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MULTIPATH CLUSTER BASED ROUTING PROTOCOL FOR NON-UNIFORM NODE DENSITY MOBILE AD HOC NETWORKS

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UNIVERSITI SAINS MALAYSIA
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MULTIPATH CLUSTER BASED ROUTING PROTOCOL FOR NON-UNIFORM NODE DENSITY MOBILE AD HOC NETWORKS

by

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LIST OF ABBREVIATIONS

AODV	Ad Hoc On Demand Distance Vector
AODVM	Multipath AODV
AODVM/PD	Multipath AODV with path diversity
AOMDV	Ad-Hoc On-Demand Multi-Path Distance Vector Routing Protocol
ARP	Address Resolution Protocol
AvHop	Average Hop Count
CAT	Cluster Adjacency Table
CBRP	Cluster Based Routing Protocol
CGSR	Cluster head Gateway Switch Routing protocol
CID	Cluster Address ID
CM	Cluster Member
CMDSR	Cluster based Multipath Dynamic Source Routing
CRID	Calculated Route List ID
D	Destination Node
DARPA	Defences Advanced Research Projects Agency
DSDV	Distance Source Distance Vector routing protocol
DSR	Dynamic Source Routing protocol
FMLB	Fibonacci Multipath Load Balancing Protocol
GSR	Global State Routing protocol
GWID	Gateway Node Address ID
GWs	Cluster Gateway nodes
HD	High Density Topology
IFQ	Interface Queue
LL	Link Layer Models

MAC	MAC Layer protocols
MANET	Mobile Ad Hoc Networks
MP-CBRP	Multipath Cluster Based Routing Protocol
MP-DSR	A QoS-aware Multi-path Dynamic Source Routing Protocol
MSR	Multipath Source Routing Protocol
NAM	Network Animator
NCHID	Neighbour Cluster Head ID
ND	Non-Uniform Node Density Topology
NDMR	Node-Disjoint Multipath Routing
NetIF	Network Interface
NRL	Normalized Routing Load
NT	Neighbour Table
OLSR	Optimized Link State Routing Protocol
PDR	Packet Delivery Ratio
QoS	Quality of Service
RC	Route Cache
RPGM	Reference Point Group Mobility model
RREP	Route Reply
RREQ	Route Request
RWP	Random Waypoint Model
S	Source Node
SMR	Split Multipath Routing Protocol
TORA	Temporally-Ordered Routing Algorithm routing protocol
WRP	Wireless Routing Protocol
ZHLS	Zone-based Hierarchical Link State
ZRP	ZRP Zone Routing Protocol

PROTOKOL PENGHALAAN BERDASARKAN KLUSTER BERBILANG LALUAN UNTUK RANGKAIAN SEMENTARA BERGERAK KETUMPATAN NOD TIDAK SERAGAM

ABSTRAK

Rangkaian sementara bergerak (Mobile Ad Hoc Networks, MANET) merupakan suatu kumpulan nod bergerak yang boleh berkomunikasi bersama tanpa memerlukan sebarang infrastruktur tetap dan pengurusan terpusat. MANET begitu popular dalam keadaan ketiadaan lokasi infrastruktur komunikasi tetap, seperti tapak bencana alam atau medan perang. Ketumpatan nod bergerak yang berbeza daripada satu subkawasan dengan subkawasan yang lain didefinisikan sebagai ketumpatan nod tidak seragam. Komunikasi di antara nod dalam rangkaian ketumpatan nod tidak seragam berdepan dengan cabaran keterikatan yang rendah, yang memungkinkan nod lebih rentan atau suseptibel untuk terputus pautan. Keadaan tersebut akan memberi impak terhadap kualiti perkhidmatan (quality of service, QoS) dalam rangkaian. Secara tipikal, ketumpatan nod tidak seragam boleh mempengaruhi prestasi rangkaian.. Sebagai contoh, nisbah penghantaran paket dijangka tinggi dalam subrangkaian ketumpatan tinggi dan rendah dalam subrangkaian ketumpatan rendah. Tesis ini mncadangkan Kluster Berbilang Laluan berdasarkan Protokol Penghalaan (MP-CBRP) untuk mengesan masalah keterkaitan yang rendah dalam rangkaian ketumpatan nod tidak seragam dan untuk menambah baik QoS bagi MANET. MP-CBRP berupaya mengelak kesesakan lalu lintas dan kerosakan pautan yang kerap berlaku dalam komunikasi melalui imbangan beban yang disediakan dan perlindungan terhadap kegagalan penghala. Laluan diagih semula dalam

kalangan set laluan yang pelbagai. Kebaikan sifat ini menjadikan MP-CBRP mampu meningkatkan QoS bagi MANET melalui pengurangan paket yang terlengah dan meningkatkan nisbah penghantaran paket dan thruput. Eksperimen simulasi menggunakan simulator rangkaian (network simulator, NS2) menunjukkan bahawa MP-CBRP adalah efektif dalam penambahbaikan QoS. Prestasi MP-CBRP, protokol penghalaan berdasarkan kluster (CBRP) dan protokol penghalaan vektor jarak berbilang laluan atas permintaan ad hoc (AOMDV) dalam topologi ketumpatan tidak seragam (ND) dan ketumpatan tinggi (HD) dengan model mobiliti random waypoint (RWP), model reference point group mobility (RPGM) dan model mobiliti Manhattan telah dinilai dan dibandingkan. Keputusan simulasi menunjukkan bahawa MP-CBRP mencapai prestasi yang tertinggi antara tiga protokol yang menyediakan sokongan QoS dalam MANET. MP-CBRP mencapai yang paling rendah normalisasi muatan penghalaan, purata kelengahan dan purata kiraan hop. Tambahan pula, nisbah penghantaran paket dan purata kendalian adalah lebih baik berbanding dengan protokol CBRP dan AOMDV.

