic stability performance of the hierarchical network structure.

3.2.1.4 Energy based clustering

In [56] proposed multicast power greedy clustering (MPGC). MPCG based on heuristic in order to reduce the energy consumption and prolong the lifetime of the network. The authors assume that each node can control its signal level transmission and each node must have several transmission levels. In Cluster formation, MPCG run in three consecutive phases: beacon phase, greedy phase and recruiting phase.

- *In beacon phase*, each node sends a signal beacon with the highest power in order to inform its neighbors of its presence. Upon receiving the signal beacon, each node collects the information of its neighbors.
- *In greedy phase*, each node send a statement of cluster head with the level of power required to reach its nearest neighbor , then increases its power level step by step until it reaches all its neighbors. In this phase, each node determines its power level adaptation about this greedy heuristic.
- *In recruiting phase*, each node has the information about the residual power of its neighbors. If the node u has the highest residual power among all its neighbors, then u is elected as cluster head in its neighborhood.

The cluster maintenance invoked in MPCG when:

- The cluster head drains its energy (low battery capacity) then the node member with the highest battery capacity in this cluster will take over the cluster head role.

- Two cluster heads are close to each other within their transmission rang then the cluster head with the less battery capacity give up its cluster head role and joins the cluster.

- Non-cluster head moves or leaves into the non-covered zone, a node cannot hear any cluster head in the zone, it declares itself as a cluster head.

This scheme does not suffer from the chain reaction effect where local changes in cluster head roles may propagate over the network and prolong network lifetime. However, it requires several steps to construct the clusters structure that increases network traffic and bandwidth consumption in the network.

In [46] proposed Flexible Weighted Clustering Algorithm based on Battery Power (FWCABP) for MANETs. FWCABP maintain stable clusters by keeping a node with weak battery power from being elected as a cluster head, minimizing the number of clusters, and minimizing the clustering overhead. This algorithm differs from others in that it is based on the clusters size and it battery power for the maintenance phase. In cluster formation, each node broadcasts a beacon message to inform its neighbors of its presence. A beacon message contains the state of the node. Based on the beacon messages received each node builds its neighbors list. The CHs election is based on the weight values like the degree of nodes, distance summation to all its neighboring nodes, mobility and remaining battery power, the node having the lowest weight in its neighborhood is selected as CH. In cluster maintenance, FWCABA called the maintenance algorithm in two cases: when the node movement to the outside of its cluster boundary and when CHs battery power reaches or goes a predefined battery power threshold value. However, FWCABP increases network traffic when the cluster head election process that degrade network performance.

In [31] proposed Enhance Cluster based Energy Conservation (ECEC) algorithm. ECEC is an energy efficient topology control protocol for MANETs which ensures minimum connectivity in the network at all times in order to decreases network traffic. The authors presented a new topology control protocols that extend the lifetime of large ad hoc networks while preserving connectivity, the ability for nodes to reach each other and conserve energy by identifying redundant nodes and turning their radios off. In cluster formation, each node broadcasts a discovery message in order to elect CHs and gateway nodes. Afterward, the nodes mobility prediction is performed. This mechanism utilizing the location and mobility information provided by GPS in order to estimate the node mobility in the whole network. While forming clusters, ECEC first elects CHs, then elect gateways to connect clusters. If a node sees that it has the highest energy among all its neighbors it declares itself as a cluster head and broadcasts CH message. After that gateway node selection performed. The cluster formation process continues until all nodes in the network attached to its clusters.

3.2.1.5 Wight based clustering

In [28] proposed a Flexible Weight Based Clustering Algorithm (FWCA) in MANETs. FWCA have the flexibility of assigning different weights and takes into account a combined metrics to build clusters automatically. In cluster formation, the authors used metrics like the node degree, remaining battery power, transmission power, and node mobility for CHs election process. Subsequently, each node maintains a counter to count the number of nodes inside a cluster. Finally, this algorithm produces stable clusters with a lowest number of cluster heads, minimize the number of re-affiliations and maximize the lifetime of mobile nodes in the whole network. In cluster maintenance, FWCA based on the clusters capacity and it used the link lifetime instead of the node mobility because the link stability metric affects the election of a CH as much as the node mobility metric.

In [1] proposed Score based clustering algorithm (Sbca) for MANETs. Sbca achieve several goals like minimize the number of clusters and to maximize lifespan of mobile nodes in the network. This algorithm used a combination of four metrics to calculate the node score, these metrics are: battery remaining (B_r), the node degree (N_n), number of members (N_m) and stability of node (S). The score of node u is calculated as:

$$Score = \Big((B_r \times C_1) + (N_n \times C_2) + (S \times C_3) + (N_m \times C_4)\Big) \tag{3.4}$$

Where C_1, C_2, C_3, C_4 are constants factors with $\sum_{i=1}^{4} C_i = 1$, and B_r represents the residual node's energy. N_n: The Number of existing neighbor nodes. S: The

total time in which the neighbors of a specific node have spent their time beside the node. N_m: Set of nodes that is handled by each cluster head.
The node stability is calculated using the following equation:

$$S = \sum_{i=1}^{n} \frac{TRF}{TRL} \tag{3.5}$$

Where TRF is the time of the first packet reception and TRL is the time of the last packet reception.
The cluster formation process can be described as follows:

- Each node calculates its score according to score equation above and broadcast it to its neighbors by sending Score-Value message.
- At the reception of Score-Value packets, each node updating its neighborhood table.
- Each node checks its neighborhood table. A node u is elected as cluster head, if u has the highest score among all its neighbors. After, each CH elected announces its status by broadcasting a MY-CH message to its neighbors.

However, the authors not explain the behavior of the algorithm in case of topology change (the cluster maintenance). Although, Sbca generates less clusters than WCA but it does not solve the limitations of WCA.

In [64] proposed An efficient weight-based clustering algorithm (EWBCA) for MANETs. Its objective to improve the usage of scarce resources such as bandwidth and energy in order to produces stable clusters, minimize routing overhead, and increase end to end throughput. In EWBCA each node has a combined weight that indicates its suitability for electing as a cluster head. This combined weight is calculated according to following four metrics: Number of Neighbors, Battery Residual Power, Stability and Variance of distance with all neighbors. In this algorithm each node in the following state: NUL, CH, member node, getaway node. Initially all nodes are in the NUL state. In cluster formation:

- Each node broadcast a HELLO message, at the reception of HELLO messages, each node finds its neighbors and updating its neighborhood table.

- After, each node calculates its combined weight and broadcast it to all its neighbors by sending a $Weight_EWBCA$ message.
- Upon reception of $Weight_EWBCA$ messages, a node u compares the received weights of all its 1-hop neighbors with its own weight and the node with highest combined weight is elected as cluster head and broadcast a Be_CH_EWBCA message to its neighbors.
- Upon reception of Be_CH_EWBCA message each node join to the favorites cluster.
- All nodes in the network periodically broadcast a HELLO message to inform their 1-hop neighbors from their current states.

In cluster maintenance, there are two situations that invoke when:

- When a node moves outside of its cluster boundary: each node moves or leaves an existing cluster at a time, the status of the node should be updated again. Even if it does not find a new cluster head then the node declare itself as a cluster head and formed a new cluster.
- Excessive battery consumption at a cluster head: if a battery power of cluster head reaches or goes a predefined battery power threshold value then the new cluster head is determined and this cluster head give up its CH role and becomes an ordinary node.

3.2.2 k-hop clustering schemes

3.2.2.1 Identifier neighbor based clustering

In [4] proposed a heuristic called Max-Min D-cluster in order to build D-clusters[2] non-overlapping, where D is the parameter of the heuristic. This algorithm uses the node ID as a metric for cluster head election. The algorithm is divided into four phases. In the first phase, each node broadcasts its ID to its three-hop neighbors, collects their IDs and keeps the highest IDs. Then it broadcasts again to its neighbors during the second phase. In the second phase, each node keeps the

[2]That are up to d-hops away from a cluster head

lowest IDs received in this phase (the lowest among the highest). The third phase consists the choice of cluster head based on the IDs saved in the two preceding phase. If a node u received its ID in the second phase, it becomes cluster head. Else, if u received an ID during each phase 1 and 2, it chooses the node with this ID as a cluster head. Otherwise, u elects CH that having the largest ID in its D-hop neighborhood. In the last phase, the gateway nodes broadcasts a converge cast message to link all nodes of the cluster to the cluster head and link the cluster head to other clusters. This algorithm produces a robust structure of clusters. However, the duration of cluster formation is significant. In addition, this algorithm needs an important information exchange to elect the cluster heads that increases the overhead in the network.

In [67] proposed an algorithm that constructs k-hop clusters (k-clusters) by generalizing the ACA algorithm [58]. Each node needs to know its k-hops neighbors. A node u that has lowest ID among all its k-hop neighbors becomes cluster head. When all nodes in its k-neighborhood having a smallest ID than him (node u) then these nodes broadcast their decision to be cluster head or attach to another cluster head. So, if any of these nodes is declared cluster head then u declares itself as CH and broadcasts this decision to its k-hop neighbors. Otherwise, u attaches to the CH with the lowest ID. The maintenance phase is the same that used in [58] by taking into account the cluster radius. The cluster maintenance invoked when a node joins or leaves the network, a link is disconnected, and a link between two existing nodes is formed after they moved closer to each other. However, we always find the same disadvantages of the algorithms generating 1-hop clusters [58], i.e. a small change in the network topology can cause a restructuring of the whole network.

3.2.2.2 Topology based clustering

In [77] proposed Associativity-based Cluster Formation and Cluster Management in Ad Hoc Networks. The authors introduced a new metric they call associativity which represents the relative stability of nodes in their neighborhood. For each node, the associativity records and accounts the time that each node in its neighborhood still effectively in its neighborhood and in fact the sum of each neighbor. At every time, a node u considers what are its current neighbors are already present in the previous period and adds one to the value associated to each of them. When a neighbor disappears, its associativity value is reset to zero. Otherwise, when a neighbor appears, it takes the value one. At each period of time, the associativity of u is the sum of the values associated to each of its neighbors. This value therefore takes into account the stability[3] of u and the degree of nodes. In cluster formation, a node considers the nodes of its k-neighborhood having a degree higher than a threshold value and elects the node that have the highest associativity in its neighborhood as cluster head. In the case of equality, u selected the node having the highest degree and if still in the same case of equality, than the node with the lowest ID will be elected as CH. This algorithm produces overlapping k-clusters which remains stable over a long period of time.

In [57] presented vote-based clustering (VC) algorithm in mobile ad hoc networks. VC used node location information, ID information and battery time information metrics in cluster head election process. The cluster heads elects based on vote function that is the weighted sum of the normalized number of valid neighbors and it is normalized remaining batter time. The node having the higher vote than its neighbors will be selected as a cluster head. The cluster formation process as the follows:

- Each node broadcasts HELLO messages periodically between neighbor nodes in order to announce its presence and build their neighbors lists based on the received HELLO messages from its neighbors.
- After, each node counts how many HELLO messages it can receive during a HELLO period and considers the number of received HELLO messages as its number of neighbors.
- Each node calculate its vote value with following vote function:

$$Vote = W_1 \times \frac{n}{N} + W_2 \times \frac{m}{M} \tag{3.6}$$

W_1, W_2: Weighted coefficient of location factors and battery time respectively, n: Number of neighbors, N: Network size or the Maximum of mem-

[3] If u is relatively stable in its neighborhood it will have a high associativity

bers in a cluster, m: Remaining battery time, M: The maximum of remaining battery time.

- Each node broadcasts its vote value in the next HELLO message. Upon the reception of vote values, a node u compares the received vote values of all neighbors with its own vote value and the node with highest vote value is elected as cluster head. In case of vote values equality, the node with lowest ID is elected as CH and broadcast a CH message to its neighbors.

After, the authors proposed an adaptive cluster load balance method. This approach used when the number of member nodes of a CH is more than a balance threshold that CH becomes a bottleneck, neither of new coming mobile nodes will be permitted to participate in the current cluster. VC can get load balance between various clusters. Thus, resource consumption and information transmission will be distributed to all clusters, not only to some certain clusters that produce a good resource management. In addition, the consideration of battery lasting time can help us to get a stable cluster structure.

3.2.2.3 Mobility based clustering

In [30] proposed Mobility-based d-hop clustering algorithm (MobDHop) in MANETs. MobDHop divided the network into d-hop clusters based on mobility metric. The objective of creating d-hop clusters is to supports larger than one-hop radius clusters and make more flexible, reducing the number of cluster heads in the CHs election phase. The metric used is relative mobility that estimated by the signal strengths of received packets. So this algorithm based on mobility metric and the diameter of a cluster is adaptable with respect to node mobility. For each two node, this algorithm estimates their relative mobility based on the variation of the measured distances between the nodes over time. The distance between two nodes is estimated using the signal strengths of the received packets that exchange by nodes in the whole network. In MobDHop the cluster formation[4] process is divided into two stages, namely: Discovery Stage and Merging Stage.

[4] In cluster formation MobDHop need to calculate five parameters as the following : the estimated distance between nodes, the relative mobility between nodes, the variation of estimated distance over time, the local stability, and the estimated mean distance.

The discovery stage is an initial setup stage for two-hop clusters when the network is first initialized. The steps of this stage as following:

- All nodes periodically broadcast HELLO messages, including their local stability value that initialized to infinity at the beginning of operation.
- Each node measures the received signal strength of every received HELLO message and estimates the distance with each its neighbor.
- Each node calculates the relative mobility with its neighbor upon receiving at least two successive HELLO messages.
- In this step all nodes in the whole network has the complete knowledge of its neighborhood, each node calculates its local stability value. Then, it broadcasts this local stability value in the next HELLO message.
- At receiving of local stability values from the neighbors, each node compares its own local stability value with those of its neighbors. If a node has the lowest value of local stability among all its neighbors, it declares itself as a cluster head. Otherwise, the node with lowest value of local stability among all its neighbors becomes cluster head.

After the discovery stage, all nodes are covered by two-hop clusters. The Merging Stage started among clusters in order to merging either individual nodes or other clusters into it when:

- A non-cluster head node requests to join the neighboring clusters.
- Two neighboring gateways request to merge their clusters.

The cluster maintenance process invoked in two cases when a node switches on and joins the network and when a node switches off and leaves the network. When a node switches on, it will initiate the merging process and chooses the neighbor with lowest variation of distance, and joins its cluster. When a node switches off and the node is a cluster head, the discovery stage will initiate in which a new cluster head will be elected.

MobDHop group the mobile nodes with similar speed and direction in the same cluster. This scheme is used to make more stable non-overlapping cluster and produce a low overheads in the network.

In [66] proposed Speed Estimation and Stay Time Prediction Clustering (SESTP) in MANETs. Due to node movement and unstable radio channel, the network topology may change frequently. These changes will cost bandwidth to transmit a great amount of control messages to update the routing table in every cluster head. SESTP focus on providing stable cluster structures, specifically for highly mobile ad hoc networks. Thus, the stability of available wireless communication connections is one of the most important concerns in this scheme. SESTP based on two algorithms that a relative speed estimation algorithm and a stay time prediction algorithm. The Doppler shifts associated with periodically exchanged Hello packets between neighboring nodes are used to estimate the relative speed between cluster head and cluster members. With the estimated speed, a node can predict its stay time in every nearby cluster. A node may only play one of the following three roles at any moment: cluster head, cluster member or undecided. This clustering scheme divided into two stages. Initially, all nodes have an undecided status. In the initial clustering stage a node joins a cluster that can provide it with the longest stay time in order to reduce the number of re-affiliations and the procedure of cluster formation as following:

- Each node in the undecided status periodically broadcasts HELLO messages twice in a time interval T, including their ID.

- Upon receiving the HELLO messages, each node i calculates the Regional Average Relative Speed with RARS function above and broadcast this to its 1-hop neighbors in a Regional Average Relative Speed message.

  The RARS of node i can be defined as:

$$v_{i-RARS} = \sum_{j=1}^{k} v_{ij} \tag{3.7}$$

  Where: k is the number of neighbors, v_{ij} is the relative speeds that stored in node i (the relative speed between i and its neighbors).

- At receiving the RARS messages, each node compares its own RARS value with the RARSs of its neighbors. If its own RARS is the smallest, it declares itself to be a cluster head. Otherwise, the node with lowest value of RARS among all its neighbors becomes cluster head. After, the cluster head elected broadcast a Cluster Claim message.
- Each node i receives a Cluster Claim message. If wishes to join the cluster then it sends a Join Request message to the corresponding cluster head, then this last sends an Accept message.
- The node i join the cluster and periodically broadcast a Cluster member message to notify its presence to the cluster head.

The cluster maintenance process invoked in two cases. First, the time varying radio channel may make the received signal strength under the minimum requirement. Second, a node may have moved out of its previous cluster when a packet should be transmitted. SESTP build stable cluster structure. However, because the speed estimation algorithm needs enough rounds to achieve the required accuracy and additional exchanged packets that overloaded the network and cost more energy.

3.2.2.4 Energy based clustering

In [91] proposed a distributed energy-efcient clustering approach for ad hoc sensor networks called HEED (Hybrid Energy-Efcient Distributed clustering). HEED achieves a connected multi-hop inter-cluster network when a specied density model and a specied relation between cluster range and transmission range hold. Its a hybrid clustering scheme that periodically selects cluster heads based on their residual energy. The nodes that have the highest residual energy metric are elected as cluster heads. This scheme used a secondary metric in cluster heads election process such as node proximity to its neighbors or node degree when two cluster heads move into the reach range of each other, when two nodes in the same zone contain the same value of residual energy and when a node falls within the range of more than one cluster head. This secondary metric called also the communication cost metric. In cluster formation, HEED divided into three phases:

- *Initialization phase:* In this phase, the algorithm first sets an initial percentage of cluster heads among all nodes. C_{prob} is the percentage value that used to limit the initial cluster head announcements to other nodes. Each node calculate its probability of becoming a cluster head CH_{prob} as follows:

$$CH_{prob} = C_p rob \times \frac{E_{residual}}{E_{max}} \tag{3.8}$$

  Where $E_{residual}$ is the estimated current residual energy in the node, and E_{max} is a reference maximum energy, which corresponds to a fully charged battery. CH_{prob} is not allowed to fall below a certain threshold p_{min} , which is selected to be inversely proportional to $E_m ax$.

- *Repetition phase:* Each node executes several iteration until if finds the cluster that it can transmit to with the least transmission power (cost). When a node cannot hear any cluster head in its neighborhood, it declares itself as a cluster head and broadcast a cluster head message to its neighbor informing them about the change of status. After, each node duplicates its CH_{prob} value and goes to the next iteration of this phase. A node stopped the execution of this phase when its cluster head its CH_{prob} reaches one (value 1). Therefore, there are two types of cluster head status that a cluster head node broadcast it to its neighbors:
  - *Tentative status:* if its CH_{prob} is less than one, in this case this node changes its status and become regular node at a later iteration if it finds a lower cost cluster head.
  - *Final status:* if its CH_{prob} has reached value one.

- *Finalization phase:* is the last phase in HEED cluster formation, each node makes a final decision on its status. It either picks the least cost cluster head or pronounces itself as cluster head.

HEED has several advantages, its distribute energy consumption to prolong network lifetime, minimize energy during the cluster head election process, minimize the control overhead of the network, fault tolerance, and load balancing. At first glance, HEED is most suitable by taking into account the residual energy of nodes in cluster heads election process for wireless sensor networks with heterogeneous residual energy.

3.2.2.5 Weight based clustering

In [55] presented a novel clustering scheme that named k-hop Compound Metric Based Clustering (KCMBC). KCMBC uses the node degree and node mobility jointly in cluster head election process. This scheme improve the network performance by generates a robust and scalable cluster structure for a dynamic and large scale ad hoc network. It uses a combing multiple metric that node degree and node mobility to elect cluster heads of k-hop clusters. According to velocity change frequency, KCMBC dynamically adjusts the period of broadcasting node location information, which eliminates redundant transmission that decreases the network overhead. In this scheme the nodes in the same area are collected in the same cluster. This strategy is able to include all members in a cluster and does not lose any member located on the cluster border. Last, an efficient mechanism is presented to maintain the cluster to deal with node activation and deactivation, which can substantially enhance the cluster stability.

In cluster formation 3.8, KCMBC applies the similar cluster formation procedure as that used in the Max-Min scheme but KCMBC takes into account the highest connectivity, host mobility and host ID to elect cluster heads.

The cluster formation in KCMBC scheme as the following:

- Each node periodically exchange HELLO messages with its neighbors. After, each node calculates the link expiration time for every link to its neighbors.
- Each node calculates the average link expiration time T_i (the mobility metric) and broadcast it in the next HELLO message to its k-hop neighbors.
- The average link expiration time T_i of each node i and the number of direct neighboring nodes are used to select cluster head candidates if and only if the average link expiration time $T_i > T_{alt}$ and node i has a highest degree.

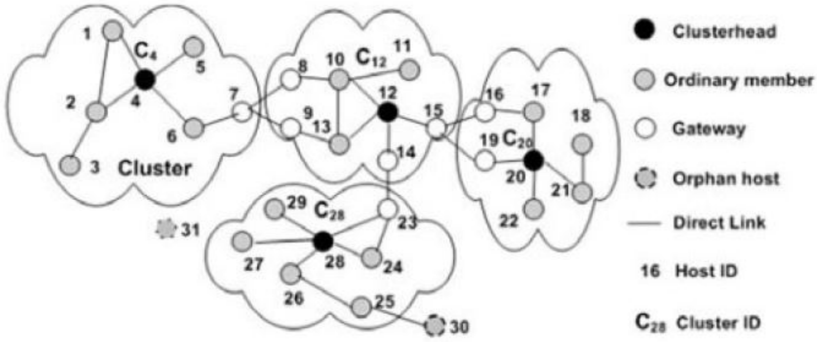


Figure 3.8: Cluster Formation in KCMBC.

Where T_{alt} is the mobility threshold that equal the average link available time in the whole network. In this case, the cluster structure becomes stable.

