MANET Performance Analysis through Gateway and Routing Selection Schemes in Network Disaster Recovery

By

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I dedicate this thesis to my husband, Wan Mohd Hasbullah and my beloved Mom, who offered unconditional love and support.

Declaration of Originality

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text. This thesis has been proofread by a professional editor who has made no contribution to the intellectual content of the thesis or been involved in rewriting text.

Nor Aida Mahiddin
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Abstract

In recent years, many natural and human-made disasters have occurred, destroying urban and rural areas worldwide. It can be devastating when existing telecommunication infrastructure is destroyed by disasters. Without telecommunication infrastructure, victims are left isolated from the rest of the world. A mobile ad hoc network (MANET) provides a solution to the problem of connectivity in disaster affected areas. A MANET has the potential to provide quick network connectivity that does not require any infrastructure. However, in disaster recovery areas, MANET performance can deteriorate because of network traffic congestion. The heavy traffic generated by the hand-held and mobile devices of victims and their loved ones can create a bottleneck at the MANET gateway.

In this thesis, an empirical investigation of the issues influencing MANET performance is described and the results are reported. The analysis and simulation results show an efficient gateway and routing selection scheme increases network performance, including higher packet throughput, lower packet end-to-end delay, lower packet loss and better packet delivery for medium-to-high traffic loads based on node density and velocity in the disaster recovery area. Performance is improved by introducing an efficient gateway selection scheme to avoid packet congestion at each gateway and manage the load balancing. Another necessary improvement in the routing selection scheme, involving simplifying the route discovery process in MANET, is presented.

The effect of node density, the velocity of a node in the disaster recovery area and node pause time, which also influence MANET gateway performance, were investigated. This thesis proposes an efficient gateway load balancing and routing selection scheme (GWRS), which considers the pause time, the density and the velocity of nodes in the disaster recovery area. A GWRS design and deployment scheme is outlined and recommendations for future work are made.

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List of Publications

Manuscripts relating to the research project have been published in the following academic conference proceedings:

1. N. A. Mahiddin and N. I. Sarkar, "An Efficient Gateway Routing Scheme for Disaster Recovery Scenario, in *33rd International Conference on Information Networking(ICOIN 2019), Kuala Lumpur, Malaysia* - Accepted

2. N. Mahiddin, N. Sarkar, and B. Cusack, "An Internet Access Solution: MANET Routing and a Gateway Selection Approach for Disaster Scenarios," *Rev. Socionetwork*, vol. 11, no. 1, pp. 47–64, 2017.

3. N. A. Mahiddin and N. I. Sarkar, "Improving the performance of MANET gateway selection scheme for disaster recovery," in *Proceedings - 18th IEEE International Conference on High Performance Computing and Communications, 14th IEEE International Conference on Smart City and 2nd IEEE International Conference on Data Science and Systems, HPCC/SmartCity/DSS 2016*, pp. 907–912, 2016.

4. N. A. Mahiddin, N. I. Sarkar, and Brian Cusack, "Gateway Load Balancing and Routing Selection Scheme of MANET in Disaster Scenario," in *2015 2nd Asia-Pasific World Congress on Computer Science and Engineeering (APWC on CSE)*, vol. 1542, pp. 1–7, 2015

List of Abbreviations and Acronyms

A4LP	A4LP Routing Protocol
ABR	Associativity-Based Routing
ANSI	Ad Hoc Networking with Swarm Intelligence
AODV	Ad Hoc On-Demand Distance Vector
AOMDV	Ad Hoc On-Demand Multipath Distance Vector Routing
AQOR	Ad Hoc QoS On-Demand Routing
ARA	The Ant-Colony Based Routing Algorithms
Beraldi	Polarised Gossip Protocol for Path Discovery
CGSR	Cluster Head Gateway Switch Routing
DAR	Distributed Ant Routing
DBR2P	Dynamic Backup Routes Routing Protocol
DDR	Distributed Dynamic Routing
DSDV	Destination-Sequenced Distance Vector
DSR	Dynamic Source Routing
DST	Distributed Spanning Tree
FORP	The Flow Oriented Routing Protocol
FSR	Fisheye State Routing

FZRP	Fisheye Zone Routing Protocol
GRP	Gathering Based Routing Protocol
GSR	Global State Routing
GWRS	Gateway and Routing Selection Scheme
HOLSR	A Hierarchical Proactive Routing Mechanism for Mobile Ad Hoc Networks
HOPNET	Hybrid Ant Colony Optimisation
IG	Internet Gateway
LANMAR	Landmark Ad Hoc Routing
LDR	Labelled Distance Routing
LMST	Local Minimum Spanning Tree
LRHR	Link Reliability Based Hybrid Routing
LSR	Labelled Successor Routing
LTRT	Local Tree-Based Reliable Topology
MANET	Mobile Ad Hoc Network
MN	Mobile Node
OD-PFS	On-Demand Packet Forwarding Scheme
OLSR	Optimised Link State Routing
QoS	Quality of Service
QMRB	QoS Routing with Traffic Distribution
QOLSR	OLSR With Quality of Service
RDMAR	Relative Distance Micro-Discovery Ad Hoc Routing
R-DSDV	Randomised Destination-Sequenced Distance Vector
ROAM	Routing On-Demand Acyclic Multipath
RPR	Recycled Path Routing

RREQ	Route Request
SLR	Source Routing with Local Recovery
SLURP	Scalable Location Update-Based Routing Protocol
SMORT	Scalable Multipath On-Demand Routing
SSBR	Signal Stability-Based Adaptive Routing
SSL	Source-Sequenced labels
STAR	Source-Tree Adaptive Routing
SWORP	Stable Weight Based On-Demand Routing Protocol
TCP	Transmission Control Protocol
TORA	Temporally Ordered Routing Algorithm
WRP	Wireless Routing Protocol
ZHLS	Zone-Based Hierarchical Link State Routing Protocol
ZRP	Zone Routing Protocol

Chapter 1

Introduction

The rising number of devices that can connect to the Internet makes living effortless. The Internet has become the communication backbone for most people. According to the research firm ABI Research, more than 30 billion devices will be connected wirelessly by 2020 [1]. However, the breakdown of essential communications caused by calamitous natural disasters affects huge numbers of victims, who lose network connectivity. They become isolated from the world. The failure of telecommunications infrastructure makes it difficult for disaster victims to use communication devices, such as cellular phones, iPads or laptops, to connect to the outside world through the Internet.

Because it requires less infrastructure and decentralised features, a mobile ad hoc network (MANET) can play an important role in improving communication in disaster recovery areas. Table 1.1 shows the generation of Wi-Fi technologies. The important functionalities of a MANET allow users to create dynamically configurable wireless networks without fixed infrastructure.

In disaster recovery areas, there is commonly a collapse of infrastructure. Power can go out, servers can go down and devices stop working because of service communication failures. Disaster victims also have problems with connectivity from communication network infrastructures. Despite being connected to the Internet, all devices in a disaster recovery area with wireless networking capability can dynamically form a network to exchange information. They can communicate without depending on the central source. Since communicating between two nodes might be out of range, each node in MANETs must have the capability to relay traffic.

Table 1.1: Wi-Fi Protocol Summary

Technology	Maximum Data Rate (Mbps)	Frequency (Ghz)	Approximate Range	
			Indoor (M)	Outdoor(M)
802.11	2	2.4	20	100
802.11a	54	5	35	120
802.11b	11	2.4	35	140
802.11g	54	2.4	38	140
802.11n	450	2.4 / 5.0	70	250
802.11ac	1730	5.0	35	100

The primary objectives of this research were to:

- identify issues influencing the performance of MANETs in disaster recovery areas
- develop efficient selection schemes of gateway and routing to enhance MANET performance
- analyse the MANET performances in mobility environment using network disaster recovery scenario.

To achieve these objectives, gateway selection method was studied to enhance the gateway selection scheme and develop an efficient way to distribute the traffic load among gateways. In a wireless ad hoc network, devices connect seamlessly to nodes in the external network and some nodes will act as a gateway. A gateway selection method is required. In a traditional wireless network algorithm, mobile nodes will choose the nearest gateway to send the data packet, regardless of the heavy traffic load. Bottleneck queuing at gateways leads to congestion and packet loss. The imbalance in traffic distribution among MANET gateways causes performance degradation. By improving the MANET gateway selection scheme, congestion can be decreased, and throughput performance can be improved.

To send a packet to the gateway through the multi-hop node, traditional AODV routing protocols perform a broadcasting algorithm for route discovery. This technique of broadcasting a packet to all nodes in the network leads to network flooding and complex routing selection. The difficulty of route selection will delay the packet. To carry out these objectives, an efficient routing selecting scheme was introduced to reduce the delay in MANET performance. This scheme simplifies the route selection process to increase the network performance.

1.1 Scope of Research

The significance of this research is to build a connection between mobile devices and the Internet in disaster recovery areas. While mobile devices form a dynamic MANET group, some of the nodes are configured to become a gateway. A node that can be a gateway is the node that receives Internet coverage. The main task of the gateway is to manage network traffic between two or more different networks. In a disaster recovery situation, victims usually search for a coverage signal to contact family and friends, which causes a high level of data traffic and leads to network congestion. The movement of nodes also affects network performance. Packet loss, packet delay and throughput degradation in MANETs are typically affected by network congestion and the mobility of nodes.

1.2 Research Methodology for Investigation

A main objective of this thesis is to identify the issues that influence MANET performance in disaster recovery areas and develop a solution to improve MANET performance by developing a better gateway selection scheme and an efficient routing selection scheme. To achieve this objective, computer-based simulation was used to estimate network performance.

One of the issues that influence the performance of MANETs is traffic congestion. Traffic congestion significantly reduces MANET performance. In MANETs, the gateway and routing schemes are the main elements that determine the efficiency of data transmission in the network. Another factor that influences MANET performance is the effect of node mobility in the disaster recovery area. Routing strategies are crucial when they involve the movement of a person with mobile devices in the disaster recovery area, in which there is a possibility that all nodes in the network are mobile and have different velocities.

A modified research design methodology, as shown in Figure 1.1, was used for the systematic design process in this thesis. The research stage began with the development of knowledge and an understanding of the problem of the disaster recovery environment. First, this thesis examines previous work to identify the problems and the opportunities of MANETs (Chapter 2). By studying MANETs, three research gaps were identified: (1) the scheme of gateway load balancing, (2) the routing selection scheme, and (3) node mobility. Existing MANET research has yet to provide a better solution for disaster recovery areas. Therefore, this research needs further improvement. After a research gap is identified, analyses of previous work on existing gateway selection schemes, existing routing selection schemes, movement patterns of mobile nodes in MANETs and MANET applications in disaster areas are carried out (Chapter 3). In this way, a research problem is formulated.

In the research design and development phase, a gateway selection scheme was developed, which efficiently selects the gateway and organises traffic load between gateways in MANET networks (Chapter 4). A routing selection scheme was also designed and developed to simplify route selection for route discovery (Chapter 5). These two schemes were used to determine the effects of node mobility on MANET performance in disaster recovery areas (Chapter 6).

Once the algorithm of the scheme was designed, a computer simulation of the scheme was performed using the OMNET++ network simulation tool with an inetmanet framework and tested with different parameters and mobility environments. OMNET++ was chosen because it is used extensively in MANET research. OMNET++ is an open source simulation tool. Another reason for using OMNET++ was that it could compare the proposed scheme to previous routing protocols, such as AODV and DSDV, within the same MANET environments, by using an inetmanet framework.

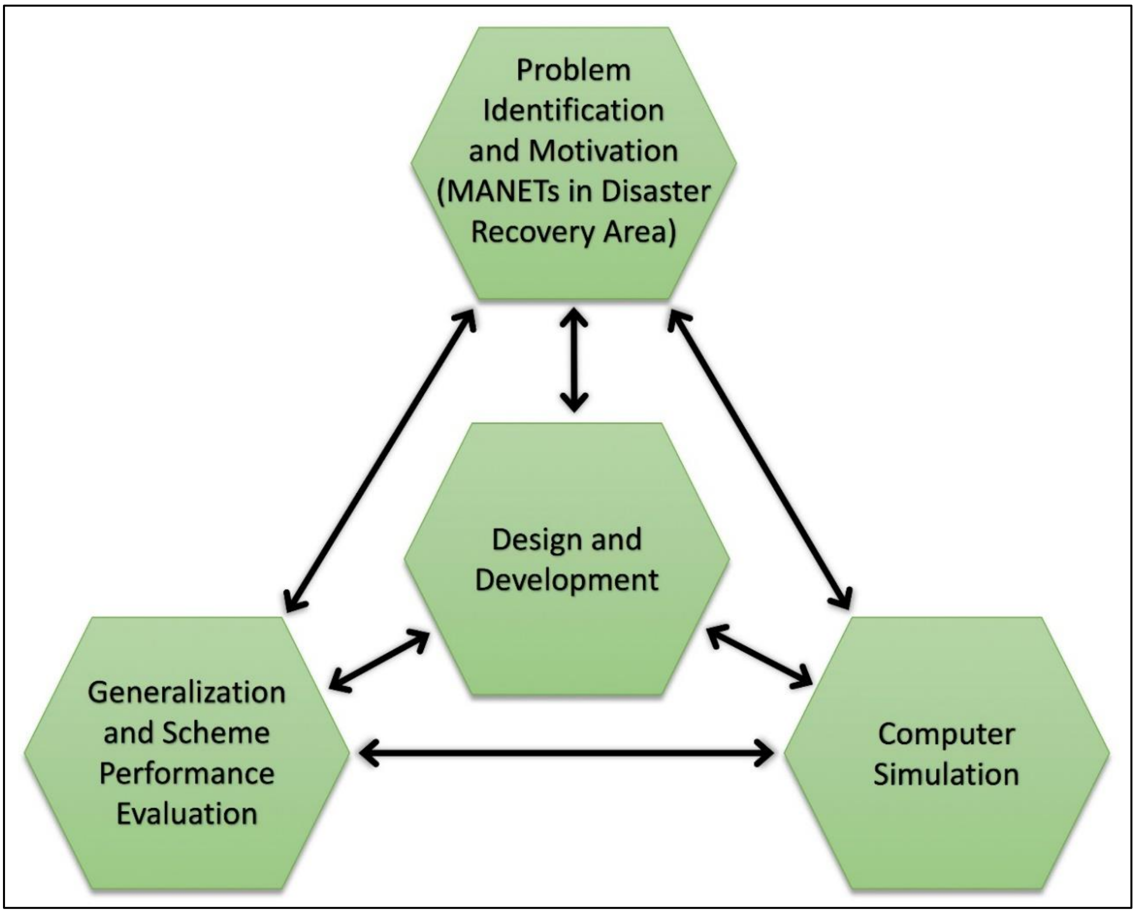


Figure 1.1: Modified research design methodology

The final stage of this thesis involves generalising the results to evaluate the proposed scheme. MANET performance in disaster recovery areas was analysed, compared, summarised and presented in each of the contribution chapters (Chapter 4, 5 and 6). Performance metrics of this research, such as packet throughput, packet end-to-end delay, packet sent rate and packet loss ratio, were used to validate the results.

1.3 Contributions and the Structure of t his Thesis

The overall structure of this thesis is shown in Figure 1.2. Accurate performance evaluation requires a basic understanding of MANET and the scenario of disaster recovery, including network architecture after disasters, traffic load at the gateway, and route discovery process during disaster recovery and performance evaluation tools. It is essential to have a strong foundation in the gateway and routing selection schemes used in MANETs and disaster recovery areas before considering enhancing performance. Chapter 2 and Chapter 3 present foundational and background material for this thesis.

Chapter 2 introduces MANETs and disaster recovery, emphasising the architecture of MANETs, applications of MANETs and issues and challenges in disaster recovery areas. In this chapter, performance studies of simulation tools for selecting the best tools are identified and described. MANET performance metrics for this thesis were chosen to confirm the validity of the results. Performance metrics, such as packet throughput, packet end-to-end delay, packet sent rate and packet loss ratio were used to compare the efficiency of the proposed schemes.

Gateway and routing schemes influence the performance of MANETs in disaster recovery. Chapter 3 addresses the issues and challenges in the design of gateway and routing selection schemes. Another factor discussed is the effect of node mobility in disaster recovery. To provide a review of the literature, previous related research on design and performance improvement are surveyed in this chapter.

The original contribution of this thesis is presented in Chapters 4, 5 and 6, which are primarily focused on quantifying the issues that influence MANET performances in disaster recovery areas. Simulation approaches were used to evaluate network performance. The disaster area in Loja City, Ecuador, was used as a simulation environment to mimic a real disaster scenario.

Chapter 4 reports the design of the proposed gateway selection scheme. In this chapter, the performance of the proposed gateway selection scheme is evaluated using the OMNET++ simulation tool. Simulation results are presented to verify that the proposed scheme performance is better in terms of packet throughput, packet delay, packet drop ratio, packet delivery ratio and sent packet rate.

In Chapter 5, the effect of the routing selection scheme on MANET performance in disaster recovery environments is investigated. The primary objective of this chapter is to compare the performance of the proposed routing scheme to the traditional AODV and DSDV routing schemes.

Chapter 6 examines the effects of node mobility on MANET performance in disaster recovery areas. It is observed that topology rapidly changes and obstacles in the disaster area have a significant effect on MANET performance.

In Chapter 7, the major findings from Chapter 4 to 6 are presented from the perspective of network planning and deployment. The evolutionary path, issues, and deployment of MANET in disaster recovery area are outlined. Several possible future developments of this research are also presented. The thesis is summarised and concluded in Chapter 8.

1.3.1 Gateway Selection Scheme

In a disaster recovery scenario, communication infrastructure may breakdown, leading to communication failure. Though a MANET can make up the communication network, it always becomes congested with a high level of data traffic as victims seek to contact family and friends. To connect with an outside network, nodes in a MANET send a packet to the nearest gateway, regardless of the gateway load. To overcome this issue, this thesis introduces a gateway selection scheme to manage traffic. This technique can significantly reduce congestion at each gateway, consequently improving MANET performance by increasing the rate of packet throughput. In a further study, this algorithm is expected to be suitable for application in any research related to network-based group.

1.3.2 Routing Selection Scheme

Routing plays an important role in choosing the best path for a packet to travel. In the traditional AODV routing scheme, the broadcast method leads to packet flooding in the network, which affects the routing table. The complexity of the routing table makes the process of routing selection difficult. Other methods, which use less hop nodes as the shortest path, cause bottlenecks, thereby decreasing network performance. A MANET is a type of ad hoc network. A node in a MANET can move randomly and connect wirelessly. Mobility has a significant effect on routing performance. The performance of the routing scheme depends on the total duration of the connection between any two nodes. However, the connection may be lost during data transmission because of mobility. Therefore, in self-organised networks, metrics need to be considered to determine the best path, such as the most reliable and stable path, instead of the path with less hop nodes. An efficient routing selection scheme will simplify the complexity of route selection to reduce delay in MANET performance.

1.3.3 Effect of Node Mobility on MANET Performance in Disaster Recovery

The proposed gateway and routing selection scheme (GWRS) is designed to manage the traffic load from mobile nodes in a MANET to the external network and simplify the routing selection process within a MANET to reduce the complexity of the original routing table. The objective is to enhance MANET performance in disaster recovery areas. However, modelling the mobility of nodes is also an important task because it represents node movement in real disaster recovery scenarios. The evaluation of results is strongly dependent on how nodes in the simulation area are distributed and how the movement of nodes in a disaster area can be represented in the simulation evaluation. Therefore, this thesis describes the characteristics of node movements in disaster recovery scenarios that need to be considered. The thesis then evaluates the effect of node mobility on MANET performance.

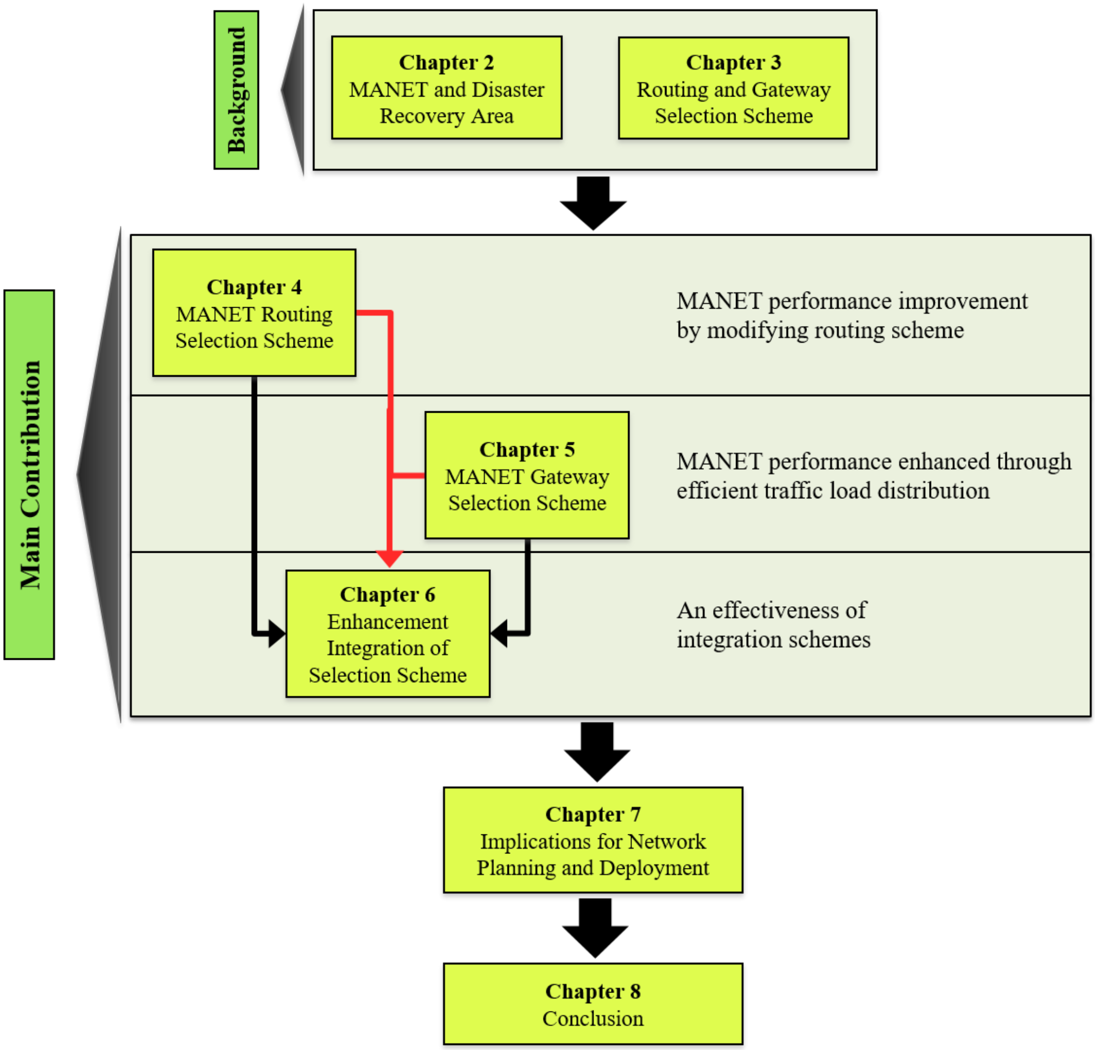


Figure 1.2: Structure of the thesis

This scheme is designed to manage all traffic in MANET gateways and simplify the routing selection process to reduce the complexity of the original routing table. A combination of gateway load balancing and an efficient routing selection scheme is designed to reduce packet delay and packet loss while achieving better MANET performance. The significance of the proposed method is the reduction of network congestion and consequently an improvement in packet delay and packet loss in MANET performance. Network fairness, throughput and packet delays were measured empirically. Network performance of this research was evaluated using the OMNET++ simulation tool.

The remainder of the thesis is organised as follows: In chapter 2, an overview of MANETs and disaster recovery areas is provided. This chapter also contains a review of simulation tools for MANET and the validation of simulation results. Chapter 3 reviews MANET routing selection schemes and gateway selection schemes. This chapter also reviews the mobility of nodes in MANETs. Chapter 4 presents the proposed scheme of gateway selection. Chapter 5 reports the proposed routing selection scheme and includes performance evaluation and discussion. Chapter 6 discusses the effects of the mobility of nodes in disaster recovery areas. Network simulations using OMNET++ are described in Chapters 4, 5 and 6. In each chapter, performance is discussed, and the simulation study is described in detail. Chapter 7 discusses the implications of this research for network planning and deployment. MANET design issues and challenges regarding the deployment of this research are outlined. Chapter 8 concludes this thesis.

Chapter 2

MANET and Disaster Recovery Areas

2.1 Introduction

In Chapter 1, the motivations for MANET performance in disaster recovery areas were highlighted. A primary objective of this thesis is to improve MANET performance by modifying routing selection schemes and gateway selection schemes. To achieve this objective, a general understanding of MANET and disaster recovery areas is necessary. Therefore, this chapter aims to introduce MANET concepts, applications, simulation tools and communication infrastructure in disaster recovery areas.

In Section 2.2, the concepts of MANET are described, including the architecture of a typical MANET and infrastructure network. Section 2.3 discusses MANET applications. Because this thesis focuses on MANET in disaster recovery environments, Section 2.4 outlines the effect of disasters on communication networks. Section 2.5 discusses challenges and issues in disaster recovery areas. Section 2.6 outlines the MANET simulation tools. Section 2.7 explains why OMNET++ was used in this research. Section 2.8 discusses the validation of simulation results.

2.2 Mobile Ad Hoc Networks

The expansion of wireless technology has brought data transmission via radio waves. Nodes in the network can communicate with each other without a fixed station access point. The structure can form and reform in a network without relying on any network system. MANET has been gaining popularity since the production of smart computing devices and the development of wireless communications. The transmission of information from a source to a destination across an inter-network is called routing. To forward data packets from a source to a destination, the neighbour's node (also known as a router, because it performs data packet forwarding) will send the data packet through multi-hop nodes until the data packet arrives at the destination. The topology of a MANET is unpredictable and can change rapidly [2].