MULTIPATH CLUSTER BASED ROUTING PROTOCOL FOR NON-UNIFORM NODE DENSITY MOBILE AD HOC NETWORKS

ABSTRACT

A mobile ad hoc network (MANET) is a group of mobile nodes that can communicate with one another without the need for a fixed infrastructure and centralized management. MANETs are popular in locations that lack a fixed communication infrastructure, such as in natural disaster sites and battlefields. The varying densities of mobile nodes from one sub-area to another are referred to as non-uniform node densities. The communication between nodes in a network with non-uniform density faces the challenge of low connectivity, in which nodes are susceptible to link breakages. Such condition affects the Quality of Service (QoS) in networks. Typically, a non-uniform node density influences network performance. For instance, packet delivery ratio is expected to be high in high-density sub networks and low in low-density sub networks. This thesis proposes a multipath cluster-based routing protocol (MP-CBRP) to address the problem of low connectivity in networks with non-uniform density and to improve the QoS for MANETs. The MP-CBRP is able to avoid traffic congestion and frequent link breakages in communication by providing load balancing and route failure protection. Traffic is redistributed among sets of multiple paths. The benefits of these features allow the MP-CBRP to enhance the QoS for MANETs by reducing delays and increasing packet delivery ratio and throughputs. Simulation experiments using the Network Simulator demonstrate the effectiveness of the MP-CBRP in improving QoS. The performances of the MP-CBRP, cluster-based routing protocol (CBRP),

and Ad hoc on-demand multipath distance vector (AOMDV) routing protocols in the a non-uniform density (ND) and high density (HD) topologies under the random waypoint (RWP) mobility model, the reference point group mobility (RPGM) model, and Manhattan mobility model are evaluated and compared. The simulation results show that the MP-CBRP achieves the highest performance among the three protocols by providing end-to-end QoS support in MANETs. The MP-CBRP achieves the lowest normalized routing load, average delay, and average hop count. Furthermore, its packet delivery and average throughput are better than those of the CBRP and AOMDV protocols.

CHAPTER ONE

INTRODUCTION

This chapter briefly introduces wireless networks, mobile ad hoc networks (MANETs), the problem statement, and the research objectives, contributions, scope, and methodology. The organization of this thesis is presented at the end of this chapter.

1.1 Background

Wireless networking has become an essential part of residential, commercial, and military applications in recent years. Several of the advantages that have led to the popularity and widespread acceptance of wireless networks are flexibility, ease of deployment and use, cost reduction, convenience, and increased mobility. However, these advantages come with some disadvantages; the most prominent is the limitation of the transmission range (Hamid et al., 2013). The rapid growth of the cellular phone industry worldwide and the increased number of subscribers have demonstrated that wireless communication is a robust and applicable data and voice transport mechanism (Sarangapani, 2007).

MANETs are among the most important and useful branches of wireless networks. MANETs are particularly popular in minimal configuration and locations lacking a fixed communication infrastructure. The mobile nodes in MANET communicate with one another dynamically and freely without using any existing network infrastructure. Thus, a rapid and random changing topology of the network is the consequence of these characteristics. In contrast to wired networks, MANET has many advantages, such as lower setup cost, shorter setup time, and higher

flexibility in node placement and mobility, and connections are location dependent (Perkins, 2001; Kok et al., 2015). Based on these characteristics, MANET is a self-configuration network that consists of a number of mobile devices: the mobile nodes that are connected to one another via wireless connections to exchange interesting information and to maintain the network connectivity. The rapid development of MANETs makes them suitable for natural disaster sites or battlefields. They are widely applicable in military and scientific applications, emergency operations, hybrid wireless networks, collaborative and distributed computing, and wireless sensor networks (Murthy and Manoj, 2004). With the increased development of intelligent transportation, Internet of things, and universal computing, MANET becomes highly popular. According to Canalys's forecast, mobile device (notebook, tablet, smart phone, etc.) shipment in the world will reach 2.6 billion units by 2016, which indicates dense tendency and a large scale of mobile networks (Tan et al. 2015).

1.2 Problem Statement

MANET is an infrastructure-less network without a defined network size. A characteristic of MANET is that it allows any device to be attached to a particular network anytime. This characteristic is limited only by the wireless transmission range, which is approximately a few hundred meters (Perkins, 2001).

Many problems need to be addressed for MANET routing protocols to be implemented in mobile devices and applications. The node movement and the dynamic change that occurs in the connectivity over a specific period of time are the main problems that need to be addressed for MANET. Depending on the available mobile device (e.g., notebook, tablet, smart phone, etc), different ranges exist for

network setups when devices require high mobility. Applications in these devices must be robust to handle such conditions when they occur.

MANET deployed in real applications with combined vehicular and pedestrian traffic or disaster regions have non-uniform node distributions. A non-uniform node density imposes a problem for MANET. For example, nodes are necessary to be near one another to be able to communicate. Such a scenario was discussed in (HeimLicher et al., 2009), who defined scenarios in their studies on partly connected networks. The irregular node distribution in an area is known to be a contributive factor to the limited or poor connectivity of a multi-hop wireless network, such as MANET.