- Each node has selected as cluster head candidate, it then uses a compound metric $CP_i = (d_i, T_i, i)$ to compete the role of cluster head within its k-hop neighborhood that selected as cluster head candidate.
- After, each cluster head candidate contains a metric called the winning metric. Initially, each cluster head candidate sets its winning metric to its own compound metric, and non-cluster head candidates u set their winning metric to $CP_u = (0, 0, 0)$.
- Every node broadcasts the winning metric to its neighbors. Upon receiving the winning metrics, the Floodmax[5] process invoked and each node in k-hop neighbors updates the winning metric by the largest winning metric that it has received in order to ensure that all k-hop neighbor nodes have the same maximum winning metric for the cluster.
- After k rounds of Floodmax, a node takes k rounds a Floodmin (with one-

[5]Floodmax is a greedy algorithm and may result in an unbalanced loading for cluster heads, the minimal metric in the second rule is used to ensure fairness and distribute the load evenly among selected cluster heads.

hop broadcasts) to propagate the smallest winning metrics. The Floodmin allows that the candidates with smaller metrics have chance to construct their clusters. Again, each node records new winning metric after each broadcast round, which is the smallest value among its previous winning metric and the winning metrics received in this round.

- A node is elected as cluster head when:

  1. Its own ID can be received during Floodmin processes.
  2. It has the maximal metric in k rounds of Floodmax.
  3. Can nd that the same node IDs occurs at least once as WINNER in both Floodmax and Floodmin, the one with the minimal metric. Here, WINNER represents the node that has the winning compound metric for a round of Floodmax or Floodmin.

The cluster maintenance procedure is important to keep a stable cluster structure. KCMBC includes an effective mechanism in cluster maintenance to cope with node/link activation and node/link deactivation. Node/link activation occurs when a node join to new cluster and node/link deactivation occurs when the node leaves from its cluster or its power is switched off.

In [81] proposed cluster-based multi-source multicast routing protocol (CBMRP) in MANETs, which achieve efcient multicasting in the multi- source multicast environment. In order to structure nodes and maintaining local topology the authors used a weight-based clustering algorithm. CBMRP maintain stable clusters by keeping a node with highest weight metrics from being elected as a cluster head, minimizing the number of clusters, and minimizing the clustering overhead. The cluster-based multicast route construction prevents the ood (broadcast) of control messages and provides robustness against node mobility. A node may only play one of the following three roles at any moment: cluster head, cluster member multicast member, cluster member not multicast member, undetermined multicast member or undetermined not multicast member. Initially, all nodes have an undetermined not multicast member status. The cluster formation 3.9 divided into three procedures: Clustering procedure, Become Head procedure, Cluster Join procedure.

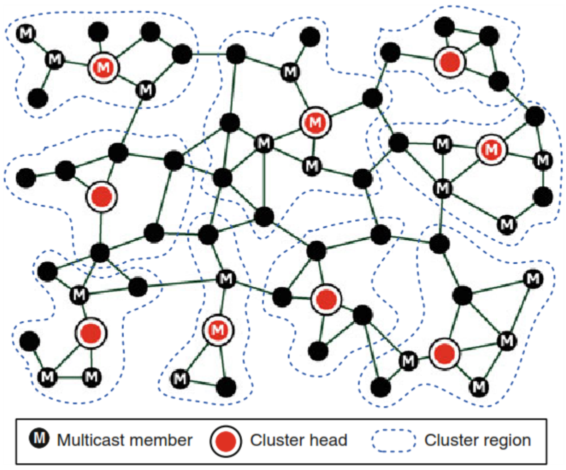


Figure 3.9: Cluster Formation in CBMRP.

In the clustering procedure, each node periodically exchange HELLO messages with its neighbors to update the cluster information. Upon receiving HELLO messages each node u calculates the weight value based on the weight function *W(u)* 3.9 and broadcast it.

$$W_u = 3 \times t(u) + 2 \times s(u) + r(u) + [status(u) = undetermined - multicastmember] \tag{3.9}$$

Where *t(u)* is the number of one-hop neighbor of node u whose statues are undetermined multicast member, *s(u)* is the number of 2-hops neighbor of node u whose statues are undetermined multicast member, *r(p)* is the number of neighbors of u within two hops whose statuses are undetermined not multicast member. After, the weight value calculation is done, each node compares the weight value with its neighbors within two hops for cluster head election process. The node which has the highest weight value will declare itself as a cluster head and proceed with the Become Head procedure.

In Become Head procedure, each cluster head selected in clustering procedure notify its neighbors by broadcasting a HEADANNOUNCE message in order to join the cluster and update their status. In Cluster Join procedure, each node with undetermined status receives a HEADANNOUNCE messages, it sends a JOINHEAD message to the corresponding cluster head for joining the cluster.

CBMRP is able to adapt to topology changes without incurring large overhead or losing performance. In order to preserve the performance of the network, the authors consider the following situations for cluster maintenance mechanisms to maintain the cluster structure.

- When a new link appears: a new node may join the network after the clustering procedure is nished.
- When Link failure: link failure between two nodes belong to the same cluster, in this case the topology of the cluster would be changed.
- When Cluster head retirement: the number of cluster head in the network may increase constantly and may tend to create clusters of small size. Too many clusters of small size may cause the cluster structure become unstable and increase maintenance overhead, thus degrading the performance of routing. In this scheme a retirement mechanism for cluster heads that can make some unsuitable cluster heads become member nodes and then join neighboring clusters. Thus, the performance of the network can be kept.

CBMRP reduce the number of cluster in the whole network that build stable and non-overlapping clusters structure and incurs less maintenance overhead. However, this scheme requires more information during the cluster formation phase that increases the network overhead.

3.3 Virtual backbone based schemes

The virtual backbone is one of the main approach used to optimize the network communications and the scalability issue in MANETs. This virtual structure is created to support the network services such as routing, broadcasting, and to optimize the usage of resources.

In last few years, many virtual backbone schemes have been proposed for MANETs [3, 6, 24, 39, 89, 94, 5]. We propose to classify these schemes into two main categories depending on the type of the building structure: Tree-based or dominating sets-based. In Tree-based virtual backbone schemes, the virtual backbone formed by a spanning tree structure. This spanning tree contains a set of nodes that cover all the network nodes which is responsible for the network services such as routing, multicast, broadcast and security issues [75]. In dominating sets-based virtual backbone schemes, a set of nodes named dominating sets which covers the whole network. The connectivity between the nodes in the dominating set (Connected dominating set) forms the virtual backbone. Moreover, each member node must have at least a one hop neighbor in the backbone. The dominating sets-based virtual backbone schemes are divided into three main classes: centralized-based, distributed-based and robust-based [94] as shown in Figure 3.10.

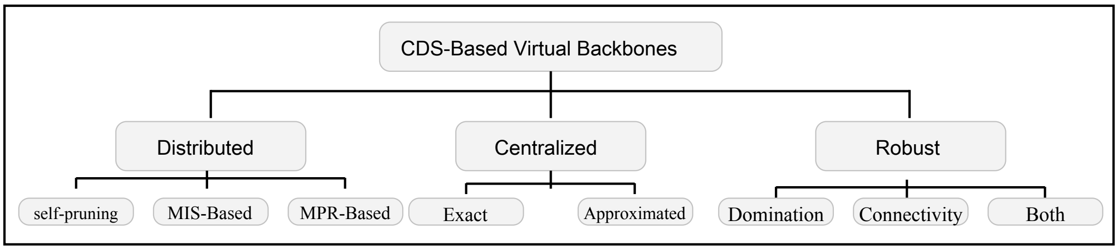


Figure 3.10: Virtual Backbone Schemes Classification

Combining the possible features, each proposed virtual backbone scheme attempts to accomplish a specic objective. In [39], proposed two polynomial time approximation schemes for minimum connected dominating set ($MCDS$) problem which they based on finding a connected dominating set of minimum size. These schemes are centralized-based. The first scheme is characterized by a greedy algorithm which has the approximation ratio of $2\ (H(\triangle) + 1)$ where $\triangle$ is the maximum degree and H is the harmonic function. This scheme builds a spanning tree T based on four main steps. The node with the highest degree is selected as the root T. Initially, all nodes are marked with white. After, the node with the largest number of white neighbors is marked as black and its neighbors are marked as grey. The black and grey nodes then become members of T. The algorithm repeats until no white node exists in the network. The non-leaf nodes of T form the CDS (the black nodes). The second scheme is an enhancement of the first scheme. It is divided into two phases. During the first phase, the algorithm nds a dominating set. During the second phase it connects the dominating set using Steiner tree algorithm [94]. The approximation factor of this algorithm is $H(\triangle) + 2$ with a ratio of $3 + ln(\triangle)$.

In [89] proposed a distributed pruning-based algorithm for calculating connected dominating set in MANETs. The proposed scheme is based on the two hops neighbors information knowledge. This algorithm uses a marking process where each node marks itself as a *CDS* member if it has two unconnected neighbors. This algorithm creates a virtual backbone but adds many redundant nodes. The authors presented an enhancement of this algorithm by adding two dominant pruning rules named marking rules. These rules reduce the size of the *CDS* by removing some redundant *CDS* members.

In [24],proposed an extended and generalization version of [89] in order to reduce the size of the dominating set in the network. The proposed dominant pruning rule referred to as Rule k which extended the *pruning rules* [89] to k-hop neighborhoods in order to achieve better results.

In [3] proposed a distributed approximation algorithm to construct a Minimum Connected Dominating Set (*MCDS*) for MANETs with a constant approximation ratio and linear time/linear message complexity. This algorithm is divided into two phases. During the first phase, a Minimum Independent Set (*MIS*) is constructed using the *2*-hops neighbors information where the node with smallest ID in its neighborhood is selected as *MIS* member and it changes its status to a dominator node. Therefore, its neighbors become dominate nodes. During the second phase, each dominator is responsible for identifying a path to connect its neighbors *MIS*. Each dominator is connected to all dominator's within three hop distance. The connecting nodes between any pair of dominator's (*MIS* members) that are at most three hops away from each other are referred to as connectors. Both of the dominator and connector nodes form the *CDS*.

In [6] proposed a Distributed Scenario-based Clustering Algorithm (*DSCAM*) for Mobile ad hoc networks which is an enhancement of The Scenario based Clustering Algorithm (*SCAM*) [5]. *SCAM* Algorithm is a centralized solution which requires knowledge of the whole network topology and is suitable for wired, sensor networks and ad hoc networks with small number of nodes and limited mobility. The main objective of *DSCAM* algorithm is the creation of stable clusters in large network with high nodes mobility. These clusters remain stable as long as possible which avoids frequent CHs re-election process and reduces the total overhead. The *DSCAM* is divided into two main phases, the first phase is the clustering setup and the second phase is the cluster formation. The clustering setup phase is designed to select in a distributed manner the optimal *(k, r)*-dominating set in the network in order to build the virtual backbone, where k represents the minimum number of cluster heads per nodes and r is the maximum distance between member nodes and their cluster heads. During the first phase, each node elects k nodes with the highest residual battery power within the r-hop distance. The elected k nodes by each node are nominated to be members of the Dominating Set (DS). After that, the DS-Computation algorithm is invoked to select the optimal number of dominating nodes from the nominated dominating set (select *(k,r)-DS* to build the virtual backbone). The selected *(k,r)-DS* nodes are potential candidates during cluster heads election process. During the cluster formation phase, each node from *(k,r)-DS* (each node selected as dominating) calculates its quality value based on five metrics: node degree, battery power, transmission rate, mobility, and connectivity. Then it broadcasts this value to its r-hop neighbors. After receiving the quality values, each member node elects the node with the maximum quality value as its CH from the k-CHs and this process is repeated until all member nodes select their CHs. *DSCAM* improves the network scalability by the proposed r-hop clusters and multi cluster heads approaches (cluster head redundancy with the parameter k), reduces the total overhead using the backbone mechanism, and ensures an acceptable clusters stability.

3.4 Comparison of topology management schemes

3.4.1 Cluster-based schemes comparison

As we describe in sections 3.1 and 3.2, there are many cluster-based schemes for MANETs available in the literature. To evaluate these schemes, we have to decide about the metrics to use for the evaluation. Based on our review in 3.1 and the work presented in [93, 33], we summarize [12] the comparison in Table 3.1. We can observe that the total overheads increase when clusters number is high and CHs change frequently. The weight based clustering scheme performs better than identifier neighbor based, topology based, mobility based and energy based clustering. The weight based clustering scheme is the most used technique for CH election that uses combined weight metrics such the node degree, remaining battery power, transmission power, and node mobility etc. It achieves several goals of clustering: minimizing the number of clusters, maximizing lifespan of mobile nodes in the network, decreasing the total overhead, minimizing the CHs change, decreasing the number of re-affiliation, improving the stability of the cluster structure and ensuring a good resources management (minimize the bandwidth consumption).

3.4.2 CDS based Virtual backbone schemes comparison

The main two major problems of CDS-based virtual backbone scheme are: time and message complexities required to find a subset $DS \subset V$ from the whole graph $G\ (V,\ E)$. Finding such subset of nodes is NP-hard problem [27]. To analyze that, Table 3.2 summarized the time and messages needed to find an optimal DS in the three approaches: centralized, distributed and robust (see Figure 3.10).

3.5 Recap of key points

- Clustering is the most convenient way to solve the critical scalability issue in MANETs, where it can provide a large scale MANETs with a hierarchical network structure and robust when topology change occurs caused by node mobility, node failures, and node insertion or removal (move or leave). Since a flat structure cannot guarantee performance of a large scale MANETs. Many clustering scheme have been proposed to solve the scalability issue.

- MANETs clustering is the process that divides the network into interconnected substructures, called clusters. Each cluster has a particular node elected as cluster head (CH) based on a specific metric or a combination of metrics such as identity, degree, mobility, weight, density, etc. The cluster head plays the role of coordinator within its substructure. Each CH acts as a temporary base station within its cluster and communicates with other CHs . A cluster is therefore composed of a cluster head, gateways and members node.

- Cluster-based schemes are divided into two main categories: One-hop clustering and K-hop clustering schemes. These schemes can be classified into five sub-categories based on their distinguishing features and their objectives as: Identifier neighbor based , Topology based, Mobility based, Energy based , and Weight based clustering.

- Several clustering schemes help to organize MANETs in a hierarchical manner. such schemes mainly focuses on important issues which remains challenge in large scale MANETs such as cluster structure stability, the total control overhead of cluster formation and maintenance, the energy consumption of mobile nodes with different cluster related status, the traffic load distribution in clusters, the resource management, the re-affiliation caused by high speed moving nodes, the fairness of serving as CHs for a mobile node, fault tolerance, load balancing ,security, cluster coverage, and multi hierarchy levels.

- The different categories of clustering schemes may have a different characteristics and objectives. However, clustering cost remains a major consideration when presented a clustering scheme, because clustering cost is important metric to evaluate the performance and scalability improvement of a clustering scheme in MANETs no matter which specific objectives it bears.

- Virtual backbone based schemes are proposed to support MANETs scalability. However, most of these schemes show their limitations in term of finding the optimal solution and messages overhead when size of network increase. Furthermore, There are only few schemes that formally describe what objective they want to optimize

Table 3.1: Cluster-based Schemes Comparison [12]

Clustering Schemes	Based on	CH election	Cluster radius	Overlapping clusters	CH number	CH change	Cluster stability	Overhead
LCA	ID-Neighbor	Lowest ID	One-Hop	Possible	High	Very High	Very Low	High
LCC	ID-Neighbor	Lowest ID	One-Hop	Possible	High	High	Low	High
ACA	ID-Neighbor	Lowest ID	One-Hop	No	High	Moderate	Low	High
Max-Min D-cluster	ID-Neighbor	Node ID	K-Hop	No	High	Moderate	Low	Very High
HCC	Topology	Highest degree	One-Hop	No	High	Very High	Very Low	High
3hBAC	Topology	Highest degree	One-Hop	No	Moderate	Relatively High	Low	Very High
α-SSCA	Topology	Node degree	One-Hop	No	Moderate	Relatively Low	High	Low
Associativity based cluster	Topology	Node degree	K-Hop	Yes	Moderate	Relatively Low	High	Relatively High
MOBIC	Mobility	Lowest mobility	One-Hop	Possible	Relatively High	Low	Relatively High	High
Stability-based mobility prediction	Mobility	Node stability	One-Hop	Yes	Relatively Low	Low	Relatively High	Relatively Low
MPBC	Mobility	Lowest mobility	One-Hop	Yes	Relatively Low	Low	High	Low
MobDHop	Mobility	Lowest mobility	K-Hop	No	Low	Low	Very High	Low
Cross-CBRP	Mobility	Mobility and Node ID	One-Hop	Yes	Relatively High	Relatively Low	Relatively High	Low
MPGC	Energy	Highest energy	One-Hop	Yes	Moderate	Relatively Low	Relatively High	Relatively High
FWCABP	Energy	Lowest weight	One-Hop	Possible	Low	Low	High	Relatively Low
ECEC	Energy	Highest energy	One-Hop	Yes	Moderate	Low	Relatively High	Relatively Low
FWCA	Weight	Weight metric	One-Hop	Possible	Low	Low	High	High
Sbca	Weight	Weight metric	One-Hop	No	Low	Low	High	Relatively High
EWBCA	Weight	Weight metric	One-Hop	No	Low	Low	Very High	Relatively Low

Table 3.2: CDS-based Virtual Backbone Schemes Comparison

	Scheme	Class	Approximation Ratio	Time Complexity	Msg Comlexity
Centralized Algorithms	Fernau et al	Exact	-	O(1.8966^n)	-
Δ : maximum degree of a graph	Fujie	Exact	-	-	-
n: number of nodes	Guha	Approximation	2 $\times$ (1+H(Δ)), 3 ln(Δ)	-	-
H: harmonic function	Butenko	Others	-	O($\|V\| \times \|E\|$)	-
Distributed Algorithms	Li	Self-pruning	O(n)	O(Δ^3)	O(1)
	Stojmenovic	Self-pruning	O(n)	O(Δ^3)	O(1)
	Dai	Self-pruning	O(n)	O(Δ^2)	O(1)
	Blum	MIS	-	O(n)	O(nlogn)
	Alzoubi	MIS	-	-	O(n)
	Adjih	MPR	-	O(Δ^2)	-
	Wu	MPR	-	O(Δ^2)	-

	Scheme	k,m	Approximation Ratio	Time Complexity	Msg Comlexity
Robust Algorithms	CDSA	k = 2 , m = 1	const 64	O(Δ^3)	O(1)
r: graph diameter	CGA	k = any val , m = any val	-	O(m $\times\Delta^{3.5}$)	O(1)
m: number of edges	MDSA	k = 1 , m = any val	-	O(m $\times$ r)	O(m(Δ+1)n)
	ICGA	k = any val , m = any val	-	O(m $\times\Delta^{3.5}$)	-
	CDSMIS	k = 1 , m = any val	m + 7 + ln5	-	-
	CDSAN	k = any val , m = k	(k+7+ln5)(2k-1)	-	-
	CDSMIS+CDSAN	k = any val , m = any val	(2k+9)(k+6+ln5)	-	-

Chapter 4

A New Weight Based Clustering Scheme for MANETs

Abstract Scalability is a fundamental problem in mobile ad hoc networks (MANETs), where network topology includes large number of nodes and demands a large number of packets in network that characterized by dynamic topologies, existence of bandwidth constrained, variable capacity links, energy constraint and nodes are highly prone to security threats. The section 4.1 presents our proposed clustering scheme, some clustering related definitions, architecture and scheme phases. The proposed scheme is suitable for large-scale MANETs exploiting the combination of metrics like trust, density, mobility and energy to choose locally the optimal cluster heads during cluster formation phase and maintain clusters locally. Then, an overview the efficiency of the proposed clustering scheme for large-scale MANETs and its performance evaluation and especially in the case of a large number of nodes in the network is presented in section 4.2.

4.1 Description of the scheme

As we describe in previous chapters, mobile Ad hoc networks (MANETs) are self-organizing and self- configuring multi-hop wireless networks without any pre-existing communication infrastructures or centralized management.

Scalability in MANETs is a new issue where network topology includes large number of nodes and demands a large number of packets in limited wireless bandwidth and nodes mobility that results in a high frequency of failure regarding wireless links. However, Clustering in MANETs is an important topic that divides the large network into several sub networks and widely used in efficient network management, improving resource management, hierarchical routing protocol design, Quality of Service and a good monitoring architecture of MANETs security. Subsequently, many clustering approaches have been proposed 3.2 to divide nodes into clusters to support routing and network management.

In this section, we describe our proposed a new efficient weight based clustering algorithm, that takes into consideration the metrics: trust (T), density (D), Mobility (M) and energy (E) to choose locally the optimal cluster heads during cluster formation phase. In the proposed algorithm, each cluster is supervised by its cluster head in order to ensure an acceptable level of security. It aims to improve the usage of scarce resources such as bandwidth, maintaining stable clusters structure with a lowest number of clusters formed, decreasing the total overhead during cluster formation and maintenance, maximizing lifespan of mobile nodes in the network and reduces energy consumption.

4.1.1 Definitions

A mobile ad hoc network is represented by a directed or undirected graph, depending on the nature of the links, *G(t) = (V(t),E(t))* where *V(t)* represents the set of nodes at time *t* and *E(t)* represents the set of links between nodes at time *t*.

Definition 14 *(MANETs graph)*
Set $n = |V(t)|, s = |E(t)|$, *edge* $e_{ij} \in E(t), e_{ij} = (v_i, v_j)$, *it represents a link between two nodes*v_i *and* v_j *at time t,* $(v_i, v_j) \in V(t), i, j = 1, 2, ., n$.

Definition 15 *(Neighbor nodes)*
For any node v, set $\Gamma(v)$ *is the neighbor nodes of v, E(v) is the list of links connecting node v with its neighbor nodes.*

Definition 16 *(Non-overlapping clusters)*
non-overlapping clusters are clusters where each node belongs to a single cluster. Set C_i *is the cluster i and* C_j *is the cluster j with* $(C_i, C_j) \subset V$*.* C_i *and* C_j *are non-overlapping clusters if* $C_i \cap C_j = \oslash, (i \neq j)$*.*

Definition 17 *(Node degree)*
Set d_v *the node degree that represents the number of neighbor nodes in a k-neighborhood.*

4.1.2 Architecture

4.1.2.1 Network topology structure

Our network topology is organized in clusters, and each node is in one of the following states: Cluster head, core member, margin member, not-decided, gateway node. Initially all nodes are in the not-decided state. As time a progress, each node tries to join a cluster by being in one of the three states CH, member or gateway.

1. *Cluster Head (CH):* it is the coordinator of the group (cluster). It has additional functions such as: channel access, routing data, bandwidth and channel allocation, forwarding inter-cluster packets, etc.

2. *Gateway:* is a node (not CH) which works as the common access point for two or more cluster heads, when a node remains within the transmission range of two cluster heads.