IEEE 802.11 is a standard for wireless communications. Two operational modes are defined by IEEE 802.11: infrastructure-based and infrastructure-less (ad hoc). Infrastructure-based modes act as wi-fi hotspots, which enable devices to connect to the Internet. However, for dynamic environments in which people or devices connect to the Internet for a temporary time, the infrastructure-less or ad hoc mode is more efficient. Nodes in this mode are the independent basic service set or ad hoc network. Every node can communicate with the others after the synchronisation phase. If one of the nodes (node A) in the network is connected to a wired network, then all nodes have wireless access to the Internet via node A. Node A will serve as a router or gateway for all nodes in this ad hoc network. In a real environment of communication, an ad hoc network is basically a communication among user's mobile networks. Users' devices will support functioning as a network that can offer network infrastructures, such as routers, switches and servers. As long as they are within transmission range, nodes can communicate.

As shown in Figure 2.1, Manet layer architecture such as an application to send a message, a device as a MANET node and some of the nodes within coverage area will react as a gateway to manage traffic. A protocol, such as wi-fi direct, is needed to allow all MANET nodes to communicate. In this thesis, the development phase focuses on gateway and routing schemes.

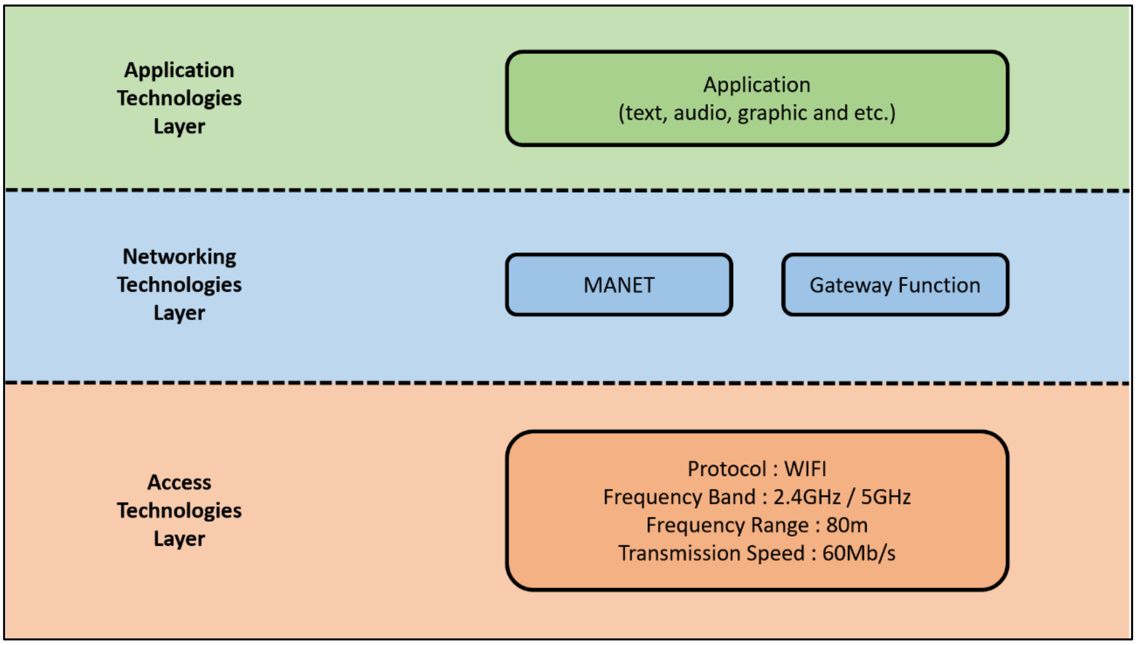


Figure 2.1: MANET layer architecture

2.3 Applications of MANET

MANET was originally proposed for military applications and was then extended to applications in other fields. Deployment in disaster scenarios is the most challenging. However, it can be a significant application [3]. After a disaster occurs, information about victims is needed so victims can be rescued quickly. For example, the earthquakes and tsunamis in Great East Japan, in Wenchuan, China and in Indonesia and the floods in Malaysia were extreme events and national disasters.

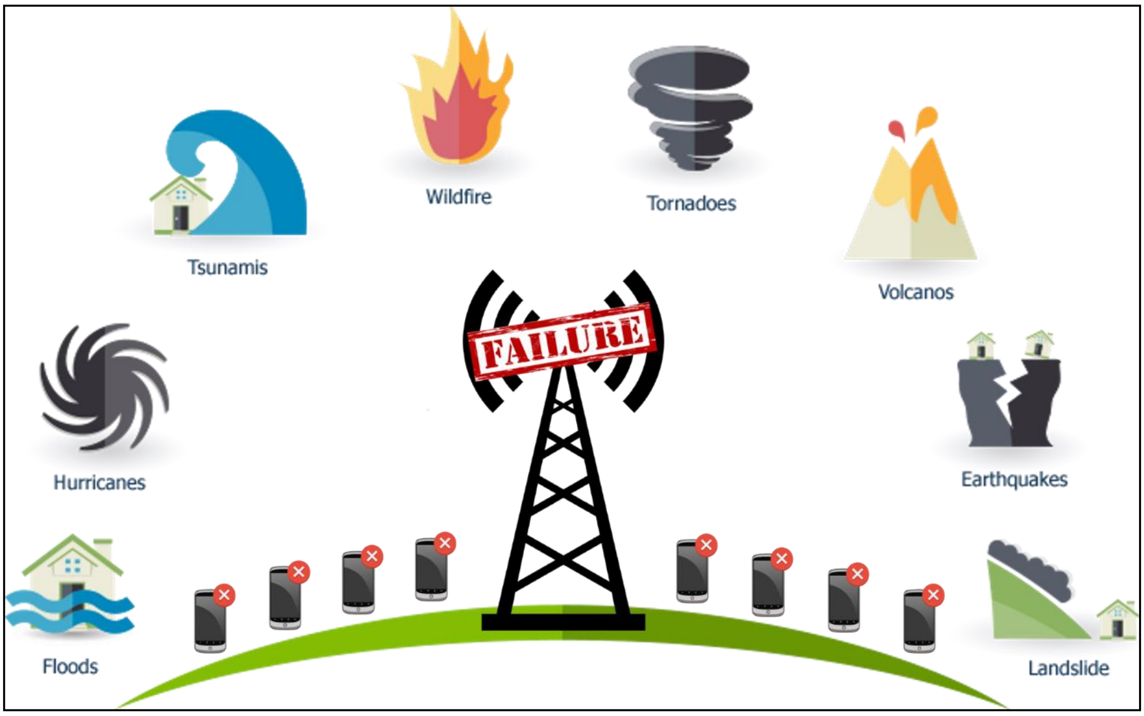


Figure 2.2: Failure in communication and information exchange

Collapsed structures are a common result of earthquakes. It is seemingly impossible for disaster victims that are trapped in the disaster to make voice phone calls using mobile devices [4]. As shown in Figure 2.2, mobile devices stop working because communication services in the area are damaged. Because MANETs are decentralised and does not require infrastructure, it can be one of the options to solve communication problems [4]. The significant functionalities of MANETs, which allow users to build dynamically reconfigurable wireless networks without fixed infrastructure, are very useful [5].

Table2.1: Applications of MANET

Application Area	Scenario and Potential services
Military Communication and Operations	• Keep the communication networks of soldiers, vehicles and military always in a good condition and ensure stay connected
Disaster Scenario	• Emergency rescue operation takes over the communication when existing communication infrastructure has damaged or cut off for a safety reason. Generally, it's usually be used in rescue operations to support medic teams such as earthquake, flood, disaster relief etc.
Commercial Sectors	• Shopping malls • Airports • Sport stadiums • E-commerce • Vehicular Ad Hoc Network
Home Networking	• Indoor and Outdoor Internet Access • Personal Area Networks
Enterprise Networking	• Indoor and Outdoor Internet Access • Conferences • Meeting Rooms
Education	• Virtual Classrooms • Ad Hoc Communication through meeting or lectures
Sensor Networks	• Smart home applications: smart sensors for home appliances • Geo-location tracking device for humans or animals
Entertainment	• Multi-user games • Robotic Pets

The development of mobile computing equipment and the infrastructure of network communication has made huge changes to the ways people communicate. People retrieve information, do their tasks and communicate with each other using mobile devices. MANETs allow information exchange anytime and anywhere without relying on fixed network infrastructures. Table 2.1 lists MANET applications and corresponding scenarios [6], [7].

2.4 MANET in Disaster Recovery Areas

Each node within a MANET network only can communicate with the nodes in the same network. Victims attempt to connect to the Internet to tell their family and friends outside that they are safe. They want to send a message, to share the information or to share a video. However, the message must go through to the Internet. Therefore, to give Internet access to disaster victims in a disaster area (see Figure 2.3), this thesis proposes an enhancement of the GWRS.

In the event of a disaster, it is common for infrastructure to collapse. Power can go out, servers can go down and devices stop working because of communication service failure. It is impossible for disaster victims to make use of communication devices, such as cellular phones, iPads or laptops, to communicate with family and friends. Nevertheless, living in technological era has brought solution in access to energy in post-disaster situations. In 2015, earthquake with 7.8 magnitude level striked Nepal's capital city of Kathmandu. The non-profit SunFarmer has provides sollar power and batteries to remote hospitals and school and to fix street light in the city [8][9]. The solar power has playing a role in Nepal's disaster relief. We understand that energy is an important factor when disaster strike, however solving the energy after disaster is not in this research scope. This research focusing on the network connection of mobile devices to the Internet after the power issues can be solved. On the other hand, devoid of connection to the Internet, all devices with wireless networking capability can dynamically form a network to exchange information as they do not require infrastructure and have decentralised features, MANETs are ideal for solving this type of problem.

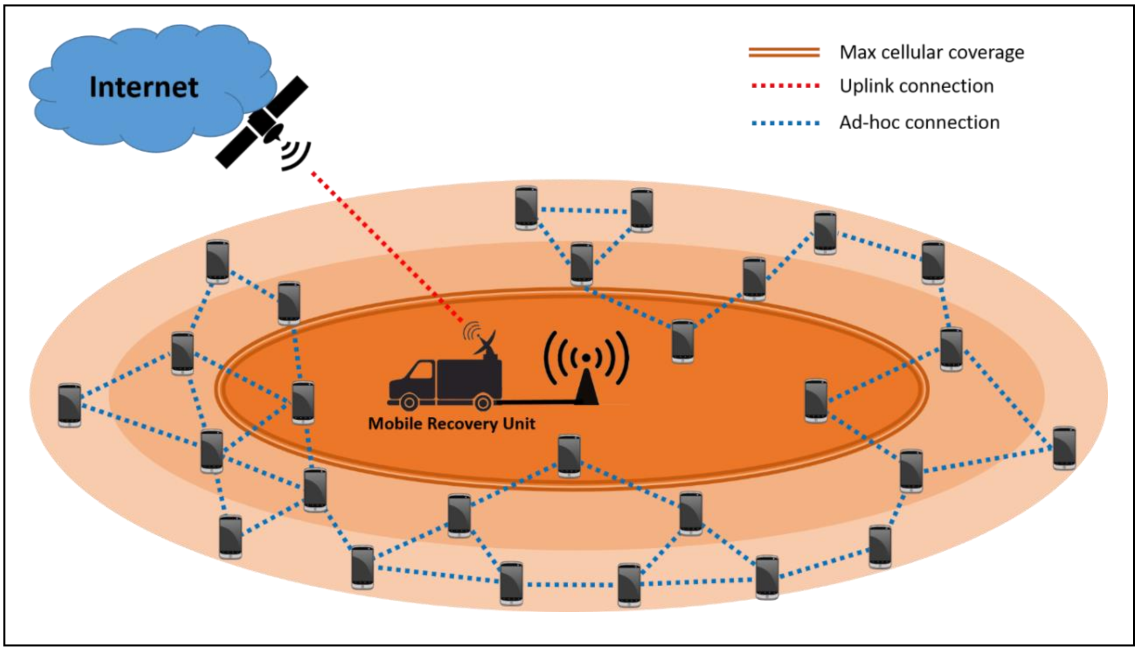


Figure 2.3: Architecture of MANET connectivity to the Internet

This thesis assumes a post-disaster scenario in which electricity sources have been maintained or have a backup because this study focuses on achieving better network performance by improving GWRSs. In this scenario, mobile devices with Internet coverage are selected as the gateway. Those with no Internet coverage will send the packet to the neighbour's node until the packet arrives at the MANET gateway.

In normal situations, most devices rely on communication infrastructure. However, after a disaster occurs, network devices are isolated because of collapsed and damaged communication infrastructure. As shown in Figure 2.4, by enabling MANET technologies, the nodes can still communicate. For example, if the destination node is not in the source range, then a neighbour node will act as a relay to forward the message until it reaches the destination (see Figure 2.5). Each node within a MANET only can communicate with the nodes in the same network. To extend communication, this thesis proposes an enhancement of GWRSs. The proposed schemes are then applied in a disaster scenario. This thesis assumes a post-disaster scenario in which the electricity source is not damaged or has a backup because in this study this thesis focuses on gateway and routing selection protocol to achieve better network performance. This thesis assumes three MANET nodes are in Internet range. These three nodes will be the gateway for the other nodes to connect to the Internet. In Chapter 4, this thesis will later consider what the effect of having more than three gateways.

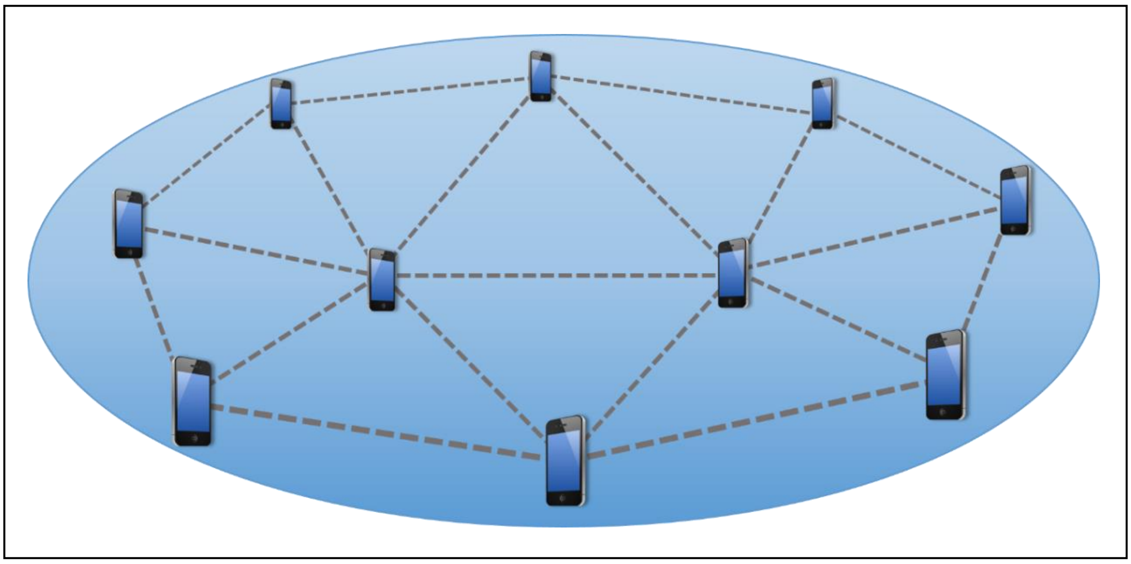


Figure 2.4: MANET only in disaster area

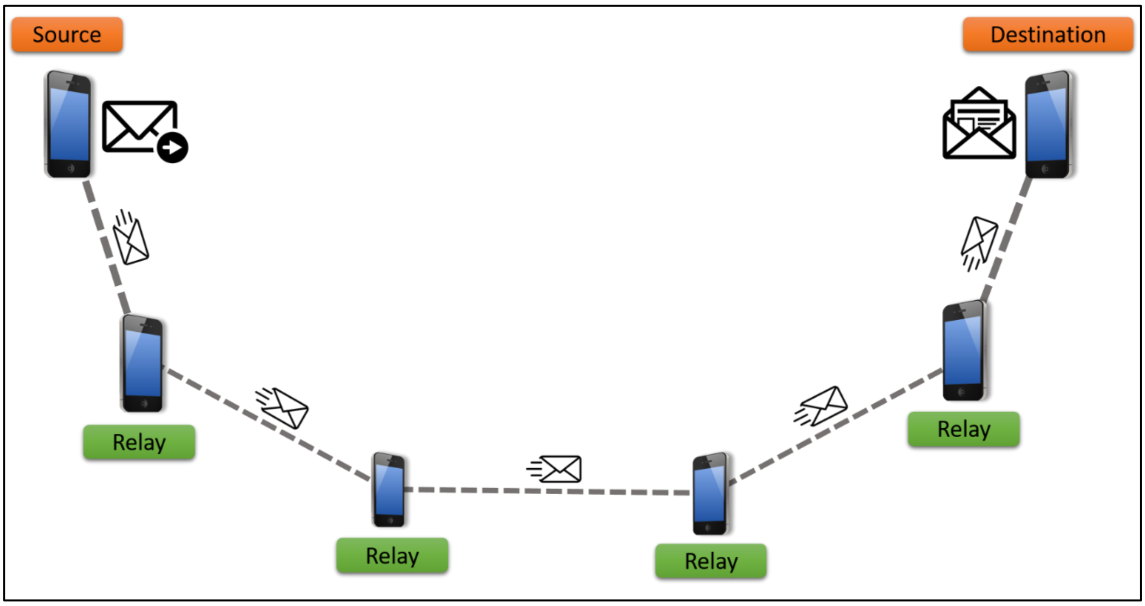


Figure 2.5: Neighbour node as a relay

2.5 Issues and Challenges of MANETs In Disaster Recovery Areas

After disaster strikes, a breakdown of telecommunications infrastructure usually follows, leading to a failure of public communications. The failure of communication is categorised according to three main issues [10]: (1) physical network damage, (2) disruption to network supporting infrastructure, and (3) network congestion. The significant effect of the sudden natural disaster is physical network damage that wipes out public communication networks. This worsens if network damage involves the disruption of network supporting infrastructure, such as fibre-optic cables or cell towers. To bring back the network is sometimes costly and time consuming. It will remain as a problem until the network service provider successfully installs the network. Each node in the disaster area—victims with mobile devices—moves randomly to find good network coverage. Damaged environments with limited power and obstacles make it more difficult for each node to move in the area. The disaster recovery must be able to provide a network backup or temporary solution for nodes in the area to communicate until normal infrastructure is restored.

Network congestion occurs because large numbers of victims in the disaster area attempt to connect to the Internet at the same time immediately after disaster, to convey information about the situation or as a panic reaction to the circumstances. A lack of efficiency in balancing the distribution of traffic load will increase the problem of existing congestion. Nodes in the disaster area try to send messages outside the network area. Without suitable traffic management, packet flooding in the network makes a bottleneck on its way to the outside network. Some routing protocols that use broadcasting techniques to discover communication routes enhance the congestion of the network. Network congestion will decrease the performance of a MANET.

2.6 Performance Study Simulation Tools

In a multi-hop wireless network, the evaluation of network performance can be done through analytical modelling, experimentation networks (testbeds) or software-based simulators. Analytical modelling involves certain simplifications and predictions of performance. Oversimplification and the wrong prediction will lead to false results. Testbeds are generally used to set up real application scenarios on real hardware. Since the experiment uses actual equipment, the results obtained are practically accurate. However, since all the actual equipment can be expensive, usually only small-scale applications with a smaller number of nodes are involved. For economical experiments, a simulation is the best option because it can be carried out without the real hardware. Moreover, simulation is more flexible in simulating MANET with a large queue size, large bandwidth and a large number of nodes.

In addition, simulation results are easier to analyse because information at critical points can be easily logged to diagnose network protocols. Table 2.2 lists commonly used simulation tools (both open and commercial) for simulation tasks [11][12].

2.7 Selecting the Best Tool

The OMNET++ (Objective Modular Network Testbed in C++) was selected for network modelling and simulation tasks because of its availability and credibility. This simulation tool is a well-designed simulation package written in C++. It is open source and has extensive GUI support to make the tracing and debugging process easier compared to other simulation tools [13]. Further, OMNET++ allows the user to design and develop a scenario of network simulation graphically. These features give a precise picture of the simulation at the state of execution. Scenario topologies can be generated as NED files. In addition, OMNET++ supports hierarchical modelling. This feature allows zooming into the component level and displaying the state of each component during the simulation to observe the data flow and node communications.

The basic entity in OMNET++ is a module. Each module has an actual behaviour and can be formed as a submodule. The modules can communicate with each other by sending and receiving messages via connections. OMNET++ can simulate a complex IT system, for example, queuing networks and hardware architecture. In addition, it has an NET extension framework to support wireless and mobile network simulations. Many network researchers have used OMNET++ for simulation and performance evaluation of MANETs [14][12][15].

Table 2.2: MANET Simulation Tools Comparison

Simulation Tools	Type	Mobility	Simulation Technique	Interface
NS-2	Open source	Support	Discrete Event Simulation	C++ / OTCL
NS-3	Open source	Support	Discrete Event Simulation	C++ / Python
OPNET	Commercial / Academic	Support	Discrete Event Simulation	C
OMNET++	Open source	Support	Discrete Event Simulation	C++
GLOMOSIM	Open source	Support	Discrete Event Simulation	Parsec (C-based)
J-SIM	Open source	Support	Discrete Event Simulation	Java
JANE	Free	Native	Discrete Event Simulation	Java
QUALNET	Commercial	Support	Discrete Event Simulation	Parsec (C-based)
SWANS	Open source	-	Discrete Event Simulation	Java
GTNETS	Open source	No	Discrete Event Simulation	C++
NAB	Open source	Native	Discrete Event Simulation	OCaml
NCTUNS	Open source	Support	Discrete Event Simulation	C

2.8 Validation of Simulation Results

This research used a network simulation tool, OMNET++, to simulate the proposed scheme within the selection environment. To validate the result, the result presented in this chapter was compared with the findings of other researchers using the same parameters. Performance metrics, such as gateway throughput, packet delay, network overhead and packet loss, were used to compare the efficiency of the proposed scheme with schemes presented by other researchers.

To simulate the environment of moving devices in a disaster recovery area, parameter join and leave nodes were used in this simulation. For all simulation scenarios, node movement was simulated according to the random waypoint mobility model. Model verification is important to test the reliability of the simulation results and evaluate the scheme. The simulation represents the results as in a reality scenario. However, if the simulation parameters are incorrectly configured, invalid results are generated. Simulation models were validated through identified measurement. Propagation measurements were repeated three times to test the repeatability of the results and to ensure the measurements were correct. The results obtained in this study were compared with the work of other network researchers.

2.9 Performance Metrics

Performance metrics [16], such as network packet throughput, packet end-to-end delay, packet delivery and packet loss ratio, were used to assess the efficiency of the proposed GWRS. Throughput is one of the major criteria used to evaluate network performance [17].

2.9.1 Average End-to-End Delay

End-to-end delay is the time it takes a packet to travel from the source to the destination. This is affected by potential delays caused by node mobility, node queuing because of congestion and retransmission of the packet. Average end-to-end delay can be formulated as:

$$\boldsymbol{mean\ p = \frac{\sum_{i=1} P_i}{N}\ , \sum P_i \leq T} \qquad \textbf{(2.1)}$$

where P_i is the transmission of the packet when i = 1, 2 …. $\leq T$, N is the total number of packets that have arrived at the destination node and T is the simulation time, which is 900 s in our parameter environment.

P is given by:

$$P = \Delta\, t = t_r - \ t_s$$

where t_r and t_s are packet received time and packet sent time, respectively.

2.9.2 Packet Loss Ratio

Packet loss ratio is the number of dropped packets during packet transmission. The packets can be dropped because of excessive waiting time or if the route is broken. Packet loss ratio can be formulated as:

$$\boldsymbol{L = \left(\frac{\sum S_i - \sum R_i}{\sum S_i}\right) \times 100} \qquad \textbf{(2.2)}$$

where *L* is a packet loss ratio, S_i is the number of packets sent by source nodes and R_i is the number of packets received by destination nodes when *i* = 1, 2 …. $\leq T$.

2.9.3 Packet Delivery Ratio

Packet delivery ratio is the number of packets that successfully arrive at the destination nodes. The number of arrived packets divided by the total number of packets sent by source nodes equals the ratio of packet delivery. Therefore, the packet delivery ratio can be formulated as:

$$\boldsymbol{D = \left(\frac{\sum R_i}{\sum S_i}\right) \times 100} \qquad \textbf{(2.3)}$$

where *D* is the packet delivery ratio, R_i is the number of packets received by destination nodes and S_i is the number of packets sent by source nodes when *i* = 1, 2 …. $\leq T$.

2.9.4 Throughput

Throughput is equal to the total number of successfully delivered messages divided by the simulation time:

$$\boldsymbol{mean\ q} = \frac{\sum \boldsymbol{R_i}}{\boldsymbol{T}} \quad \textbf{(2.4)}$$

where q is a packet throughput.

2.10 Justification of Research Methodology

The performance of MANETs in disaster recovery areas can be measured by the performance metrics of mean throughput, packet delay, packet loss and packet delivery. This section describes methods for evaluating MANET performance in disaster recovery areas. Since this thesis focuses on performance evaluation of MANETs, it is necessary to adopt a methodology that can measure the performance. Experiments using computer simulations were used to measure MANET performance in disaster recovery areas. The measurements-based approach is the number of mobile nodes in the simulation that present as a density of people in the disaster recovery area, with different velocity and the number of MANET gateways. It is difficult to capture a disaster area in which people are always mobile and have changing velocities. Therefore, many leading network researchers have used computer simulations to study the performance of computer and wireless communication networks [18]. To ensure a realistic network performance measurement, different parameters were used in each simulation. Node mobility behaviours also affect network performance. The placement of the nodes was set as random to mimic people in a disaster area who move randomly in any direction at different velocities. Obstacles in a disaster area may cause signal attenuation when nodes try to select the next hop as a relay to the destination node. To overcome this problem, computer simulation was used. In the simulation, a next destination was determined by the signal strength within node transmission range. Therefore, simulation methods were used to analyse MANET performance and investigate the effects of MANET node mobility in disaster recovery areas.