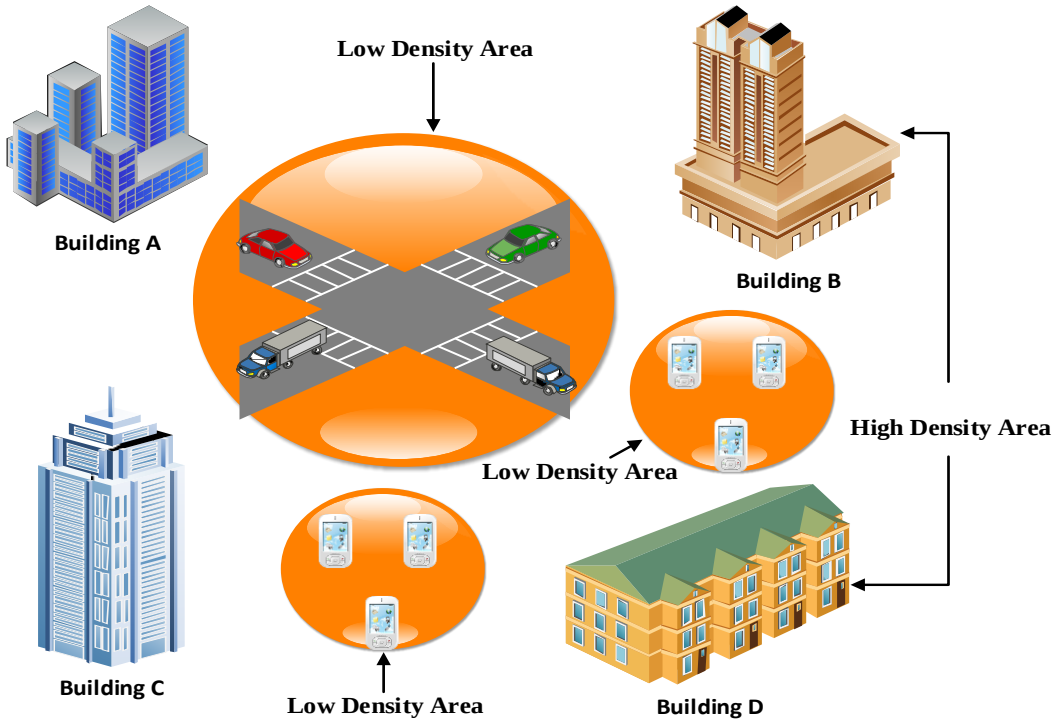

Figure 1.1 Example of non-uniform node distributions in real life scenarios

A non-uniform node density in a network can be observed in an urban region, as shown in the example in Figure 1.1. Node density in buildings is usually higher than that in open areas. As shown in Figure 1.1, Buildings A, B, C, and D have a

high node density, whereas moving cars (vehicular traffic) and mobile devices (pedestrian traffic) are assumed to have low node density. The communication among the nodes in mobile devices and buildings or vehicles particularly has a network with lower connectivity (HeimLicher et al. 2009). In such conditions, MANET nodes are vulnerable to broken links, which influence the quality of service (QoS) of the network. One solution for reducing broking links is via the use of multipath routing protocols (Mohammed et al., 2009). The effect of broken links in non-uniform node density network will lead to low packet delivery ratio, low data throughput rate, high end-to-end delays and high traffic load.

This thesis attempts to address the above issues by proposing a new routing protocol that is more robust and more efficient than existing protocols. This new routing protocol can be supported by real time application, such as VoIP, and it also enhances the QoS of MANETs.

1.3 Research Objectives

The main goal of this research is to propose an enhanced MANET routing protocol. The enhancement can solve the problems in MANETs with a non-uniform node density and improves the QoS of this network. This study is divided into the following three main objectives:

(a) To propose a suitable MANET routing protocol to enhance the QoS for a non-uniform node density topologies for decreasing routing overheads, delay and increasing delivery ratios and throughput.

(b) To evaluate the performance and determine the effectiveness of the proposed MANET routing protocol via simulation by comparing it with existing related

MANET routing protocols for non-uniform node density and varied relevant mobility models, such as random waypoint (RWP), reference point group mobility (RPGM), and Manhattan.

1.4 Research Contributions

This research contributes to the enhancement of MANET routing protocol and the QoS of MANETs with a non-uniform node density. The contributions are as follows:

(a) Enhanced routing protocol for MANETs to address the issue of non-uniform node density for clustered users, which is analyzed mathematically for a two-path model

(b) Performance comparison and analysis of the enhanced routing protocol in various non-uniform node density scenarios via simulation

1.5 Research Scope

This research focuses on simulating MANET routing protocols in network environments with a non-uniform node density. This thesis is conducted based on the following assumptions:

(a) The physical layer used in the network simulations is based on a free space propagation model with no obstacles or terrain effects.

(b) The transmission ranges used in the network simulations are the same for all mobile nodes.

(c) The mobility of the nodes for different groups is defined in predefined areas.

(d) Various mobility models, such as RWP, RPGM, and Manhattan mobility models, are used to evaluate the performance of routing protocols for vehicles and pedestrian.

(e) The results obtained in this research focus on the performance of routing protocols for MANET.

(f) Issues in other layers will not be discussed except which it relates to the MANET routing protocols.

1.6 Research Methodology

Considering the research objectives mentioned in Section 1.3, MANET routing protocol is proposed to address the problem of low connectivity in non-uniform density networks and to improve the QoS of MANET. Mathematical modeling using queuing models is used to characterize the behavior of single path and dual paths to formulate suitable approaches for the proposed protocol**.** Network Simulator 2 (NS2) is used to evaluate the performance of the existing protocols and proposed protocol. The proposed protocol was testbed using scenarios which considered the non-uniform distribution of nodes in a given geographical area. In addition to this, the proposed protocol is based on the cluster-based routing protocol (CBRP) (Jiang et al., 1999; Yu et al., 2012) because CBRP is proven as a robust and scalable routing protocol. CBRP and ad hoc on-demand multipath distance vector (AOMDV) protocol (Marina and Das, 2001b, 2003) are used to be compared with the proposed protocol. Mobility models, such as RWP, RPGM, and Manhattan are used to evaluate the performance of the proposed protocol, CBRP and AOMDV protocols because they are the most widely used and more efficient in MANETs**.** The simulation is repeated numerous times to validate the implementation.

The enhancements are justified through a series of graphs derived from the simulation results. Finally, the results are discussed, compared, and analyzed. Figure 1.2 shows the steps of the research methodology.