3. *Core Member Node (COM):* is an ordinary node (not a gateway or CH). The cluster-head is one of the core members of the cluster. All members of the core are 1-hop neighbors to the cluster-head.

4. *Margin Member Node (CAM):* is an ordinary node but it is the k-hop neighbors of the cluster-head with $k \geq 2$.

Figure 4.1 illustrates the main features and elements of our structure.

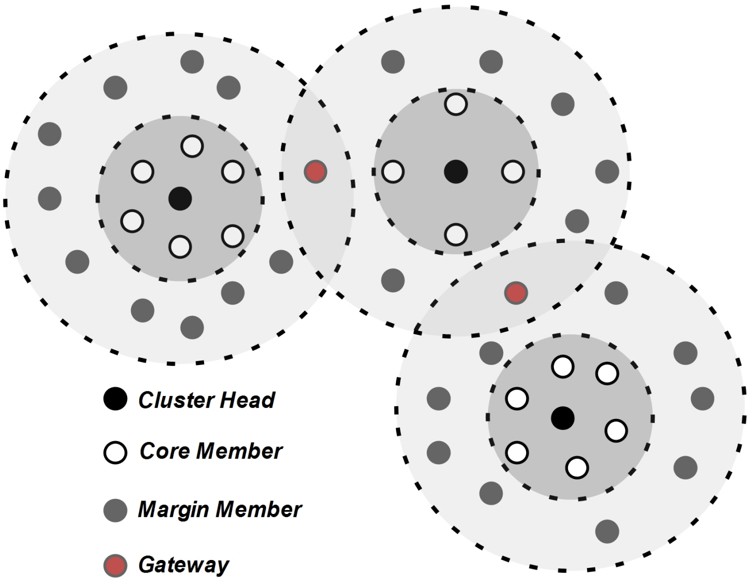


Figure 4.1: General Structure of our Network Topology

4.1.2.2 Node trust value calculation

Trust is fundamental to maintain a certain level of security. This is an important aspect in the conception and analysis of networks as it is an essential component by which the relations between the nodes can grow or stop. Trust can be defined as Trust, is a particular level of the subjective probability with which an agent will perform a particular action, both before we can monitor such action (or independently of his capacity of ever to be able to monitor it) and in a context in which it affects our own action [35].

In our algorithm we used the method described in [8] to calculate the trust value. The trust value T_{v_i} of node v_i is used to decide whether the selected node v_i is a normal or malicious node. Trust value defines the level of confidence of a node v_i on neighbor node v_j depending on the performance evaluation of the assigned task. The trust model [8] used in our algorithm is distributed over the network nodes. Each node in the network computes its own trust value based on the direct relations relating to its 1-hop neighbors and indirect relations relating to its k-hop neighbors 4.2. So it is necessary for each node, to maintain a record for each of its neighbor nodes. This record contains information about different trust metrics such as: control packet/message forwarded, control packet/message precision, availability based on control message/hello messages, reputation, and Packet address modified. Figure 4.2 depicts the total trust values on node v_i given by its neighbor nodes.

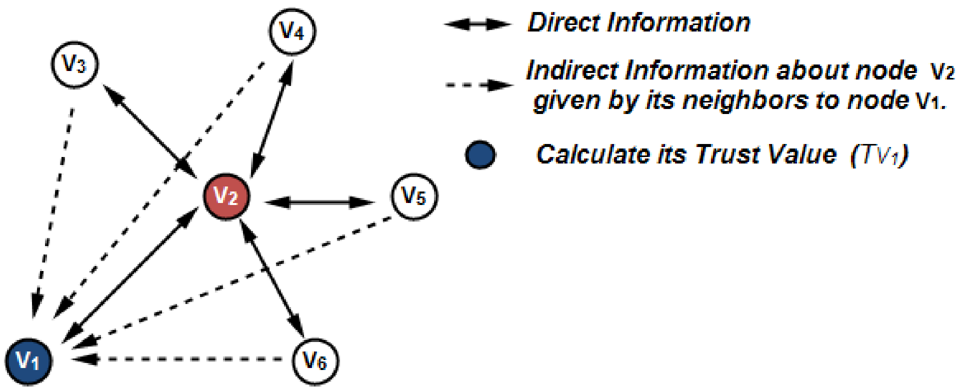


Figure 4.2: Network Nodes Trust Relationship & trust value calculation of a node v_1

The direct trust (DT) of any node v_i is the geometric mean of all trust metrics of different events that occurred on that particular node. Direct trust ($DT_{v_i}(v_j)$) of a node v_i on node v_j is calculated as:

$$DT_{v_i}(v_j) = \left[\prod_k (m_k)\right]^{\frac{1}{k}} \tag{4.1}$$

The indirect trust (IT) of any node v_i is defined as the geometric mean of the DTs of neighbor nodes. Indirect trust ($IT_{v_i}(v_j)$) of node v_i on node v_j is calculated as:

$$IT_{v_i}(v_j) = \left[\prod_{l} \Big(DT_l(v_j) \Big) \right]^{\frac{1}{l}} \tag{4.2}$$

$(DT_l(v_j))$ are the DTs given by each neighbor of node v_j and l represent the IDs of the neighbor nodes.

The total trust (TT) After calculating the direct and indirect trust, each node v_i calculates its total trust (TT). The total trust of a node is a weighted function (combination) of Direct Trust *(DT)* and Indirect Trust *(IT)*. Total Trust $(TT_{v_i}(v_j))$ of node v_i on node v_j is calculated as:

$$TT_{v_i}(v_j) = w_1 \times DT_{v_i}(v_j) + w_2 \times IT_{v_i}(v_j) \tag{4.3}$$

Where w_1, w_2 are the respective weight factors for DT and IT with the constraint that $w_1 + w_2 = 1$.

In our algorithm we propose and calculate the trust value T_{v_i} of node v_i that represents the sum of total trust values on node v_i . The trust value (T_{v_i}) of node v_i is calculated as:

$$T_{v_i} = \sum_{j=1}^{n} TT_{v_j}(v_i) \tag{4.4}$$

Where n is the number of k-hop neighbor nodes of v_i and $(TT_{v_j}(v_i))$ represents the total trust of neighbor nodes $v_1, v_2, v_3....v_n$ on v_i.

4.1.2.3 Node density calculation

The density metric [62], is the ratio between the number of links and the number of nodes in a k-neighborhood. The k-density of a node v_i defined as:

$$D_{v_i} = \frac{|e = (u, w) \in E, u \in \{v, \Gamma k(v_i)\} w \in \Gamma k(v_i)|}{d_{v_i}} \tag{4.5}$$

Where, $\Gamma k(v_i)$ represents the list of k-neighborhood of node v_i and d_{v_i} is the degree of node v_i (the number of nodes in its k- neighborhood).

4.1.2.4 Node mobility estimation

The mobility metric estimation presented in [66] is based on the relative speeds estimation for each node in the whole network. It uses the Doppler Shifts that are associated with periodically exchanged HELLO packets between neighboring nodes, and a serial of mobility-based clustering strategies to estimate their relative speeds 4.3. The relative speed value of node v_i toward node v_j is calculated as:

$$v_{i\to j} = \frac{\sqrt{cf_{dB}^{\sqrt{\alpha}}}}{P_\Delta f} \times \sqrt{2P_\Delta P_B - \alpha P_B^2 + \alpha\Big(\frac{P_B^{\alpha+1}}{P_C}\Big)^{\frac{2}{\alpha}}} \tag{4.6}$$

Where f_{dB} represents the Doppler shift at location B and P_B represents the average power of the received signal at location B, f_{dC} and P_C , respectively, represents the Doppler shift and average power of the received signal at location C. P_Δ represents the average power difference of the received signal at location B and location C ($P_\Delta = |P_C P_B|$), α is the path loss exponent and f is the necessary frequency to transmit the Hello packets.

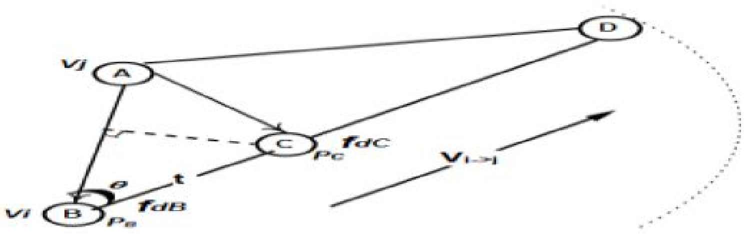


Figure 4.3: Relative Speed Estimation of node v_i toward nodev_j

After all network nodes estimate their relative speeds, each node v_i calculates its effective average relative speed based on the estimated relative speeds of its neighbors which represents the mobility metric estimation M_{v_i}. The effective average relative speed of node v_i is defined as:

$$M_{v_i} = \frac{\sum_{j\in\Gamma(v_i)} v_{i\to j}}{\Gamma(v_i)} \tag{4.7}$$

4.1.2.5 Node residual energy estimation

The battery energy is a serious constraint that affects directly the lifetime of the network. Hence energy limitation is one of the important parameters that affect the network performance. Our algorithm uses the residual energy as metric in calculating the weight value for cluster head election process in order to extend the lifetime of the cluster structure. Each node v_i in the network estimates its residual energy value using the following function:

$$\begin{cases} Ev_i = E_{total} - E_{v_i consumed} \\ E_{v_i consumed} = E_{v_i send} + E_{v_i receive} \\ E_{v_i send} = \sum\limits_{j \in \Gamma v_i} [|MSGs| \times (E_{elec} + PW^{\alpha}_{v_{i \to j}}) \times E_{amp}] \\ E_{v_i receive} = S \times |MSGs| \times E_{elec} \end{cases} \tag{4.8}$$

Where:
Ev_i represents the residual energy of node v_i, E_{total} is the initial energy, $E_{v_i consumed}$ is the consumed energy at node v_i, $E_{v_i send}$ is the energy required by node v_i to send packets to its neighbor nodes, $E_{v_i receive}$ is the energy required by node v_i to receive packets sent by its neighbor nodes.
$MSGs$ is the number of packets, E_{elec} is the energy radio electronics, E_{amp} is the power amplifier,$PW^{\alpha}_{v_{i \to j}}$ is the power level needed to reach neighbor nodes and S is the communication cost of the links.

4.1.3 Scheme phases

Our cluster-based scheme consists of two main phases, which are: cluster formation phase and cluster maintenance phase.

4.1.3.1 Cluster formation phase

Our cluster formation phase (Algorithm 1) is divided into four major steps 4.4

- *Neighbor nodes detection*: Initially, all nodes of the network (in not-decided state) exchange the HELLO messages periodically to notify neighbor nodes of their presence. The HELLO message contains the status of the node. After, each node builds their neighbors list based on the received HELLO messages from other nodes and records the information about its neighbor nodes in its neighbor table.

- *Cluster heads election process*: After neighbor nodes discovery phase, the cluster head election process is invoked. Each node v_i calculates its weight value $W(v_i)$ using cluster head election algorithm 2. and broadcasts this weight to its K-neighbors through *weight-val* message. Upon reception of *weight-val* messages, each node updates its neighborhood table and compares the received weights of all its K-hop neighbors with its own weight value. If its own weight value is the highest, it declares itself a cluster head. In case of more than one node with the same highest weight, the node with highest trust value T_{v_i} is selected as cluster head. But if the conflict is not resolved, the highest density D or highest ID is used. The CH elected broadcasts a *CH-elect* message with its ID as cluster ID to its K-neighbors.

- *Cluster node join process*: Once a node receives a $CH - elect$ message and if it wishes to join the cluster it sends a Join Request message to the corresponding cluster head. The cluster head sends an Accept message and this node updates its status to either core member (if it is a direct neighbor of CH) or margin member. Each node joins the cluster with the highest weight value (when it receives several *CH-elect* messages).

- *Gateway election*: Once Cluster heads are elected each cluster head choses its gateway nodes to communicate with other clusters. The margin member nodes between two adjacent clusters are candidate to be gateways. Each CH selects its gateway nodes using the gateways election algorithm 4.

1. Neighbor nodes detection process algorithm

Initially, all network nodes are in not-decided status. Each node in the network broadcasts periodically HELLO messages to notify its neighbor nodes of its presence. The HELLO message contains: the source node address, status of the node, the list of the neighbor nodes, the address of cluster head, the addresses

Algorithm 1 Cluster Formation Algorithm

procedure CLUSTER FORMATION ALGORITHM
    Input: $G = (V, E), v_i \in V$ **with uncompleted valid cluster structure**
    Output: $G = (V, E)$ **with valid cluster structure**
    for All $v_i \in V$ **do**
        Neighbor-Nodes-Detection(v_i)
        CH-Election-Process(v_i)
        if $Status(v_i) =$ Cluster Head **then**
            Gateway-Election(v_i)
            EXIT
        else
            Cluster-Node-Join(v_i)
        end if
    end for
end procedure

of neighbor clusters and the weight value. This information allows each node to build and maintain its neighbors list (maintain local topology). After that, each node records the information about its neighbor nodes in its neighbors table.

2. Cluster heads election process algorithm

After neighbor nodes detection algorithm, the cluster head election process algorithm is invoked. During this step, our proposed algorithm 2 uses a combination of the following four metrics: node trust value T_{v_i}, node density D_{v_i}, node mobility M_{v_i}, battery remaining energy E_{v_i} to compute weight of node v_i. The weight value $W(v_i)$ of node v_i is calculated as:

$$W(v_i) = w_1 \times T_{v_i} + w_2 \times D_{v_i} + w_3 \times M_{v_i} + w_4 \times E_{v_i} \tag{4.9}$$

Where w_i: the weighting factors for the corresponding metrics with $\sum_{i=1}^{4} w_i = 1$.

3. Cluster node join process algorithm

Upon reception of the *CH-elect* messages each node joins its favorite cluster by sending a *Join Request (my-id, my-trust-value)* message to the corresponding cluster head. The cluster head sends an accept message and this node updates

Algorithm 2 Cluster Heads Election Process Algorithm

procedure CLUSTER HEADS ELECTION ALGORITHM
  Input: $G = (V, E), v_i \in V$
  Output: $CHs =$ **Cluster Heads**
  Intialization:
  $T_{v_i} = D_{v_i} = M_{v_i} = E_{v_i} = 0$
  $W(v_i) = 0$, $C_{id-v_i} = 0$
  $K = 5$
  for (All $v_i \in V$) **do**
    $T_{v_i} =$ **Trust-calculation**(v_i)
    $D_{v_i} =$ **Density-calculation**(v_i)
    $M_{v_i} =$ **Mobility-estimation**(v_i)
    $E_{v_i} =$ **Energy-estimation**(v_i)
    $W(v_i) = w_1 \times T_{v_i} + w_2 \times D_{v_i} + w_3 \times M_{v_i} + w_4 \times E_{v_i}$
    Broadcast-K-Neighbors(weight-val-msg(W(v_i)))
    for (All $v_j \in \Gamma(v_i)$ **and** $v_i \neq v_j$) **do**
      •Store the information extracted from the weight-val
      messages received in its neighbor table.
      •Compares the received weights of all its K-hop
      neighbors with its own weight value
      if ($W(v_j) =$ MAX) **then**
        $CH_{v_j} = v_j$
        $Status(v_j) =$ Cluster Head
        $C_{id-v_j} = CH_{v_j}$
        Broadcast-K-Neighbors(CH-elect(v_j))
      else
        •v_j waits reception of CH-elect message sends by the node
        that has the highest weight value in its k-neighborhood
      end if
    end for
  end for
end procedure

its status to either core member or margin member. Our node join algorithm is presented in 3.

4. Gateways election process algorithm

Once Cluster heads are elected, each cluster head selects its gateway nodes to communicate with neighbor clusters. For that reason, we propose gateway nodes

Algorithm 3 Cluster Node Join Process Algorithm

```
procedure CLUSTER NODE JOIN ALGORITHM
    Input: G = (V, E), v_i ∈ V
    Output: v_i ∈ One Cluster
    for (All moving v_i ∈ V and/or status(v_i) = not-decided) do
        •v_i sends a join request message to the corresponding
        cluster head and waits a certain period of time for response.
        if (no response message arrives after time t ) then
            •v_i increases its transmission power to reach the furthest CHs.
            •v_i sends a Join request message to the corresponding CH
        else
            if (v_i receives one Join Accept message) then
                •v_i joins the corresponding Cluster and changes its status
                 to member node and updates all necessary information.
            else
                •v_i joins the cluster that has the highest weight value among
                all CHs that have replied with Join Accept message.
                •v_i changes its status to member node and
                updates all necessary information.
            end if
        end if
    end for
end procedure
```

election algorithm 4 to ensure both a communication between neighbor clusters and certain level of security because gateway nodes have a critical role (data routing between two or more clusters). Our gateways election algorithm is based on the trust value. Each cluster head chooses its gateway nodes, from candidate nodes, to communicate with other clusters based on the trust value. For each neighbor cluster, the gateway node g_i with highest trust value T_{g_i} among other gateway nodes candidate is selected. In the case of more than one candidate nodes with the same highest value of trust, the node with the highest weight is selected. But if the ambiguity is not solved by the weight than the node with the lowest ID is chosen.

Algorithm 4 Gateways Election Process Algorithm

procedure GATEWAYS ELECTION ALGORITHM
  Input: $G = (V, E), v_i \in \Gamma(CH_{vi}), v_i =$ **CAM**
  Output: $g_i =$ **Gateway node**
  for (Each nighbor cluster) **do**
    for (All $v_i \in \Gamma CH_{vi}$ **and** Status(v_i)= CAM) **do**
      if (T_{v_i} = MAX) **then**
        $g_i = v_i$
        Status(v_i)= Gateway
      else
        for (All $v_j \in \Gamma CH_{vi}$ **and** Status(v_i)= CAM **and** $v_i \neq v_j$) **do**
          if ($T_{v_i} = T_{v_j}$) **then**
            •CH_{v_i} chose the gateway node with the lowest ID
          end if
        end for
      end if
    end for
  end for
end procedure

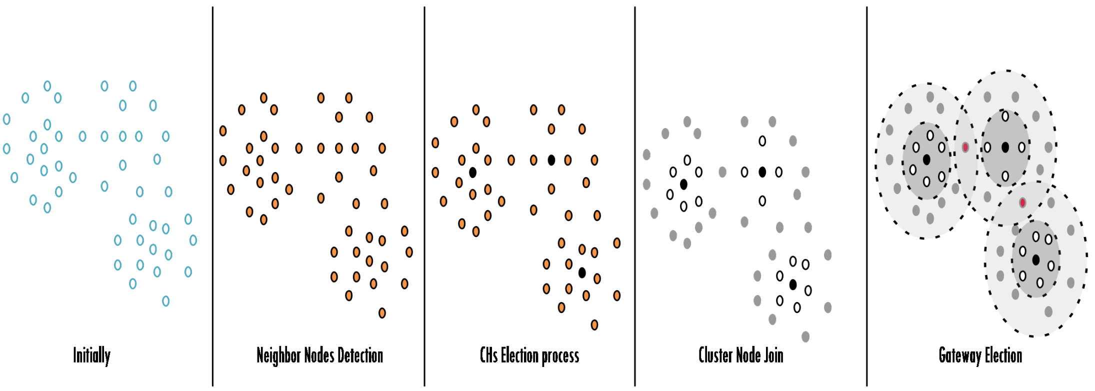


Figure 4.4: Clusters formation phase

4.1.3.2 Cluster maintenance phase

The second phase is the cluster maintenance that tries to adapt the structure of clusters to all topology changes that can occur due to nodes mobility. In our scheme the cluster maintenance is invoked locally 5 in three distinct types of events, namely: the trust threshold property, node movement and weight value change in the cluster head. In each event, each node updates the information required.

Algorithm 5 Cluster Maintenance Algorithm

```
procedure CLUSTER FORMATION ALGORITHM
    Input: G = (V, E), CH ∈ V with topology changes
    Output: G = (V, E) with valid structure after maintenance
    for All CH ∈ V do
        switch(event)
            case 'Node movement':
                Node-Movement(CH)
            case 'Trust threshold property':
                Trust-Threshold-Property(CH)
            case 'Weight value change':
                Weight-Value-Change(CH)
        end switch
    end for
end procedure
```

1. Node movement algorithm

We define two types of node movement. The first type when a new node enters the range of new cluster, in this case the new node sends Join Request message to the corresponding cluster head and waits for the response (ACK or NACK). The second type when a node moves outside the boundaries of its cluster, whenever this happens, the status of the node should be updated and this node tries to find an existing cluster to join. These events will have only local effects on clusters topology structure. For each type, the status of the node should be updated. Algorithm 6 represents our topology maintenance algorithm due to node movement event.

2. Trust threshold property algorithm

The Trust value changes over time based on interactions between nodes. Mobility can also change the status of clusters and trust relationships between nodes. In fact, when a node acquires new neighbors or loses some due to mobility, the trust value of this node changes. Since we are dealing with a vulnerable network, each node could become malicious node. In our algorithm 7, the trust

Algorithm 6 Node Movement Algorithm

procedure Node Movement Algorithm
  Input: $G = (V, E), v_i \in V$
  Output: $G = (V, E)$ **Maintained**
  for (All moving $v_i \in V$) **do**
    if (Status(v_i) = Cluster Head) **then**
      •v_i broadcasts a give up role message to its cluster members
      •v_i updates status to not-decided
      •**Cluster-Node-Join(v_i)**
      for (All $v_j \in \Gamma(v_i)$) **do**
        •v_j updates cluster information
        •CH-Election-Process(v_j)
      end for
    else
      if (Status(v_i) = CAM **or** COM **or** Gateway) **then**
        •v_i sends a moving message to its CH
        •v_i updates status to not-decided
        •**Cluster-Node-Join(v_i)**
        for (All $v_j \in \Gamma(v_i)$) **do**
          if (Status(v_j) = Cluster Head) **then**
            •v_j updates information related to the moving node.
            •v_j updates information related to the moving node.
            •v_j **invokes Broadcast-K-Neighbors(move-msg(v_i)**
            if (Status (v_i) = gateway) **then**
              •CH invokes **Gateway-Election(v_i)**
            end if
          else
            •Updates information related to the moving node.
          end if
        end for
      end if
    end if
  end for
end procedure

value of each node is verified periodically. If the malicious node is the CH then the members nodes should change their cluster head by re-invoking locally the cluster formation phase to avoid the re-clustering (more overhead) of the whole network. The nodes seeking to change its malicious cluster head, find the node with highest weight value amongst the k-hop neighbors to be their CH. When the malicious node is member node or gateway then, the CH eliminates this node from its cluster.