2.11 Summary

In this chapter, the fundamentals and essential background of MANET were provided. The scenario and environment of disaster recovery areas were also highlighted. The challenges of overcoming network communication failure during disasters were discussed in this chapter. To simulate a real situation, MANET simulation tools were studied and listed. Simulation results were validated. In Chapter 3, this research discusses more details of the proposed scheme. Details of MANET gateways, routing and node mobility are discussed in the next chapter.

Chapter 3

Gateway, Routing and Node Mobility

3.1 Introduction

The fundamentals of MANETs were discussed in Chapter 2. The essential background of the challenging issues after disasters and the selection of the best simulation tools for performance evaluation were also presented in the previous chapter. In this chapter, a review of literature is considered to lead to the proposed schemes. In Section 3.2, previous work on MANET gateways is discussed in detail. Section 3.3 presents a list of studies of MANET routing selection schemes. Section 3.4 presents previous studies of node mobility in disaster recovery areas. These three factors are important elements for improving MANET performance in disaster recovery areas. The issues of each factor are discussed in each section.

3.2 MANET Gateways: A Review of Literature

To allow communication between MANET nodes and the Internet, a gateway is required, which functions as a door for the entry and exit of packets from the network. This gateway is the Internet gateway (IG), which will route all packets to and from the Internet. A gateway is also a node in a MANET network. The main task of a gateway is to control network traffic between two or more different networks. One network can have more than one gateway. Each gateway has an average queue size to monitor.

To recover communications in a disaster area, when large number of victims want to connect to the Internet at the same time, an organised gateway selection scheme is essential to manage packet congestion at each gateway and maximise network throughput. The purpose of a gateway load balancing scheme is to make the task equal among all gateways. Equalisation will balance gateways with heavier or lighter loads. Previous works [19] have proposed several techniques to reduce congestion through load balancing, such as the Queue Base Load Balancing Algorithm, Aggregate Interface Queue Length and the Hybrid Registration Mechanism. All these techniques are an enhancement of the AODV routing protocol method. Gateway load balancing plays an important role in avoiding congestion. If there is more than one gateway in one network, load balancing between the gateways must be considered to improve network performance. Miao. et al. [20] proposed the intelligent selection gateway scheme to allow identifying overload of acceptance gateway message. Although this thesis researched the integration of two networks—combining MANET and Satellite—the gateway selection scheme solution is introduced only for the MANET network. To continuously deliver Quality of Services (QoSs) and Quality of Experience, the MONET approach is a hybrid MANET-Satellite network. This is one of the solutions to the problems created by highly mobile, dynamic and remote environments [21].

A gateway selection process is required for communication nodes between infrastructure networks and non-infrastructure networks, such as the Internet and MANET. The shortest path selection is based on minimum hop count. This path will be a relay for traffic between MANET and the Internet. Various gateway selection scheme studies have aimed to improve only a single network performance, such as network throughput, end-to-end delay or packet delivery ratio. Bouk et al. [22] proposed a gateway selection scheme that improved overall network performance, path availability computation accuracy, path load capacity and latency. Manoharan and Mohanalakshmie [23] proposed that the path should be chosen by trusted nodes and uncongested routes to reach the gateway of the network. They introduced a trust-based hybrid gateway selection scheme with security element parameters to find node trust, route trust and residual route load capacity. Zaman et al. [24] conducted the same integration research but focused on gateway load balancing strategy. The idea was taken from AODV, one of the wireless ad hoc routing schemes, and was modified to propose a new gateway selection strategy that could distribute the packet evenly between the gateways in a network.

Recently, there have been many studies of gateways. Gateways are the entry points for nodes in a MANET to connect to the external network. There might be a scenario in which, after a disaster occurs, a communication network fails, and it takes a period of time to restore the communication that has been damaged. Since MANET can provide an immediate solution in this scenario, the main challenge is heavy traffic load, because people want to contact their family and friends.

In this section, this thesis will discuss previous studies of gateway selection schemes. It has been observed that some of the proposed techniques are modifications of traditional routing protocol methods, such as AODV and DSDV [3] [4] [5]. Tashtoush et al. [6] proposed a method that used a hop count as a weight value for gateways. To choose the effective route, the number of routes was limited via the weight of Fibonacci. The smallest hop count was selected as the route to the gateway. However, the continual computation of route weight affected the network overhead.

To recover communications in a disaster area, Liu et al. [7] presented a method to find gateway nominees without a heavy computation load. However, this method considered only one channel and only one gateway to serve in one area. Because throughput is one of the criteria for performance evaluation, electing different gateways will affect network performance.

Prabhavat et al. [8] evaluated many load distribution methods over a multipath network with different criteria. They stated that the main techniques for achieving better performance of load balancing in the network were the techniques of splitting traffic and route selection. This study does not discover a routing method to establish multiple paths. The load balancing scheme is a part of how gateways are selected and how each node chooses a particular gateway for packet transmission. Congestion may occur because many nodes focus on the same gateway. Efficient techniques for maintaining packet ordering to prevent packet loss are very important because an efficient technique can maximise throughput performance.

3.2.1 Issues in Gateway Selection Schemes

A gateway is a mobile device that has connectivity to the external networks, which significantly affects MANET performance. Congestion may occur when the number of packets being transmitted to the gateway exceeds a pre-set threshold queue size. Packet loss can severely degrade packet throughput performance. If only one gateway is available in a MANET, all packets will go through this gateway to the Internet. The queue size will quickly fill when all nodes in the network send packets to one gateway at the same time. Multiple gateways can help solve this problem. However, balancing the traffic load between gateways is the critical problem [25].

3.2.1.1 *Broadcast*

Based on the gateway literature discussed in 3.2, previous schemes have used the technique of sending a gateway broadcasting advertisement message to all nodes in the network seeking notification of the gateway coordinates. Gateways also sent advertisement message periodically. The intermediate nodes rebroadcast the message to neighbour nodes. This technique led to packet flooding in the network and increased the traffic load at each gateway.

3.2.1.2 *Uneven traffic load*

Gateway traffic load can be varied and uneven because of user demand. In the first situation, there are few user demands. In the second situation, there are very many users demands at the same time. Although multiple MANET gateways can be used, the possibility of uneven traffic load within gateways can exist if traffic distribution is not efficiently managed.

3.2.1.3 *Gateway failure*

If there is only one gateway between MANET nodes and the external network, the whole network is dependent on this single gateway. If the single gateway fails, the whole network will be disconnected from the external network. However, when multiple gateways are available in the network, if a single point is non-functional, nodes can still have access to the external network. Nodes in range of non-functional gateways must re-direct to other MANET gateways that are still available. The proposed scheme will focus on how to choose the gateway based on the circumstances of the network, how to provide stable load balancing within gateways and how to maintain high throughput in the network.

3.3 MANET Routing: A Review of Literature

Routing protocols are usually grouped into three classes: proactive, reactive and hybrid. Proactive protocols are table-driven protocols, in which routing information is always updated to all nodes in the network. This means it is easier for source nodes to find the path to the destination node to launch a complete route when all paths were set up in advance. This algorithm is stable and easy to apply in a static network topology. Routes can be quickly calculated locally. In disaster recovery areas, a node represents a person in the area. Each node is free to move randomly. To update all the routing information periodically for each node in the mobile environment is not efficient. This method increases network overhead caused by high channel usage. In addition, to extend battery life, sometimes a node in the network will join and leave the network. To keep refreshing the routing information in this high mobility environment with changeable network topology is not effective. The benefit of this technique is that it can reduce waiting time for each node. Examples of well-known proactive routing protocols that have been used are OLSR (Optimised Link State Routing Protocol) and DSDV (Destination-Sequenced Distance Vector). Table 3.1 summarises routing schemes in ad hoc networks.

AODV (Ad Hoc On-Demand Distance Vector Protocol) and DSR (Dynamic Source Routing) are reactive algorithms. In reactive algorithms, source and destination routes are created only upon request. This method differs from the proactive method and can reduce network overhead. However, because the route is established only on-demand, the waiting time of nodes for route information is increased. This technique increases the total delay in the network. When a node wants to communicate with another node, two components are involved: (1) route discovery, to find a specific destination node location, and (2) route maintenance, to be able to manage route failure. One method for finding a destination node involves flooding the message to the entire network. This method can work well when there is a low volume of traffic. However, if the volume of traffic is high and each node in the network wants to send a message, the network will collapse because of congestion, which leads to packet loss. In disaster recovery areas, the advantage of using a reactive protocol is that it enables energy saving during communication. Because there is no constant updating of table routing information, energy conservation can be improved.

The hybrid protocol uses a combination of advantages from proactive and reactive algorithms. This algorithm was created to minimise the weaknesses of the reactive and proactive approaches by using zone and cluster routing. Hybrid approaches are suitable in a very wide range. In other situations, reactive or table-driven approaches are suitable.

AODV is one of the reactive routing schemes that are used in MANETs [26]. This scheme practices hop counting to determine the shortest path from sender to receiver. It is a trusted, simple and effective metric. Even though routing overhead can be reduced, the main problem is packet delay because nodes must wait for the route connections to be established from sender to receiver. Routes are only set up upon request. This type of routing may be right for a disaster scenario in which there are no obstacles in the path [27]. However, with no updated information, communication may be lost if nodes suddenly disappear from the network. When the nodes in the network are fast and mobile, this can bring more problems [28].

This section will focus on previous MANET routing schemes. Much of the literature since the late 1990s has proposed new routing protocols to overcome the problems of routing selection schemes, such as packet broadcasting to the whole network, multiple routes from source to destination node, node mobility and network overhead.

In 1997, routing protocols ABR [29] and TORA[30] were developed to increase route stability and recover link failures in MANETs. ABR increased route stability in route selection to avoid frequent route restarts. This routing approach was a loop free protocol. A year earlier, WRP [31] was presented, based on a pathfinding algorithm, to reduce looping in routing. This protocol distributed frequent routing update packets to maintain routing tables. Chiang et.al [32] introduced a cluster-based method called Least Cluster Change(LCC). Nodes aggregated into clusters were controlled by a cluster head. Clustering aimed to solve problems in large-scale MANETs. Different types of clustering schemes had different objectives, such as power awareness, cost and connectivity. Numerous main issues focused on serving fairness to the cluster heads. Based on schemes that cluster heads are capable of handling the network and maintaining fairness, it may not suitable for all scenarios [33]. The clustering method OD-PFS [34] used a combination of hierarchical and virtual backbone routing. Network topology was mapped onto the virtual grid topology, then nodes were divided by cluster. Each cluster had their own cluster head. The cluster head kept the links in the neighbourhood alive.

In a study of network topology, Chen et.al [35] maintained a global knowledge of network topology, containing the neighbours list, next hop and distance. The next hop table contained a list of the next hop neighbours. Several studies in 1999, [26], [36], [37] and [38], suggested improvements on broadcast methods. The AODV routing protocol aimed to reduce packet flooding throughout the network by introducing route information on demand rather than keeping route information updated. However, LBAQ, presented in 2007, still implemented flooding techniques by using unique source-sequenced labels (SSLs) to flood route request messages (RREQs) within the network. Destination nodes were required to answer once they received the messages. Relay Sequenced Label only replied to unique RREP messages with SSL to avoid path loops before the source forwarded the packet using the path.

The ROAM and STAR schemes used an on-demand routing algorithm with an improved topology broadcast protocol. Routes were established and maintained using diffusion computations to prevent routers from sending irrelevant packet requests to unreachable destinations. Each node had information about a favoured link to the possible destination. FORP [39] schemes used a multi-hop handoff mechanism, in which mobility prediction information was used to assume topological changes. RDMAR [40] proposed a route discovery and route maintenance improvement with a loop free routing protocol to minimise reaction in the case of topological network change.

In the 2000s, continuous routing methods were suggested. LANMAR [41] and FSR [42] used a fisheye method to minimise routing overhead. Each node recognised neighbours in the surrounding fisheye scope area. Yang et al. [43] combined the routing technique of FSR with Zone routing protocol. Packets were sent between the borders of the zone. Each node had routing table information for their own zone and an extended zone. ARA schemes [44] similarly aimed to reduce routing overhead. They adopted the behaviours of ants searching for food. The route discovery process used was the Ant technique, which involved flooding forward and backward messages. The DAR [45] routing technique used the same approach, based on Ant behaviour, to reduce computation complexity. The next hop was decided based on weight value. To find a new path, Ant forwarded. The route was chosen based on the highest probability of the next hop. ANSI [46] used Swarm Intelligence for routing selection. This method was also adapted from the Ant routing technique and maintained multiple routes to the destination. Route discovery used a technique to find multiple routes, typically as a backup if a route was broken or failed. Some of the routing schemes showed that routing overhead can be decreased when a node has an alternative path to send a packet to the destination node. Until 2009, researchers still applied the Ant technique in studies. Wang et al. highlighted that the routing method HOPNET [47] was based on ZRP, DSR and the combination of Ant Colony Optimisation. This technique is based on a picture of ant hopping at each zone. Forward ants will collect information about the destination node based on routing table information they receive from local nodes. Then, ants move from one zone to another zone via border nodes. In the late 2000s, Reddy and Raghavan [48] improved network overhead by proposing a multipath routing protocol with one path as the primary route. The regular primary path was set as the shortest path. Each node was allowed to receive multiple copies of the route request packet but not allowed to reply to the source node, to reduce the network overhead.

AQOR [49] used limited flooding in route discovery. Route requests included bandwidth and end-to-end delay constraints. This technique rebroadcast messages to the next hop if satisfied with the constraints. SLR [50] introduced a bypass routing technique to improve the route discovery process in the case of broken links. It initiated a local recovery procedure to bypass the broken link. Yu et al. [51] were also interested in replacing broken routes. They proposed a technique to intelligently change the damaged routes. Intermediate nodes that overheard the transmission between the source and destination node were potential candidates for replacing a failed node. DDR [52] is used today as a backup because of its high cost. The connection is established only when needed and turned off automatically when there is no information to be sent. Many researchers have utilised AODV routing protocols, such as GRP [53]. Source nodes broadcast a destination query packet until the packet arrives at the destination node. Some schemes used for source routing do not rely on a routing table [54]. DBR2P [55] uses no routing table. Source node receive complete information on routes from the destination node. Multiple backup routes, also set by destination nodes aided by intermediate nodes, are used in the event of a link failure. After almost ten years, routing failure connection is still a concern in many studies. SCaTR [56] proposed a solution: if the route to a destination was not available, a *proxy request* was forwarded. Each node advertised itself as the proxy destination when a *proxy request* message was closer to the destination node. *Advertisement* suggests a route to the destination and *solicitation* asks for information to the destination [57]. For networks with asymmetric links, A4LP, [58], [59], introduced a limited packet forwarding technique. The receiver qualified a pre-set fitness value with the sender before rebroadcasting a packet.

To date, several studies have used a weight mechanism for route expiration time, error count and hop count. Similar to previous protocols, the source node initiates an RREQ message and destination nodes reply with RREP messages. If more than one RREQ message is received through a different path, the weight mechanism will evaluate the largest value to set as the primary route [60]. LBAQ [51] measured link quality based on node mobility in the network. The weight of the link chosen was based on link availability, link quality and energy consumption. LRHR [61] created several routes from the source to the destination. Each route had a value of edge weights. The value was higher when link reliability was better. QMRB [62] proposed a route selection scheme based on QoS for each pair of source and destination. The weight value for QoS was Static Resource Capacity, Dynamic Resource Availability, Neighbourhood Quality and Link Quality and Stability.

A number of techniques have been developed based on previous routing protocols. R-DSDV [63] is a randomised version of DSDV protocol. It used a routing probability distribution technique, in which nodes changed their parameters to the route that had a lighter load. OLSR [64] used Hello and multipoint relays to discover information about routes. When forwarding a packet, the source node did not know the complete route—it just had information about the next hop. Based on this scheme, HOLSR [65] introduced a hierarchical design with several ad hoc networks (clusters) within the network. Each cluster kept the information about routing and nodes in the cluster. QOLSR [66] proposed a multipoint relay selection, adding delay and bandwidth parameters to previous OLSR routing techniques using three heuristics—QOLSR1, QOLSR2 and QOLSR3. John et al. [67] carried out a bit difference method by introducing the weight of *hot* and *cold* in the forwarding strategy. Nodes closer to the destination were assumed to be hotter and responsible for rebroadcasting the RREQ message. Nodes with a *cold* value discarded the message. Beraldi et al. [68] used meta-information in forwarding packets by sending *hints* to the neighbourhood. Packets were discarded if the neighbour did not exist.

Table 3.1: Optimisation of MANET Routing Schemes

Routing Scheme	Shortest Path	Broad -cast	Multiple Routes	Route Repository in RP	Over -head	Disaster Scenario	Node Mobility
ABR [29]	Strongest Associativity	✓	-	✓	Medium	✗	✓
TORA [30]	✓	✓	✓	✓	High	✗	✗
SSBR [69]	Signal Strength	✓	-	✓	Medium	✗	✓
FORP [39]	-	✓	-	✓	Medium	✗	✓
AODV [26]	✓	✓	-	✓	High	✗	✗
ROAM [36]	✓	-	✓	✓	Low	✗	✗
DSR [54]	✓	✓	✓	-	High	✗	✓
ARA [44]	✓	✓	✓	✓	Medium	✗	✓
AQOR [49]	Link Bandwidth	✓	-	✓	Medium	✗	✓
DBR2P [55]	✓	-	-	-	-	✗	✓
RPR [67]	✓	✓		✓	High	✗	✗
GRP [53]	✓	✓	✓	-	High	✗	✓
SLR [50]	✓	-	✓	-	High	✗	✓
Beraldi [68]	-	✓	✓	-	High	✗	✓
LDR [57]	✓	-	-	✓	High	✗	✓
SMORT [48]	-	✓	-	-	-	✗	✓
Yu [70]	✓	-	-	-	-	✗	✓
LBAQ [51]	-	✓	✓	-	High	✗	✓
LSR [71]	-	-	✓	✓	High	✗	✓
SWORP [60]	-	-	-	✓	High	✗	✓
OD-PFS [72]	-	-	-	✓	Medium	✗	✓
DAR [45]	Weighted	-	✓	✓	Medium	✗	✗
QMRB [62]	-	-	-	✓	High	✗	✓
SCaTR [56]	-	-	✓	✓	High	✗	✓
DSDV [73]	✓	✓	-	✓	Low	✗	✗
WRP [31]	✓	-	-	✓	Low	✗	✗
CGSR [32]	✓	-	-	✓	Low	✗	✓
GSR [35]	✓	✓	-	✓	Low	✗	✓
STAR [37]	✓	-	-	✓	Low	✗	✓
R-DSDV [63]	✓	-	-	✓	Low	✗	✗
OLSR [64]	✓	-	-	✓	High	✗	✗
HOLSR [65]	✓	-	-	✓	High	✗	✓
QOLSR [66]	Periodic	-	-	✓	High	✗	✓
ZHLS [74]	✓	✓	✓	✓	Medium	✗	✓
DST [38]	Tree neighbour	-	✓	✓	Low	✗	✗
RDMAR [38]	✓	✓	-	✓	High	✗	✓
DDR [52]	Stable Routing	-	✓	✓	Low	✗	✗
LANMAR [41]	✓	-	-	✓	Medium	✗	✓
FSR [42]	Scope Range	-	-	✓	Low	✗	✓

Routing Scheme	Shortest Path	Broad -cast	Multiple Routes	Route Repository in RP	Over -head	Disaster Scenario	Node Mobility
SLURP [75]	InterZ / IntraZ	-	✓	-	High	×	×
ZRP [76]	✓	-	-	-	-	×	✓
ANSI [46]	✓	✓	✓	✓	Medium	×	✓
FZRP [43]	✓	-	-	✓	Medium	×	✓
A4LP [58] [59]	Power Consumed	✓	✓	✓	Medium	×	✓
HOPNET [47]	✓	-	-	✓	High	×	✓
AOMDV [77]	-	✓	✓	✓	-	×	✓
BATMAN [78]	✓	✓	-	-	Medium	×	×
BCHP [79]	-	✓	-	✓	-	✓	✓
DYMO [80]	✓	-	✓	✓	High	×	✓

Routing is a challenging problem in mobile wireless networks. The objective of routing is to determine the best path for the packet to travel. A standard algorithm measuring routing parameters involves distance, bandwidth, delay and load for a path [2]. Routing consists of a routing protocol or scheme and routing algorithm. The task of a routing scheme is to exchange the information of topology and link weights. A routing algorithm calculates the distance between the nodes. The standard algorithm used to compute the shortest path is Dijkstra and Belman-Ford’s [81].

A number of routing schemes have been developed by researchers to find the best alternative solutions in routing. Ad hoc routing schemes can be divided into three categories (see Figure 3.1). The first category is proactive, which is based on a routing table. A routing table is a set of rules in a table that is used to determine where a data packet travels in the network. This is also known as table-driven. Table-driven will keep nodes updated with routing information, regardless of when and how often such routes are wanted. Routing information is stored in the routing table of each node in the network. Keeping a routing table up to date will lead to communication overhead.

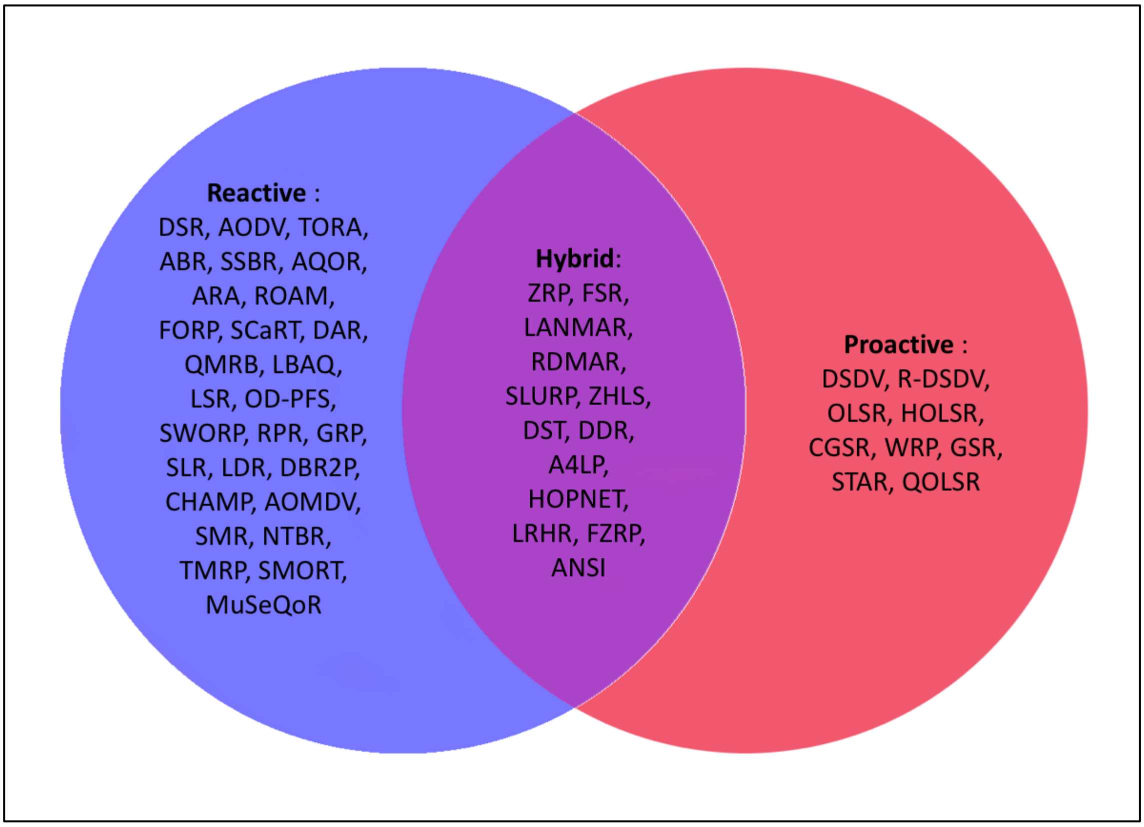


Figure 3.1: Routing schemes in MANETs

The second category is reactive. Reactive is routing on demand, which means the information of a route from the sender to the receiver will only be provided when requested. Some reactive routings have achieved the main goal of routing: to reduce the network traffic overhead. However, route discovery procedures that consist of flooding the network via a broadcast technique, such as AODV, TORA, and DSR, are not efficient.

The third category is Hybrid. Hybrid routing combines the advantages of reactive and proactive protocols. In addition, this routing scheme identifies a zone to minimise the number of packets flooding a MANET when it is broadcast [82]. By combining these two elements, the overall performance is improved.

Generally, routing schemes in MANETs emphasise the shortest route from sender to receiver as the best solution for the success ratio in a network. However, they forget to guarantee QoS. The goal of QoS routing schemes is to determine one or more paths from a source to a destination with a bandwidth requirement that is less than the total bandwidth available. Connections require sufficient bandwidth for transmission. Bandwidth is one of the critical issues, especially in real-time applications [83]. Examples of real-time applications are video conference applications, Voice over Internet Protocol, online gaming and some e-commerce transactions.

These applications require functions to be implemented over a period of time. Response time must less than the maximum time given (usually measured in seconds). [83] proposed a multipath QoS multicast routing protocol in a MANET. This protocol aimed to meet the needs of QoS and bandwidth requirements while sending data for real-time applications.

One of the well-known algorithms is Ant routing. [81] focused on analysing the performances of Ant routing in MANETs. Simulations were done in two case studies: first, on the static network, and second, on dynamic network topologies. The performance results of AODV and DSR were compared. The Ant routing algorithm performs well in static network topologies. However, because of limited capacity and restrictions on the buffer size, it does not perform well in dynamic topologies. [84] proposed a dynamic selection path method that was dependent on node and obstacle density. The author was also concerned about the possibility of destination selection based on a number of nodes that select the same destination and node distance.

As shown in Table 3.1, routing schemes have been distinguished according to several categories, for example, broadcast technique, route metric used between source and destination in single or multiple routes, route depository in the routing table or route cache and level of communication complexity. This table is a review of previous works that study methods for enhancing existing routing techniques.