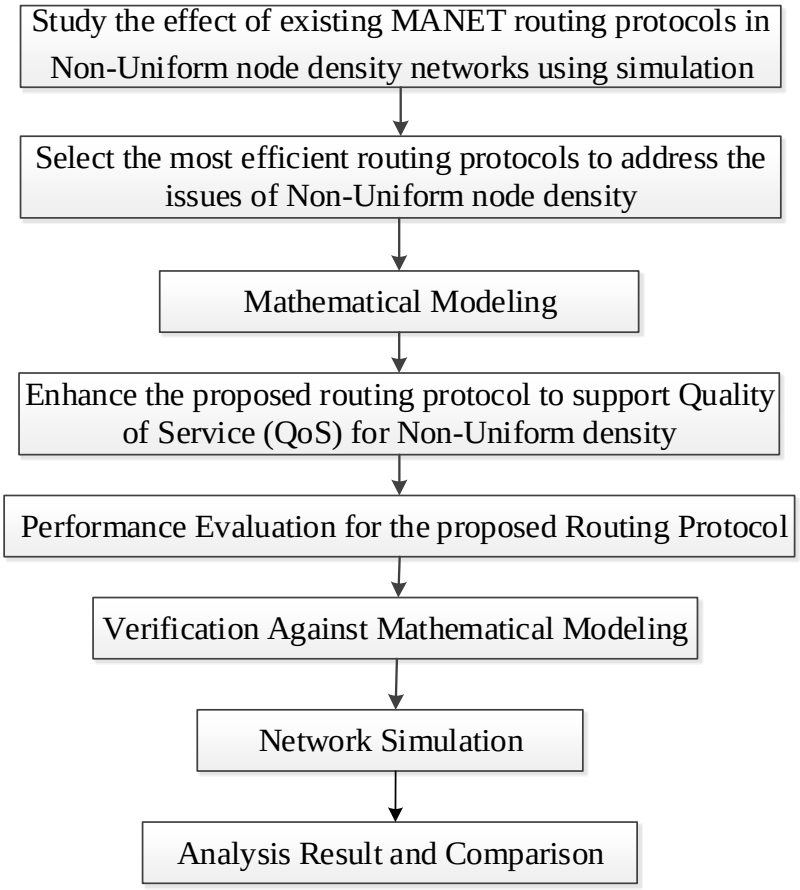

Figure 1.2 Research Methodology Steps

1.7 Thesis Organization

This thesis consists of six chapters. **Chapter 1** introduces the overall content of the thesis and provides a short summary of its significance. This chapter also presents and describes the problem statement, research objectives, contributions, scope, and methodology.

Chapter 2: This chapter presents the components, characteristics, and applications of MANET. It gives an overview of the routing protocols in MANETs, including reactive single-path and multipath protocols. It also discusses the node density in MANETs and explains the mobility models in MANETs.

Chapter 3: This chapter explains the proposed work and describes the proposed algorithm and design.

Chapter 4: This chapter provides the details of the simulation environment and presents the performance evaluation metrics.

Chapter 5: This chapter presents and analyzes the simulation results and discusses the performance of the proposed work.

Finally, Chapter 6: This chapter concludes the thesis and outlines suggestions for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter begins with a review of the components, characteristics, and applications of MANETs. Then, an overview of the routing protocols in MANETs, including single-path and multipath reactive protocols is presented. The node density and mobility models for MANETs are also discussed.

2.2 Mobile Ad Hoc Networks (MANETs)

MANETs are among the most essential and useful branches of wireless networks that are based on the IEEE 802.11. They were first called “packet radio” networks by the United States Defense Advanced Research Projects Agency (DARPA) in the early 1970s. MANETs are defined as a set of wireless mobile devices (laptops, smartphones, routers, tablets, etc.), which are mobile nodes that are linked together via wireless links to exchange exciting information and to maintain network connectivity without any central control or permanent infrastructure (access points, bridges, base stations, etc.) (Misra et al., 2009). The mobile nodes in MANETs can move randomly and sort themselves arbitrarily. Consequently, network topology may change rapidly and unpredictably (Sarkar et al., 2008). MANETs can operate in a stand-alone manner or be connected to a large network, such as the Internet. Unlike fixed wireless networks, wireless ad hoc networks are characterized by their lack of infrastructure. Compared with wired networks, MANETs have a lower bandwidth and location-dependent connections (Perkins, 2001).

The rapid development of MANETs makes them suitable for emergency cases, such as natural disasters, military operations, and emergency medical situations (Yang, 2008). MANETs are also widely used in military and scientific applications, emergency operations, hybrid wireless networks, collaborative and distributed computing, and wireless sensor networks (Murthy and Manoj, 2004).

The application and improvement of mobile devices are the main motivations of researchers in considering relevant issues in the wireless area. However, providing facilities such as those found in wired networks for wireless networking is a difficult and challenging task because the radio channel used in wireless networks is not reliable or secure. As a result of the dynamicity of this area, the location of resources typically changes, and this characteristic gives rise to several technical challenges, such as high energy consumption and high security overhead.

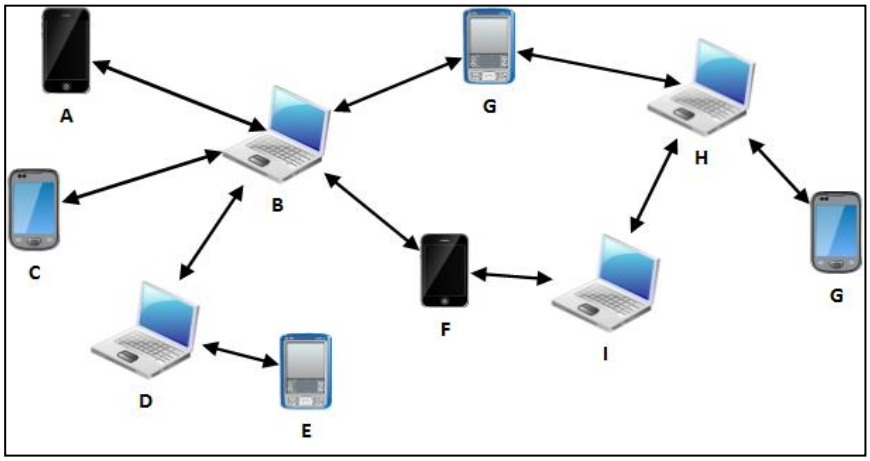

Figure 2.1 Mobile Ad Hoc Networks (MANETs) (Sarkar et al., 2008)

The network topology in MANETs is unpredictable, and the number of nodes within a network can change significantly within a short period of time. However, research efforts to improve the performance of MANETs have intensified in recent years because portable and mobile devices have become common. Future ubiquitous and wireless networks must consider factors such as mobility, different levels of

node densities, and changing network sizes. An example of a MANET that comprises 10 mobile nodes is shown in Figure 2.1.