Algorithm 7 Trust Threshold Property Algorithm

procedure TRUST THRESHOLD PROPERTY ALGORITHM
  Input: $G = (V, E), v_i \in \Gamma(CH_{v_i})$
  Output: m_i = **Malicious node**
  for (All $v_i \in \Gamma(CH_{v_i})$) **do**
    T_{v_i} = **Trust-calculation**(v_i)
    if ($T_{v_i} < Trust - Value - Threshold$) **then**
      if (Status(v_i) = Cluster Head) **then**
        $m_i = v_i$
        Status(v_i) = Malicious node
        for (All $v_j \in \Gamma(CH_{v_i})$) **do**
          •v_j removes the node v_i form its neighbor list.
          •v_j invokes **CH-Election-Process**(v_j)
        end for
      else
        •The CH of node v_i removes this node form its cluster
        and from its neighbor and member lists
        •CH invokes **Broadcast-K-Neighbors(Exclude-msg**(v_i)**)**
      end if
    end if
  end for
end procedure

3. Weight Value Change

The nodes mobility changes the weight value of nodes. In algorithm 8, the weight value of each node is verified periodically. In the case when the weight value of a member node becomes higher than the weight value of its cluster head then re-election of new cluster head is invoked locally. The CH gives up its role and becomes a member node and the member node that has the highest weight value becomes a CH.

Algorithm 8 Weight Value Change Algorithm

```
procedure WEIGHT VALUE CHANGE ALGORITHM
    Input: G = (V, E), v_i ∈ Γ(CH_{v_i})
    Output: CH = Cluster Heads
    for (All v_i ∈ Γ(CH_{v_i})) do
        W(v_i) = Weight-calculation(v_i, T_{v_i}, D_{v_i}, M_{v_i}, E_{v_i})
        if (W(v_i) > W(CH_{v_i}) ) then
            •CH_{v_i} = Member node
            •Status(v_i) = Cluster Head
            •v_i informs neighbors of its new status.
        else
            •CH_{v_i} remains the cluster head of its cluster
        end if
    end for
end procedure
```

4.2 Experimental analysis

In this section, we present the performance evaluation of our proposed scheme. In order to properly examine the effectiveness of our proposed scheme, a performance evaluation, featuring its main objectives, is done using the optimum network performance (OPNET) [63]. Therefore, the main purpose of this simulation evaluation is to study the performance of our proposed clustering scheme when network size increases (large scale MANETs). To accomplish this objective, a set of different simulation environments with different performance metrics, featuring the network size and different simulation parameters, were defined. Moreover, we compare our scheme to previous clustering schemes such as: LID [29], highest degree [37], and WCA [16] which have aimed to solve the scalability problem. Figure 4.5 represents a comparison between previous cluster-based schemes in term of clusters election, change, number, stability and total overhead.

4.2.1 Simulation model and parameters

For the experiments results, we have used the input parameters shown in Table 4.1.

The network model 4.6 that we designed to simulate and evaluate our scheme

Clustering schemes	Main objective	CHs election	Clusters number	CH change	Cluster stability	Total overhead
LID (Ephremides *et al.*, 1987)	Organize the network into clusters	Lowest-ID	Very high	Very high	Low	Very high
HCC (Gerla and Tsai, 1995)	Decrease number of clusters and cluster maintenance invocation	Highest degree	High	High	Very low	Very high
DCA (Basagni, 1999)	Stable cluster formation	Generic weight	Very high	Moderate	Low	High
WCA (Chatterjee *et al.*, 2002)	Distributed clustering formation and improve lifetime of the network	A combined weight metric	Relatively low	Relatively low	Relatively high	Relatively high

Figure 4.5: LID, HCC, DCA and WCA Comparison [13]

may have from 500 to 3,000 mobile nodes placed randomly in an area of 2,000 × 2,000 meters. The mobility model used is the urban environment mobility. We assume IEEE 802.11b for both physical and MAC layers. We assume that the radio model uses data-rate of 11 Mbits/s, transmission range 250 meters, and packet size 128 bytes. The simulation time is 900 seconds.

The main goal of our clustering scheme is to provide scalability for large MANETs (large number of mobile nodes). So, to evaluate the performance of our clustering scheme in large-scale MANETs, we look at the common evaluation metrics used by previous works [23, 7, 41, 17]. These metrics are: average number of cluster heads, average number of cluster head changes, total number of re-affiliation, clusters stability and total overhead.

◊ *Average number of cluster head* represents the average number of clusters formed in the network during cluster formation phase.

◊ *Average number of cluster head changes* is the average number of cluster head status changes to another status.

Table 4.1: Simulation Parameters

Parameter	**Meaning**	**Value**
N	Number of Nodes	[500 3000] nodes
X × Y	Area of simulation	2 km × 2 km
Speed	Nodes Speed	0 m/s - 100 m/s
AP	Fixed Nodes	Dynamically Network size based
Mobility	Mobility Model	Urban Mobility
Tx	Transmission range	250 m
PT	Pause Time	0 sec
HI	Hello Interval	2 sec
Phy Char	Physical characteristic	Direct Sequence
Pkt Size	Packet Size	128 bytes
Data Rate	Data Rate	11 Mbits/s
Init Energy	Initial Energy	Battery (10.8V, 4000 mAh, 44 Wh)
Tran Power(W)	Transmit Power	0.001 watt
Rec Power(dBm)	Reception Power	-95 dBm
Sen Power(W)	Sensing Power	Negligible
Dev Tp	Devices Type	Homogeneous Laptop
$w_{1,2,3,4}$	Weight Factor	0.25 for each
Duration	Simulation Time	900 secs

◊ *Total number of re-affiliation* represents the number of member nodes that have re-affiliated from their clusters and got associated to another cluster.

◊ *Clusters stability* is the stability of clusters structure during network topology changes.

◊ *Total overhead* represents the total number of messages required by the clustering scheme to create the cluster network topology.

4.2.2 Variation of average number of clusters

Figure 4.7 illustrates the variation of average number of clusters formed during the clusters formation phase with respect to the total number of nodes in the network. We observe that when the number of nodes in the network increases, the average number of clusters increases in all schemes. However, our scheme

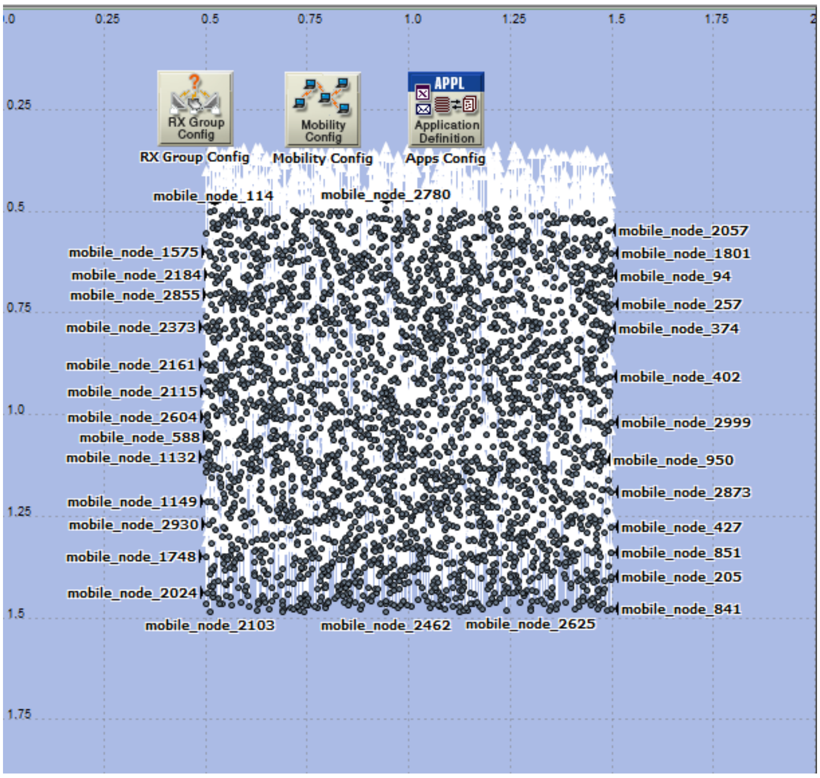


Figure 4.6: The Network Model

produces constantly fewer clusters in comparison with other clustering schemes which results in low overhead. In addition, our scheme creates k-hop clusters that have the effect of spacing between the adjacent cluster heads in order to reduce the number of creation of new clusters and reduces the number of re-election of cluster heads.

4.2.3 Variation of number of cluster head changes

Figure 4.8 shows the variation of number of CH changes with respect to the total number of nodes in the network. In most cases, we observe that the CH changes in our proposed scheme are less than the other clustering schemes. This is due to both the cluster head selection criteria and the k-hop approach that results in a more stable network clusters and smaller number of CHs. Also, the distributed algorithms that are used in our scheme are invoked periodically to adapt the

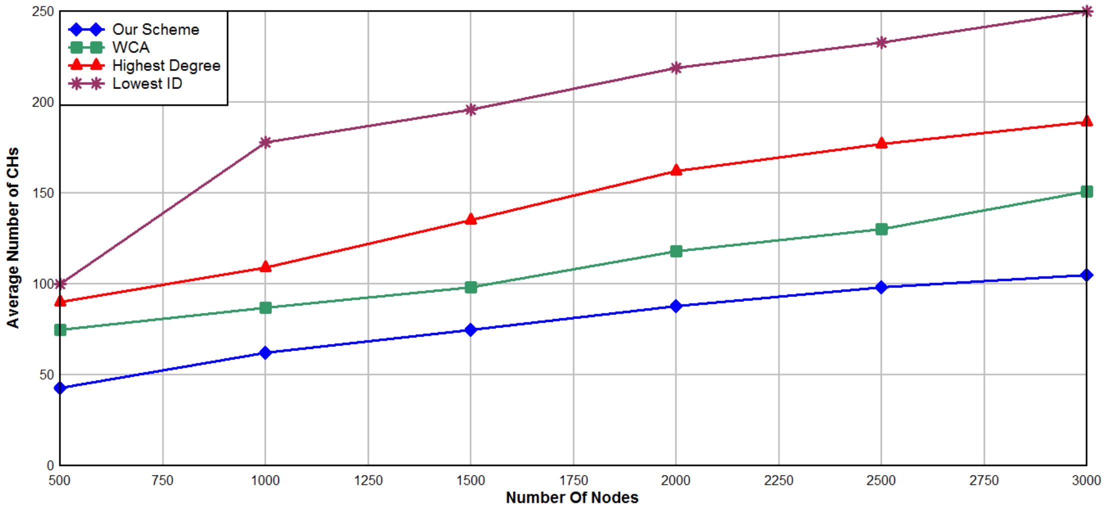


Figure 4.7: Number of Nodes vs Average Number of CHs

structure of network clusters to all topology changes. Furthermore, our scheme provides a stable clusters structure in large network size that results in a low CHs change.

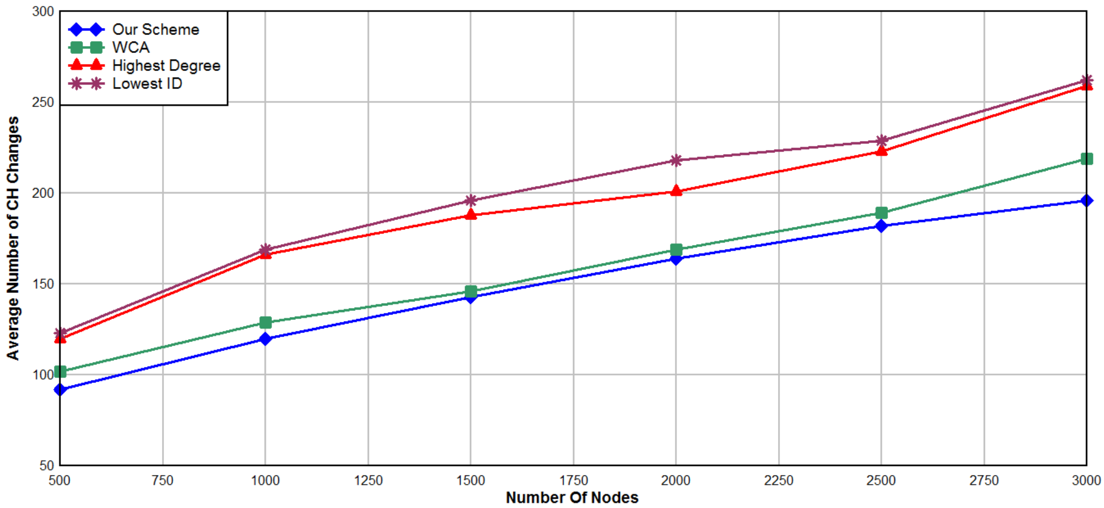


Figure 4.8: Number of Nodes vs Average Number of CH Changes

4.2.4 The total number of re-affiliation

Figure 4.9 describes the total number of re-affiliation. Our proposed scheme constantly generates less number of nodes re-affiliation in comparison with other clustering schemes. When the number of nodes is high, our scheme produced 30 and 46.5 percent less re-affiliation than WCA for 1,500 and 3,000 nodes, respectively. This is due to the fact that our scheme produces a more stable clusters during cluster formation phase (choose the more stable node as CH based on the mobility metric estimation) and the strategy to maintain clusters locally.

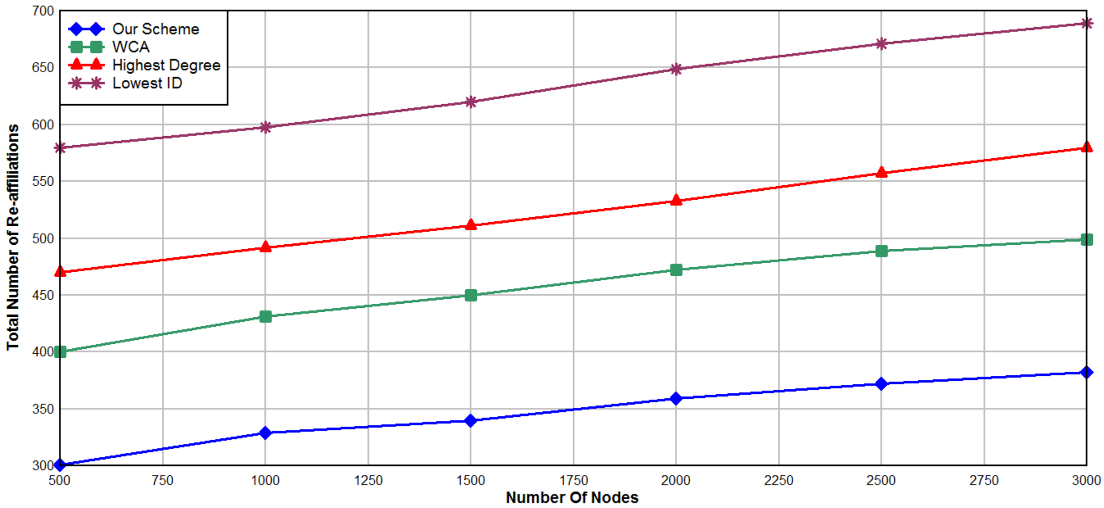


Figure 4.9: Number of Nodes vs Total Number of Re-affiliation

4.2.5 Cluster stability

Figure 4.10 represents cluster stability with respect to the total number of nodes in the network. We observe that when the number of nodes is 500, clusters (generated by different schemes) are highly stable. But when the number of nodes increases to more than 1,000, our scheme provides better clusters stability in comparison to other clustering schemes. This outcome is due to the criteria used during CHs election process (mobility metric) which leads to choosing the most stable node as the CH. This results in more stable clusters even when the number of nodes in the network is high.

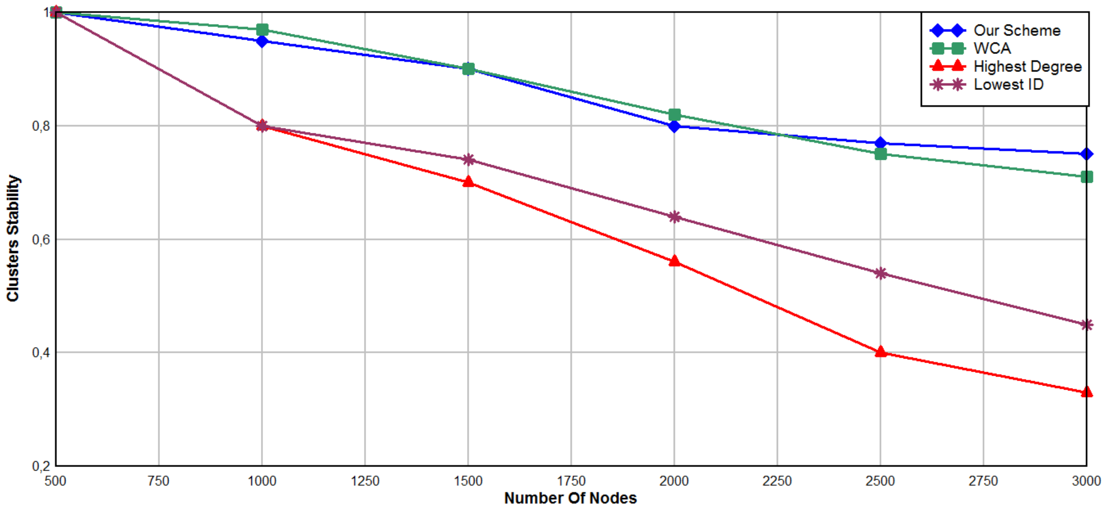


Figure 4.10: Number of Nodes vs Clusters Stability

4.2.6 Total overheads

Figure 4.11 shows the total overhead with respect to the simulation time when the number of nodes in the network is 3,000. We observe that our scheme outperforms other clustering schemes in large-scale MANETs. In all schemes the total overheads increases as the time of simulation increases. But in our scheme, after simulation time 10 minutes, our scheme produces a stable number of overhead. Moreover, our scheme provides a better stability of the cluster topology, a less number of CHs and a less number of cluster maintenance invocations which lead to low overhead.

In summary, our scheme is more efficient than other clustering schemes in terms of the performance metrics considered, especially for large-scale MANETs (the number of nodes in the network is high).

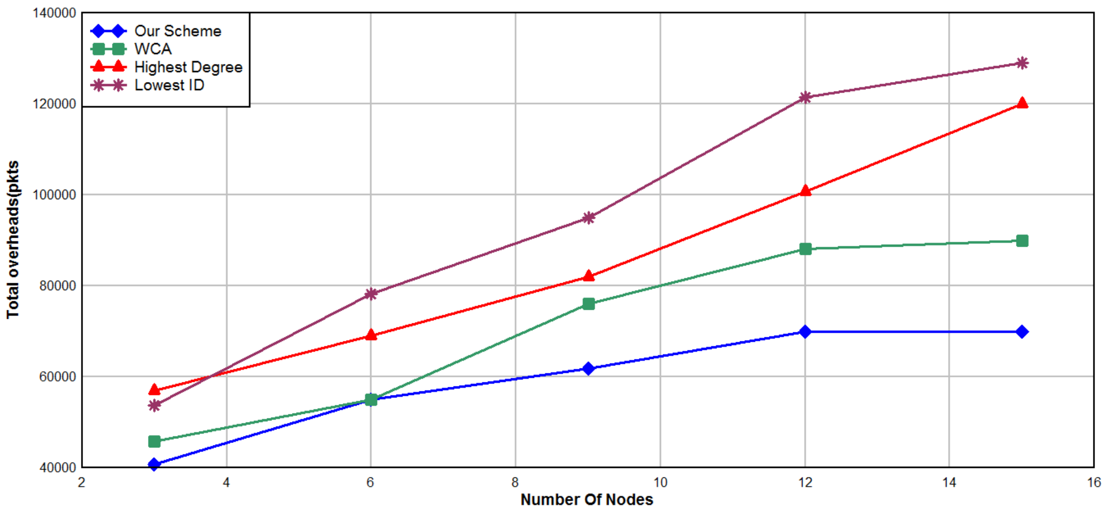


Figure 4.11: Simulation Time vs Total Overhead with 3,000 nodes

4.3 Recap of key points

- Scalability is a fundamental problem in mobile ad hoc networks (MANETs), where network topology includes large number of nodes and demands a large number of packets in network that characterized by dynamic topologies, existence of bandwidth constrained, variable capacity links, energy constraint and nodes are highly prone to security threats.

- Clustering can provide large-scale MANETs with a hierarchical network structure to facilitate routing operations.

- Designing clustering schemes for MANETs, which are efficient and scalable in the case of large number of mobile nodes, has received a great attention in the last few years. It is widely used to improve resources management, hierarchical routing protocol design, quality of service, network performance parameters such as routing delay, bandwidth consumption, throughput and security. MANETs are characterized by limited wireless bandwidth, nodes mobility that results in a high frequency of failure regarding wireless links, energy constraint and nodes are highly prone to security threats. Due to all these features, the design of a scalable and efficient clustering scheme is quite complex. Many clustering schemes have been proposed to divide nodes into clusters, focusing on different metrics and purposes

- The different proposed clustering schemes are not scalable when the network size increases to a very large number.
- We proposed a new weight based clustering scheme for Mobile Ad hoc Networks that takes into account a combination of four metrics as follow: trust, density, mobility and energy during the cluster formation phase and maintains clusters locally.
- proposed scheme each cluster supervised by its cluster head in order to ensure a good level of security, improve the usage of scarce resources such as bandwidth, minimize the CHs change, decrease the number of CHs re-affiliation, minimize the number of clusters, decrease the total overhead. It also creates fewer and more stable clusters achieving high scalability.
- The obtained results show that the different proposed clustering schemes do not allow the scalability when the network size is very large. The scheme supports scalability efficiently when the number of nodes increases in the network (more than 2,000 nodes).
- Simulation experiments have shown that our scheme performs generally better than the other clustering schemes such as: LID, HCC, DCA and WCA, in terms of: average number of CHs, average number of CH changes, total number of re-affiliation, clusters stability, and total overhead. The experiment results show that the different proposed clustering schemes LID, HCC, DCA and WCA do not allow the scalability when the network size is very large. The proposed scheme supports scalability efficiently when the number of nodes increases in the network (more than 2,000 nodes). Moreover, it ensures an acceptable level of security by using the trust metric in calculation of the weight value for CHs election process, improves the usage of scarce resources such as bandwidth, minimizes the CHs change, decreases the number of CHs re-affiliation, minimizes the number of clusters, and decreases the total overhead.