3.3.1 Issues in Routing Schemes

A major problem with routing schemes [85] in MANETs is that nodes have to perform route discovery to find selected gateways to connect with the external network. Nodes in disaster areas can be static or mobile. Some mobile nodes are unreliable because devices are connected and disconnected because of limited battery power. In addition, based on the literature discussed in 3.3, some routes fail after several transmissions. This shows that the scheme might have a problem if it involves constant packet retransmission. To perform route discovery in the network, nodes broadcast a route request and destination nodes respond with the route in reply messages sent to nodes in the network. As a result, the network is flooded by broadcast messages. This issue decreases the performance of MANETs. One of main network elements is to have congestion control to ensure the stability and reliability of the network.

3.3.1.1 *Network congestion*

Victims in a disaster recovery area attempt to connect to the Internet, which will cause an elevation in the level of data traffic flowing into the same gateway. Congestion of networks occurs when many mobile devices connect to the network at the same time. Allowing a certain amount of data at each time for each gateway will help to reduce network congestion. Therefore, without an efficient routing selection scheme, congestion at each gateway cannot be improved.

3.3.1.2 Complexity of route selection.

To send a packet to the gateway through the multi-hop node, traditional AODV routing protocols perform a broadcasting algorithm for route discovery. This technique broadcasts a packet to all nodes in the network, which leads to network flooding and complexity of routing selection. The difficult process of route selection delays a packet's arrival at the destination. This thesis will introduce an efficient routing selection scheme to reduce delay in MANET performance. This scheme will simplify the route selection process to increase network performance.

3.4 Node Mobility in Disaster Recovery Scenarios

A MANET is a group of mobile devices that can be formed without any infrastructure. A mobility model was chosen in the simulation because it defines the behaviour of the nodes. In a disaster scenario, the nodes in the network can be highly mobile because of panic reactions and attempts to escape from the disaster area. Because the nodes are highly mobile, there is a possibility that the destination node will suddenly leave the coverage range. In the Great East Japan Earthquake, K. Suto et al. [86] predictable that victims walking around during postdisaster situation to discover good wireless access. Therefore in MANET, mobile devices that often work as both hosts and relay need to cater distruptions and changes of network topology because end-to-end connectivity depends on nodes position and mobility [87]. Based on the high mobility, proposed scheme designed have to deal with circumstances in which the network environment is dynamically changed [88].

3.4.1 Topology Rapidly Changes

Disasters can bring about a loss of power so that nodes in the network should efficiently use mobile devices only when needed. Network topology is changed when nodes in the network join and leave the network. Some of the nodes are not static. They change their location randomly at different velocities in the disaster area. Node motion, node failure, nodes being switched off and node speed make it difficult to maintain communication in disaster recovery areas [85]. These issues can lead to highly dynamic networks, which directly affects the performance of MANETs.

3.4.2 Obstacles

In AODV routing schemes, each node waits for a signal before communication between two nodes is started. Nodes send request messages to open communication. After the initial communication of two nodes, the information is kept in the routing table. However, problems arise when destination nodes are affected or there are obstacles after disaster strikes. Messages then cannot arrive at the destination [27]. DSDV routing schemes always update routing table information in the network. If the destination node suddenly cannot be reached because of obstacles or other barriers, a node will quickly find another way and constantly update the information in the routing table. This scheme provides an information table for each node in the network that contains information about the number of hops to the destination and sequence numbers to the destination node. Continuously updating complete routing information that includes information about nodes that might not communicate may increase packet in the network and lead to packet delay and packet loss. Hence, this practice is not suitable for disaster recovery situations.

3.5 Summary

In this chapter, a review of the literature was presented. The issues in gateway, routing, and node mobility in the disaster recovery area were identified. Section 3.2 discussed three main issues of gateways selection schemes. These issues are required to be solved to reduce the congestion at the gateway. The proposed scheme to solve these problems will be discussed in Chapter 4 while section 3.3 presented issues related to routing selection scheme. Both issues are required to solve because it related to MANET performances. In addition, section 3.4 focussed on the effects of nodes mobility in the disaster area. The topology rapidly changes, and the problems arise when there are obstacles nearby the nodes. Therefore, in Chapter 4, 5 and 6, the main contributions of this thesis are presented.

Chapter 4

MANET Gateway Selection Schemes

4.1 Introduction

A MANET is a group of mobile nodes (MNs) in which communications are performed through multi-hop routing using a multi-hop wireless link. By forwarding packets to neighbours, each node plays an important role as a user and as a relay. The advantage of a MANET is that it can be created without any support from existing infrastructure. It can rapidly form and reform without centralised management. Therefore, MANETs are suitable solutions for communication problems after a disaster occurs.

In disaster areas, the environment commonly includes collapsed buildings and damaged communication infrastructures. Natural disasters, such as earthquakes, tsunamis and typhoons, occur frequently worldwide and cause the destruction of a large amount of communication equipment, for example, base stations and wireless routers. It is extremely expensive and time consuming to replace or repair major installations, such as cell towers or fibre-optic cables. To keep communications alive in a disaster recovery area, MANET features and advantages are very feasible. However, victims seeking to contact family and friends cause a high level of data traffic, which leads to network congestion.

To allow communication between MANET nodes and the external network, a gateway is required to enable the entry and exit of packets from the network. This gateway is the IG, which will route all packets to and from the Internet. A gateway is also a node in MANET networks. The main task of a gateway is to control network traffic between two or more different networks. One network can have more than one gateway. As shown in Figure 4.1, each gateway has an average queue size to monitor. Congestion may occur when the number of packets being transmitted to the gateway exceeds the pre-set threshold queue size. How MNs choose a gateway has been a problem in recent years because it affects the network throughput performance.

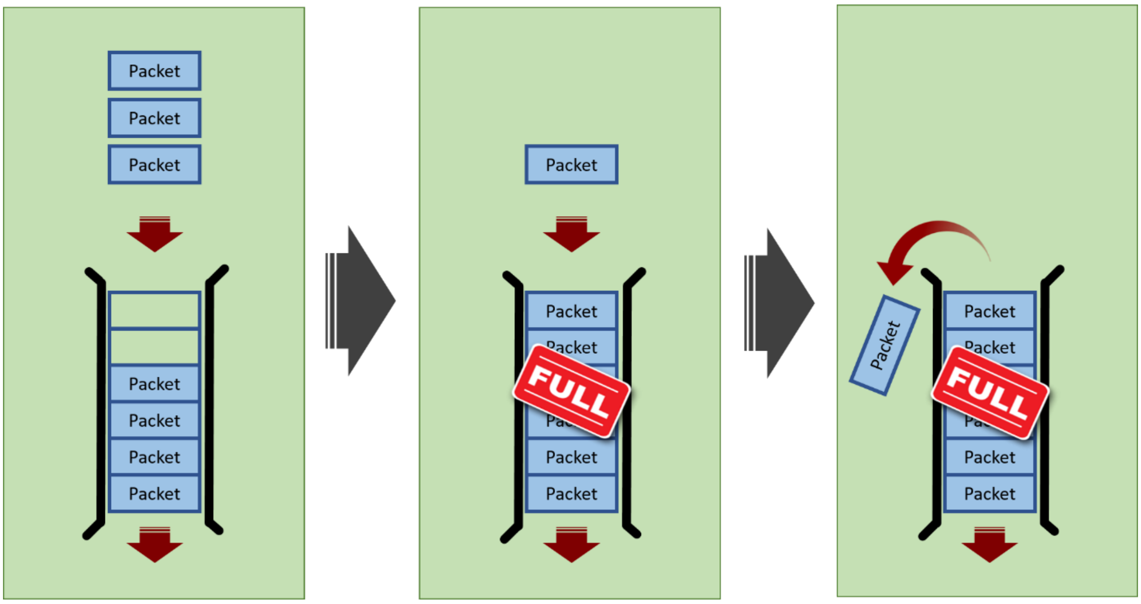


Figure 4.1: Buffer packet queuing when full

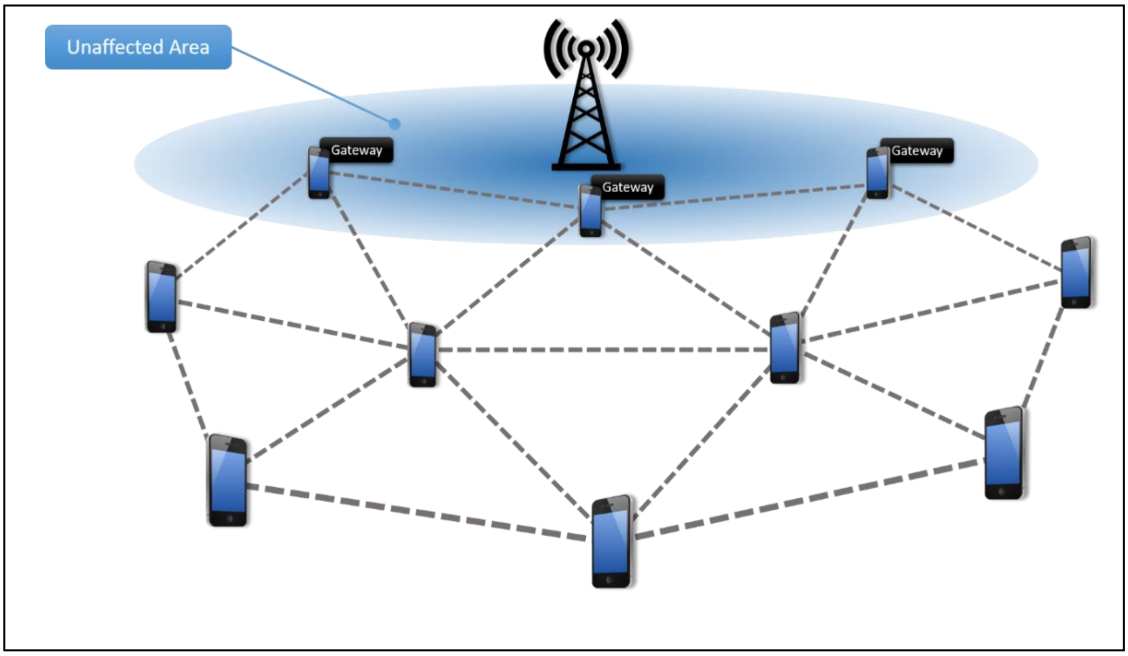


Figure 4.2: Three MANET nodes as a gateway

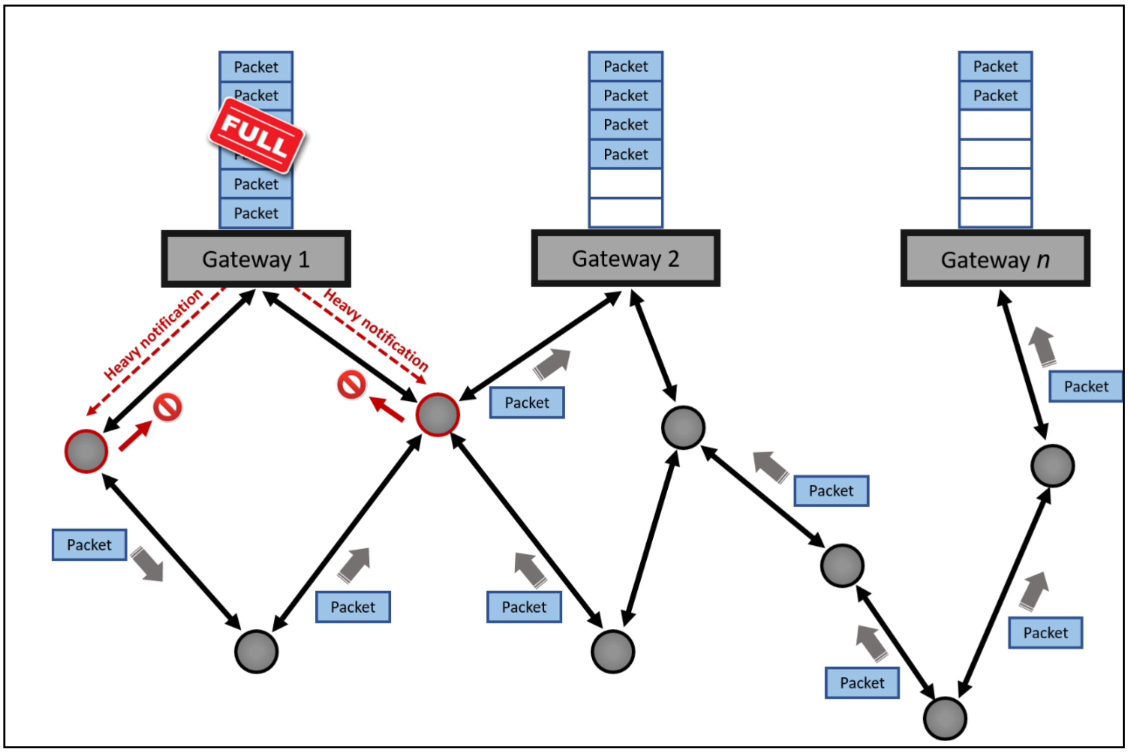


Figure 4.3: Gateway selection scheme

In a traditional wireless network algorithm, as shown in Figure 4.3, MNs will send a data packet to the nearest gateway, regardless of the heavy traffic load [1]. Bottleneck queuing at gateways leads to congestion and packet loss [2]. Unbalanced traffic distribution among MANET gateways causes network performance degradation. This study aims to introduce an enhancement of gateway selection schemes in disaster recovery areas to maintain the throughput performance in MANETs. The main contribution of this research is to optimise the throughput in MANET performance by developing a gateway selection scheme that considers node mobility.

4.2 Proposed Gateway Selection Scheme

To maintain communications, MANET characteristics are significantly helpful after disasters. Figure 4.2 shows an example of MANET infrastructure in a disaster recovery area. Some nodes in the MANET are configured as gateways. These gateways will be a relay for other nodes in the MANET to connect to the Internet. These gateways are chosen because the nodes have wireless coverage. If a node in a MANET wants to send a packet to the Internet and that node is not in a gateway range, the neighbour's node will forward the packet to the upper level route using the proposed routing selection scheme, discussed in Chapter 5. In this study, electricity and power are assumed to be undamaged or to have a backup. The security of the nodes is outside the scope of this research.

In a disaster recovery area, when a MANET is set up to recover communications, the heavy load of data traffic, as victims seek to contact family and friends, cannot be avoided. Nodes in the MANET send packets to the nearest gateway, regardless of the gateway load. A bottleneck at one gateway occurs when many nodes send packets to the same gateway at the same time. To overcome the problem of uneven traffic loads at different gateways, this thesis proposes a gateway selection scheme to manage load balancing between gateways, to optimise throughput in MANET performance. Figure 4.4 shows the network communication layer between MANET nodes, gateways and external nodes, such as the Internet host. A gateway is a mobile node in the disaster area, but this node also receives coverage from an external network, such as the Internet. To allow communication between the internal and external network, a gateway node should have two network interfaces, which consist of the proposed GWRS at layer three build in MNs protocol. This thesis focuses on the proposed scheme for MANET and performance evaluation through simulations.

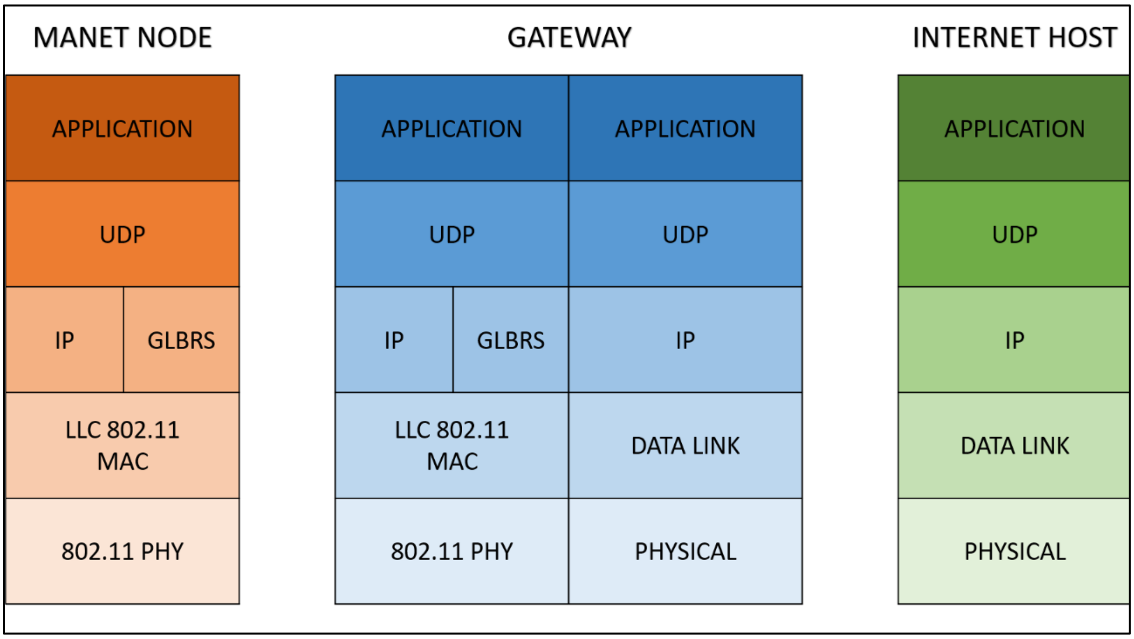


Figure 4.4: Network communication layers

The proposed scheme was as follows:

Step 1: Only neighbours of the gateway (nodes within gateway range) received an advertisement and notification. This technique aimed to prevent packet flooding in the network. The selected nodes that received the advertisement stored the information about the nearest gateway.

Step 2: If neighbours received a notification of heavy load from one of the gateways, that gateway was no longer able to receive packets at for a certain time. The node sent the packet to other gateways in range. The notification of heavy load from a gateway aimed to effectively reduce packet loss and eliminate congestion in MANET gateways.

Step 3: If the gateway was out of range, the node sent the packet to the upper level node within node range (based on our routing selection scheme). A neighbour node in the MANET forwarded the packet until the packet reached the gateway. This method aimed to significantly reduce the complexity of the routing selection scheme and consequently reduce packet delay.

Step 4: The mobility of nodes was considered because nodes in a MANET move randomly and can connect wirelessly. Because nodes are mobile, mobility has a significant effect on MANET performance.

Step 5: The MANET performance of the proposed gateway selection scheme was determined through observation of packet loss, packet delay, average throughput and network overhead.

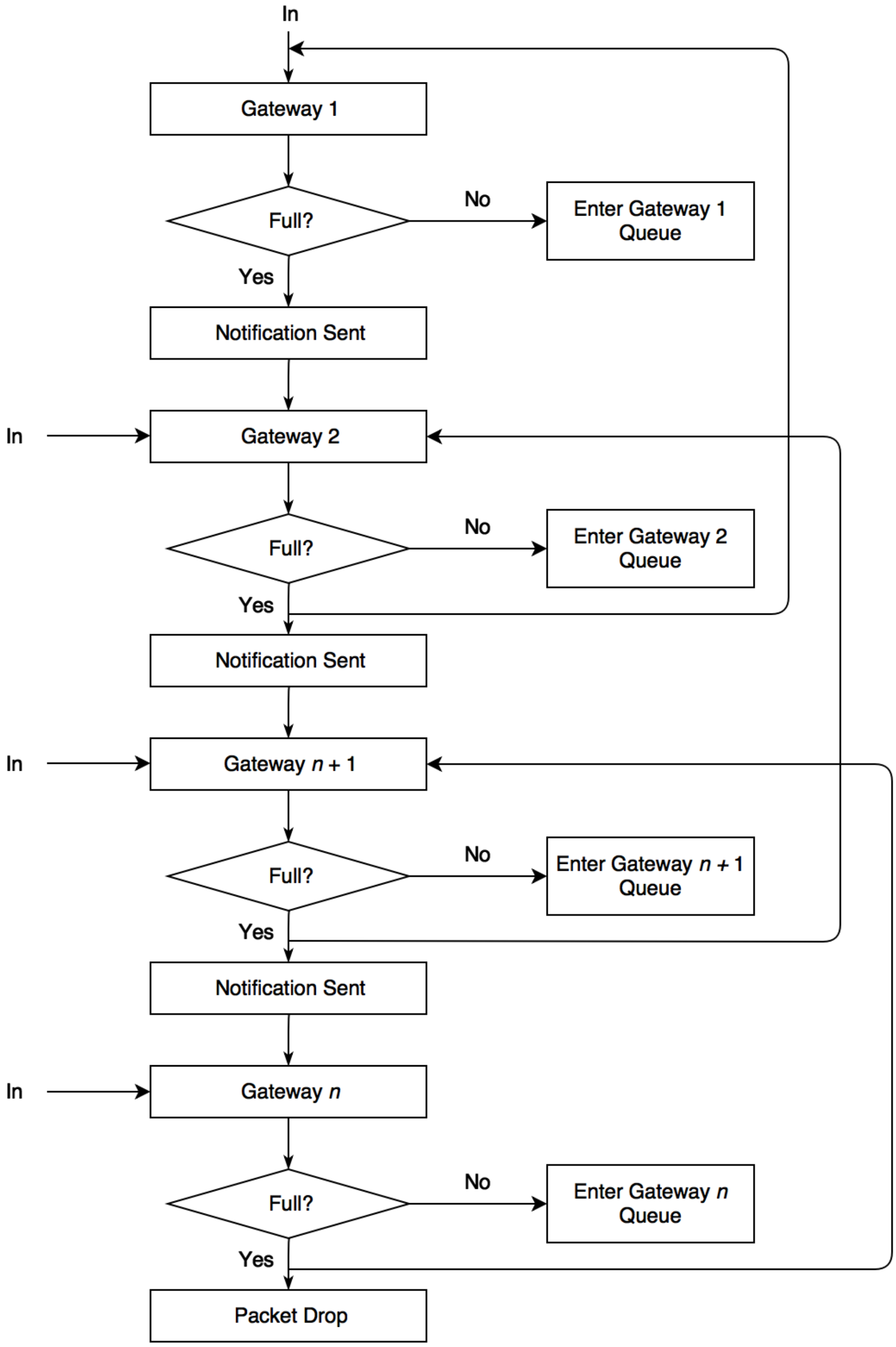


Figure 4.5: Flowchart for the proposed gateway load balancing scheme

In this study, all nodes in the MANET network were isolated, except three nodes that were in Internet range. As shown in the flow chart (Figure 4.5), other nodes that wanted to communicate with nodes outside the MANET network had to go through these three nodes. These nodes were a gateway for the MANET network. Only the gateway broadcast an advertisement to the nearest node in their coverage range. Nodes that received the advertisement kept the information about all gateways. When the nodes received a heavy notification from one of the gateways, the message was not sent to that gateway. The message was forwarded to other gateways that were available. Each gateway had an average queue size to monitor. If the queue size was approaching full, a heavy notification was sent to nodes in gateway coverage range.

4.3 Simulation Environment and Parameters

The proposed gateway scheme was simulated using a network simulation tool. To evaluate the performance, results were obtained from each gateway. The results are presented, following the explanation of our simulation setup. The simulation environment of the disaster recovery area was set up using the simulation tool OMNET++. There were two scenarios that were set up in this simulation.

4.3.1 Scenario 1

The first scenario used most general environment parameter. The environment area was set as 1200 m x 800 m, with 100 MNs distributed in the area. In MANET, MNs are interconnected by multi hop communication paths or radio links, which each mobile node can move randomly at any speed in any direction. This simulation used IEEE 802.11b (2.4 GHz) and the transmission range of each node was set to 250 m. The free-space is the default propagation model of Inetmanet framework of OMNET++. This simulation used a free-space propagation model as it is for the large-scale category such as disaster recovery area. Despite this model assume an obstacle-free area, we have considered parameter of nodes velocity and nodes pause time to mimic the movement of victims in the disaster recovery area. Using a random waypoint model, mobility speeds were fixed at 2 Mbps and the data rate was 2 Mbps. In traffic type selection for the disaster area scenario, CBR (Constant Bit Rate) traffic is widely used in modelling the data traffic in simulation. Although people encouraged to use text messaging to help reduce network congestion, in certain situation with today's smartphone technology, people intend to share video to show what real situation is happen in disaster area to their family and friends. Therefore, this research used CBR traffic in the simulation to observe the characteristics of real-time voice application which is more challenging to support in the disaster situation. Non-CBR traffic such as text message are not considered as it is comparatively easier to support.

Table 4.1: Scenario 1 Simulation Parameter

Parameter	Value
Simulation area (m^2)	1200 x 800
Simulation time (s)	900
Mobility model	Random waypoint
Mobile node placement	Random
Pause time (s)	0–2
Gateway	3
Traffic Type	CBR
Wireless MAC Interface	IEEE 802.11b
Radio propagation model	Free-space model
Packet Size	512 bytes
Node speed (Mbps)	2
Transmission range (m)	250
Number of nodes	100

In this simulation, node 8, 15 and 49 were configured as gateways. These three nodes were assumed to have wireless Internet coverage. Therefore, these nodes were gateways for all MANET nodes without Internet coverage. The simulation time was fixed at 900 s. The destination of all MNs in the disaster recovery area is a gateway. Gateways first initialised current positions and then determined who their neighbour was. Nodes at each level then determined their neighbour to discover the shortest route to the gateway. The simulation environment is summarised in Table 4.1.

4.3.2 Scenario 2

The simulation of scenario 1 was expanded to represent the environment of a disaster scenario that happened in the real world. The second simulation created a scenario of the disaster area in Loja City, Ecuador [27]. The same simulation tools were used, and the environment area was set as 1000 m x 2000 m. As shown in Table 4.2, some of the parameters were reformed to show the different results when the density of MNs and number of gateways were increased in the disaster area. Other parameters remained the same.