2.2.1 Characteristics of MANETs and Related Challenges

A MANET consists of mobile nodes that are free to move randomly without needing any pre-existing communication infrastructure. These mobile nodes use wireless transceivers to communicate with one another. Consequently, MANETs have the following characteristics, and their application involves obvious challenges. (Chlamtac et al., 2003; Conti and Giordano, 2014; Misra et al., 2009; Sarangapani, 2007; Stefano et al., 2004)

a) **Autonomous and infrastructure-less:** MANETs do not rely on any central administration point or fixed infrastructure. Each node can work as a router to forward packet to other nodes, and these nodes may not be within the same transmission range.
b) **Dynamic topologies:** Mobile nodes are free to move arbitrarily. Thus, the network topology, which is typically multi-hop, may be changed randomly and rapidly at unexpected times. Such change leads to changing routes, frequent network partitions, and packet losses.
c) **Multi-hopping:** A multi-hop network is a network where packets traverse from a source to a destination via several other nodes without a default router because every node acts as a router.
d) **Energy-constrained operation**: Mobile nodes possess a limited power source and lack the capability of generating their own power because they depend on limited battery sources. Thus, saving power is an essential consideration in the design of MANETs.

e) **Network scalability:** Scalability is critical to the successful deployment of MANETs. The development of a large network consisting of nodes with limited resources is not simple and presents many challenges that need to be addressed. These challenges include addressing, routing, location management, configuration management, interoperability, security, high-capacity wireless technologies, and so on (Stefano et al., 2004).

f) **Physical security limitation:** MANETs are generally more vulnerable to threats to physical security compared with fixed wired networks. The lack of infrastructure and the vulnerability of wireless channels and nodes make securing MANETs challenging.

g) **Routing:** Routing packets between any pair of mobile nodes in a MANET is a challenging task because the topology of a MANET can change frequently as a result of mobility. Efficient MANET routing protocols are required to establish connection paths between a pair of nodes without causing considerable control traffic overhead or computational load on power-constrained devices (Jeroen et al., 2004)

h) **Reliability:** Reliability is the probability of delivering a message generated at a source in the network to the actual destination. Reliability is a significant challenge in MANETs because packets delivered may be lost because of frequent topological changes and the limited wireless transmission range. Packet loss is typical in areas where mobile nodes are sparsely located.

i) **QoS:** Providing different QoS levels in a MANET is a challenging issue that has led to considerable research activity (Perkins and Hughes, 2002). Compared with their wired counterparts, MANETs typically involve more difficult challenges in

terms of providing QoS, potentially lower data rates, higher bit error rates, and higher delay times (CCSDS, 2015).

2.2.2 Applications of MANETs

With the increasing number of mobile devices and the progress in the field of wireless communications, MANETs have become significant because of their widespread applications. The most important applications of MANETs include the establishment of robust, efficient, and dynamic communications for emergency operations, disaster recovery, and military applications. A majority of the applications of MANETs are focused on areas that require rapid deployment and dynamic reconfiguration and lack wired networks (Conti and Giordano, 2014; Misra et al., 2009; Sarangapani, 2007; Sarkar et al., 2008).

The most important applications of MANETs are as follows.

a) **Military applications**: The most popular application of MANETs in battlefields is military communication. MANETs offer a reliable means of communication and a fast failure recovery in such environments (NIST, 2008). A fixed network for military communication is not efficient to build in battlefields.

b) **Personal area and home networking**: A personal area network (PAN) is a short-range, localized network that is mainly designed for individual use. MANETs are suitable for home and personal area networking applications. Mobile devices, such as laptops, tablets, and cellular phones, can be easily configured to form an ad hoc network by using Bluetooth or WLAN cards. These devices can easily be connected to the Internet at home. Thus, the use of these types of networks has practical applications and usability (Taniar, 2009).

c) **Rescue/emergency services:** MANETs can be easily deployed to provide solutions to emergency services. For instance, MANETs can be utilized when the

existing network infrastructure, such as telephone lines, backbones, and access points, is destroyed because of disasters, such as earthquakes, flood, and fire (Aarti and Tyagi, 2013). MANETs can also be used for search and rescue operations, retrieval of patient data remotely from hospitals, and many other important services.

d) **Commercial and civilian use:** MANETs can be used to make electronic payments anytime and anywhere. Users can share information during meetings, and participants in a conference can exchange documents or presentations.

e) **Entertainment services**: MANET can be used for entertainment, such as multi-user games, wireless peer-to-peer networking, outdoor Internet access, robotic pets, and theme parks.

f) **Education:** MANETs can be used in university and campus settings, virtual classrooms, and ad hoc communications during meetings or lectures that allow students to use their laptop computers.

g) **Coverage extension**: MANETs can be used to extend cellular network access and link up with the Internet, intranets, and so on.

h) **Location-based services:** MANETs provides useful services when integrated with location-based information. The global positioning system (GPS) is a worldwide radio-based navigation system that relies on satellites and their ground stations. GPS is an effective tool to determine the physical location of a device, and it can be used to determine and monitor the movement of people regardless of their activity (Stefano et al., 2004) .

i) **Sensor networks:** Sensor networks represent a special type of ad hoc network. They consist of nodes equipped with sensing, processing, and communication capabilities (Sarangapani, 2007). Sensor networks are used to monitor remote or

inhospitable physical environments. They can be used to extract accurate information, such as for temperature and data tracking of environmental conditions. These devices can also be used for security applications (Yang, 2008). Table 2.1 presents an overview of the current and future MANET applications.