Chapter 5

A New k-hop Scalable Topology Management Scheme For Large Scale Mobile Ad Hoc Networks

Abstract The recent rapid growth of cities, the evolution of wireless/mobile technologies and diverse demanding applications, the world is becoming more and more urban. Obviously, the urban environment represents a combination between communication systems, social systems and several mechanisms to increase the quality of urban living. Currently, wireless and mobile communication systems play a vital role in building a smart urban environment like smart cites, where virtually each device is communicate with each other via wireless network. As well as it ensures supporting of demanding applications such as multimedia applications which requires satisfying the scalability and QoS properties in large scale mobile network. Supporting demanding applications and services in a complex, distributed, large wireless and mobile network and diverse environments considers one of the main issue affecting the improvement the urban life and build-up a sustainable society. Section 5.1 presents a general description of our QoS-based two level hierarchical scheme for large scale MANETs including some definitions, classification, our scheme phases in detail, and illustrative example with numerical results. After, both analyses and comparison the performance of the proposed scheme by simulation is presented in section 5.2.

5.1 Description of the scheme

In this section, we present our proposed topology management scheme that is suitable for large scale MANETs, and satisfies the urban environment properties and QoS requirements of demanding applications. Firstly, we introduce some dentitions used in the scheme, and then present some related work about network topology managements in MANETs secondly. Finlay, we introduce the steps of the proposed scheme.

5.1.1 Preliminaries

A mobile ad hoc network is represented by a directed or undirected graph, depending on the nature of the links, $G = (V, E)$ where V represents the set of nodes (Vertices) and E represents the set of links (Edges) between nodes.

Definition 19 *(Graphs)*
A graph $G = (V, E)$ or $G = (V(G), E(G))$ consists of two nite sets. V, E can be denoted by $V(G)$ and $E(G)$, V represents the vertex set of the graph (the number of nodes $n = |V|$), which is a non-empty set of elements called vertices and E represents the edge set of the graph (the number of edges $w = |E|$). Each edge e in E is assigned as an unordered pair of vertices (u, v), called the end vertices of e.

The clustering in mobile ad hoc networks is the process that consists of dividing the network $G = (V, E)$ into interconnected groups, called clusters Ci where $i = 1, 2,, r.$ with $r < n$. In each cluster Ci, each node v has a set $\Gamma(v)$ representing the set of its neighbor nodes and $E(v)$ is the list of links connecting node v with its neighbor nodes.

Definition 20 *(Sub-Graphs)*
Given a graph $G = (V, E)$, a sub-graph of G is a graph of the form $S = (Y, F)$, where $Y \subseteq V$ and $F \subseteq E$ such that any edge of F has its end vertices in Y.

A dominating set $DS \subseteq V$ of a network $G = (V, E)$ is a subset of nodes dominating the whole network, *i.e.* all member nodes which are not in the dominating set DS have at least one neighbor in the set DS. Nodes in DS are also called dominator's or dominating nodes and the other nodes (member nodes) are called dominated nodes.

Definition 21 *(Dominating Set)*
A dominating set *(DS)* in graph G = *(V, E)* is a subset $DS \subseteq V$ such that for all vertices $u \in V \setminus DS$, there is at least a dominator node $v \in DS$ for which $(u, v) \in E$.

Definition 22 *(m-dominating set)*
A set of nodes S is a mDS of a graph $G = (V, E)$ if and only if every member nodes $u \in V \setminus S$ are joined to at least m members of S by some edges (in mobile network, each member node must have at least *m-DS* in its neighborhood).

Definition 23 *(Distance)*
The distance metric in $G = (V, E)$ represents the number of edges $w^\star$ with $w^\star < w$ that form the shortest path between two vertices$u$and v, denoted by $d(u, v)$. In other words, the distance from vertex u to vertex v is the minimum number of edges on the path from u to v.

Definition 24 *(k-dominating set)*
The *k-DS* of graph $G = (V, E)$ is a subset $V^\star \subseteq V$ such that for each node $u \in V \setminus V^\star$ there is at least a dominator $v \in V^\star$ for which $d(u, v) \leq k$.

Definition 25 *((k, m)-dominating set)*
The optimal *(k, m)-DS* for $G = (V,E)$ represents a subset $R \subseteq V$ such that for all nodes $u \in V \setminus R$ there is a subset $R^\star \setminus R$ such as $|R^\star| \geq m$ and $\forall\ v \in R^\star : d(u, v) \leq k$.

Definition 26 *(l-vertex connected graph or l-connected graph)*
A connected graph $G = (V, E)$ is l-vertex connected or l-connected graph if after removing any $(l - 1)$ vertices from G, the graph G is still connected.

Definition 27 *((l, m)-dominating set)*
The *(l, m)-DS* of graph G = *(V, E)* is a l-connected m-dominating set (or m-*CDS*) of G if the sub-graph S= *(*$V^\star$*,* $E^\star$*)* where $V^\star \subseteq V$ and $E^\star \subseteq E$ is l-vertex connected.

Definition 28 *((l, k, m)-Dominating Set)*
A *(l, k, m)-DS* is a l-vertex connected m-vertex, $k$level dominating set (l-connected *(k,m)-DS* or *(k,m)-CDS*).

Definition 29 *(Articulation Point or Cut-vertex)*
A vertex $v \in V$in a connected graph G= *(V, E)* is a cut-vertex or articulation point of G if G \ v is disconnected.

Definition 30 *(Virtual Backbone)*
A virtual backbone is a sub-graph VB = *(*$V^\star$*,* $E^\star$*)* of the network G = *(V, E)* where V is the set of mobile nodes and E is the set of links. $V^\star$ is the backbone nodes set (dominating set) and $E^\star$ are the set of communication link with both ends in $V^\star$ which forms a *CDS*.

5.1.2 Related topology management schemes

In the last few years, several research papers about network topology managements in MANETs have been published which aim to address the related issues in these kind of network such as: routing, QoS, scalability, security [9, 12, 23, 86]. Among those, the scalability with QoS guarantee for multimedia services in large scale MANETs is one of the main challenges. To the best of our knowledge, most of the proposed schemes are based on the clustering technique or virtual backbone construction mechanism [9, 12, 23, 14, 54]. However, the majority of these schemes resolve the scalability issue only without supporting the QoS of demanding applications like multimedia services. Actually they are limited in scalability when the network size increases to a very large number similar to urban environment scenario. In other word, they do not take into consideration the applications kinds and network size.

For more details, refer to chapter 3 that represents a state-of-the-art of topology managment schemes. These schemes are divided into two main categories: cluster based schemes and virtual backbone based schemes.

5.1.3 Topology construction in our scheme

Our scheme 5.1 builds two hierarchical levels based on a trade-off between the clustering approach in the first level and the virtual backbone techniques in the second level for large scale MANETs.

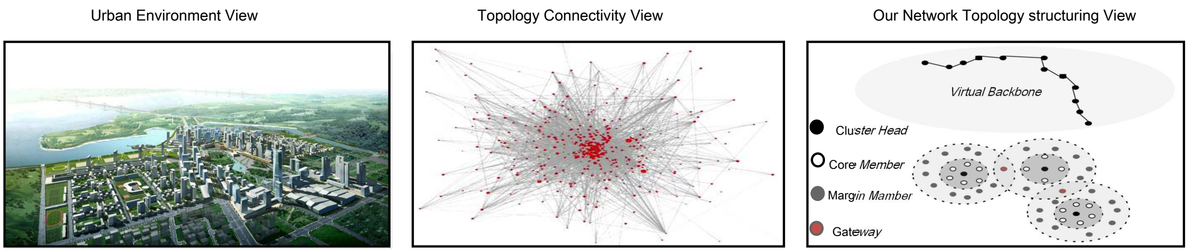


Figure 5.1: Our Network Topology Structure

5.1.3.1 cluster formation phase

In the first level, we applied our clustering scheme to organize the network topology into clusters. Each node is in one of the following states: cluster head (CH), core member (COM), margin member (CAM), not-decided (ND), gateway node (GW) depending on its roles (see Figure 5.2) [13].

Our cluster formation phase consists of four main stages to build the clusters structure [13]: neighbors detection process, cluster heads election process, network node join process and gateway election process.

I. Neighbors detection process

Initially all network nodes are in not-decided state. During this stage, all network nodes exchange a D-HELLO message 5.3 periodically so that each node notifies its neighbor nodes of its presence and builds/maintains its local topology information. The exchanged D-HELLO message has several fields: node

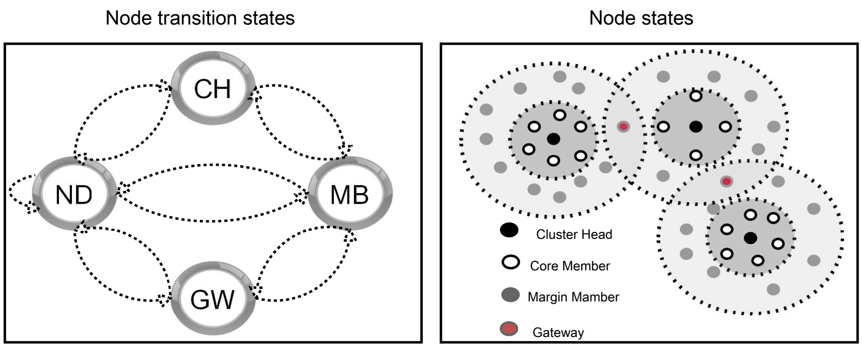


Figure 5.2: General Structure of Our Network Topology

source address, node state, neighbors list, cluster head address, neighbor clusters addresses, and the weight value. Based on the messages exchanged, each node builds, maintains its neighbors list, and records the neighbor nodes information in its neighbors table (neighbor, hops).

II. Cluster Heads election process

Once nodes neighbor detection stage 5.1.3.1 is completed, the cluster head election process is invoked 5.4. This stage is dedicated to the cluster heads election in the whole network. In the following, we propose a cluster head election algorithm that allows to select a set of robust and optimal cluster heads in large scale network and divides the network into a number of clusters. During this stage, each node v_i computes its weight value W_i based on a combination of QoS metrics and clustering metrics and broadcasts it to its k-neighbors in the next D-HELLO message 5.3. On reception of D-HELLO message, each node v_i compares the received weight values of its neighbors with its own weight value. If its own weight value is the highest, it declares itself a cluster head. Otherwise, it chooses the neighbor having the highest weight value among all its k-neighbors as its cluster head and broadcasts locally its choice using a specific D-HELLO message named locally election message E-HELLO 5.5. The node that has the highest number of votes (selected by several neighbors as CH in its neighborhood), is chosen as a cluster head in its neighborhood.

```
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |          Node ID          |  F  |      Htime      | Node State |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Link Code    |   Reserved    |         Link Message Size      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Weight Value      |   Node Trust Value Neighborhood    |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                 Neighbor Interface Address                      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                 Neighbor Directed Trust                         |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                          Link Quality                         |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |               Neighbor Cluster Head Address                     |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 :                             .  .  .                             :
 :                                                                 :
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Link Code    |   Reserved    |         Link Message Size      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                 Neighbor Interface Address                      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                 Neighbor Directed Trust                         |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                          Link Quality                         |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |               Neighbor Cluster Head Address                     |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 :                             .........                           :
```

Figure 5.3: D-HELLO Message Format

II.1 Clustering Metrics

◇ ***Trust Value (T):***

In our algorithm, we used the method described in [8] to calculate the trust node value (Tv_i). This algorithm [8] is distributed over the network nodes. Each node in the network computes its own trust value based on the direct relations relating to its *1*-hop neighbors and indirect relations relating to its k-hop neighbors (formula 5.1).

$$\begin{cases} Tv_i = \sum_{j=1}^{n} TTv_j(v_i) \\ TTv_i(v_j) = w_1 \times DTv_i(v_j) + w_2 \times ITv_i(v_j) \\ DTv_i(v_j) = [\prod_k (m_k)]^{\frac{1}{k}} \\ ITv_i(v_j) = [\prod_l (DT_l(v_j))]^{\frac{1}{l}} \end{cases} \tag{5.1}$$

Where: n is the number of k-hop neighbor nodes of v_i and $TTv_j(v_i)$ represents the total trust of neighbor nodes v_1, v_2, v_3.. v_n on v_i. $DTv_i(v_j)$ represents the

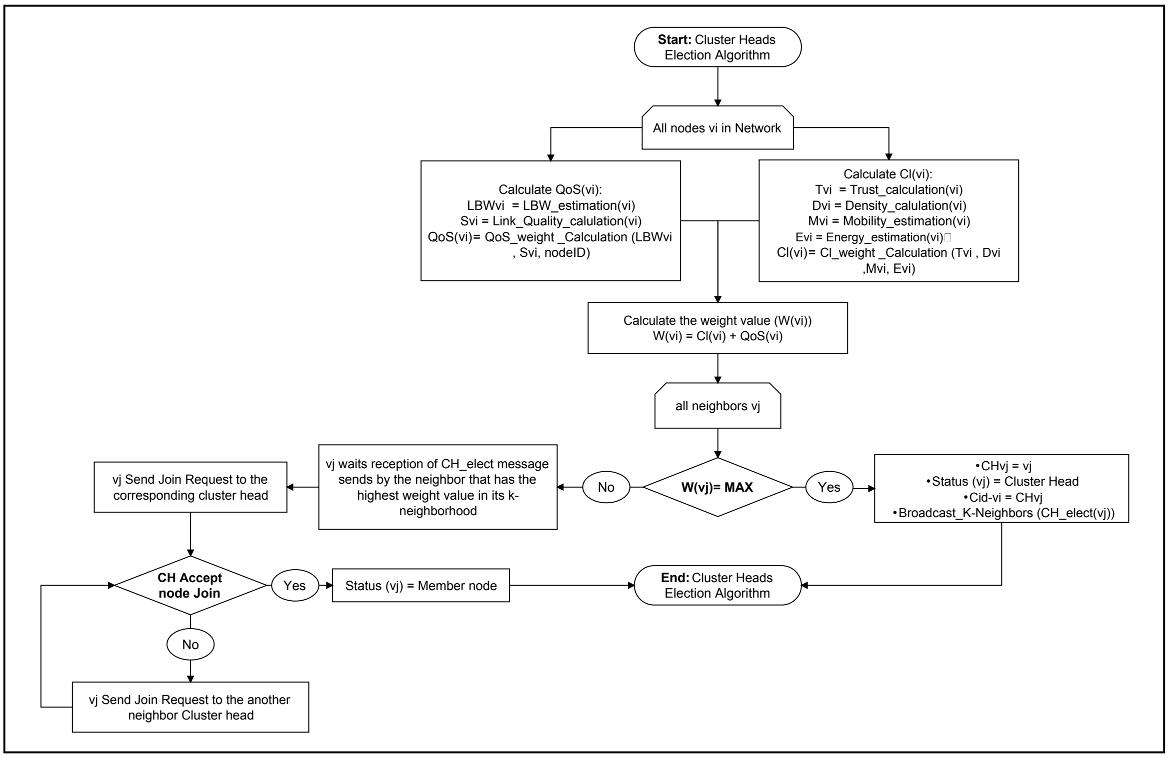


Figure 5.4: Cluster Heads Election Algorithm Flowchart

direct trust of a node v_i on node v_j, $ITv_i(v_j)$) represents the indirect trust of node v_i on node v_j and m_k is set of K trust metrics.

◇ ***Node Density (D):***

Each node has a density metric [62] which represents the ratio between the number of links and the number of nodes in k-hop neighbors. The k-density of a node v_i is calculated as (formula 5.2):

$$Dv_i = \frac{|e = (u, w) \in E, u \in \{\ v, \Gamma k(v_i)\}\ w \in \Gamma k(v_i)|}{dv_i} \tag{5.2}$$

Where, $\Gamma k(v_i)$ represents the list of k-hop neighbors of node v_i and dv_i is the degree of node v_i (the number of nodes in its k-hop neighbors).

```
0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Node ID             | F  |     Htime       | Node State |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Link Code    |   Reserved     |        Link Message Size       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Weight Value     |       Elected Cluster Head ID               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5.5: E-HELLO Message Format

◇ ***Node Mobility (M):***

Each node v_i uses the method described in [66] to compute its mobility value Mv_i. The mobility value Mv_i of node v_i represents its effective average relative speed which is calculated as (formula 5.3):

$$v_i = \frac{\sum_{j \in \Gamma(v_i)} v_{i \to j}}{\Gamma(v_i)} \tag{5.3}$$

Where: $Gamma(v_i)$ represents the list of neighbors of node v_i and $v_{i \to j}$ represents the relative speed of node v_i toward node v_i.

◇ ***Battery Remaining Energy (E):***

The energy metric is a critical metric that affects directly the lifetime of the cluster structure and network. Each node v_i computes its residual energy value Ev_i using the following function (formula 5.4):

$$\begin{cases} Ev_i = E_{total} - E_{v_i consumed} \\ E_{v_i consumed} = E_{v_i send} + E_{v_i receive} \\ E_{v_i send} = \sum\limits_{j \in \Gamma v_i} [|MSGs| \times (E_{elec} + PW^{\alpha}_{v_{i \to j}}) \times E_{amp}] \\ E_{v_i receive} = S \times |MSGs| \times E_{elec} \end{cases} \tag{5.4}$$

Where:

Ev_i represents the residual energy of node v_i, E_{total} is the initial energy, $E_{v_i consumed}$ is the consumed energy at node v_i, $E_{v_i send}$ is the energy required by node v_i to

send packets to its neighbor nodes, $E_{v_i receive}$ is the energy required by node v_i to receive packets sent by its neighbor nodes.
$MSGs$ is the number of packets, E_{elec} is the energy radio electronics, E_{amp} is the power amplifier,$PW^{\alpha}_{v_{i\to j}}$ is the power level needed to reach neighbor nodes and S is the communication cost of the links.

II.2 QoS Metrics

During the cluster election process, each node v_i computes its QoS value ($QoS(v_i)$) based on the following metrics:

◇ ***Local Available Bandwidth (LBW):***

The local available bandwidth of node v_i is defined as the unconsumed bandwidth at node v_i. Each node v_i defines its own $LBWv_i$ by passively listening to network activities. In our algorithm, we use the model described in [90] to calculate the local available bandwidth (LBW) in each node which is based on the fraction of idle channel time during the past history as an indication of local available bandwidth at a node. The local available bandwidth of node v_i ($LBWv_i$) is computed as (formula 5.5):

$$LBWv_i = \alpha LBWv_i + (1-\alpha)\frac{T_{idle}}{T_p}BW_{channel} \tag{5.5}$$

Where: $BW_{channel}$ is the total channel bandwidth, $\alpha \in [0,1]$ is a weight factor and T_{idle} represents the amount of channel idle time during every period of time T_p.

◇ ***Link Quality (S):***

The link quality metric is defined as the estimated number of transmissions required to successfully send a packet over the link. The link quality metric value is calculated using the forward d_f and reverse d_r delivery ratios of the link. The link quality value Sv_i of node v_i represents the sum of the link quality value for each link to each k-hop neighbors $Sv_{i\to j}$ (formula 5.6). Furthermore, link stability metric allows us to ensure the high clusters stability which increases network lifetime 5.2.2.

$$\begin{cases} Sv_i = \sum_{j=1}^{n} Sv_{i \to j} \\ Sv_{i \to j} = \frac{1}{d_f \times d_r} \end{cases} \tag{5.6}$$

Where: n is the number of k-hop neighbor nodes of Sv_i , $Sv_{i \to j}$ represents the link quality value between Sv_i and v_j , d_f is the probability that a packet successfully arrives at the receiver and d_r is the probability that the packet is successfully received.

Finally, each node Sv_i computes its weight value (Function 5.7) based on a combination of *QoS metrics* and *clustering metrics* and selects the optimal cluster head that has the *highest weight value* W in its neighborhood. The selected cluster head declares its leadership to its k-hop neighbors by broadcasting a cluster head election message[1] (NCH-HELLO) with its ID as cluster ID to its k-neighbors.

$$\begin{cases} Cl(v_i) = w_1 Tv_i + w_2 Dv_i + w_3 Mv_i + w_4 Ev_i \\ QoS(v_i) = \acute{w}_1 LBWv_i + \acute{w}_2 Sv_i + \acute{w}_3 nodeID \\ W(v_i) = \tilde{w}_1 cl(v_i) + \tilde{w}_2 QoS(v_i) \end{cases} \tag{5.7}$$

Where w_i , $\acute{w}_i$ and $\tilde{w}_i$ are weight factors for the corresponding metrics with $\sum w_i = 1, \sum \acute{w}_i = 1$ and $\sum \tilde{w}_i = 1$.

III. Network node joins process

Once the neighbor nodes receive a cluster head election message, each node without status joins a suitable cluster by sending a join request to the corresponding cluster head[2] and receiving a positive answer from the concerned cluster.

IV. Gateway Election Process

Once cluster heads are elected and nodes join process is completed, each cluster head selects its gateway nodes to communicate with its neighbor clusters

[1]The Flag F field in HELLO packet used to define the type of the HELLO message (D-HELLO , E-HELLO, NCH-HELLO).

[2]Node v_i joins the neighbor cluster head that has the largest weight value

based on the QoS metrics. Nodes are candidate to be gateways if they have margin member status and they are able to hear two or more cluster heads. The gateway node g with highest QoS value ($QoS(GW)$) among other gateway nodes candidates is selected (Figure 5.6).

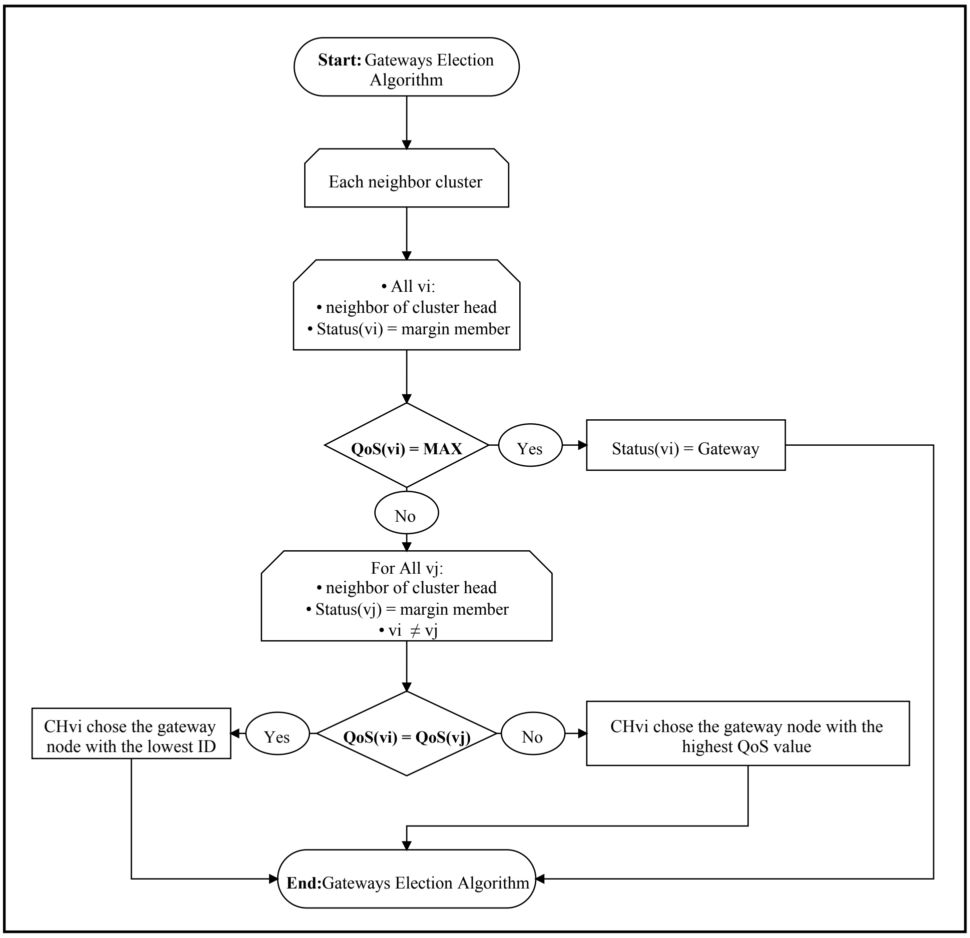


Figure 5.6: Gateways Election Algorithm Flowchart

5.1.3.2 Virtual Backbone Construction Phase

Once the gateways are selected in the network and the clusters are formed, the virtual backbone construction algorithm is invoked in order to build a virtual backbone in the network at level two. Our virtual backbone construction algorithm is divided into two parts. The first one is a distributed algorithm to find the optimal dominating set (DS) which covers all member nodes in the whole network (Definition 21 5.1.1 to Definition 25 5.1.1) and has a height QoS value. The second part is a connectivity algorithm to connect the dominating set and form the Connected Dominating Set (Definition 26 5.1.1 to Definition 30 5.1.1). A virtual backbone is formed by constructing a Connected Dominating Set (CDS).

I. Dominating Set Construction And Connectivity

Once the first level is done and the clusters structure is generated, the connected dominating set algorithm (Algorithm 9) is invoked in order to select the set of CDS and generate the virtual backbone.

Initially, all cluster heads and gateways nodes are selected as DS member (part 1). After, each cluster head selects a set of connectors from its member nodes based on the QoS value (the one with high QoS value from its member nodes) in order to ensure the connectivity between DS members (part 2). This mechanism leads to construct a partial virtual backbone in each cluster. After that, the set of partial virtual backbone are connected using the clusters gateways to construct the complete VB. In Algorithm 9 we define two new states: DS member and Connectors.

5.1.4 Network topology maintenance in our scheme

Our topology maintenance tries to adapt our network structure to all topology changes that can occur due to nodes mobility. We define several types of events for topology maintenance invocation. In the first level we define three types of event: the node movement, the trust threshold property and the cluster head weight value change.

5.1.4.1 Cluster head weight value change

The dynamic nature of network topology in MANETs due to the node mobility has direct impact on the weight value change in each node. So, in our algorithm we propose a technique that verifies the weight value of each node periodically (Figure 5.7).

Algorithm 9 Connected Dominating Set Construction Algorithm