Table 4.2: Additional Simulation Parameter

Parameter	Value
Simulation area (m^2)	1,000 × 2000
Number of nodes	50, 97, 100, 120, 160, 200
Number of Gateway	1, 3, 6, 10, 15, 20
Nodes speed (mps)	Uniform (0 – 2)

Based on the area of Loja City, as presented in Figures 4.6 and 4.7, the densities of nodes in the simulation area were approximately 97, 100, 120 and 160. The number of nodes was also set from the minimum of 50 and the maximum of 200 for this simulation. In the first scenario, the number of gateway set was only 3, and there were 100 MNs. In the second scenario, the number of gateways increased from a minimum of 1 to a maximum of 20. The number of gateways in each simulation was varied to understand the connection between density of nodes and number of gateways. This scenario also took into account the mobility of nodes in the simulation area. Details of the mobility of nodes is described in Chapter 6.

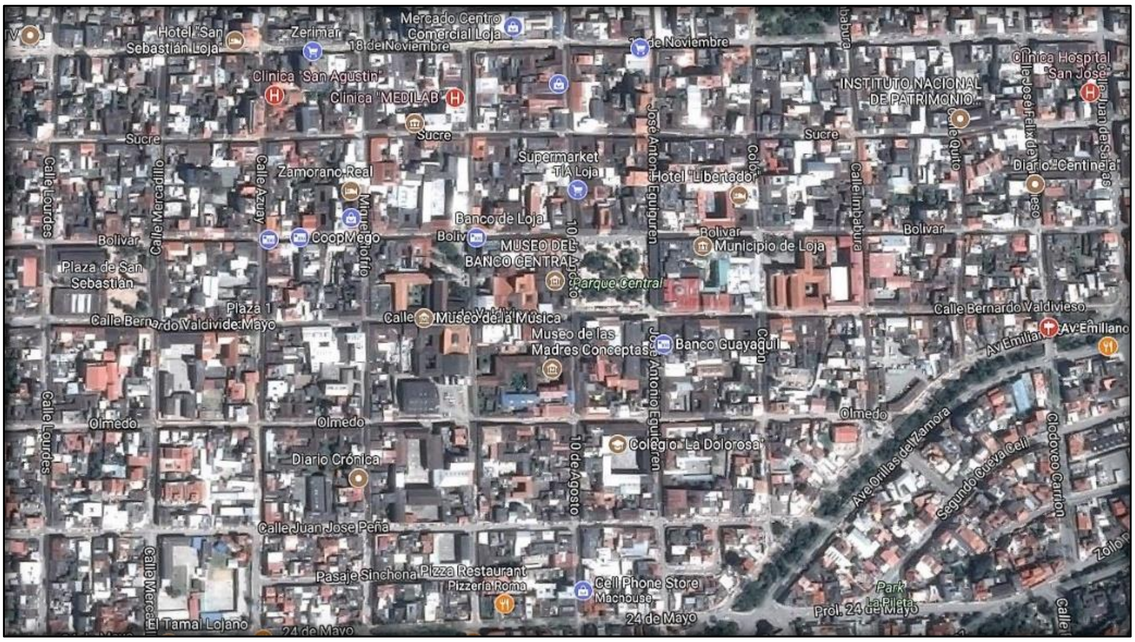


Figure 4.6: Loja City on Google maps

Figure 4.7: Loja City map segment [27]

4.4 Modelling the Network

In the simulation, the network area of Loja City was adopted as the OMNET++ simulation area. Figures 4.8 and 4.9 show the Omnet++ representation of the minimum density of people in the disaster area. The minimum number of mobile nodes in this simulation was defined as 50 nodes. Figures 4.10 and 4.11 show the Omnet++ representation of the maximum density of people in the disaster area. The maximum number of mobile nodes in this simulation was defined as 200 nodes. Each person in the simulation model was defined as one mobile device. The GWRS network (top left box) defined the behaviour of all nodes in the simulation model. Channel control defined the channel used and the parameter of signal transmission range for each node. The routing table recorder recorded the flow of the routing scheme, as described in detail in Chapter 5.

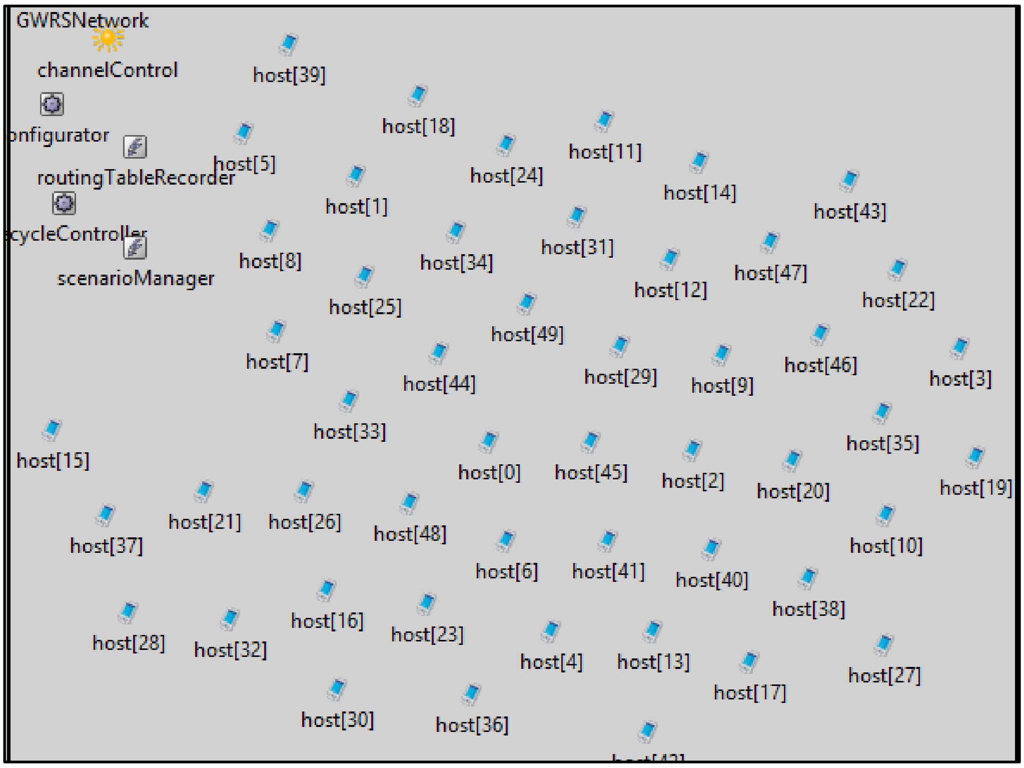


Figure 4.8: Omnet++ representation of minimum density in disaster area

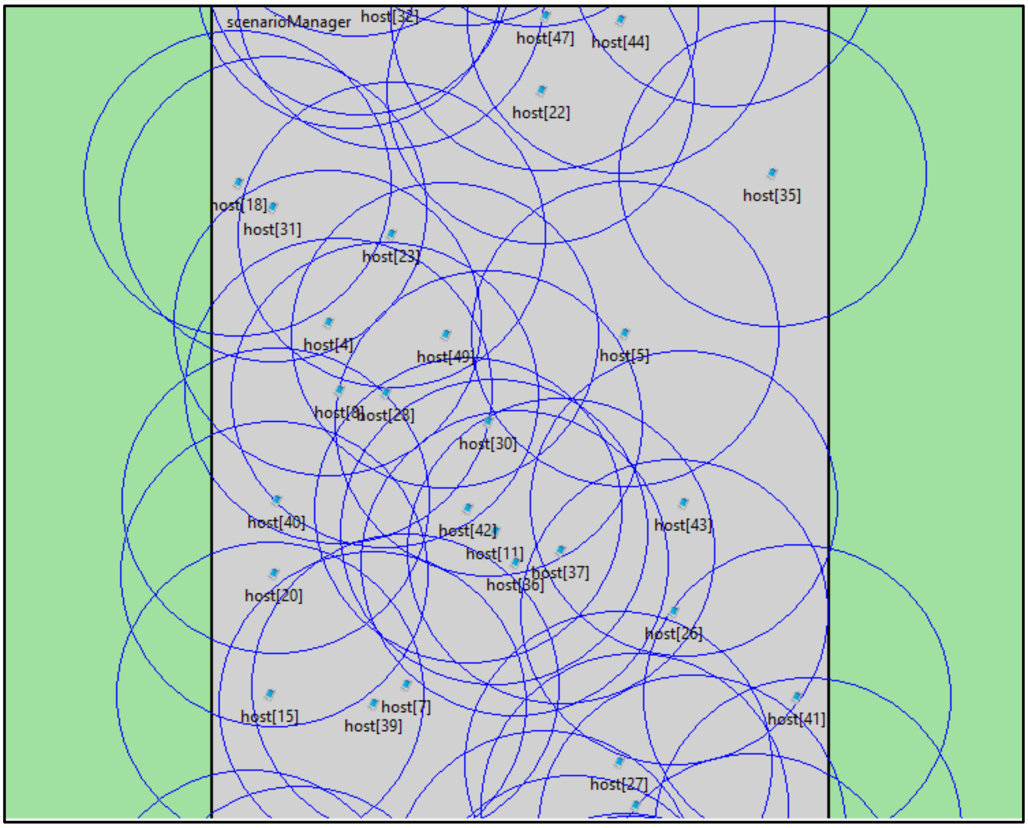


Figure 4.9: Omnet++ representation of minimum density nodes moving around

Figure 4.10: Omnet++ representation of maximum density in disaster area

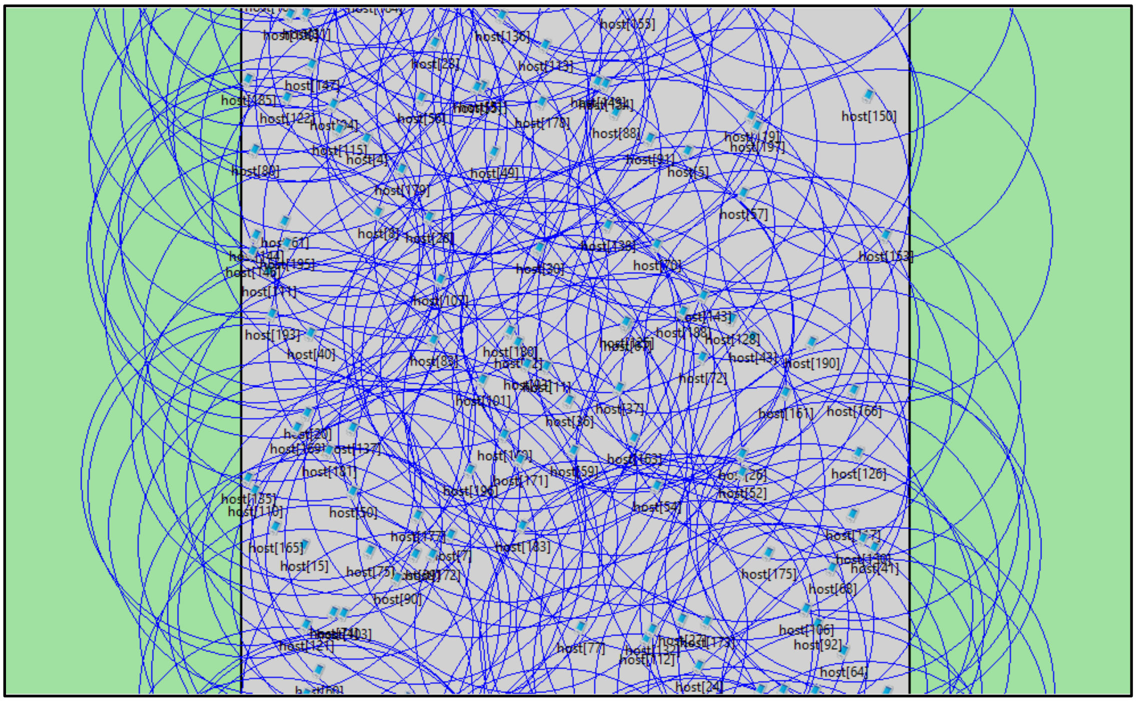


Figure 4.11: Omnet++ representation of maximum density nodes moving around

4.5 Results and Discussion of Scenario 1

In the scenario 1 simulation, load balance deviation between each gateway to measure the packet throughput in MANET performance was observed. The performance metric used to evaluate the results is given below.

4.5.1 Throughput

The proposed scheme results showed the respective throughput of Gateway 1, Gateway 2 and Gateway 3. Figure 4.12 shows almost perfect load balancing: the throughput of the three gateways was almost equal until the number of nodes increased to hundred. The largest throughput was at Gateway 2 when the number of nodes was 50. However, the throughput decreased slowly as the number of nodes increased.

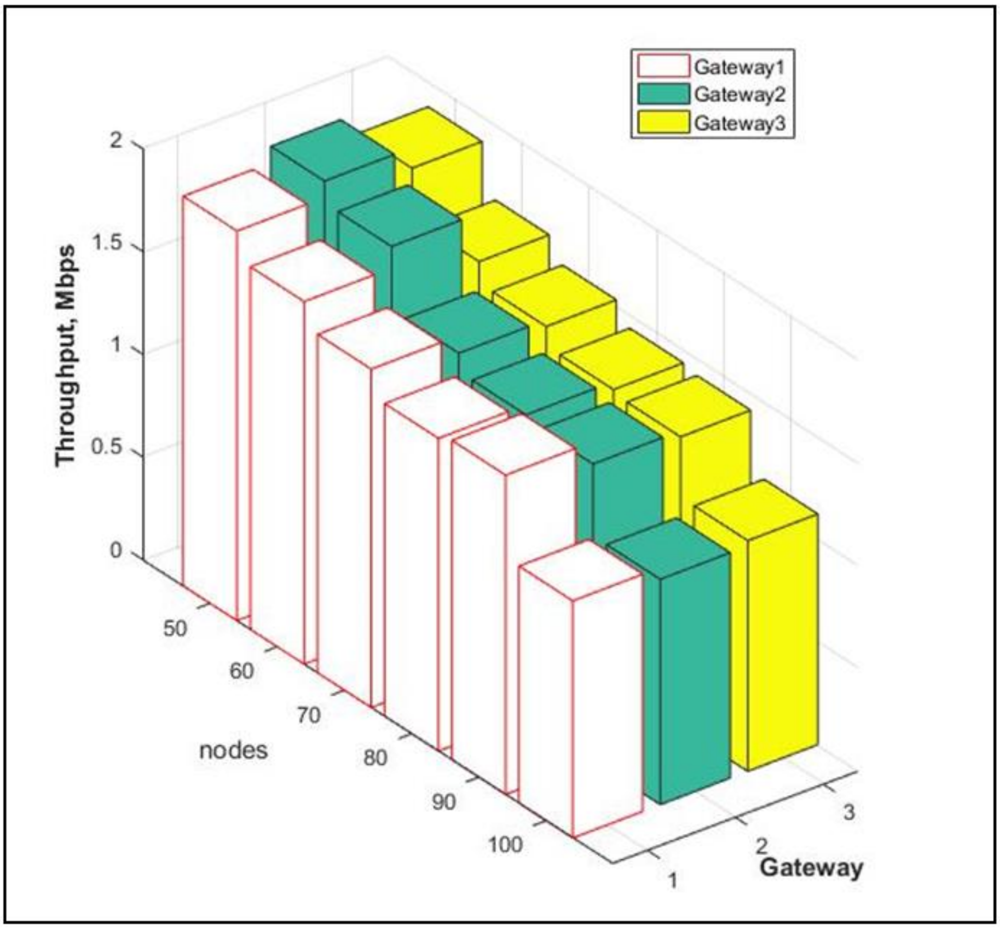


Figure 4.12: Throughput of three gateways for scenario 1

4.5.2 Packet Drop Ratio

The varied distribution of traffic loads at gateways affected the bottleneck that led to packet loss and packet delay. In Figure 4.13, zero packet loss can be seen up to the number of 60 nodes. In other words, using our proposed gateway selection scheme, the imbalance problem at each gateway was solved and the packet drop ratio was reduced. However, when the number of nodes reached 70, packet loss slightly increased. Nevertheless, the traffic distribution of our scheme still avoided traffic congestion.

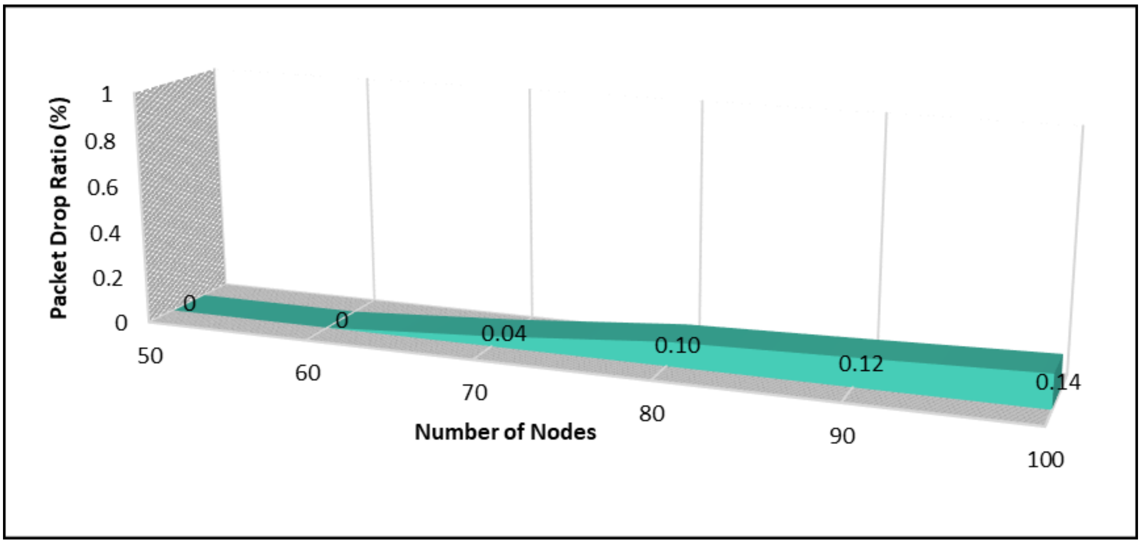


Figure 4.13: Packet drop ratio for scenario 1

4.5.3 Packet Delay

As shown in Figure 4.14, the research confirmed that the proposed gateway selection scheme achieved a lower packet delivery delay as the number of nodes increased. The packet delivery delay was still small. The overall MANET performance in this simulation shows the effectiveness of our scheme. The results of the scheme revealed that MANET performance was improved by the gateway selection scheme. Total throughput of the whole network, small packet loss and reduced packet delay clearly enhanced MANET performance. Each user in the disaster recovery area could still send messages, even with the higher traffic load. In addition, the results of this simulation efficiently delivered Internet connectivity to the people in the disaster area, in which there was a significantly high number of users.

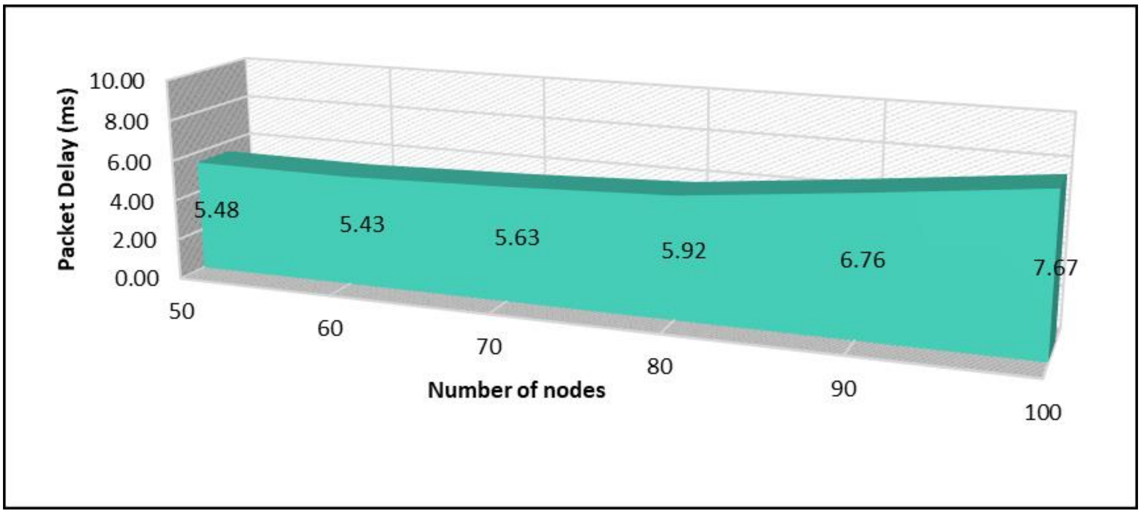


Figure 4.14: Packet delivery ratio for scenario 1

4.6 Results and Discussion of Scenario 2

An efficient gateway load balancing scheme leads to an improvement of MANET performances in disaster recovery. The gateway selection scheme by MNs in the simulation area leads to different outcomes in network throughput, packet delay, packet drop ratio and packet sent rate. Performance analysis can be confirmed by varying the number of gateways and the number of nodes. Other factors, such as node velocity and node pause time, also affect network performance. In disaster recovery, the communication network is essential. Therefore, an efficient gateway selection scheme is important to facilitate communication in the disaster recovery scenario.

4.6.1 Throughput

In this simulation, all MNs had access to IGs via neighbour nodes. The results in Figure 4.15 show different gateways gave different results because results depended on the load capacity of the gateway while it served the nodes. Fluctuation occurred when only one gateway node was available to serve user demand. This happened because as the number of MNs increased, all load was put on one gateway. When the number of gateways increased to three, results still fluctuated, but this was slightly reduced because the load was distributed between gateways. As the number of gateways increased, the performance showed a better throughput. However, as the node density increased, packet throughput reduced.

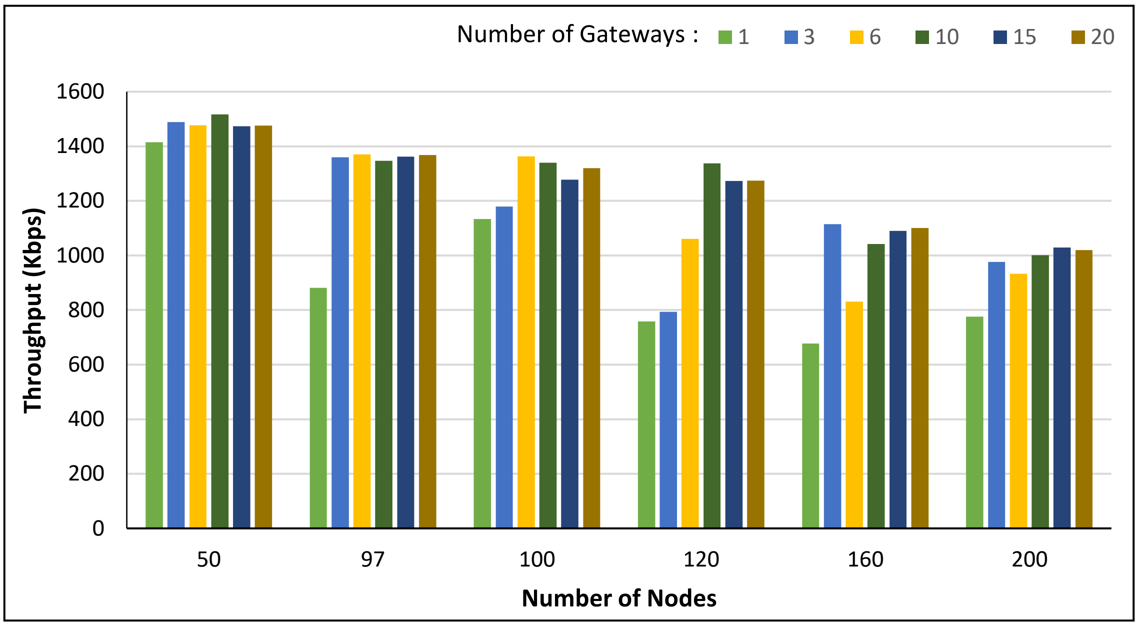


Figure 4.15: Gateway throughput versus number of nodes

4.6.2 Average Delay

Average delay is used to calculate the average time the packet data of all nodes in a MANET take to arrive at the final destination. It can be observed from Figure 4.16 that the load distribution between gateways 1, 15 and 20 was middling even as the number of nodes increased. However, for gateways 3, 6 and 10, the graph shows the average delay increased suddenly when the number of nodes reached 200. When there were 160 MNs, the network with 10 gateways indicated slightly higher compared to network with 1,3,6,15 and 20 gateways. Despite 1 gateway expressing the lowest delay from minimum to maximum number of nodes, this actually demonstrated the maximum service 1 gateway can serve.

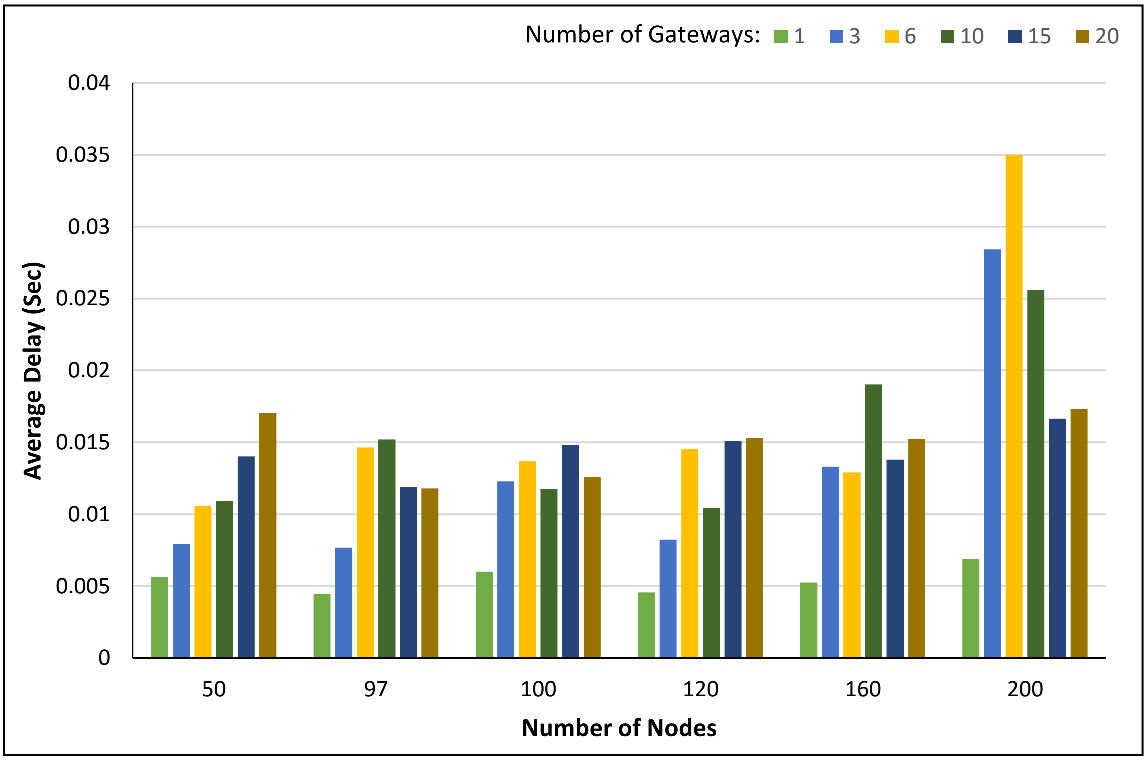


Figure 4.16: Average delay versus number of nodes

4.6.3 Packet Drop Ratio

From Figure 4.17, it can be seen that the single gateway set up in the network could not handle the flow of traffic to another network. The minimum packet drop was more than 60%, which is the highest packet drop recorded. What stands out from the graph is that the gateway selection scheme was not reliable for one gateway. A routing scheme must be employed to solve this problem. From the results, it can be seen that the proposed gateway selection scheme could manage the flow of traffic from the disaster recovery area when packet drop was not above 45% even for the maximum number of nodes, except in the case of 3 and 6 gateways when the number of MNs reached 120 and 200, respectively.