Table 2.1 Summary Review of MANET Applications (Jeroen et al., 2004; Misra et al.,2009)

Application	**Possible Service**
Military applications	• Military operations and communication • Battlefield operations
Rescue/emergency services	• Operation search and rescue • Disaster recovery • Fire-fighting and policing • Supporting doctors and nurses in hospitals
Commercial and civilian use	• E-commerce: electronic payments anywhere and anytime • Business: Dynamic database access, mobile workplaces • Vehicular services: navigation, weather updates, inter-vehicle networks • Shopping malls and airports
Personal area and home networking	• Home/office wireless networking and Internet • Conference and meeting rooms
Education	• University and campus settings • Virtual classrooms • Ad hoc communications during lectures or meetings
Entertainment	• Multi-user games • Wireless pair-to-pair networking • Outdoor Internet access • Theme gardens
Sensor networks	• Home applications: smart sensors and actuators embedded in consumer electronics • Data tracking of environmental conditions, chemical/biological detection • Security applications
Location-based services	• GPS navigator: determining and monitoring the movement of people • Infotainment: information tourism
Coverage extension	• Extending access to cellular networks • Connecting to the Internet, intranets, and so on

2.3 Overview of MANET Routing Protocols

Routinlg in MANETs is challenging because of the frequent change in topology and the tendency of active routes to break down because of the movement of mobile nodes from one place to another. Each routing protocol reacts in a different manner to node mobility and density. Routing schemes in MANETs must include mechanisms to overcome difficulties incurred by the mobility of nodes and changes in the network topology while ensuring low energy consumption, bandwidth communication, and resource computing (Boukerche et al., 2011). Many routing protocols for MANETs have been proposed to overcome these problems. Routing protocols play the most important role in the communication and connection within a network. A primary goal of routing protocols is to establish and maintain a route between a pair of nodes so that messages are delivered in a reliable and timely manner (Misra et al., 2009)

MANET routing protocols can be classified according to the strategy of discovering and maintaining routes into three categories, namely, proactive (table-driven), reactive (on demand), and hybrid (Abolhasan et al. 2004). In proactive routing protocols, the routes from a source to a destination are determined when a node joins the network or changes its location and are maintained by frequent route updates. In reactive routing protocols, routes are discovered when needed and expire after a particular period. Hybrid routing protocols combine the features of the reactive and pro-active routing approaches to scale well with increasing network size and node density (Sharma et al., 2014). The reactive approach is more effective and efficient than the proactive approach because the routes among nodes are only discovered when a source node needs to broadcast a data packet. Thus, reactive

routing protocols have low network control packet overheads and end-to-end delay increases (Balaji and Duraisamy, 2014).

The routing protocols in MANETs can also be differentiated as single or multipath, unicast or multicast, or distance vector or link state (Sangi et al., 2010). Reviews and comparisons were conducted in the work of various researchers on MANET routing protocols (Abolhasan et al., 2004; Boukerche et al., 2011; Hamid et al., 2013; Royer and Toh, 1999; Sarkar et al., 2008). Many examples of MANET routing protocols exist. Proactive routing protocols include the distance source distance vector (DSDV (Perkins and Bhagwat, 1994)) routing protocol , wireless routing protocol (WRP) (Murthy and Garcia, 1996), cluster head GW switch routing (CGSR) protocol (Chiang, 1997), optimized link-state routing (OLSR) protocol (Clausen and Jacquet, 2003) and Multipath Optimized Link State Routing for Mobile Ad Hoc Networks (MP-OLSR) (Yi et al., 2011). Reactive protocols include the ad hoc on-demand distance vector (AODV) routing protocol (Perkins et al., 1999), dynamic source routing (DSR) protocol (Broch et al., 1999), cluster-based routing protocol (CBRP) (Jiang et al., 1999), node-disjoint multipath routing (NDMR) protocol (Li and Cuthbert, 2004), and ad hoc on-demand multipath distance vector (AOMDV) routing protocol (Marina and Das, 2001), QoS multipath routing protocol (QMPSR) (Zheng and Li, 2011), ad hoc on-demand multipath distance vector with dynamic path update (AOMDV-DPU) (Kumar et al.,2013) and Multi-constrained and Multipath QoS Aware Routing Protocol (MMQARP) (Balachandra, 2014), multipath routing protocol for effective local route recovery (MP-LRR) (Jagadeesan and Srivatsa, 2012), multi-path dynamic address routing (M-DART) (Caleffi and Paura, 2011). Hybrid routing protocols include the zone routing protocol (ZRP) (Haas et al., 2002) and zone-based hierarchical link state (ZHLS) routing protocol

(Joa-Ng and Lu, 1999). The taxonomy of MANETs routing protocols is shown in Figure 2.2.