```
procedure CDS–Construction Algorithm
    Input: G = (V, E), v_i ∈ V
    Output: VB = Virtual Backbone.
    Intialization:
    CHv_i = Clusterhead of node v_i = DS member.
    GWv_i = Gateway of v_i = DS member.
    k = m = 2   //Virtual Backbone Parameters
    StatusVB(v_i) = 0
    for All v_i ∈ C do
        LBWv_i = LBW-estimation(v_i).
        Sv_i = Link-Quality-Calculation(v_i)
        QoS(v_i) = ẃ_1 LBWv_i + ẃ_2 Sv_i + ẃ_3 nodeID
        if Status(v_i) = Cluster Head then
            StatusVB(v_i) = DS member.
            for Each Gateway do
                for ((All v_j ∈ Γ(v_i))and (Status(v_j) = Core member)and
    (StatusVB(v_j) = 0) and(v_u ≠ v_j)) do
                    if QoS(v_j) = MAX then
                        •v_i select the core member that has the high QoS value
                        •StatusVB(v_j) = Connectors
                        •Send Connectors message to v_j
                    end if
                end for
            end for
        else
            if StatusVB(v_i) = Connectors then
                for ((All v_i ∈ 1 − hopΓ(v_i)) and(v_u ≠ v_j)) do
                    if QoS(v_j) = MAX then
                        •v_i select the margin member that has
                        the high QoS value.
                        •StatusVB(v_j) = Connectors
                        •Send Connectors message to v_j and its cluster head
                    end if
                end for
            else
                if Status(v_i) = Gateway then
                    Status(v_i) = DS member
                end if
            end if
        end if
    end for
end procedure
```

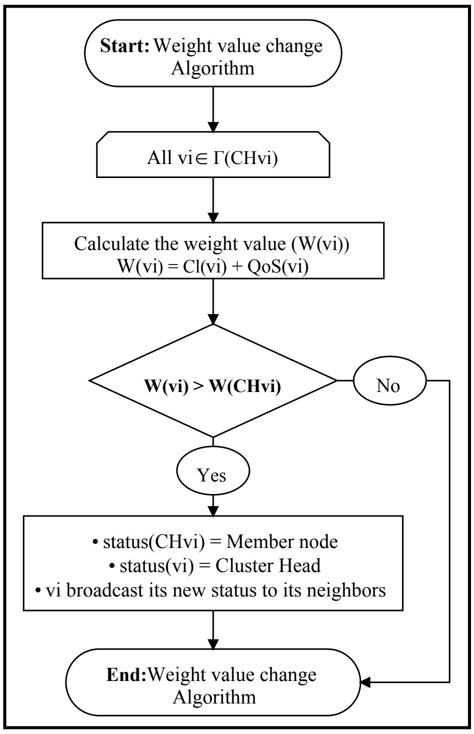


Figure 5.7: Weight Value Change Algorithm Flowchart

5.1.4.2 Node Movement

The node movement event is divided into two types. The first one, when a node moves to the outside of its cluster range. The second type, when a new node moves into the range of new cluster. In the first case, the moving node changes its status to ND and tries to find an existing cluster to join. When second case occurs, the new node sends a join request to the corresponding cluster head and waits for the response. In our algorithm (Figure 5.8), the node movement is verified locally and periodically in each cluster.

5.1.4.3 Trust Threshold Property

The trust value represents the level of confidence between a node and its neighbors based on interactions between nodes. This level of confidence is affected by two factors: mobility and interactions between nodes. Since we are dealing with

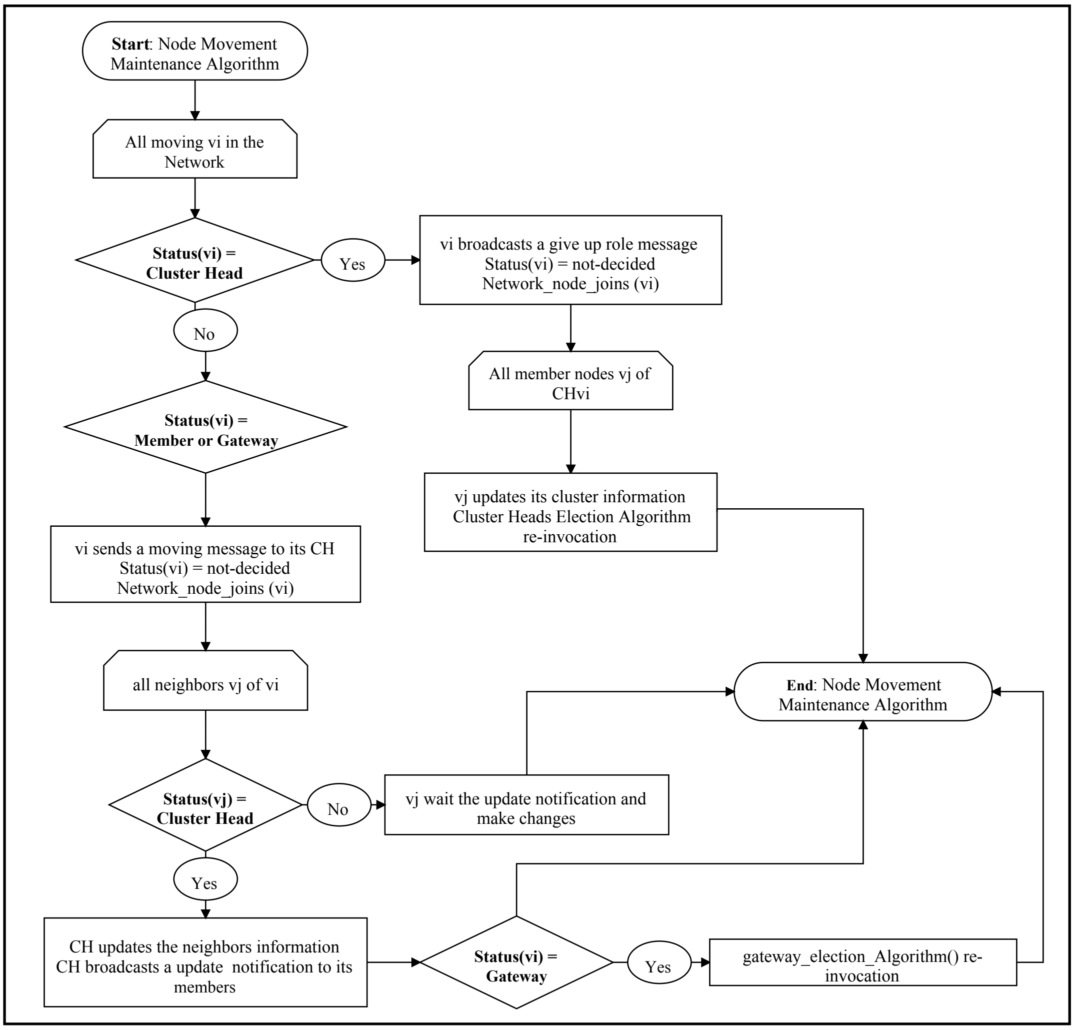


Figure 5.8: Node Movement Algorithm Flowchart

vulnerable network, each node could become a malicious node. So in our algorithm, the trust value of each node is verified periodically (Figure 5.9) in order to eliminate the malicious nodes in each cluster.

5.1.4.4 Dominating Set And Connectors Recovery Mechanism

In the second level, some DS or connectors nodes may cause link failures due to dynamic topology that leads to the virtual backbone structure imbalance and network instability. Therefore, we introduce a new mechanism named dominat-

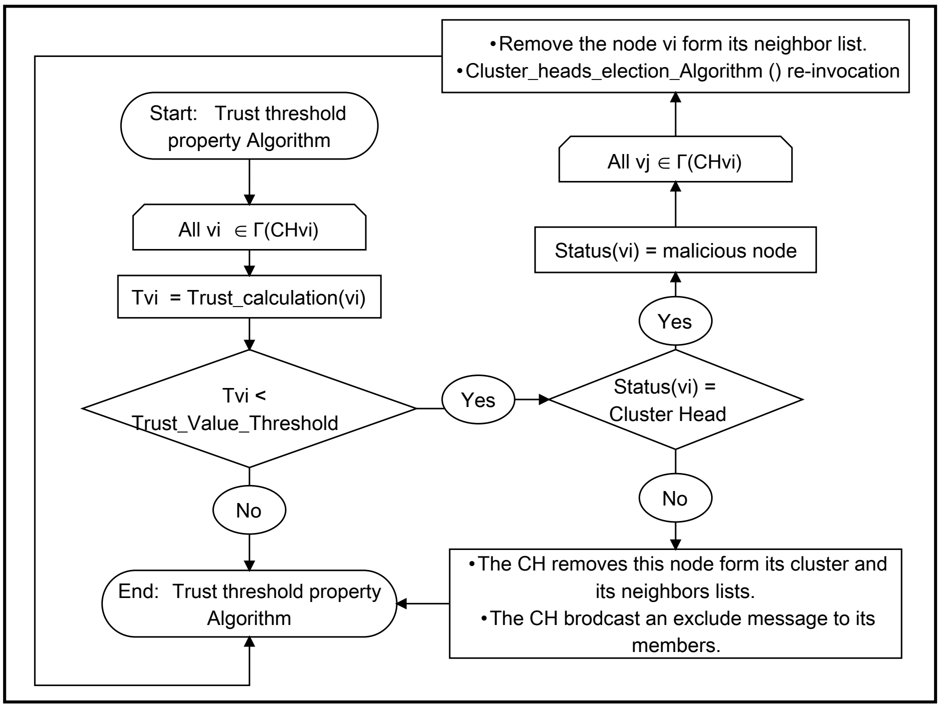


Figure 5.9: Trust Threshold Property Algorithm Flowchart

ing set and connectors recovery mechanism (Algorithm 10) which is capable to select alternative dominating or connector nodes (according to the situation that occurs) from the set of candidate nodes in each cluster periodically. Our proposed topology maintenance mechanism aims to keep the network connected and reduce the number of re-elections. Thus, we are able to maintain the network stability during the topology construction for large scale MANETs.

Algorithm 10 Local DS members and connectors recovery Algorithm

procedure DS–RECOVERY ALGORITHM
    for All Moving $v_i \in$ VB **do**
        if $StatusVB(v_i)$ = DS member **then**
            $C_{id-v_i} = CHv_i$
            if $Status(v_i)$ = Cluster Head **then**
                •**Node–Movement–Maintenance–Algorithm**(C_{id-v_i}, v_i, CH).
                •$StatusVB(v_i) = 0$
                •**Algorithm 9**$(C_{id-v_i}, new\text{–}CH, CH)$
            else
                •**Node–Movement–Maintenance–Algorithm**(C_{id-v_i}, v_i, GW).
                •$StatusVB(v_i) = 0$
                •**Algorithm 9**$(C_{id-v_i}, new\text{–}GW, GW)$
            end if
        else
            •**Algorithm 9**(C_{id-v_i})
            •$StatusVB(v_i) = 0$
        end if
    end for
end procedure

5.1.5 Illustrative example and numerical results

In this part, we explain with an illustrative example the various phases of our scheme starting from the topology construction and its phases 5.1.3 to the maintenance of topology and its causes 5.1.4.

5.1.5.1 Topology construction example

Initially, all network nodes have the same status which is *not-decided* (Figure 5.10 (a)). After, each node in the network launches the *neighbors discovery process* (Figure 5.10 (b)). Table 5.1 represents the *2*-hops neighbors of some interesting nodes in the network:

During *neighbors discovery process*, each node calculates its metrics 5.1.3

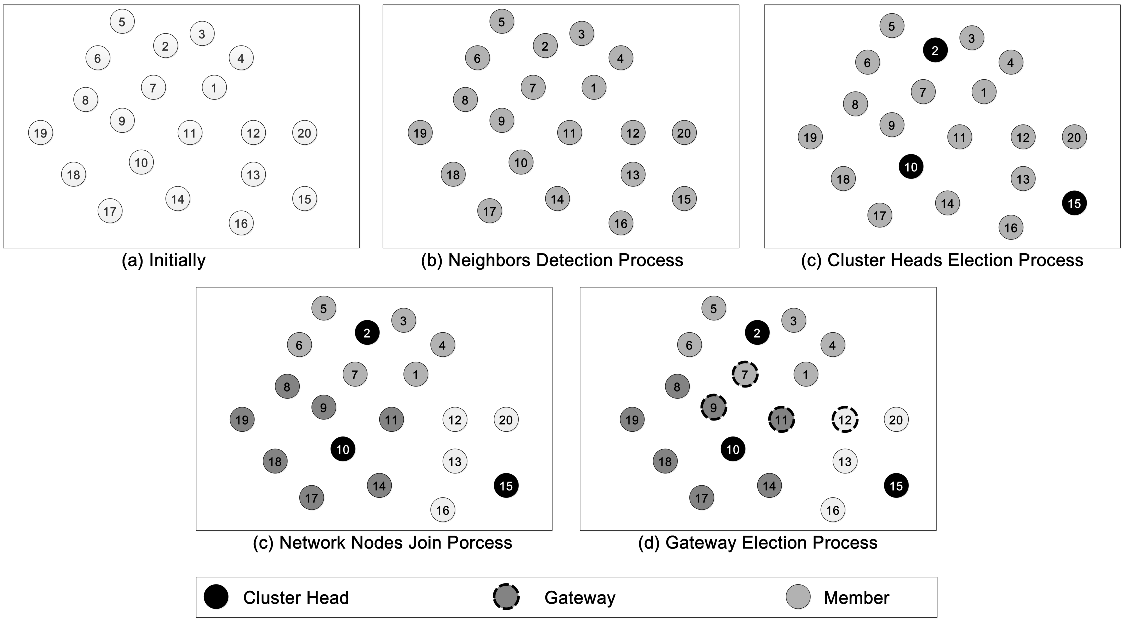


Figure 5.10: Cluster Formation Example

within 2-hops neighbors. In Table 5.2, we summarize the calculation of metrics ratio by each node.

After *neighbors discovery process*, the *cluster head election process* is invoked. During this step, each node calculates its total weight value 5.3 and chooses one node with the *highest weight value* within k-hops neighbors as its cluster head . As we see in Figure 5.10 (c), the set of nodes $\{1,3,4,5,6,7\}$ choose node $\{2\}$ as a cluster head , nodes $\{8,9,11,14,17,18,19\}$ choose node $\{10\}$ as a cluster head and node $\{15\}$ was selected by nodes$\{12,13,16,20\}$ as a cluster head. These three cluster heads $\{2,3,15\}$[1] have the highest weight values **(0.73,0.77,0.71)** respectively in their k-neighbors (Table 5.3).

Thereafter, each cluster head:

- Sends a CH election messages which allows the neighbor nodes to join 5.1.3.1 their favorite cluster (Figure 5.10 (c)). Where:
  - The set of nodes $\{1,3,4,5,6,7\}$ join th the cluster head $\{2\}$.

[1] $\star$ represents Cluster Head, $*$ represents Gateway and $\triangleleft$ represents Connector

Table 5.1: Network Nodes Neighbors

Node ID	1-hop Neighbor	2-hop Neighbor
1	7,2,3,4	5,6,8,9
2	1,3,5,6	7,4
7	1,6,9,11	2,3,4,5
9	7,8,10	1,6,11,14,17,18,19
10	9,14,17	8,11,17,18,19
11	7,12	9,10
12	11,13,20	7,15,16,14
13	12,15,16	20,11
14	10,11,17	9,18,12
15	13,16,20	12,11,14

Table 5.2: Nodes Metrics Values

Node ID	Trust (T)	Density (D)	Mobility (M)	Energy (E)	Local Bandwidth (LBW)	Link Quality (S)
1	0.81	0.75	0.0625	0.0145	0.454	0.5
2	0.96	1	0.05	0.0109	0.818	1
3	0.8	0.7142	0.0942	0.0127	0.4727	0.7457
4	0.75	0.8	0.088	0.0090	0.5454	0.78
5	0.77	0.6666	0.085	0.0109	0.454	0.7
6	0.79	0.714	0.05	0.0127	0.3909	0.6428
7	0.85	0.875	0.0525	0.0145	0.7272	0.9875
8	0.7	0.5	0.0733	0.0109	0.5	0.8166
9	0.87	0.9	0.055	0.018	0.6636	0.9
10	0.93	1	0.03	0.01454	0.818	1
11	0.83	0.75	0.045	0.0072	0.7818	1
12	0.89	0.8571	0.0571	0.0127	0.7272	0.9714
13	0.78	0.6	0.088	0.0090	0.518	0.5
14	0.8	0.66	0.095	0.0109	0.5454	0.6
15	0.97	1	0.05	0.0109	0.818	1
16	0.57	0.6	0.096	0.0090	0.4636	0.718
17	0.66	0.66	0.07	0.0109	0.4545	0.65
18	0.69	0.6	0.066	0.009	0.445	0.75
19	0.72	0.8	0.078	0.009	0.436	0.75
20	0.9	0.75	0.075	0.0072	0.6	0.95

- The set of nodes {*8,9,11,14,17,18,19*} join th the cluster head {*10*}.
- The set of nodes {*12,13,16,20*} join th the cluster head {*15*}

• Selects its gateways nodes 5.1.3.1 that have the highest QoS metric value 5.1.3.1 to communicate with neighbor clusters (Figure 5.10 (d)). Where:

- The cluster head {*2*} selects node {*7*} as its gateway to communicate

Table 5.3: Weight Values

Node ID	Clustering Weight	QoS Weight	Total Weight
1	0.4092	0.4772	0.4432
2 ⋆	0.5052	0.9090	**0.7271**
3 ◁	0.4053	0.6092 ←	0.5072
4 ◁	0.4117	0.6627 ←	0.5372
5	0.3831	0.5772	0.4802
6	0.3917	0.5168	0.4543
7 ∗	0.4480	0.8573 ⇐	0.6526
8 ◁	0.3210	0.6583 ←	0.4896
9 ∗	0.4607	0.7818 ⇐	0.6213
10 ⋆	0.4936	0.9090	**0.7713**
11 ∗	0.4080	0.8909 ⇐	0.6494
12 ∗	0.4542	0.8493 ⇐	0.6518
13	0.3692	0.5090	0.4391
14 ◁	0.3931	0.5727 ←	0.4829
15 ⋆	0.5077	0.9090	**0.7084**
16	0.3187	0.5908	0.4547
17	0.3518	0.5522	0.4520
18	0.3412	0.5977	0.4695
19	0.4017	0.5931	0.4974
20 ◁	0.4330	0.7750 ←	0.6040

with the cluster of the cluster head {*10*}. In which, {*7*} is a margin member and has the highest QoS metric value (**0.86**) compared to other margin members like node {*4*}.

– The cluster head {*10*} selects nodes {*9*} and {*11*} as its gateways to communicate with the clusters of the cluster heads {*2*} and {*15*} respectively. In which, {*9*} and {*11*} are a margin members and have the highest QoS metric values (**0.78, 0.89**) respectively compared to other margin members such as node {*14,17..etc*}.

– The cluster head {*15*} selects node {*12*} as its gateway to communicate with cluster of cluster head {*10*}.

In this example, our scheme builds three clusters {*2,10 and 15*} 5.10 which represents the first level of hierarchical topology. At the end of *gateways election process*, the *virtual backbone construction algorithm* 5.1.3.2 is invoked in order to build a virtual backbone in the network at level two Figure 5.11.

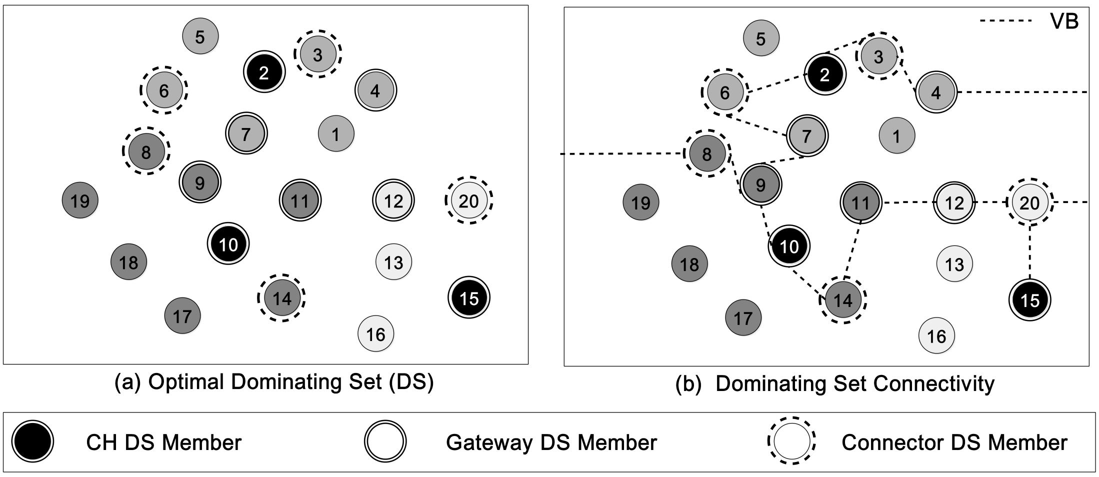


Figure 5.11: Virtual Backbone Construction Example

During the *virtual backbone construction*, in each cluster, the cluster head and gateways are marked as *DS* member. Furthermore, each cluster head selects a set of its members that has a highest QoS value as a connector in order to ensure the connectivity between *DS* members and build the virtual backbone (Algorithm 9). As we see in Figure 5.11:

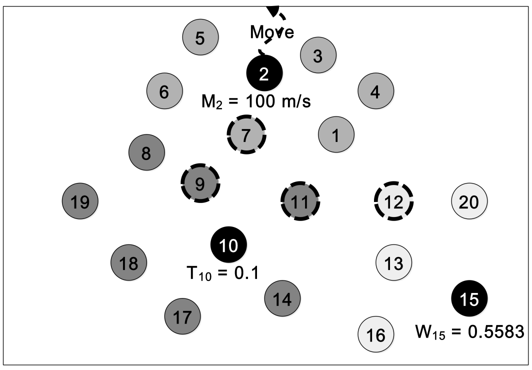
- The cluster heads {*2,10 and 15*} and their gateways {*7,9,11,12*} respectively are marked as a *DS* member Figure 5.11 (a).
  - The cluster head {*2*} selects core/margin members nodes {*6, 3 and 4*} with highest QoS value metric as a connector to build the partial virtual backbone $VB1_{Partial}$ = {*2,3,4,6,7*} in its cluster.
  - The cluster head {*10*} selects core/margin members nodes {*8 and 14*} with highest QoS value as a connector to build the partial virtual backbone $VB2_{Partial}$ = {*8,9,10,11,14*} in its cluster.
  - The cluster head {*15*} selects core member node {*20*} with highest

QoS as a connector to build the partial virtual backbone $VB3_{Partial} = \{12,15,20\}$ in its cluster.

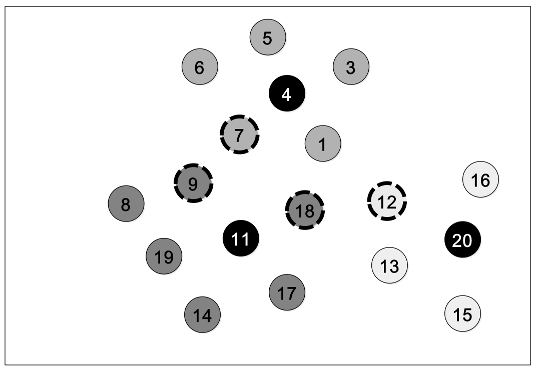
- The *Union* of the partial virtual backbones [1] $\{VB1_{Partial}, VB2_{Partial}$ *and* $VB3_{Partial}\}$ constructed in each cluster builds the total virtual backbone $VB_{Total} = \{2,3,4,6,7,8,9,10,11,14,12,15,20\}$ in the network 5.11 (b).

5.1.5.2 Topology Maintenance Example

Due to MANETs characteristics and its dynamic nature, at any time the clustering and QoS metrics are subjected to change which leads to the topology maintenance. Our scheme ensures a topology maintenance locally when one of Mobility, Total weight value changes and/or trust value changes events occur Figures 5.12,5.13.



(a) Before Changes



(b) After Changes

Figure 5.12: Cluster Head Metrics Values Change Example

As we see in Figure 5.12:<u>In Cluster *2*:</u> the cluster head $\{2\}$ moves outside of its cluster range with Mobility $M_2 = 100m/s$, which leads to re-invocation of cluster head election process 5.1.3.1 locally 5.4. The algorithm selects the node $\{4\}$ as a new cluster head based on the highest weight total value (Figure 5.12 (b)).

[1]The connectivity between the partial virtual backbones ensured by gateways of each cluster

In Cluster *10*: The trust value changes in the cluster head {*10*} from T_{10} = **0.96** to T_{10} = **0.1** (Table 5.4). Our Trust value changes algorithm 5.9 considers the node {*10*} as a malicious node, [1] which leads to re-elect 5.4 the node {*11*} with the highest weight value 5.4 as a new cluster head (Figure 5.12 (b)).

In Cluster *15*: The weight value changes in the cluster head {*15*} from W_{15} = **0.7084** to T_{15} = **0.5583** (Table 5.5). Our Weight value changes algorithm 5.7 is invoked locally in order to re-elect a new cluster head 5.4 and changes the statue of node {*15*} to member node 5.12(b) . The new elected cluster head is node {*20*} (5.5) with highest weight value (**0.6**).

Table 5.4: Cluster 10 Trust Value Changes

Node ID	Trust (T)	Total Weight
8	0.92	0.52
9	0.87	0.62
10 ⋆	**0.1**	0.60
11	0.83	**0.65**
14	0.5	0.45
17	0.7	0.46