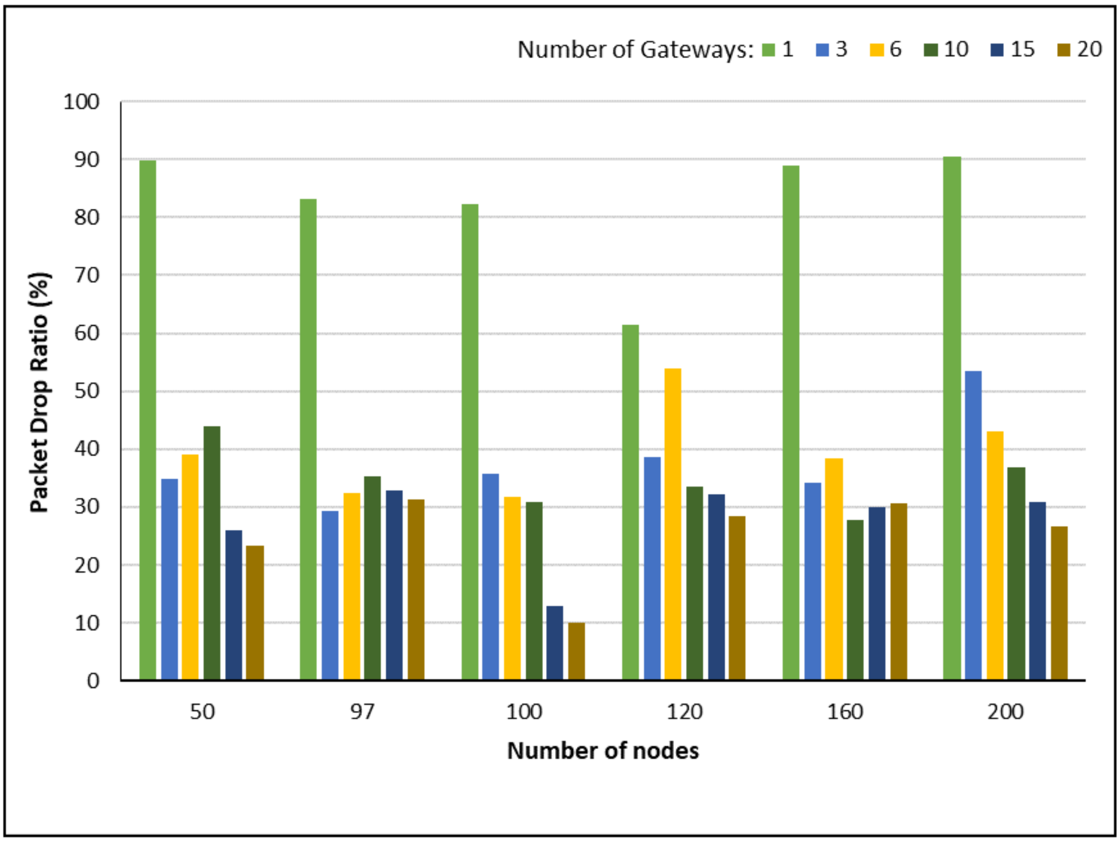


Figure 4.17: Packet drop ratio versus number of nodes

4.6.4 Packet Delivery Ratio

Further analysis, in Figure 4.18, showed the expected results of packet drop and packet delay performance: the single gateway had the lowest packet delivery ratio. When the proposed selection scheme was applied to gateways, packet delivery could be performed smoothly to any number of gateways. The ratio of packet delivery for 3 gateways reached more than 70%, while the highest was 90% for 20 gateways when it was built into the disaster recovery network. On average, packet delivery from the minimum to 200 MNs in the disaster area, with three gateways, reached 62%. It increased slightly to 65% for 10 gateways and 75% for 20 gateways. Based on the results, in ensuring higher packet delivery, it shows develop efficient gateway selection scheme is significant.

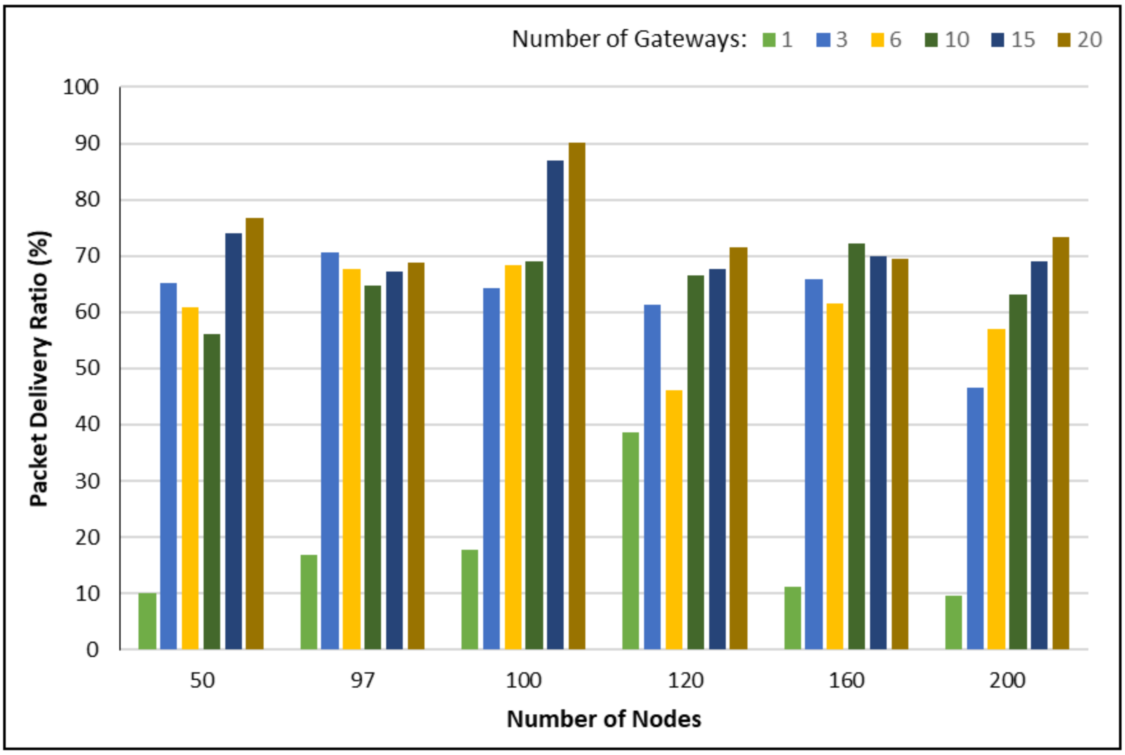


Figure 4.18: Packet delivery ratio versus number of nodes

4.6.5 Sent Packet Rate

From the graph below (Figure 4.19), it can be seen that the rate of sent packets per second increased gradually when the number of nodes was increased. A positive correlation was found between this result and packet delivery ratio. The graph shows that the proposed scheme successfully managed traffic flow with an increase in sent packet rate and packet delivery. Interestingly, when 3–20 gateways were built into the network and there was an increased number of MNs, and a corresponding increase in nodes wanting to send messages to the Internet, the proposed scheme still gave a higher performance on packet delivery. In the case of one gateway, the packet sent rate was high, even though there were only 50 MNs in the network, because all nodes focused on sending a packet to the only gateway. Therefore, there was a low result in performance in packet delivery for one gateway because all packets were congested at one exit route.

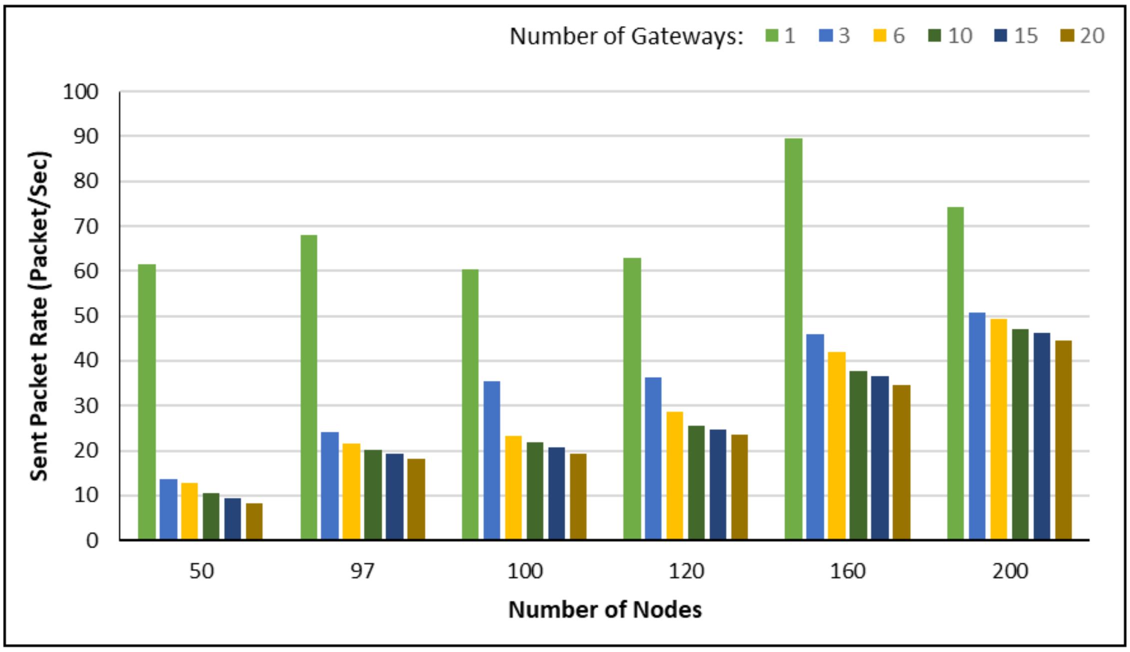


Figure 4.19: Sent packet rate versus number of nodes

Increased density of nodes in the area increased the sent packet rate. However, there remained a high output for the packet delivery ratio when the scheme in the network gateway could efficiently handle the traffic flow.

4.7 Summary

In this chapter, a gateway selection scheme was proposed to optimise the throughput for MANETs in disaster recovery areas. In a disaster recovery scenario, the communication infrastructure may break down, leading to a communication failure. Although MANETs can be deployed for applications such as disaster recovery, the network will become congested with a high level of data traffic because victims seek to contact family and friends. To connect to an external network, the nodes in a MANET send a packet to the nearest gateway, regardless of the gateway load. To overcome this issue, this thesis introduced a gateway selection scheme to manage traffic. This scheme can be used at gateways to equalise the task between all gateways. Our simulation results show the proposed scheme reduced network congestion and consequently improved throughput, packet delay and packet loss in MANET performance. Load efficiently distributed between gateways reveals that our proposed scheme can maximise packet throughput in MANETs. In addition, this technique can significantly reduce congestion at each gateway, consequently improving MANET performance by increasing the number of packet throughputs. Performance enhancement for the routing selection scheme using MANET in disaster recovery areas is further discussed in Chapter 5.

Chapter 5

MANET Routing Selection Scheme

5.1 Introduction

In Chapter 4, an efficient gateway selection scheme was presented to show how managing load balancing can enhance the performance of MANETs in disaster areas. This thesis will continue the study to improve MANET performance. This chapter will focus on routing selection schemes. Chapter 3 presented a literature review and discussed the problems with MANET routing protocols. An efficient routing selection scheme may relieve routing problems.

This study will compare the proposed scheme with AODV and DSDV routing protocols. AODV is one of the routing schemes used in MANETs [85]. The scheme uses hop count to calculate the shortest path from sender to receiver. It is a trusted, simple and effective metric. It uses a reactive routing scheme. The route from sender to receiver is only established when it is needed. A sender node will broadcast an RREQ for connection and an intermediate node will forward the message until it arrives at the destination node. This broadcast technique will create a broadcast storm because of inefficiency and flood the network by sending messages to all nodes within range to find the best route [27]. Each node that receives the message will record temporary routes back and then the routes with lower hop numbers are chosen. Therefore, routing overhead can be reduced. However, the main problem is delay because nodes must wait for the route connection to be established from sender to receiver. When the nodes in the network are high-speed mobile devices, this can create more problems [28].

This thesis found that most of the methods are modifications of AODV routing protocol. AODV uses hop count for path selection but does not deal with load traffic. Therefore, this thesis proposed a scheme of gateway load balancing and routing selection protocol to balance the load at the gateway node and to intelligently choose the route. Our scheme used both reactive and proactive routing schemes. Before communication between nodes in the network begins, the gateways in a MANET network advertise their location periodically to all nodes within range. Each node that receives the advertisement will store the information about the nearest gateway in a routing table. When a node outside the gateway range wants to send a message, other nodes will forward the message until it arrives at one of the gateways. However, if a gateway is in a heavy load condition, the notification will be advertised. The nearest node will find another nearest gateway that is available. As in our previous work [27], this thesis will use the forward and backward technique to prevent packet loss. Because we know packet delay will increase as the technique is used, an improvement has been made by using the notification of heavy loads at the first stage.

5.2 Related Work

A natural disaster is a sudden and exceptional event that can strike anywhere in the world, for example, floods, hurricanes, tornadoes, earthquakes and tsunamis. Disasters can damage or destroy telecommunication infrastructures. Cellular communication may not possible after a disaster, which can leave many people isolated from information and communication. Nowadays, most people can connect to the Internet using smart devices, making calls, sending text messages and using many social networking applications. When infrastructure goes down after a disaster, as in shown in Figure 2.2, traditional phone calls might not be possible. To rebuild the physically damaged cellular network is expensive and takes time. MANETs are one of the solutions in this situation.

A MANET can be a self-organised, self-recovering, decentralised, tariff free operation, which is easy to use and inexpensive. MANETs are suitable for unexpected conditions, and are consequently suitable for disaster response and recovery, in which it is difficult or perhaps impossible to immediately build a new fixed infrastructure. MANETs are suitable for search operations, for instance. Rescue teams can quickly take action as victims' responses can provide coordination. MANETs are also suitable for recovering networks after disasters in indoor or outdoor environments because MANETs can be set up without any underlying infrastructure. A node in a MANET can be the source, the destination and the relay to deliver the packet to the destination node. However, each node, which is a mobile device, has a power limit and a limited coverage area. More nodes in the area should improve QoS. However, the density of nodes in a network will also create network congestion. In disaster recovery situations, victims regularly contact family and friends to give updates about their situation, which creates heavy traffic in the disaster recovery network. Cell towers that are not damaged are typically too overburdened to handle the flow of congested network traffic. Hence, an efficient routing scheme is important to reduce congestion.

In this chapter, a list of routing schemes was studied in MANETs, focusing on a case study of emergency and disaster recovery scenarios. The network topography in disaster areas always changes because people move around using mobile devices (node mobility). Mobility features are node speed, direction and pauses of nodes. After a disaster, commonly there are obstacles, so nodes change direction. Consequently, devices may disconnect from the network. Because node battery life is also limited, victims are not usually connected to the network. The nodes will not appear in the routing list because they are not connected to the network. This scenario can help to reduce network congestion. However, a problem arises when other nodes do not have a neighbour to act as a bridge to the destination node. This chapter focuses on routing selection schemes in disaster recovery. The main contribution of this chapter is to propose a routing selection scheme in a realistic environment of disaster recovery to compare the performance of the proposed scheme with selected previous routing schemes.

5.3 Use Case Scenario

There is a relatively small body of literature that is concerned with MANET routing protocols in emergency and rescue scenarios. An analysis of routing schemes shows that, among the reactive routing schemes, AODV performs best. DSDV performs similarly well among proactive routing schemes in emergency scenarios. DSDV has the better packet delivery performance. In the simulation, the performance of our proposed routing selection scheme, DSDV and AODV is compared by using a case study of a disaster recovery area. AODV and DSDV were chosen because these protocols perform best in their categories. Reina et al. [89] believed that routing protocols in MANETs significantly affect performance in disaster scenarios because no infrastructures are needed.

To compare the proposed scheme to AODV and DSDV, this thesis used the realistic environment [27] mentioned in the Chapter 4. This thesis chose Loja City to simulate our proposed scheme, AODV and DSDV routing schemes, using the same parameter environment. AODV uses a hop count to find the shortest path from sender to receiver. The route from sender to receiver is only established when it is needed. A sender node will broadcast an RREQ for connection and an intermediate node will forward the message until it arrives at the destination node. This broadcast technique will create a broadcast storm because of inefficiency and flood the network by sending messages to all nodes within range to find the best route. Broadcasting messages to discover a path to the destination increases network overhead. Each node that receives the message records temporary routes back and the routes with lower hop counts are chosen.

In disaster recovery areas, a node represents a person in the area. Each node is free to move randomly. Updating all the routing information periodically for each node in the mobile environment is not efficient. This method will drive network overhead because of high channel usage. In addition, to extend battery life, sometimes a node in the network will join and leave the network. To keep refreshing the routing information in a high mobility environment with changeable network topology is not effective.

Developing a routing scheme for MANETs in disaster recovery areas involves several problems: (i) network congestion, (ii) node mobility, (iii) network overhead and (iv) energy resources. This thesis does not focus on the energy problem, but rather assumes the energy problem has been solved.

5.4 Proposed Routing Selection Scheme in Disaster Recovery

The scheme intelligently manages the transmission of messages from nodes to gateways. To initialise the route from sender to receiver, nodes will refer to routing tables to select which routes are available. In order to develop an energy efficient routing scheme, the proposed routing selection scheme update the information in routing table when there is new information, therefore energy conservation can be improved. The algorithm compared current information with the previous one and the routing table will be updated only if different information has been detected. A flow chart of the proposed scheme is presented in Figure 5.1. No constant updating of table routing information will improve energy saving. By modifying the algorithm, this proposed scheme can be turn into an energy efficient scheme in future work.

This thesis proposes a routing selection scheme that simplifies route selection. Before communication commences, as in Algorithm 1, each gateway broadcasts its coordinates and current moving speed to its neighbours within a maximum transmission range. Each gateway has an assigned, pre-set, threshold. When a gateway is almost full, the gateway node sends full notifications to nodes at level one. The objective of this technique is to reduce network congestion.

Algorithm 1: Gateway Coverage Range

Procedure for G: Determines Neighbour Within Range (T1)	
1: T1 ← Level 1	
2: Check redundant {}	// Function redundant
3: **Return**	

As can be seen from Algorithm 1, each gateway will determine their neighbours which is node within gateway coverage range. Neighbours of the gateway are stored in the routing table at level one. Then nodes in level one determines their neighbour's node within range and are stored at level two as shown in the Algorithm 2. This process continues until all neighbours' nodes are stored in the routing table. After each node complete determine their neighbour, Algorithm 3 simultaneously has a responsibility to check the redundancy at each level to ensure nodes are not redundant.

Algorithm 2: Nodes in T1 Coverage Range

Procedure for T1: Each Node Determines Their Neighbour Within Range (T1)	
1: T2 ← Level 2	
2: Check redundant {}	// Function Redundant
3: While find one S neighbours in upper level	
4: Do send a packet	
5: If U = 0	
6: Then find one S neighbours in S level	// No S neighbour at upper level
7: Upper level	
8: N ← S neighbours	
9: Send a packet	
10: Else if waiting then	
11: **Return**	

Algorithm 3: Function to Check Redundancy

Procedure to Compare Node Level Tn to Tn + 1
1: If at level Tn + 1 ← same nodes
Then {
2: Remove the node
}
3: **Return**

According to Algorithm 4, when a node wants to send a packet out of the local network, the source node generates a route request to the gateway. The first procedure is to check the level of the source node. Looking for the next hop considers the neighbour of the source node that is located at an upper level and is in source node coverage range.

Algorithm 4: Source Node Generates an RREQ for the Internet Via a Gateway

Procedure to Check the Level of the Source Node (S)	
1: S ← sources node	
2: U ← next hop	// U = Upper level
3: While (U ≠ 0)	
4: Do send a packet	// Send to one neighbour only
5: **Return**	

Algorithm 5: Route Discovery for RREQ

Procedure to Check the Level of the Source Node (S)	
1: S ← sources node	
2: U ← next hop	// U = Upper level
3: While find one S neighbours in upper level	
4: Do send a packet	
5: If U = 0	// No S neighbour at upper level
6: Then find one S neighbours in S level	
7: N ← S neighbours	
8: Send a packet	
9: Else if waiting then	
10: **Return**	

If there is no neighbour node in the upper level in source node coverage range, the next procedure (presented in Algorithm 5) is generated. The route request will be passed to another node in the network coverage range on the same level to find neighbours in the upper level. This method will probably increase packet delay. However, it prevents packet loss. In disaster recovery communication, information is very important.

To make the proposed schemes clearer, the efficient routing selection scheme is illustrated in Figure 5.1. The methodology process involves gateways on the very first level of our routing scheme to send the packet out of the network, followed by the next level, which consists of gateway neighbours. The process continues until the last level of nodes.

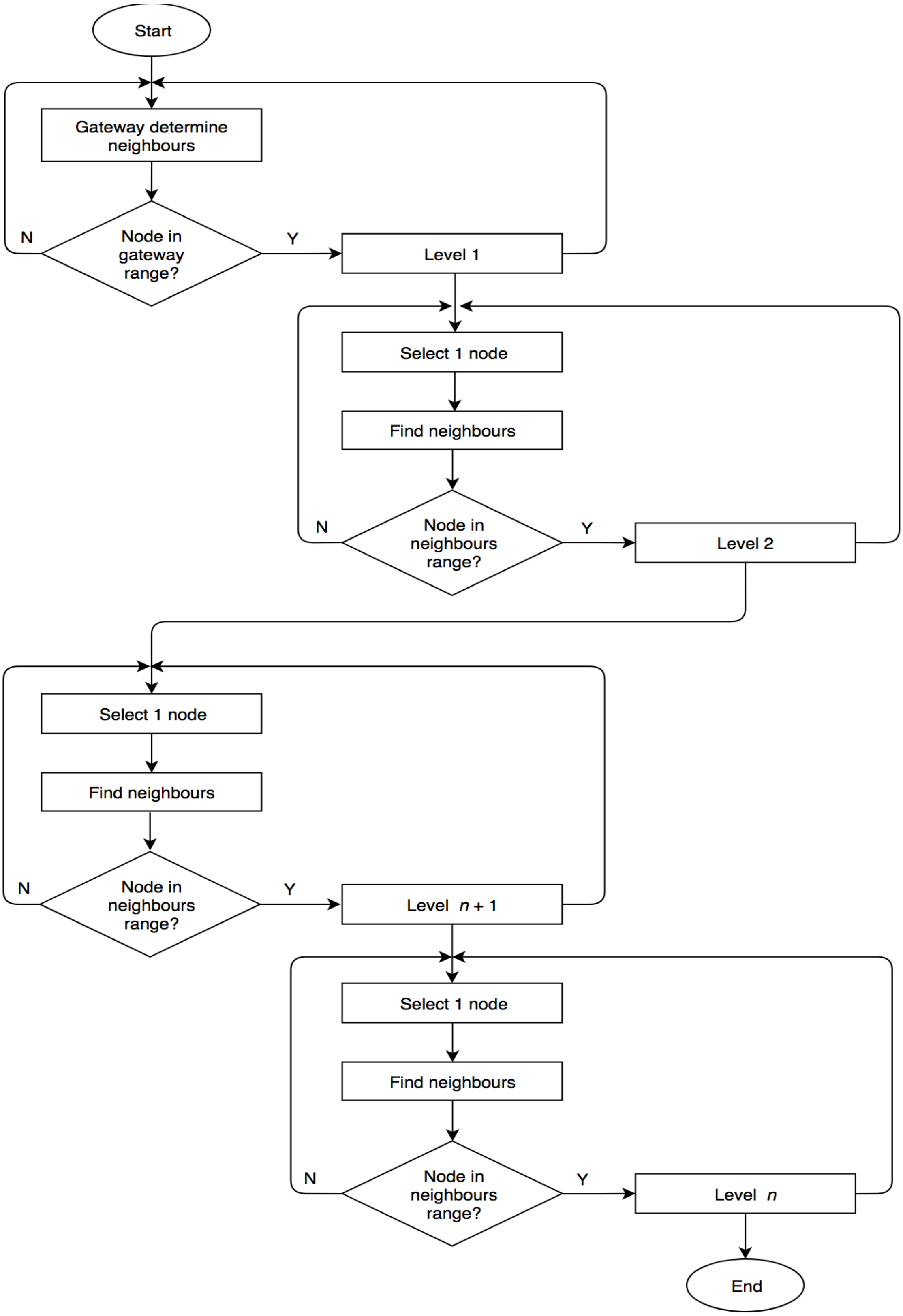


Figure 5.1: Flowchart of proposed efficient routing selection scheme

5.5 Modelling Network Architecture in Disaster Recovery Areas

5.5.1 Routing Table

As mentioned in Chapter 3, in conventional routing schemes, nodes prefer to distribute the packet through broadcasts, either to nearest neighbours or to the whole area. Figure 5.2 shows an example of the AODV routing protocol broadcast technique, which results in packet flooding in the network, especially when there are many nodes in the network. This causes node redundancy and complexity in the routing table. This complexity will lead to packet congestion, network overhead and decrease the network throughput.