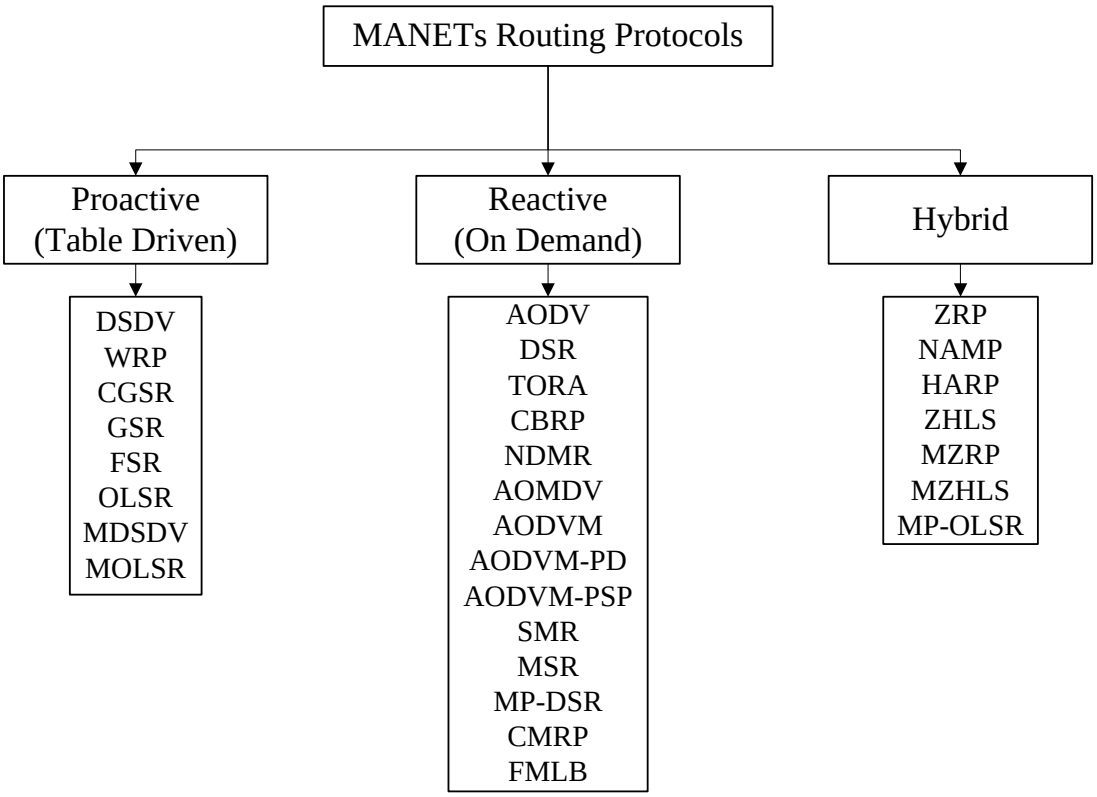

Figure 2.2 MANETs Routing Protocols Taxonomy

2.3.1 Properties of MANET Routing Protocols

Considering the special properties of MANETs on the basis of any routing protocol, we generally expect the following properties, although not all of these properties can be incorporated in a single solution (Boukerche et al., 2011; Kioumourtzis et al., 2012; Royer and Toh, 1999; Sharma et al., 2014).

(a) Reliability: Reliability is a significant challenge in designing routing protocols for MANETs. Thus, these routing protocols should be distributed in a manner that could increase their reliability.

(b) Unidirectional link support: Nodes in MANETs can communicate only through unidirectional links because wireless links can be opened in a unidirection only as a result of certain physical factors. Thus, routing protocols must be designed such that they support both unidirectional and bidirectional links.

(c) Power efficiency: Mobile nodes in MANETs usually use batteries as their energy source. Thus, saving power is important, and routing protocols must be designed to save battery time.

(d) Security: MANET routing protocols, in most cases, are not secure. A wireless link is generally highly vulnerable and susceptible to various sorts of threats and attacks. Thus, routing protocols should be support with good security mechanisms to address these vulnerabilities.

(e) Hybrid protocols: Advantages of different routing protocols can be combined to propose a robust and efficient protocol. A protocol should be much more reactive than proactive to avoid protocol overhead.

(f) QoS support: The most important challenge in designing a routing protocol is QoS, which should thus be considered in designing routing protocols. Routing protocols should offer efficient QoS while minimizing delays, increasing throughput, and reducing protocol overhead for the route from a source to a destination pair (Misra et al., 2009).

(g) Path optimality: Routing protocols in MANETs are focused more on avoiding broken paths between source nodes and destination nodes than on path optimality. To avoid the excess transmission of control packets, networks may be allowed to operate with suboptimal paths until they break. However, the routing protocol in this case should reduce the control overhead along with path lengths. Otherwise, excessive delivery delays and power loss will occur.

(h) Complexity: The storage space utilized for routing is another problem in routing architecture. MANETs may be applied to small portable devices, such as personal digital assistant (PDA) devices, which offer limited memory and hardware. Thus, routing protocols should be designed to require low storage complexity.

(i) Scalability: Scalability is an important issue in designing efficient MANET routing protocols. A good routing protocol should be scalable and adaptive according to changes in network topology. Routing scalability is most important for large networks. The lack of a scalable routing protocol affects the stability and performance of a network (Alazzawi and Elkateeb, 2008; J. Yu, 2000).

(j) Multicasting: Multicasting is also an important issue in designing efficient MANET routing protocols, especially in terms of transmitting real-time data (for example, multimedia data) to many nodes at the same time (Kioumourtzis et al., 2012).

2.3.2 Single-Path Reactive Routing Protocols in MANETs

The single-path reactive routing protocols in MANETs are routing protocols designed for single routes between source nodes and destination nodes. The most popular routing protocols are the AODV, DSR, and CBRP, which are explained in the following section.

2.3.2(a) Dynamic Source Routing (DSR) Protocol

The DSR protocol (Broch et al., 1999) is based on the concept of the source routing scheme. Each node in the DSR protocol is necessary in maintaining a route cache (RC), which contains the source routes to the destinations. The DSR protocol

is designed to reduce network bandwidth overhead, save battery power, and decrease the probability of packet collision. This routing protocol rapidly adapts to changes in node movement.

The DSR protocol consists of two main processes, namely, route discovery and route maintenance. When a source node aims to send data packets to a destination node, it checks its RC to determine whether a route to the destination is available. If a route to the destination is available, then the source node sends the data packet through such route. Otherwise, it initiates a route discovery process by propagating a route request (RREQ) packet to its neighbors.

When an intermediate node receives a copy of the RREQ, it checks its record list for newly seen RREQs. If a match is found, then the RREQ is simply discarded. Otherwise, the source node checks the availability of a route to the destination node. If no route to the destination is available, the source node propagates the RREQ to its neighbors again.