18	0.52	0.45
19	0.77	0.50

Table 5.5: Cluster 15 Weight Value Changes

Node ID	Clustering Weight	QoS Weight	Total Weight
12	0.4041	0.6593	0.5317
15 ⋆	0.2077	0.7090	**0.5583**
16	0.2187	0.5009	0.3598
20	0.4230	0.7750	**0.60** ⇐

Figure 5.13 shows the mobility and trust value changes occurring in each cluster gateway and member nodes.

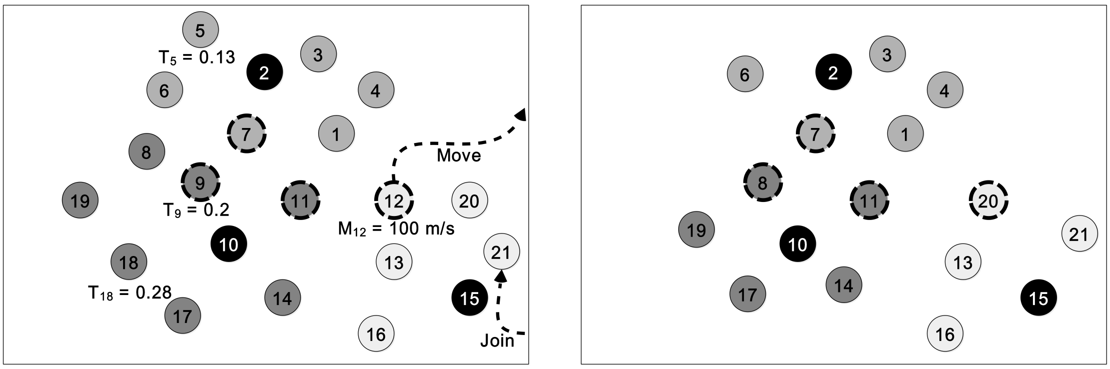
In cluster *2*, the trust value of the member node {*5*} changes from T_5 = **0.77** to T_5 = **0.13** (Figure 5.13 (a)). In order to ensure a good level of security, the cluster head {*2*} considers this node as a malicious[1] node and exclude it from its cluster 5.13 (b).

In cluster *10*, the cluster head {*10*} eliminates the gateway node {*9*} and the member node {*18*} for the cluster *10* 5.13(b) , this is due the changing of the trust value in nodes {*9, 18*} from T_9 = **0.87** to T_9 = **0.2** and T_{18} = **0.69** to T_{18} = **0.28** respectively 5.13 (a). In addition, the cluster head {*10*} selects the

[1]In our implementation, we have fixed the Trust Threshold at **0.3**. In the Illustrative example, T_{10}, T_5, T_9, T_{11} less than Trust Threshold (**0.3**).

node {*8*} as its new gateway 5.6 to communicate with the neighbor cluster {*2*} 5.13 (b).

In cluster *15*, two mobility event are occurred, where the gateway node {*12*} moves outside the cluster *15* and a new node {*21*} joins the cluster *15* 5.13 (a). The cluster head {*15*} selects the node {*20*} as its new gateway 5.6 to communicate with the neighbor cluster {*10*} and accept the joins of the new node {*21*} as a member node 5.13 (b).



(a) Before Changes (b) After Changes

Figure 5.13: Gateway/Member Metrics Values Change Example

In the second hierarchical level, virtual backbone is subjected to the disconnection issue due to *DS* members and/or connectors mobility (Figure 5.14 (a)). Our *DS* members and connectors recovery mechanism 5.1.4.4 detects quickly this changes and selects locally in each cluster a new nodes as *DS* member and/or connector keep the network connected and reduce the number of re-elections (Figure 5.14 (b)). As we see in Figure 5.14:

In cluster *2*, the connector node {*3*} moves outside the cluster, which leads to disconnection of partial virtual backbone in this cluster. Our recovery algorithm (Algorithm 10) running in the cluster heads selects node {*5*} with highest QoS value (W_5 = **0.58**) as an alternative connector 5.14 (b) and re-build the partial virtual backbone $VB1_{Partial}$ = {*2,4,5,6,7*}.

In cluster *15*, the *DS* member node {*12*} moves outside the cluster, which leads to disconnection of partial virtual backbone in cluster *15*. The cluster head

15 selects node {*20*} with the highest QoS value ($W_{20} = \mathbf{0.79}$) as a *DS* member as well node {*21*} as a connector 5.14 (b) and re-build the partial virtual backbone $VB3_{Partial}$ = {*15*,*20*,*21*}.

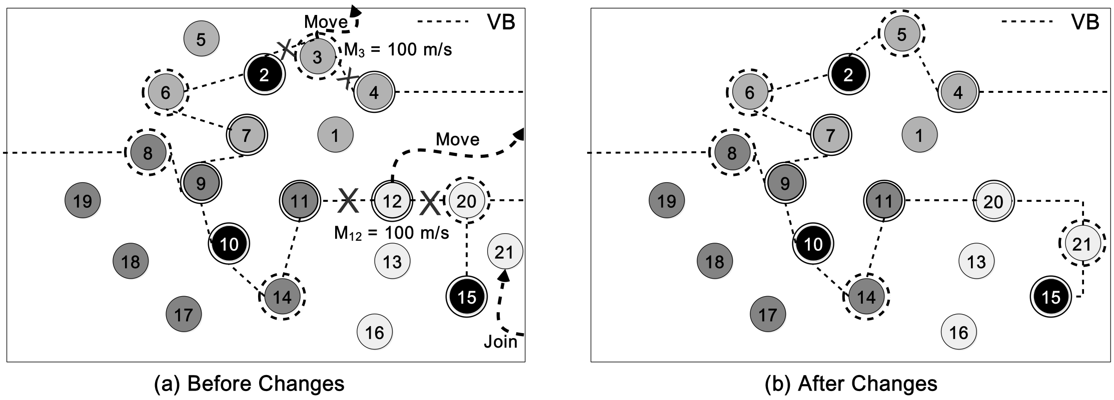


Figure 5.14: Virtual Backbone Disconnection and Maintenance Example

5.2 Experimental analysis

In this section, we present the performance evaluation of our proposed scheme using Optimum Network Performance simulator (OPNET [63]). In Table 5.6, we provide the simulation parameters.

It is important to note that, we used the default settings of the Enhanced Distributed Channel Access (EDCA) to apply QoS in our network (Table 5.7).

5.2.1 Simulation model and parameters

The network model that we designed to simulate and evaluate our scheme consists of 500 - 8000 mobile nodes of type MANETs placed in an area of simulation 10×10 kilometers square. The mobility model we have chosen is the model urban mobility, node speed between 0 to 100 m/s, IEEE 802.11e as Physical and MAC layer. We assume that the radio model uses data rate of 11 Mbits/s, transmission range 250 meters, packet size 128 bytes, and simulation time is 21600 seconds.

Table 5.6: Simulation Parameters

Parameter	Meaning	Value
N	Number of Nodes	[500 8000] nodes
X $\times$ Y	Area of simulation	10 km $\times$ 10 km
Speed	Nodes Speed	0 m/s - 100 m/s
AP	Fixed Nodes	Dynamically Network size based
Mobility	Mobility Model	Urban Mobility
Tx	Transmission range	250 m
PT	Pause Time	0 sec
HI	Hello Interval	2 sec
Phy Char	Physical characteristic	Direct Sequence
Pkt Size	Packet Size	128 bytes
Data Rate	Data Rate	11 Mbits/s
Init Energy	Initial Energy	Battery (10.8V, 4000 mAh, 44 Wh)
Tran Power(W)	Transmit Power	0.001 watt
Rec Power(dBm)	Reception Power	-95 dBm
Sen Power(W)	Sensing Power	Negligible
Dev Tp	Devices Type	Homogeneous Laptop
Traffic Type	Type of service	AC–{ VO, VI, BE, BK }
W_i	Weight Factor	Equally
Duration	Simulation Time	21600 secs

In our experimental study we validate the scalability and QoS of our proposed scheme in very large network in terms of number of generated clusters and average lifetime duration of cluster. Furthermore, we evaluate our scheme in terms of average number of CHs, average number of CH changes, total overhead, clusters stability, and number of dominating set. Also, we compared our scheme to previous network topology management schemes [6, 12, 24, 40, 62, 80] . As the simulation results show in the next sections, our scheme performed better than others schemes.

5.2.2 Results Discussion

The main goal of our scheme is to support the network scalability when network size increases (thousands of nodes), supports the multimedia services with an

Table 5.7: Traffic Types

Traffic Type	AC	CWmin	CWmax	AIFSN
Voice	AC–VO	$\frac{(PHY\ CWmin+1)}{(4-1)}$	$\frac{(PHY\ CWmin+1)}{2-1}$	2
Video	AC–VI	$\frac{(PHY\ CWmin+1)}{(2-1)}$	$PHY\ CWmin$	2
Best Effort	AC–BE	$(PHY\ CWmin)$	$(PHY\ CWmax)$	3
Background	AC–BK	$(PHY\ CWmin)$	$(PHY\ CWmax)$	7

acceptable level of QoS.

5.2.2.1 Variation of average number of clusters formed

Figure 5.15 shows the variation of average number of clusters formed during the first level of our topology construction with respect to the total number of nodes in the network. We observe that the generated clusters increase when the number of nodes in the network increases in all schemes. As described in [51], generating a large number of clusters causes the congestion problem. However, our scheme generates a constantly fewer clusters than those generated in the other schemes. This is due to our k-hop clustering technique that has the effect of spacing between the neighbor cluster heads which results in low overhead, prevent the creation of new clusters and reduces the number of cluster heads re-election.

5.2.2.2 Variation of number of cluster head changes

Figure 5.16 illustrates the variation of number of CH changes with respect to the total number of nodes in the network. The CH changes in our topology management scheme are fewer compared with other schemes. This is due to our distributed cluster head election algorithm which uses a new cluster heads election criteria during cluster formation phase. Also, our cluster heads election criteria chose only the stable node as CH which results in a more stable network topology. Furthermore, the distributed algorithms that are used in our scheme are invoked periodically to adapt the structure of network clusters to all topology

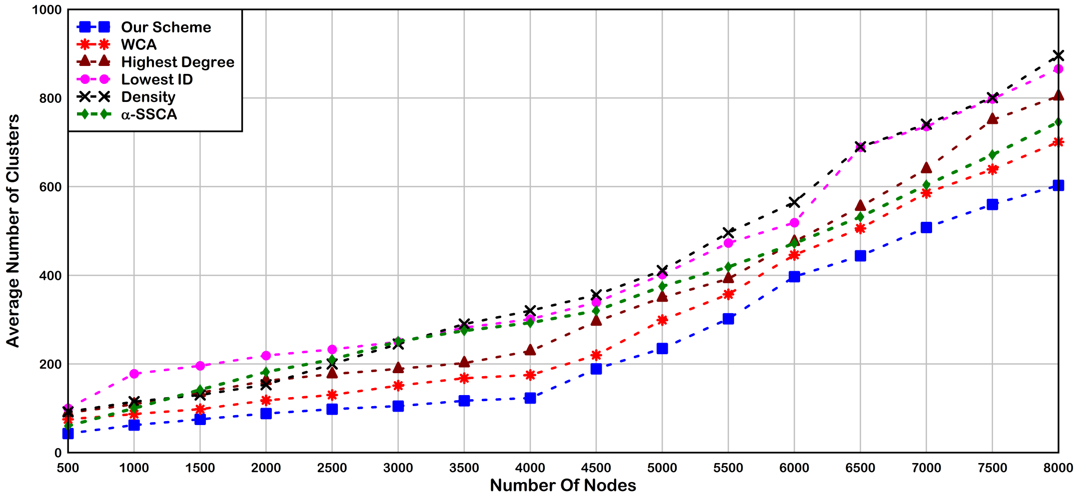


Figure 5.15: Number of Nodes vs Average Number of CHs

changes.

5.2.2.3 Clusters stability

Figure 5.17 describes the clusters stability with respect to the total number of nodes in the network. This figure shows the clusters stability decreases in all schemes depending on the node density. When the node density increases in the network, we observe a decreasing in the clusters stability for all schemes. When node density is 500, we note that the cluster stability is equal to one, this indicates that the topology structure is highly stable in all schemes. However, when the number of nodes increases to more than 1,000, our scheme provides better clusters stability in comparison to other schemes, where we observe a significant decrease in clusters stability value in the other schemes compared with our topology management scheme. This result is due to the cluster heads selection metrics during CH election algorithm which chooses the more stable nodes as cluster heads in their k-neighborhood. This leads to produce a more stable clusters structure in the network.

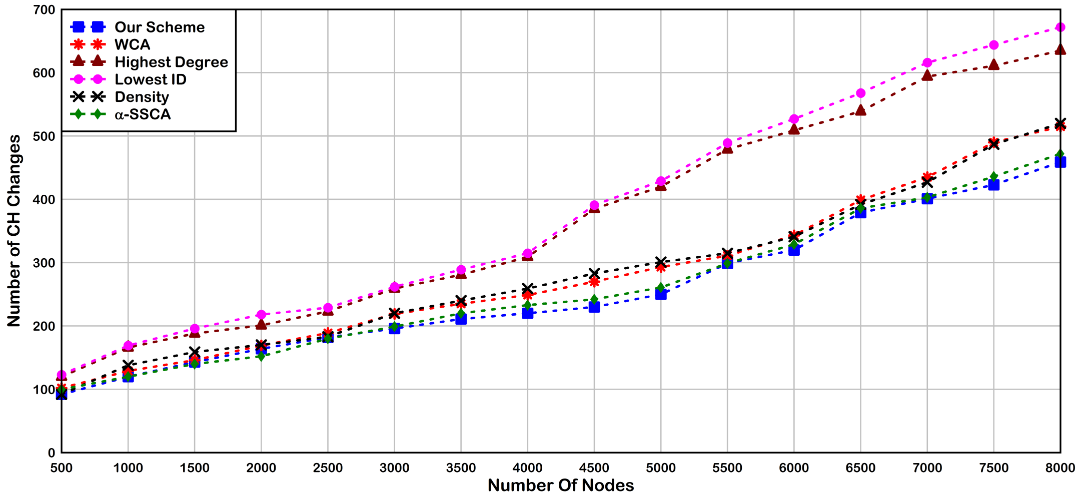


Figure 5.16: Number of Nodes vs Average number of CH changes

5.2.2.4 Total number of overhead

Figure 5.18 illustrates the total number of overhead with respect to the number of nodes. Simulation result shows that our scheme reduces significantly the number of control messages than those generated by other schemes especially when the number of nodes is very high. Our topology management produces less than 50 % compared with to highest degree and lowest ID schemes, less than 19.2% compared to the WCA scheme and less than 5.9 % compared to the α-SSCA scheme. Moreover, our scheme produces a stable topology structure, a less number of CHs and a less number of clusters maintenance invocations which leads to low overheads. Therefore, more bandwidth is available which can be used to improve the network performance like the network throughput, delay, and packet loss.

5.2.2.5 Total number of backbone nodes

Figure 5.19 and 5.20 describe the number of backbone nodes (*DS* member only) with different values of k and m with respect to the total number of nodes in the network. In general, after node density exceeds 1500 nodes, we observe that our

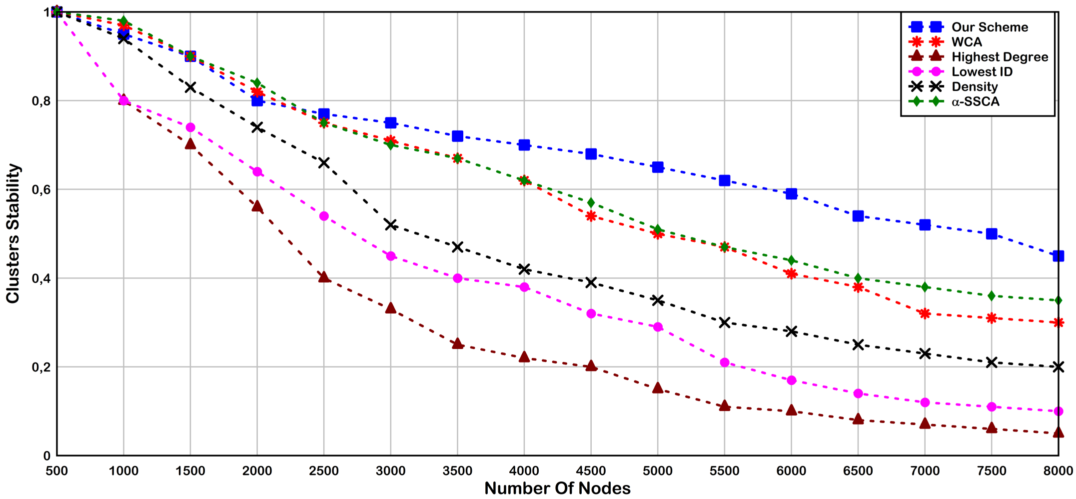


Figure 5.17: Number of Nodes vs Cluster Stability

scheme produces relatively small number of backbone nodes compared to DSCAM [6], Dai and Wu [24], and Blackbone 2 [80] schemes. When the number of nodes in the network increases the number of backbone nodes increases significantly in all schemes. Moreover, from 500 to 1500 nodes, our scheme generates a high number of backbone nodes compared to the other scheme. This is due to our topology structure that generates k-hop clusters[1] in the first level resulting in the spacing of the selected backbone nodes during virtual backbone construction phase. However, with a large number of network nodes (more than 1500) the number of backbone nodes, generated by our scheme, increases much slower than other schemes. This is due to our virtual backbone construction phase that selects a set of optimal nodes as a DS member in the second level.

5.2.2.6 Packet delivery ratio (PDR)

Figure 5.21 shows the Packet delivery ratio (PDR) with respect to the number of nodes. When network nodes increasing, we observe that our scheme achieve a good Packet delivery ratio compared to other topology management schemes. Where, when network nodes density between 500 and 4000, we see a

[1]Our algorithm generates large cluster radius compared to the other schemes.

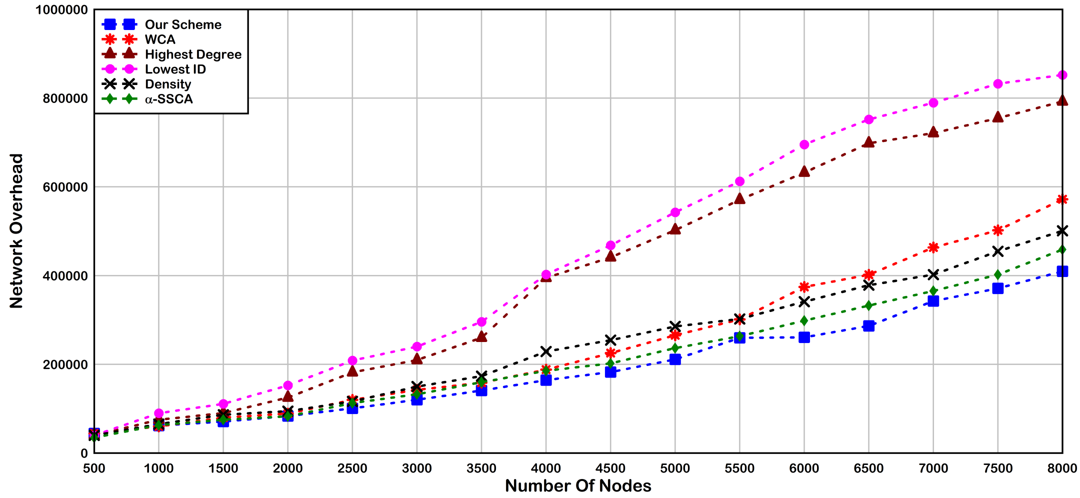


Figure 5.18: Number of Nodes vs Network Overhead

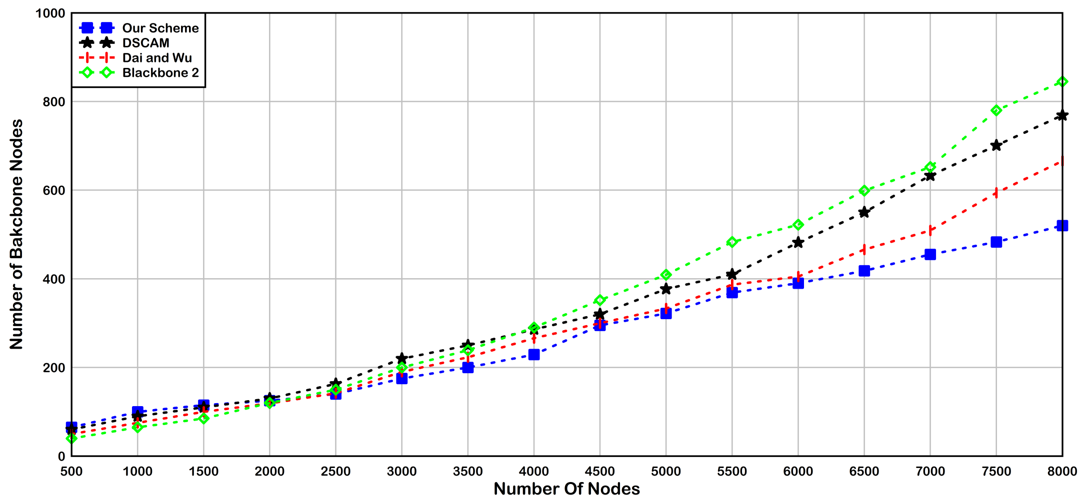


Figure 5.19: Number of Nodes vs Number of Backbone Nodes (k=1, m=1)

slight decreasing of PDR in our scheme compared to other topology managements schemes. In which our scheme ensures 99% to 80% α-SSCA ensures 90% to 50%, WCA achieves 85% to 30% of packet devilry. However, when network size increases more than 4000 nodes, we see in the other schemes a sharp decreasing in

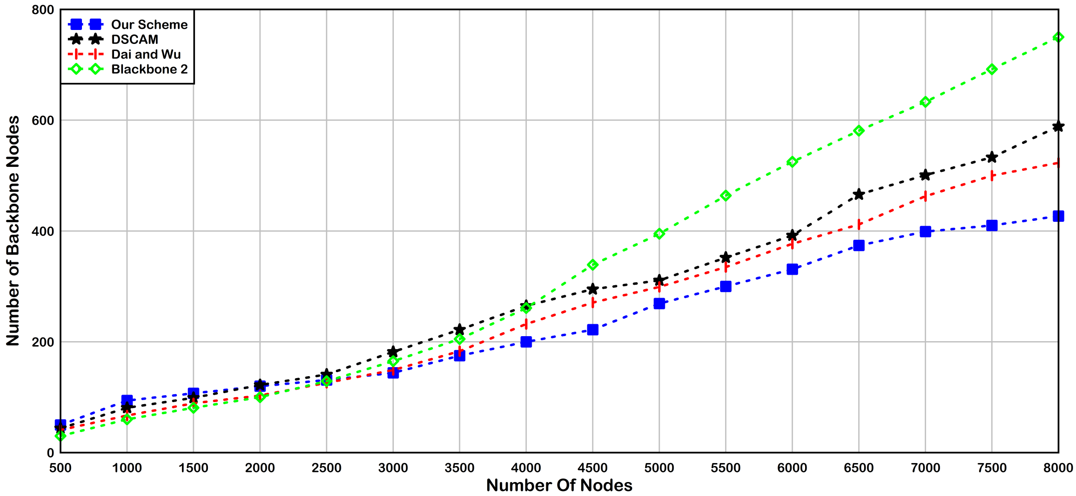


Figure 5.20: Number of Nodes vs Number of Backbone Nodes (k=2, m=1)

PDR compared to our scheme where it achieve 50% of PDR when network size exceed 7000 nodes, this due to the hight flexibility, clusters stability offed by our scheme when network size increase.

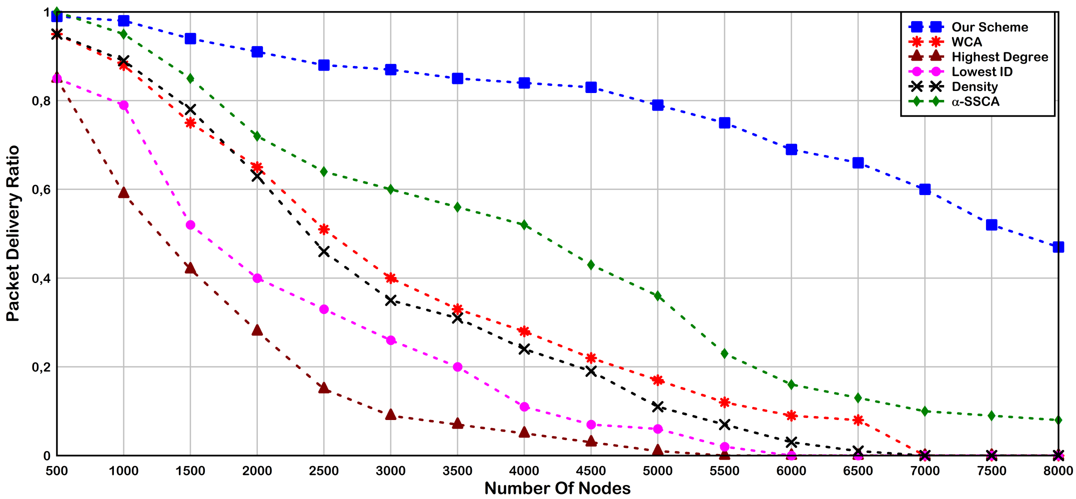


Figure 5.21: Number of Nodes vs Packet Delivery Ratio

5.2.2.7 Network life time

In oder to evaluate the network life time efficiency, we have implemented the energy consumption metric 5.4 in WCA [12] and DSCAM [6] schemes. Figure 5.22 illustrates the Network life time metric with respect to the number of nodes. We observe, the life time of network is decreasing when the number of nodes increased and this is due to the increasing in the number of packets transmitted/received during topology re-construction. Our scheme is more energy efficiency than both WCA and DSCAM schemes. Our scheme decrease number of topology re-construction [1] by conserving the topology structure as much as possible and this is due to various metrics used during the topology construction phase which chooses the best nodes in term of stability, energy, QoS..etc as CH in first level and as *CDS* member in second level. In addition, the flexibility and efficiency offered by our cluster maintenance and connectors recovery Algorithms which occur locally in case of topology changes due to nodes mobility.