Node	Neighbour	Neighbour	Neighbour	Neighbour
0	11	44	33	25
1	32	35	36	13
2	39	14	42	18
3	46	10	24	0
4	12	27	9	43
5	38	43	33	6
6	1	5	33	44
7	2	22	4	17
8	28			
9	27	19	43	38
10	3	46	24	25
11	30	44	23	26
12	4	27	19	37
13	1	5	6	15
14	39	14	42	2
15	31	45	32	36
16	49	48	47	41
:	:	:	:	:
43	6	1	5	38
44	23	26	45	32
45	44	26	23	31
46	3	10	24	
47	16	49	48	28
48	49	16	29	47
49	29	16	48	47

Figure 5.2: The complexity of a conventional routing table

To reduce congestion and the complexity of routing selection, this thesis proposes a technique to simplify the routing table into several levels. Each node in the level that receives the message will forward the message to the next upper level instead of broadcasting it to all the nodes. If a message is received by a higher-level node and that node is not the destination, the node will forward the message to the higher level in range. This process will be repeated until the message arrives at the destination node. If the higher-level node is small (TTL=<1), the message cannot be forwarded.

After applying the proposed algorithm, the complexity of the routing table can be simplified, as shown in Figure 5.3.

					15	49	8				
	31	45	32	36	35	13	29	16	48	47	28
6	23	26	44	5	1	38	41	49	7	8	
33	11	30	0	43	4	17	20	22	9	2	
40	25	24	10	3	27	12	39	19	14	42	18
21	46	34	37								

Figure 5.3: Routing table after the algorithm is applied

Table 5.1: Total Hop of Nodes

Gateway Nodes
Level 1 (One Hop)
Level 2 (Two Hop)
Level 3 (Three Hop)
Level 4 (Four Hop)
:
:
Level n (n Hop)

This thesis describes in detail how the proposed scheme works. An example of the realistic scenario is as follows: Node 11 wants to send a message to another node outside the MANET. However, node 11 is not in range of an IG. The message must go through a multi-hop communication via nodes 8, 15 or 49 to reach the Internet. According to our proposed routing selection scheme, as shown in Figure 5.3, node 11 is at level 3. Thus, this node will look to the upper level, which is level 2, to determine which node in level 2 is in node 11's range. The scheme authenticates that node 44 is a neighbour of node 11 that is in range of node 11. Therefore, the message is forwarded to node 44. The same step is repeated until the message arrives at the gateway node. According to Table 5.1, the total number of hops will be 3. The complexity of the route can be simplified using this proposed routing selection scheme. This method indicates that the total number of hops can be minimised, and the shortest path determined. Interestingly, this method can be executed on any network group with the gateway concept.

5.5.2 Performance Evaluation

In the simulation model, this thesis used the same mobility model which is random waypoint to simulate the disaster recovery area referred to the map Loja City in southern Ecuador [27]. In this disaster recovery scenario, the thesis used 1000 x 2000 m of the city of Loja. According to this model, before nodes change direction or speed, they will pause. The thesis set the pause time at 0–2 s. The movement pattern of this model was similar to the random walk mobility model when the pause time was zero.

The placement of nodes in the network was set as random because people in that area would randomly connect to and disconnect from the network. Similar to the parameter used by Quispe et al. [27], the thesis set the number of connections at 20 and 40. The number of nodes in this simulation referred to the density of people in that area. There were 50, 97, 100, 120, 160 and 200 nodes. Difference in density numbers can determine the behaviour of routing schemes. To assess which was the best scheme, the thesis simulated AODV [90], DSDV [91], [92] and our proposed routing selection scheme using the OMNET++ simulation tool. Model verification is important to check the reliability of simulation results and evaluate the scheme. The simulation represents the results in a reality scenario. The simulation experiment is repeated three times to ensure repeatability of results and the correctness achieved. Table 5.2 presents the parameters used in this simulation in detail.

Table 5.2: Parameters used in the Simulation

Parameter	Value
Simulation area (m^2)	1,000 × 2000
Simulation time (s)	900
Mobility model	Random waypoint
Mobile node placement	Random
Pause time (s)	0–2
Transmission range (m)	250
Number of nodes	50, 97, 100, 120, 160, 200
Number of connections	20 and 40
Network layer protocols	AODV, DSDV and Proposed GWRS
Transport layer protocol	Transmission control protocol (TCP)
Nodes speed (mps)	Uniform (0 – 2)

5.6 Results and Discussion

In this simulation, performance analysis was carried out by an increment of the number of nodes in the simulation area and the increased number of connection nodes. Three schemes were considered for comparison: AODV, DSDV and the proposed scheme. The performance metrics, end-to-end delay, packet loss ratio, packet delivery ratio and packet throughput, were presented and analysed.

5.6.1 End-to-End Delay

End-to-end delay is the time that packets take to travel from the source to the destination. This include the delay caused by route discovery, buffer queuing because of congestion and packet retransmission. Figure 5.4 presents the results of 50–200 node density in the Loja City area, with 20 randomly made connections. From the bar chart, it can be seen that the proposed scheme slowly increased the end-to-end delay as the number of nodes increased. However, the proposed scheme had a smaller delay than AODV and DSDV.

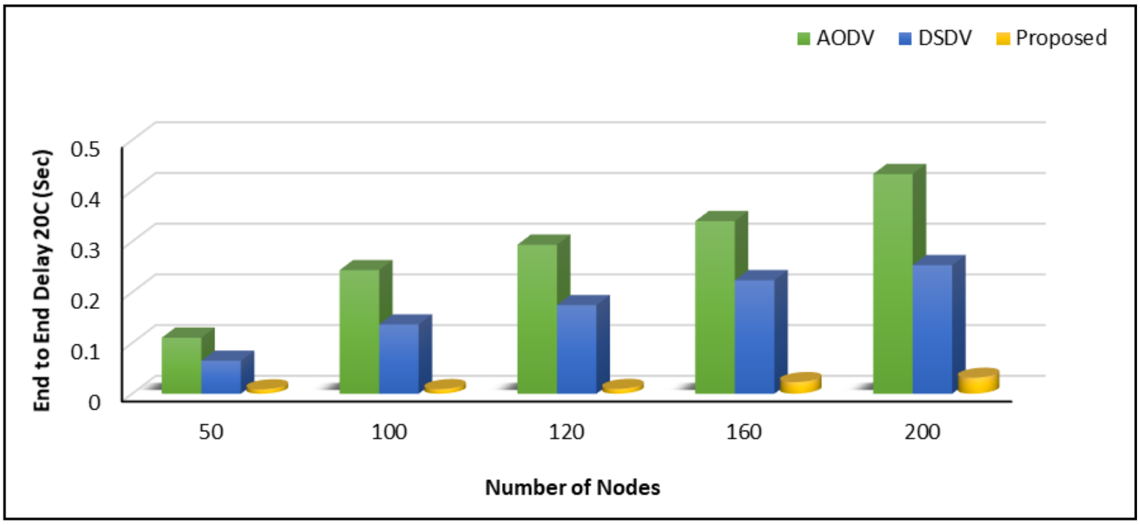


Figure 5.4: End-to-end delay for 20 connections

5.6.2 Packet Loss Ratio

In disaster recovery, node mobility in an actual situation represents victims with mobile devices. Topology changes rapidly because of node mobility. As shown in Figure 5.5 when nodes are static, the results obtained the end-to-end delay is slightly high. This bar chart is revealing in several ways. First, it is apparent that, at a node density of 50, packet loss ratio between the three schemes was similar. Second, as nodes increased, the form of the charts of AODV and DSDV was similar. Even though these three protocols were cumulative, our proposed scheme showed a lower ratio of packet loss. At a density of 200 nodes, the proposed scheme increased to 31%, while AODV and DSDV increased to 45% and 46%, respectively.

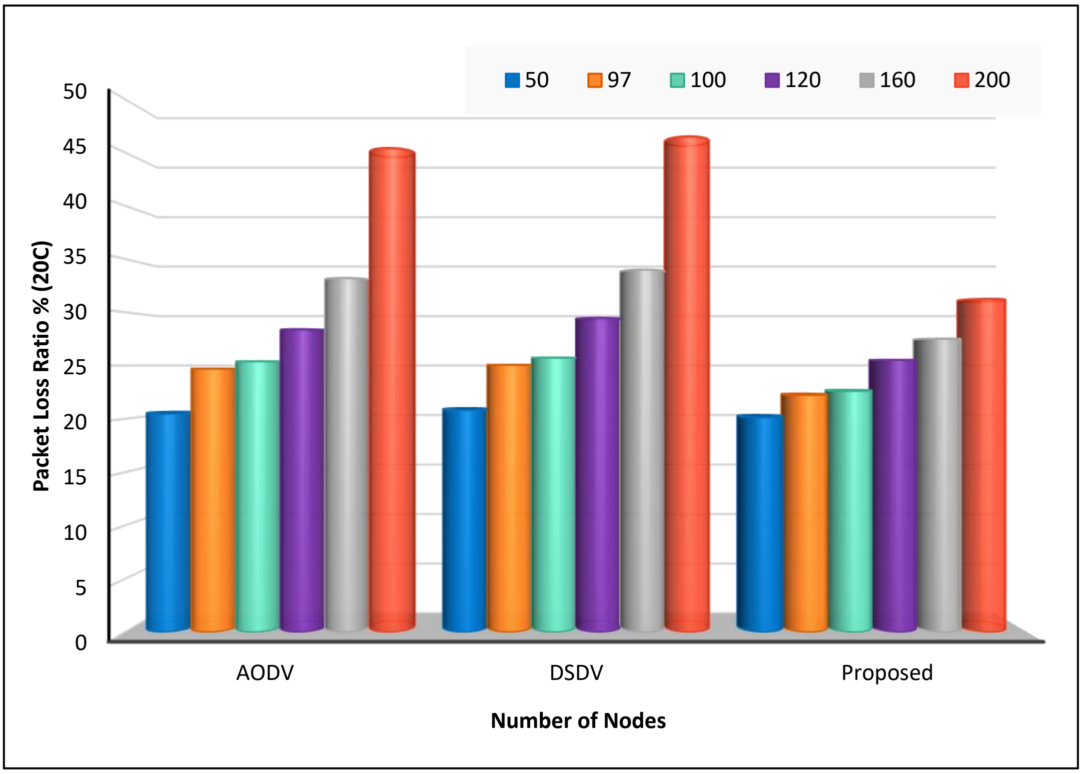


Figure 5.5: Packet loss ratio for 20 connections

5.6.3 Packet Delivery Ratio

Packet delivery is the ratio of successfully delivered packets to the destination nodes. The graph in Figure 5.6 shows that when there were only 50 nodes in the disaster area, 80% of the packets arrived at the destination nodes. When there were 97 nodes, there was only a 3% gap between the packet loss ratios of DSDV and proposed scheme. The gap gradually increased as the number of nodes increased. Packet delivery fell slowly for the DSDV scheme, making this scheme the poorest compared to the two other schemes.

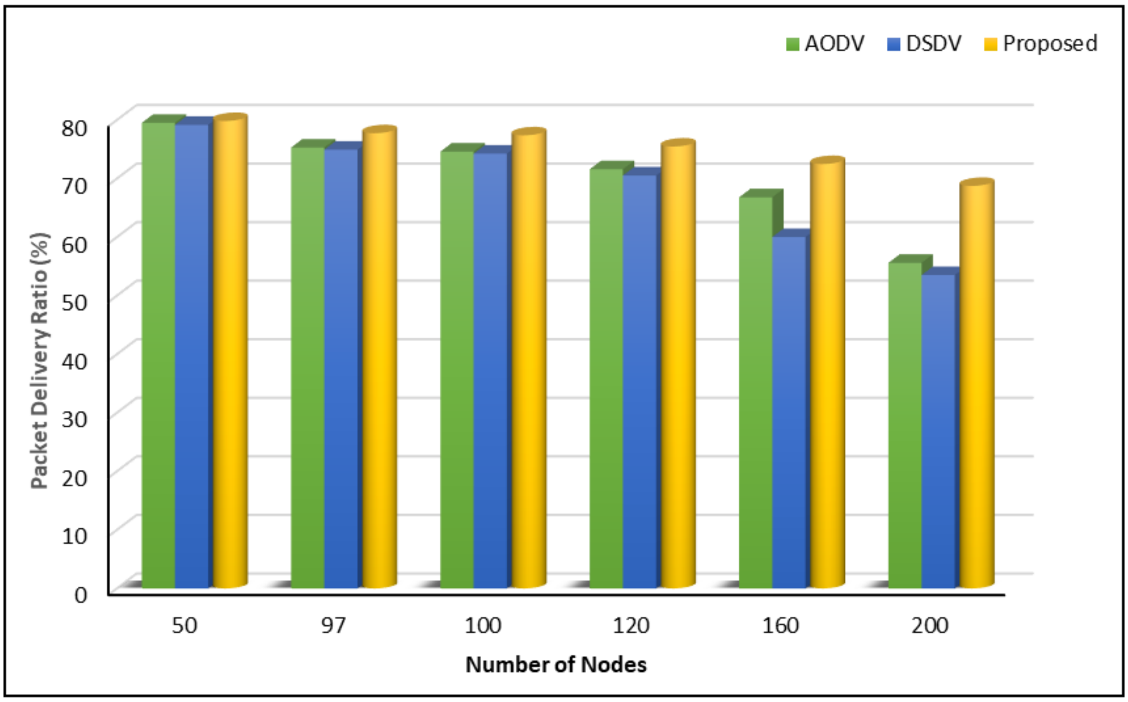


Figure 5.6: Packet delivery ratio for 20 connections

5.6.4 Packet Throughput

Our effort was to minimise packet loss because communication is in high demand and very important during disaster recovery. Another important finding was that our proposed scheme showed a significant result that provided better basic Internet access to the population of users in the recovery area. As can be seen from the graph below (Figure 5.7), the proposed scheme maintained high throughput compared to AODV and DSDV schemes, which had steadily low throughputs from beginning. This was probably because nodes were moving randomly. Our proposed scheme improved the problem of node mobility.

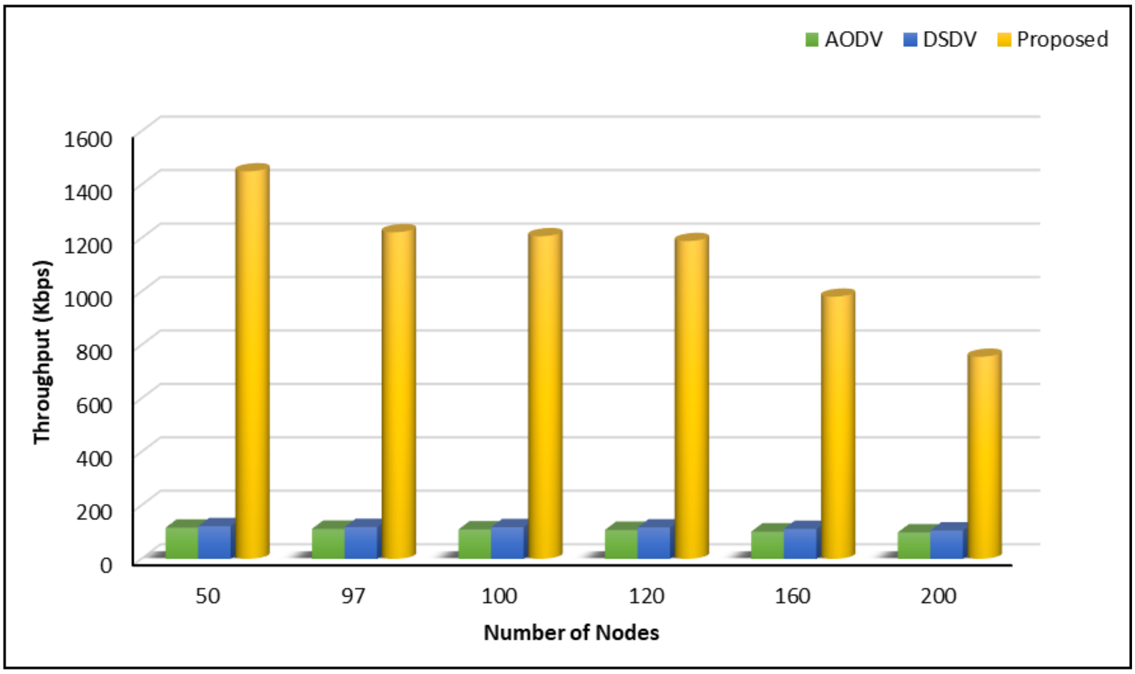


Figure 5.7: Packet throughput

5.6.5 End-to-End Delay

Further simulation with 40 connections is shown in Figure 5.8. The proposed scheme demonstrated a lower increase of delay than DSDV. However, DSDV schemes had better results than AODV. AODV showed the highest packet delay when the number of nodes was 50. The figure rose higher when the number of nodes reach 200.

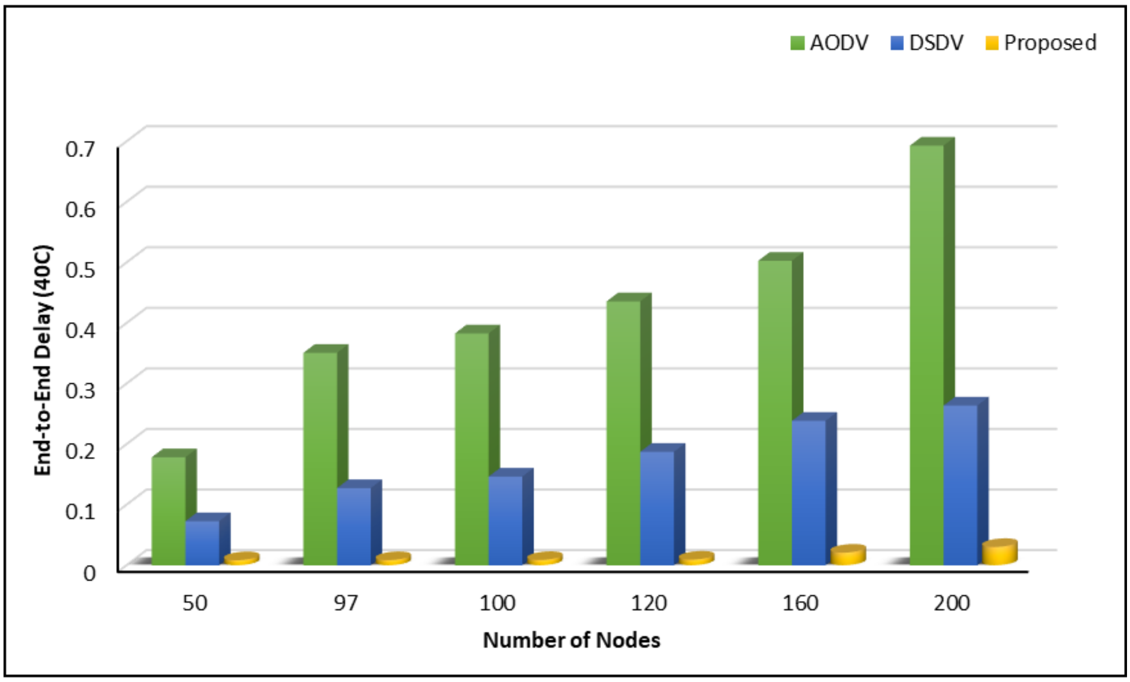


Figure 5.8: End-to-end delay for 40 connections

5.6.6 Packet Loss Ratio

Figure 5.9 presents the results for 40 connections when the number of nodes was 50. The lowest packet loss ratios were 36% for AODV, 37% for DSDV and 25% for the proposed scheme. When the number of nodes was multiplied by two, the loss ratios of the AODV and DSDV schemes were similar, while the loss ratio of the proposed scheme was 27%. As the number increased to double, the loss ratio of the proposed scheme slowly increased to 39% and remained the lowest packet loss ratio.

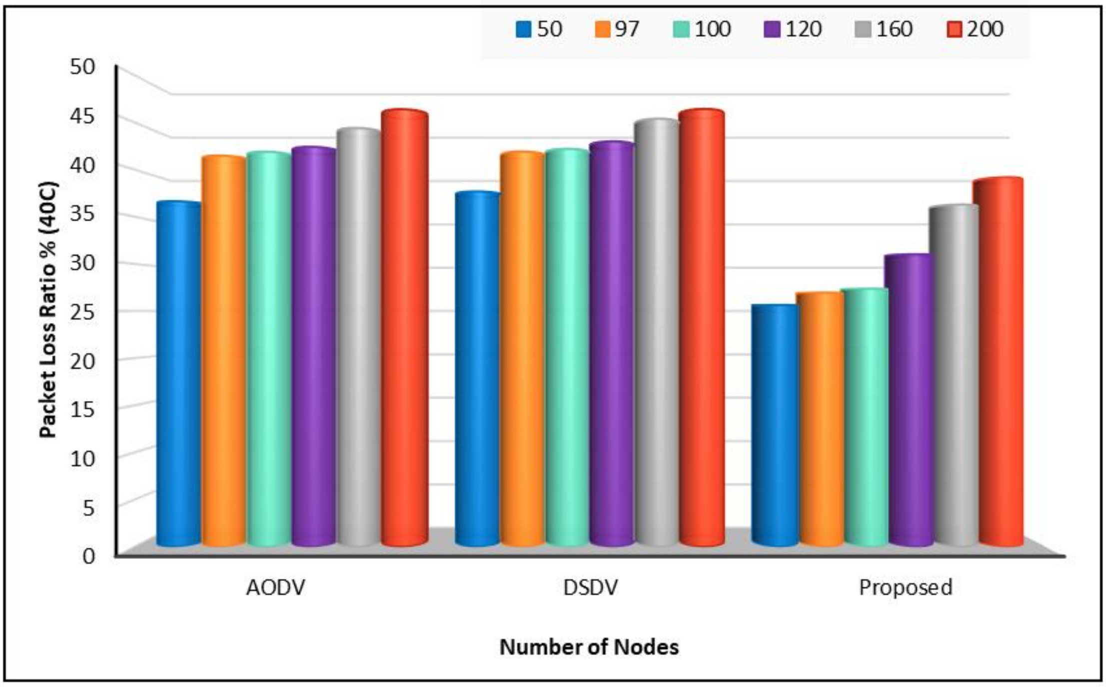


Figure 5.9: Packet loss ratio

5.7 Summary

This thesis examined a list of MANET routing schemes. Despite the fact that there has been a great deal of research on MANET routing, there is still room for improvement, especially in disaster recovery scenarios. As seen in our analysis, only a few routing schemes have been concerned with disaster environments. This thesis proposed an efficient routing selection scheme to manage network congestion in disaster recovery areas. The thesis considered a realistic disaster recovery scenario and compared the performance of our proposed scheme with that of AODV and DSDV routing schemes. The performance of these three routing schemes was evaluated using the computer simulation tool OMNET++. The results of the simulations showed that the proposed scheme performed better than AODV and DSDV routing protocols in selected performance metrics. Although this study focused on disaster recovery, the proposed scheme may work well in other scenarios.

Other methods use routes with fewer hop nodes as the shortest paths. However, this causes bottlenecks, which decrease network performance. MANET is a type of ad hoc network. A node in a MANET can move randomly and nodes can connect to each other wirelessly. Because nodes are mobile, mobility has a significant effect on routing performance. The performance of a routing scheme depends on the total duration of the connection between any two nodes. Because of node mobility, the connection may be lost during data transmission. The concern of this thesis was to simplify the routing selection process in an environment of mobility to reduce the complexity of the original routing table. The significance of the proposed scheme is the reduction of network congestion and, consequently, improved packet transmission in MANET performance. In Chapter 6, the effect of node mobility in disaster recovery areas is investigated.

Chapter 6

Effects of MANET Node Mobility in Disaster Recovery

6.1 Introduction

In Chapter 4, the proposed gateway load balancing scheme was discussed, while in Chapter 5 the proposed routing selection scheme was presented. A random waypoint mobility model was chosen as the mobility model in the network simulation to represent the free and random movement of victims in the disaster recovery area. In previous chapters, this thesis focused on the enhancement of routing and gateway selection schemes, while mobility speed was set at a constant value. In this chapter, the proposed GWRS will be discussed in detail for a realistic mobility model. Using the selected mobility model, the significant effect of node mobility speed in disaster recovery on the performance of GWRS was analysed and identified.

A MANET consists of wireless mobile devices in a network that communicate with each other through neighbours that act as relays. In a simulation, node mobility represents victims with mobile devices who move around in the disaster recovery area. This chapter will identify how GWRS performance is significantly affected by node mobility in

MANETs because MNs connect to each other using multi-hop wireless links [83]. The communication link will probably connect and disconnect because nodes in the network can join and leave randomly.

In addition, MANET topology is uncertain and may change rapidly because of node mobility. In a disaster recovery environment, it is challenging to deal with the node mobility in the network. Each node is a neighbour to another node. When the neighbour node is always moving, it is likely that the packet will be dropped during packet transmission. This chapter addresses two challenges in disaster recovery scenarios: (1) how nodes deal with the mobility of neighbours and (2) how to manage the joining and leaving of nodes. To overcome this challenge, the proposed GWRS was analysed in relation to different node velocities to determine the effects of realistic node mobility on MANET performance in disaster recovery areas.