A *route reply* (RREP) packet is created when an RREQ reaches the destination or when an intermediate node has a route to the destination. To send the RREP packet to the source, the destination or intermediate node must determine an available route to the source in its RC. If such route is found, the destination or intermediate node may use this route to unicast the RREP in the same way as that used in source routing. Otherwise, the destination or intermediate node may reverse the route in the route record from the RREQ and use this route to send the RREP to the source node.

2.3.2(b) Ad-Hoc On-Demand Distance Vector (AODV) Routing Protocol

The AODV routing protocol (Perkins et al., 1999) is a combination of proactive DSDV and reactive DSR protocols. The AODV protocol creates routes on

the basis of the DSR protocol to minimize the number of requested broadcasts. This routing protocol maintains a complete list of routes, similar to the DSDV routing protocol. It uses sequence numbers (SQs) to avoid long-term loops. The AODV protocol uses route discovery to find routes. As discussed by (Das et al., 2001) , the AODV protocol involves two major processes, namely, route discovery and route maintenance. The route discovery process starts when a source node needs to send data packets to a destination node but has no access to a route. Route discovery initiates with the source node broadcasting an RREQ packet to its neighbors. When a node receives an RREQ, it examines whether such RREQ is the same RREQ as that broadcasted by the source node. If the RREQs are indeed the same, the node simply discards the RREQ it received.

When the RREQ reaches the destination, an RREP packet is generated. A reverse path is set up from the destination to the source through the corresponding RREP. The RREP is sent to the source along a reverse path and to each node along the path. The address of the neighbor from which the source received the RREP is recorded in its routing table.

2.3.2(c) Cluster-based Routing Protocol (CBRP)

The CBRP (Jiang et al., 1999; Yu et al., 2012) is an efficient, scalable, and robust routing protocol for MANETs. It features more advantageous metrics than existing routing protocols (Abolhasan et al., 2004; Jiang et al., 1999); its overhead is less than that of the AODV protocol, whereas its throughput is higher than that of the AODV protocol (Boukerche, 2004). The CBRP is designed to be used in medium-to-large MANETs.

The nodes in MANETs are grouped into clusters. These clusters either overlay one another or are disjointed at a two-hop distance in a distributed way. Each cluster selects a head to keep the information for cluster membership. The “lowest ID” cluster algorithm is used to select a cluster head (CH).

The CBRP consists of two main mechanisms, namely, cluster formation and routing. Cluster formation can be conducted as follows: when a node comes up, it enters the network in an “undecided” (U) state and broadcasts a “hello” message for all neighbor nodes. “U” means that the node is looking for its host cluster. All nodes enter the network in a U state. When a CH receives a “hello” message from a U node, it sends out a triggered “hello” message immediately. If the U node receives a “hello” message from a CH indicating a bi-directional link in between, it sets its own status to a cluster member (CM). When the U node times out, it transforms itself to a CH, particularly if it has a bi-directional link to some neighbor; otherwise, it remains in the U state and repeats the process again. CHs change as infrequently as possible. A CH regards all neighbor nodes that it has bi-directional links to as its member nodes. A node regards itself as a member node for a particular cluster if it has a bi-directional link to the corresponding CH. Figure 2.3 shows the topology of the CBRP in MANETs.

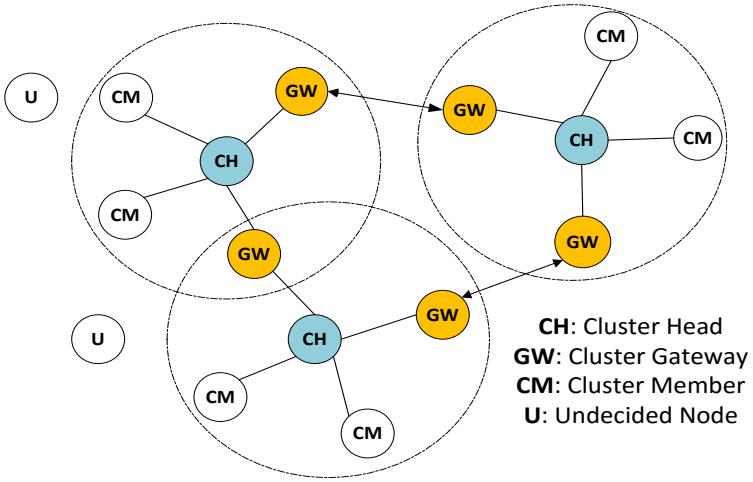

Figure 2.3 Cluster Based Routing MANET topology

CHs keep the information on neighboring clusters and all members in the same cluster. Each node maintains a neighbor table (NT) and a cluster adjacency table (CAT). The NT in every node of the CBRP retains the information about link states (bi-directional or unidirectional) and the state of its neighbors. The CAT keeps the information about the neighboring cluster. This information includes the CHs of neighboring clusters and cluster GW nodes, which connect clusters together. The CAT is maintained with the adjacent cluster discovery process, in which all bi-directionally linked adjacent clusters for a certain cluster are identified. Periodic "hello" messages are used to update the information kept in these tables (NT and CAT) (Jiang et al., 1999).

Routing in the CBRP is based on the route discovery process, which a path from a source node to a destination node is determined. This process starts when a source node needs to send a data packet to a destination node and no route is available in the NT or RC of the source node. The source node sends an RREQ message to its CH node. When the CH node receives the RREQ, it broadcasts the RREQ to all the neighbor clusters through its GW. When the GW' in the neighbor cluster receives the RREQ, it unicasts the RREQ to the corresponding CH. The CH in the neighborhood checks if a destination node exists in the same cluster. If a destination node is found, the CH then sends the RREQ to this node directly. Otherwise, the CH broadcasts the RREQ to neighbor clusters. The process is repeated until the RREQ reaches the destination node. When the destination node receives the RREQ, it sends an RREP message to the source node. Finally, the RREP contains multiple routes for subsequent data delivery, and the source node stores the discovered routes in its RC.