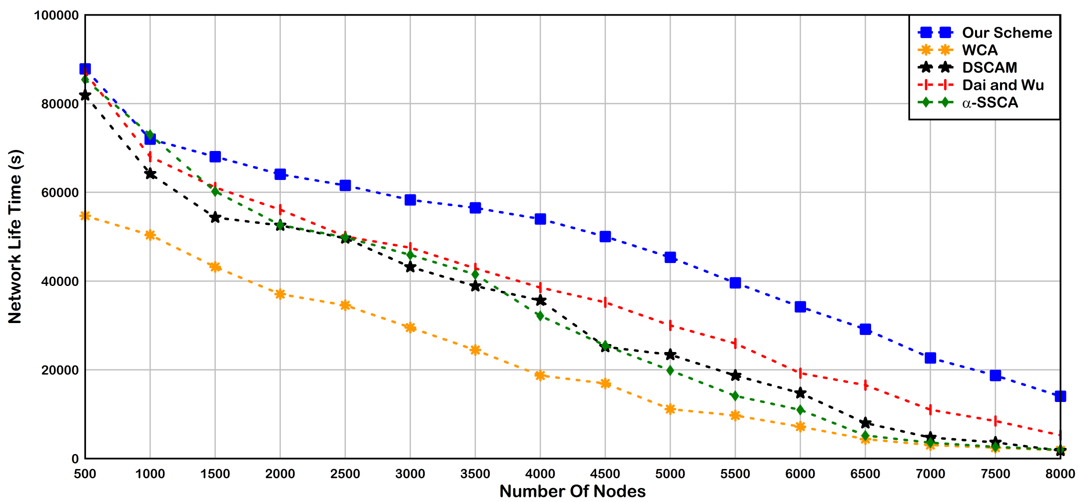


Figure 5.22: Number of nodes vs Network Life Time

[1] This mechanism leads to reduce the number exchanging messages during topology reconstruction which leads to increase life time of the network

In summary, our proposed scheme is a QoS-based hierarchical scheme for large scale MANETs in urban environment that is able to:

- Support the scalability and QoS requirement of demanding applications like multimedia services.
- Maximize lifespan of the network, minimize the number of clusters and satisfy the QoS requirements.
- Decrease the network overhead, create stable structure and improve the usage of scarce resources.

5.3 Recap of key points

- The recent rapid growth of cities, the evolution of wireless/mobile technologies and diverse demanding applications, the world is becoming more and more urban. Today, wireless and mobile networks as well multimedia applications play an essential challenging role within urban environment and they are take a considerable attention to improve and render the urban environment increasingly sustainable and livable.
- The main purpose of wireless and mobile networks is to share the fresh updated information collected around the urban environment between the stakeholders and the citizen constantly. However, it is very difficult to achieve this task in a complex, distributed, large (billions of heterogeneous connected devices) and diverse innovative demanding applications and services in urban environment.
- Demanding applications and services require constructing a wireless network that satisfy the scalability and QoS in such environment (e.g. urban environment).
- The network topology management approach is one of the solutions that got a great attention in last few years.

- we propose an efficient k-hop scalability and QoS topology management scheme for large scale Mobile Ad Hoc Networks which is suitable for demanding application in urban environment.

- The proposed scheme considers a trade-off between clustering approach and virtual backbone approach in order to build a 2-level hierarchical scheme. It implemented and evaluated using OPNET simulator.

- The proposed scheme compared with a number of existing network topology management schemes such as: WCA, Highest degree, Lowest-ID, Density, α-SSCA, DSCAM, Dai scheme and Blackbone2. Simulation results have shown that the proposed scheme performs generally better than the other network topology schemes in terms of: average number of CHs, average number of CH changes, total overhead, clusters stability and number of backbone nodes, especially for large-scale MANETs (the number of nodes in the network is high) and with high QoS for demanding applications like multimedia applications (e.g. video streaming applications).

Chapter 6

Conclusions and Perspectives

6.1 Conclusions

Through this dissertation, our goal has been to address two main problems, which are the scalability and quality of service (QoS) problems in mobile ad hoc networks (MANETs) in order to satisfy both the scalability and QoS in such networks and improve network performance. The extensive comprehensive study of the previous solutions has guided our work towards the concepts of clustering and virtual backbone to take advantage of these approaches and achieve our goal. In this context, we have taken a great interest and focus in studying the clustering technique and virtual backbone approach to propose a new suitable schemes for scalability and QoS issues. To achieve this last, we designed, initially, a one-hop topology management cluster-based scheme with aims to avoid various issues related to the flat structure and improve the scalability of hierarchical cluster topology as well. Then, we planned to generalize the scheme to K-hop clustering in order to avoid the scalability issues especially in the case when nodes increase to a high number in the network (many thousands). The extensive analyze of existing clustering schemes and virtual backbone schemes allowed us then to propose a new scalable network topology management scheme which can satisfy the urban environment properties (size and service differentiations of multimedia applications). The proposed topology management scheme constructs two hierarchical levels based on the clustering and virtual backbone technique for large scale MANETs. it takes into account the network scalability (large number of nodes), and the QoS needed to support demanding applications such as multimedia services.

6.1.1 A survey of topology management schemes in MANETs

In the survey, we first have presented fundamental concepts about clustering, including the definition of clustering, design goals and objectives, advantages and disadvantages, and cost of network clustering. Then, we have classified clustering schemes into five categories based on their distinguishing features and their objectives as: Identifier Neighbor based clustering, Topology based, Mobility based, Energy based, and Weight based clustering. We have reviewed several clustering schemes which help organize MANETs in a hierarchical manner and presented some of their main characteristics, objective, mechanism, and performance. We have also identified the most relevant metrics for evaluating the performance of existing clustering schemes. Most of the presented clustering schemes focus on important issues such as cluster structure stability, the total control overhead of cluster formation and maintenance, etc. In addition, the different categories of clustering schemes have different characteristics and objectives. Finally, we reviewed some interesting work on virtual backbone schemes with there performance analysis.

6.1.2 A new weight based clustering scheme for MANETs

On the basis of our one-hop cluster based algorithm (**it not described in the dissertation**), we have proposed a new generic k-hop weight based clustering scheme for MANETs to cover wider networks (avoid scalability issues).

Thus, we have proposed in this dissertation a new weight based clustering scheme for Mobile Ad hoc Networks that takes into account a combination of four metrics as follow: trust, density, mobility and energy during the cluster formation phase and maintains clusters locally. In our proposed scheme each cluster supervised by its cluster head in order to ensure a good level of security, improve the usage of scarce resources such as bandwidth, minimize the CHs change, decrease the number of CHs re-affiliation, minimize the number of clusters, decrease the total overhead. It also creates fewer and more stable clusters in order to achieve high scalability. Simulation results in OPNET simulator have shown that our scheme performs generally better than the other clustering schemes like LID, HCC, DCA and WCA in terms of: average number of CHs, average number of CH changes, total number of re-affiliation, clusters stability, and total overhead. The experiment results show that the different proposed clustering schemes do not allow the scalability when the network size is very large. Our scheme supports scalability efficiently when the number of nodes increases in the network (more than 2,000 nodes). Moreover, it ensures an acceptable level of security by using the trust metric in calculation of the weight value for CHs election process, improves the usage of scarce resources such as bandwidth, minimizes the CHs change, decreases the number of CHs re-affiliation, minimizes the number of clusters, and decreases the total overhead.

6.1.3 A new k-hop scalable topology management scheme for large scale MANETs

Based on our weight based clustering scheme, we have proposed a k-hop scalable topology management scheme for large scale Mobile Ad hoc Networks (MANETs). it aims to address the scalability and QoS issues for large scale mobile ad hoc networks in urban environment. Our scheme considers a trade-off between clustering approach and virtual backbone approach in order to build a 2-level hierarchical scheme. We implemented and evaluated our network topology management scheme using OPNET simulator. We have compared the performance of our scheme to a number of existing network topology management schemes such as WCA, Highest degree, Lowest ID, Density, α-SSCA, DSCAM, Dai and Wu and Blackbone2. Simulation result have shown that our scheme performs generally better than the other network topology schemes in terms of: average number of CHs, average number of CH changes, total overhead, clusters stability and number of backbone nodes.

6.2 Perspectives

The work done during this dissertation can raise new issues that could be the subject of new research directions or extension.

1. The study and analyze of two proposed clustering schemes, was made by simulation in the OPNET simulator. This study can be completed by a theoretical analysis after explaining the necessary formulas.

2. Verification and validation formal of the proposed schemes: verification and validation of QoS and Scalability proprieties within urban environment using model checking approaches.

3. Complement our topology management scheme with a routing protocol that is efficient for multimedia and real time applications for large scale MANETs in urban environment. In addition, it needs also to make a detailed study about energy consumption, the network lifetime, end-to-end delay and throughput, as well the multimedia services QoS achievement by the proposed protocol in a real urban environment scenario with different proprieties, also in testbed.

4. Extend the proposed schemes to enable Multicast routing, represents an interesting perspective of our work. this extension can be based on the concept of core based tree (CBT) protocol in order to take advantage from our cluster-based algorithms. Selecting multiple k-hop cores, three solutions using three different structures may be considered.

    - *Mesh structure*: Without construction, each source and each intermediate node selects their potential core of the group when they have data to send. After, they broadcast packets to all members and all cores that are in their k-hop vicinity.
    - *Source tree*: Each source select multiple cores that cover all k-hop group members. It sends a message that contains all of the selected cores. Such message will be transmitted from one core to another to build the tree that be used in the contruction/distribution of the data group.

- *Shared tree*: All members of a group participate to elect multiple cores that form a subset of the dominant group in K-hop neighbors. Each node and each core will then connect to the nearest core.

5. Real deployment of the proposed schemes in real Internet of Things (IoT) devices.

6.3 List of Publications

1. Bentaleb, A., Boubetra, A., and Harous, S. (May12-14 2013). *A New Weight Based Clustering Scheme For Mobile Ad Hoc Networks*, UAE Forum on Information and communication technology research (ICTRF 2013), Abu dhabi, UAE.

2. Bentaleb, A., Boubetra, A., and Harous, S. (2013). *Survey of clustering schemes in mobile ad hoc networks.* Communications and Network Journal, 5(2B), pp.8-14.

3. Bentaleb, A., Harous, S. and Boubetra, A. (2013)., *A Weight Based Clustering Scheme for Mobile Ad hoc Networks*, The 11th International Conference on Advances in Mobile Computing and Multimedia (MoMM2013), Vienna, Austria, 161-167.

4. Bentaleb, A., Harous, S., and Boubetra, A. (2014). *A scalable clustering scheme and its performance evaluation.* International Journal of Pervasive Computing and Communications, 10(1), 27-42.

5. Bentaleb, A., Harous, S., and Boubetra, A.(2015) *A Topology Management scheme with scalability and QoS guarantee for Large Scale Mobile Ad Hoc Networks in Urban Environment.*2nd International Conference On New Technologies and Communication, University of Chlef, Algeria.

6. Bentaleb, A., Harous, S. and Boubetra, A. (2015)., *A New Topology Management Scheme for Large Scale Mobile Ad Hoc Networks*, 2015 IEEE Inter-

national Conference on Electro/Information Technology, DeKalb, IL, USA, pp. 1-6.

7. Bentaleb, A., Harous, S. and Boubetra, A. (2015)., *A k-hop Scalable Topology Management Scheme For Large Scale Mobile Ad Hoc Networks*,Submitted in Springer Wireless Personal Communications Journal.

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