6.2 Related Work

To simulate node mobility in a MANET in disaster recovery, a mobility model should mimic the movement of real victims in a disaster area. The mobility pattern will determine node speed, direction, position and the way the nodes move within the set area. This behaviour affects node signal strength, battery power and bandwidth use and has consequences for MANET performance. There are several mobility models [93] for MANETs, such as the random walk model, the random waypoint model, the reference point group model and the Gauss-Markov mobility model. In this thesis, the random waypoint model was chosen as the mobility model in the simulation of the disaster recovery scenario because this model can represent the random motion, speed and direction of nodes in the disaster area. The randomness is consider the nodes in the network can randomly move [88], after the moving speed range has been set in the simulation. MANETs are most commonly simulated by applying the random waypoint mobility model. This model mimics people moving around randomly using their mobile devices [30] in disaster area.

Figure 6.1 shows the interconnection between mobility and routing. In the random waypoint model, MNs randomly choose a destination and move towards it within the minimum and maximum allowed speed. After reaching the destination, MNs stay in one location for a specified time (pause time) before they randomly choose another destination node. This process is repeated until the simulation ends. Radha and Shanmugavel [93] show how throughput performance using the random waypoint model is preferable in comparison to another mobility model. In reality, lower mobile speeds will lead to a better performance by increasing throughput and controlling network overhead.

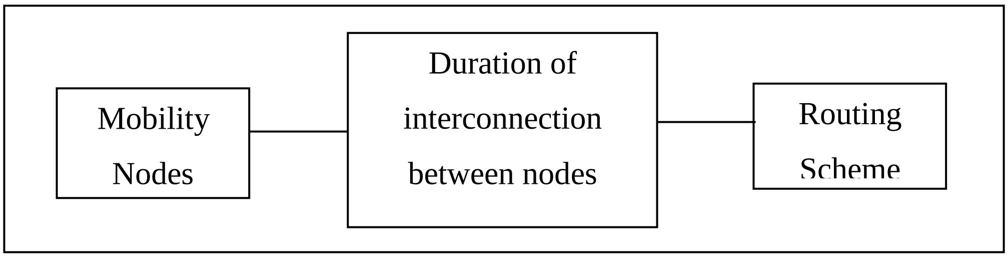


Figure 6.1: Mobility and routing connection

As shown in Table 6.1, there are seven different models for node mobility. Two of them are commonly used in MANETs. The first model is random walk mobility and the second model is random waypoint mobility.

Table 6.1: Node Mobility Model Comparison

Mobility Model	Types	Method
Random Walk Model	Random	Random direction and speed
Random Waypoint Model	Random	Pause time between changes direction and speed
Reference Point Group Model	Spatial Dependency	*MN travel to the edge of the simulation area before changing direction and speed
Gauss-Markov mobility	Temporal Dependency	Use one tuning parameter
Smooth Random Mobility Model	Temporal Dependency	Change node speed and direction incrementally and smoothly
Pathway Mobility Model	Geographic Restriction	Simulation modeling the map of a city
Obstacle Mobility Model	Geographic Restriction	*MN changes its trajectory to avoid an obstacle. Obstacles do affect *MN movement behavior

6.2.1 Random Walk Mobility Model

This model represents the characteristics of a node that moves independently in unpredictable ways. This model was first proposed for particle movement in physics. Because of node mobility in MANETs, nodes move randomly. Therefore, this model is used to mimic MANET node behaviour. According to Sarkar et al. [94], nodes move from their existing location to another location at their own speed and in their own direction. MN does not rely on previous speed and direction because of the memoryless mobility process. In the simulation, this model uses a random roaming pattern.

6.2.2 Random Waypoint Mobility Model

The random waypoint mobility model [94], as indicated in Figure 6.3, is usually used in MANET routing schemes because of its ease and wide availability. According to the behaviour of this model, before nodes change direction or speed, they pause for a time. Before the pause time expires, the node randomly chooses the next destination within range and speed. After the node completes the move to the selected destination, it again waits for a pre-set pause time, before the same process is repeated. Divecha et al. [95] give an example of a mobile node that uses the random waypoint mobility model as a travelling pattern. The movement pattern of this model is similar to the random walk mobility model (Figure 6.2) if the pause time is zero. In most of the research on MANET performance evaluation, this model is commonly used for simulations.

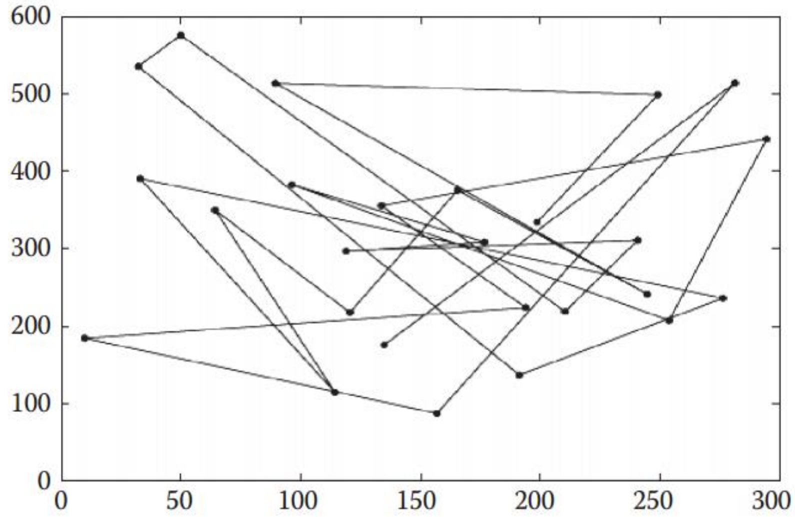


Figure 6.2: Random walk mobility model [75]

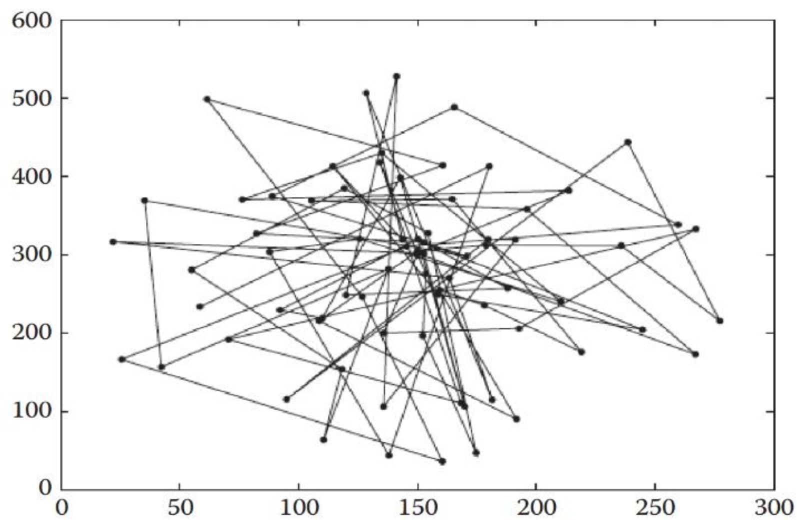


Figure 6.3: Random waypoint mobility model [75]

To allow people to connect to the Internet, [96] proposed a wireless networking architecture in which MANETs connect to the cellular network via a terrestrial gateway and the cellular network connects the MANET to the Internet. Mu et al. [97] used a similar case study as [96], which involved the communication architecture for maritime sectors that uses an integration of cellular, satellite, WiMAX and wi-fi. While access to cellular coverage is limited, [98] introduced a combination of MANET and cellular networks to increase the delivery packet ratio in MANETs.

Transmission control protocol (TCP) is a transport protocol, primarily for reliable, ordered and error checked delivery. TCP can misinterpret the status of the route as congested and appeal to congestion control. Chandran et al. [9] introduced a feedback scheme to overcome route failure during packet transmission. When the route changes, the node sends a route failure notification packet to the sender to freeze its timer and stop sending the next packet. When the route is re-established, a route re-establishment notification is sent to resume timers and continue packet transmission. Thus, packet retransmissions are required, which may lead to delays and unfairness of packet throughput.

In the case of node mobility, before communication starts, each node will broadcast information about its coordinates and current moving speed to other nodes within maximum transmission range. Each node assembles the information about its neighbours and builds its own graph. Each node has its own moving speed. Nishima et al. [99] introduced a dynamic method to measure performance in MANETs in terms of connectivity ratio. Li et al. [100] proposed a topology control algorithm, namely Local Minimum Spanning Tree (LMST), and [101] proposed the Local Tree-based Reliable Topology (LTRT), which is a combination of LMST and TRT. LMST is the most cost-effective because each node only has one path. There is no path redundancy. However, the biggest problem is that when one of the links fails, there will be no connectivity to the related node. [101] introduced the LTRT algorithm, a mathematical solution shown below, to ensure k-edge connectivity of the topology:

$$O(k(m + n \log n))$$

where k is the connectivity of the resulting topology, n is the number of neighbouring nodes and m is the number of edges.

[102] measured the error of hop counts based on distance approximation and named mobility as the main influencing factor. There are some factors taken into account that affect mobility in MANETs, such as speed, direction and similarity of movement in neighbourhoods. Movement of devices in MANETs highly depends on the application and the environment.

As described in Chapter 4, a node in the simulation represents a person in the disaster recovery area. Each node was free to move randomly using the random waypoint mobility model. In this chapter, the thesis aims to implement the proposed routing and gateway selection schemes in a realistic mobility model for a disaster recovery scenario. In this chapter, this thesis will focus on the effects of node mobility on MANET performance. In the previous chapter, the results of the routing and gateway selection schemes with a constant node mobility speed of 2 s were shown. In Section 6.3, results obtained by varying the parameters of node speed and pause time while keeping the other parameters constant are discussed. In Section 6.4 the characteristics of node movement relating to how humans bypass obstacles in disaster recovery scenarios is determined. In Section 6.5, the joining and leaving of nodes is examined.

6.3 Node Mobility Speed and Pause Time

When the simulation began, to arrive at the destination, each mobile node first selected a neighbour node based on the proposed GWRS method. For nodes representing walking victims in the disaster recovery area, the average walking speed was between 1 and 2 m/s [103]. Therefore, the node speed for walking victims was set as N_{walk} [1:2] m/s. The maximum node speed in the simulation, which represented vehicles moving in the area, was set as N_{veh} [5:32] m/s. The minimum vehicle speed was 5 m/s. In a normal situation, vehicle speed in the city is 13 m/s. However there are two possible situations in disaster scenarios: either they increase speed to up to 32 m/s because of a panicked attempt to escape the disaster area, or they decrease to under 5 m/s to avoid moving into an affected area [104]. When nodes are moving faster, topology changes rapidly, which increases the packet drop ratio. High network mobility affects the connection between nodes. Links might fail because nodes move quickly. Therefore, pause time was needed in this simulation. Speed of movement and pause time determine the behaviour of the MNs. Pause time in this simulation represented victims facing an obstacle blocking the way to their destination. Nodes chose another direction by determining neighbour nodes in the coverage range. In this simulation, the pause time, P , was set randomly between $P_{min} = 0s$ and $P_{max} = 300s$. When $P = 0s,$ the nodes were continuously moving to the final destination node. Upon facing an obstacle, the node stopped for a certain duration between 1 and 300 s, determined by the complexity of the obstacle. This process was repeated until simulation time$= T$.

6.4 Use Case Scenario

The placement of the nodes in the network was set as random because people in the area would move randomly in any direction. This thesis used the same parameters as Quispe et al. [27] for our proposed GWRS in Chapters 4 and 5. The thesis considered the natural disaster that struck a 1000 x 2000 m area of Loja City. The number of nodes in the simulation referred to the density of people in the Loja area. There were 50, 97, 100, 120, 160 and 200 nodes. The area was classified as D. The public communication network failed to function. As described in Chapter 5, a similar solution is considered in this chapter which used the architecture of alternative disaster recovery technologies by using cellular on wheel when the communications failure after disaster.

In communications during disasters, people are advised to use text messages when attempting to contact family and friends. Figure 6.4 presents the simulation model of people moving around. People in that area are waiting to connect their mobile devices to the cellular network. Three groups of victims are represented by node movement in the disaster scenario: people walking randomly to find cellular coverage $=N_{walk}$, people in vehicles moving around trying to find the best place, which is usually the higher place, $=N_{veh}$, and people remaining in the same place $=N_{stat}$. For the movement of N_{walk} and N_{veh} in the disaster area, typically people are hindered by obstacle $=O$. In general, using the proposed GWRS scheme, the minimum node speed for N_{walk} and N_{veh} was set as S_{min} and the maximum node speed $=S_{max}$. Each N moved randomly from one destination to another destination. Therefore, the route was defined as source $= S$ to destination $=D$. When there was O between S and D, N stopped for pause time $= P$ while finding another available route.

Input:

$$d \in D$$

$$d = (N_d^{walk},\ N_d^{stat},\ N_d^{veh},\ O_d)$$

6.5 Obstacle and Signal Propagation

Physical obstacles in a disaster area can reduce signal power between wireless nodes. Nodes change direction when the path is hindered by obstacles. In an effort to implement realistic mobility of nodes in a disaster recovery area, the Voronoi diagram [105], [106], also referred in designing a simple polygon of the obstacles. Figure 6.6 shows an obstacle in the route of source node $S = N1$ to the destination node $D = N5$. In a typical transmission, as shown in Figure 6.5, the straight path $\{N1, N2, N3, N4, N5\}$ is the shortest route. However, the obstacle may cause signal attenuation of the next relay neighbour. Therefore, the direction of the next hop was changed (Figure 6.7) to ensure the transmission of the packets. The new path to the destination was $\{N1, N2, N6, N7, N8, N4, N5\}$. In the simulation, this path was determined by the signal strength within node transmission range. The method of next hop relay selection was solved by the proposed GWRS scheme.

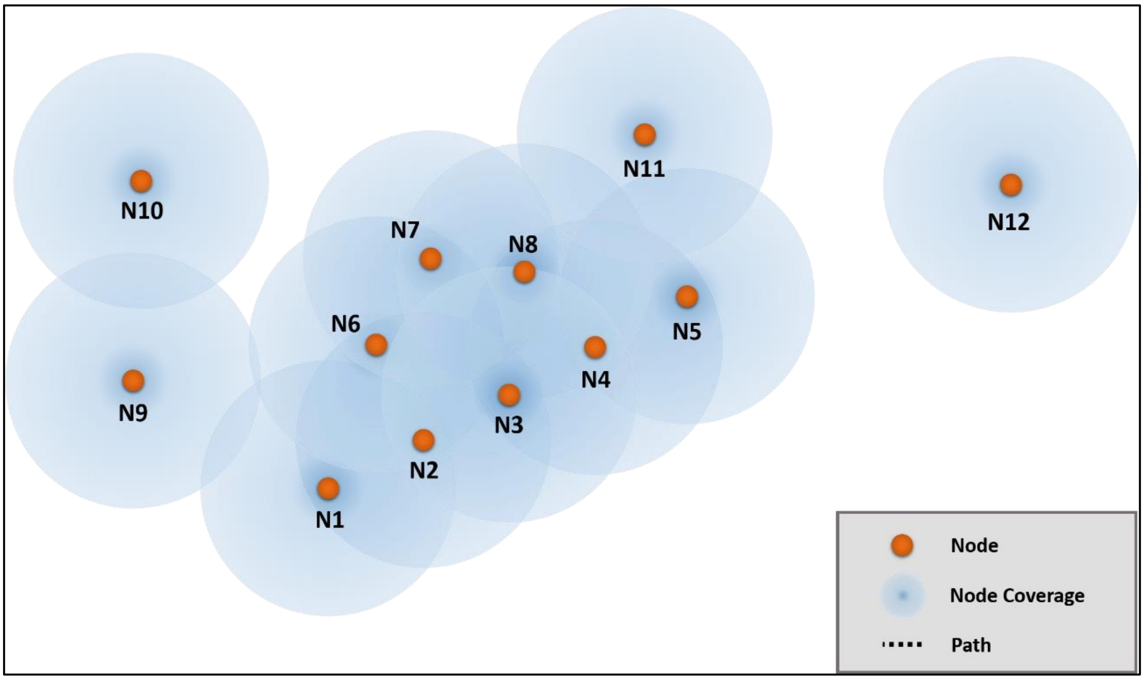


Figure 6.4: Node mobility in the disaster recovery area

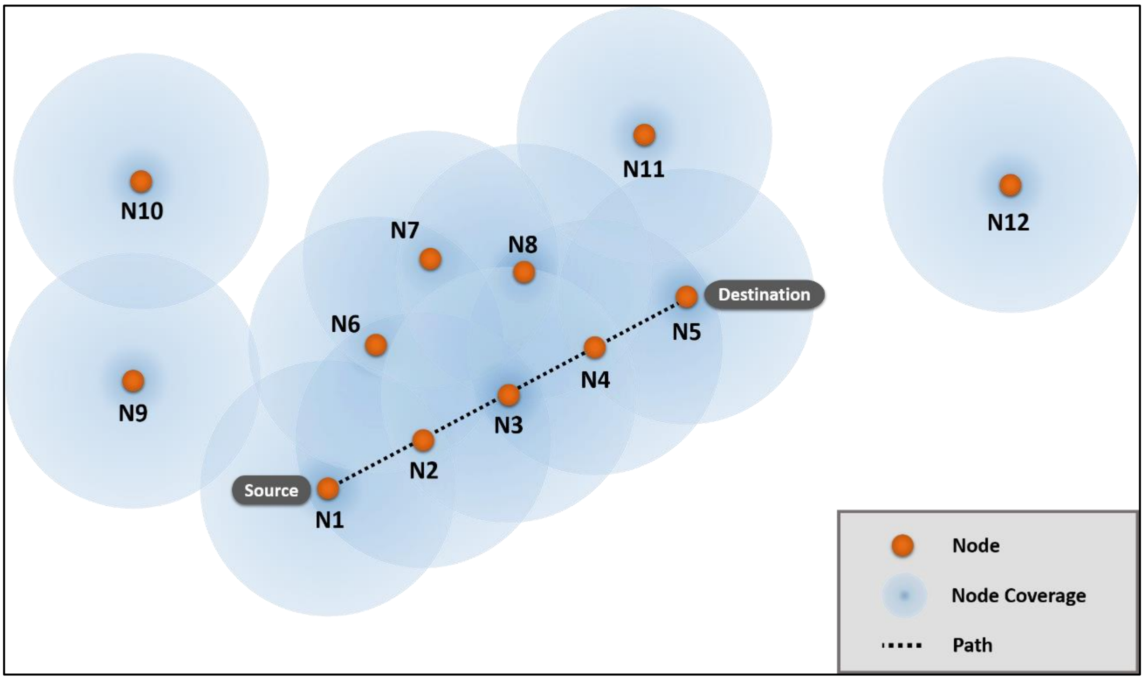


Figure 6.5: Path from source to destination node

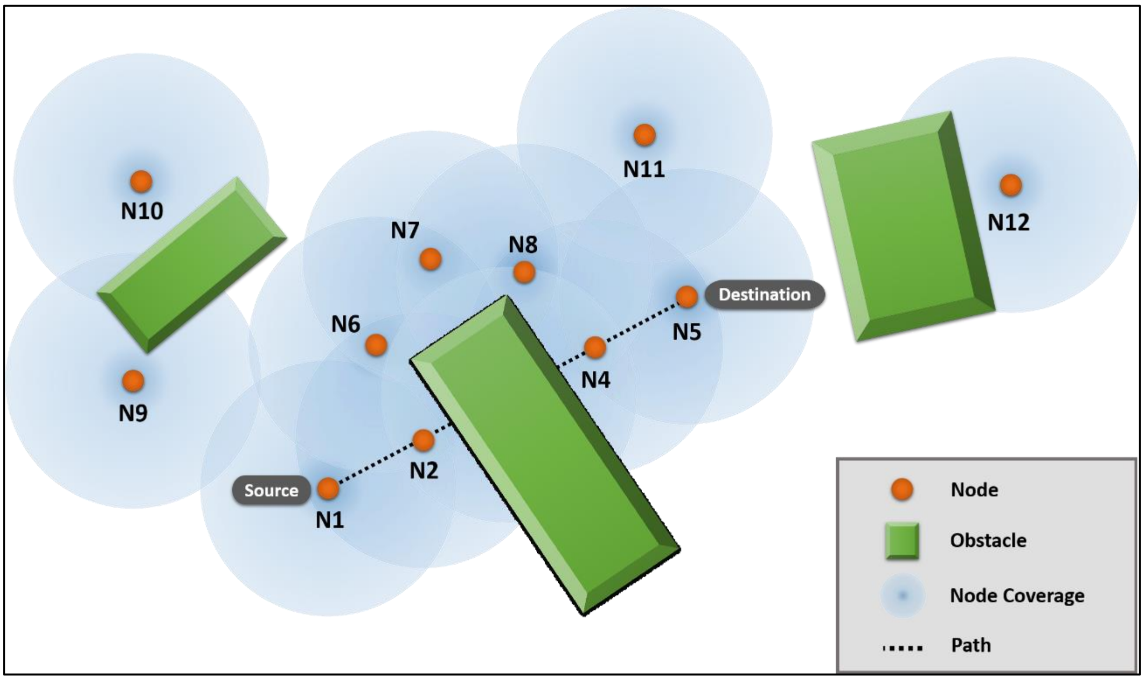


Figure 6.6: Obstacle between source node and destination

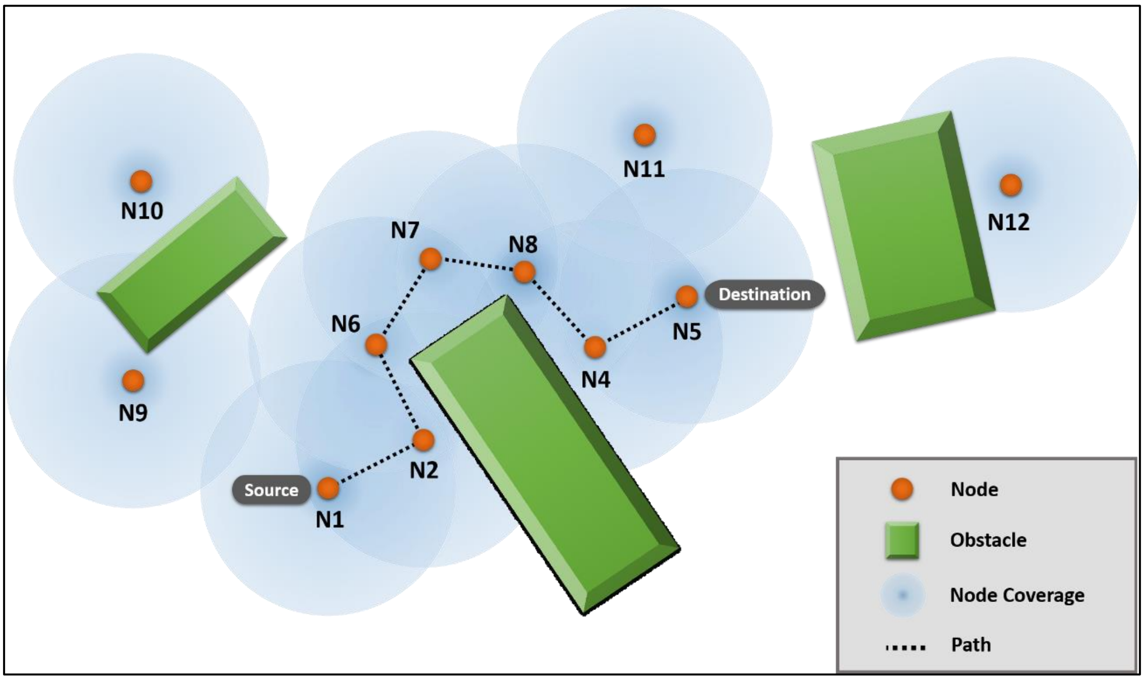


Figure 6.7: Route discovery to avoid obstacle

6.6 Simulation Environment

The simulations were run using the OMNET++ simulation tool. The network scenario was based on the disaster in Loja City, as described in Section 6.4. The simulation area was 1000 x 2000 m. The random waypoint mobility model was used in this simulation. The number of nodes referred to the density of people. There were between 50 and 200 nodes. At the beginning of the simulation, the nodes were randomly distributed using the random waypoint mobility model. The maximum transmission range of each node was 250 m, even though, in the presence of obstructions, actual transmission range is limited. MAC protocol IEEE 802.11b with 11 Mbps of bandwidth was chosen. In modelling the disaster scenario, network performance was evaluated by varying the speed of nodes. Node mobility speeds from 1 to 2 m/s represented walking people. Speeds of 5 to 32 m/s represented people moving by vehicle. There were also static nodes that remained in the same place. To study the effect on performance, the density of nodes was increased gradually. The simulation time of each experiment was 900 s, with different speeds for every execution.

This scenario included pause time. Pause time, P, represented nodes stopping for a while at one destination to choose another nearest neighbour because their final destination node was obstructed. In this simulation, when P is set as 0, this thesis assumes there is no hindrance throughout the route. Based on the study of pause time in real world environments, the pause time was set between 0 and 300 s [107], [108], [109].

6.7 Simulation Results

In this chapter, the results show the effects of node mobility on GWRS performance using a MANET in a disaster recovery scenario. The velocity of each node referred to the movement of people with mobile devices in the disaster recovery area. Therefore, the mobility of nodes was set according to the minimum and maximum velocity of people walking, driving or remaining stationary in a disaster situation. For static nodes, the velocity was set at 0.

6.7.1 Throughput

As shown in Figure 6.8, it was expected that when nodes were static, the average throughput of nodes would be the highest. Surprisingly, nodes that represented people walking in the disaster area with a velocity between 1 and 2 m/s indicated that even when node density increased from 50 to 200, the throughput outcome was still above 1 Mbps. For nodes in vehicles at maximum velocity, beyond a certain level of node density, the throughput dropped below 1 Mbps but was still above 700 Kbps. This result can be compared to the previous work of Sarmah et al. [110] that measured the performance of AODV, DSDV, DSR and OLSR with varying mobility, speed (0–50 m/s) and node density. DSR showed the best performance among four protocols at speeds from 20 m/s to the maximum, with throughput between 120 and 140 Kbps. AODV performed the best, with a peak throughput of 167.5 Kbps with 80 nodes. However, these schemes did not sustain performance when the network load was higher than 80. This is a significant positive reason why the proposed GWRS scheme can help manage large networks during disasters.

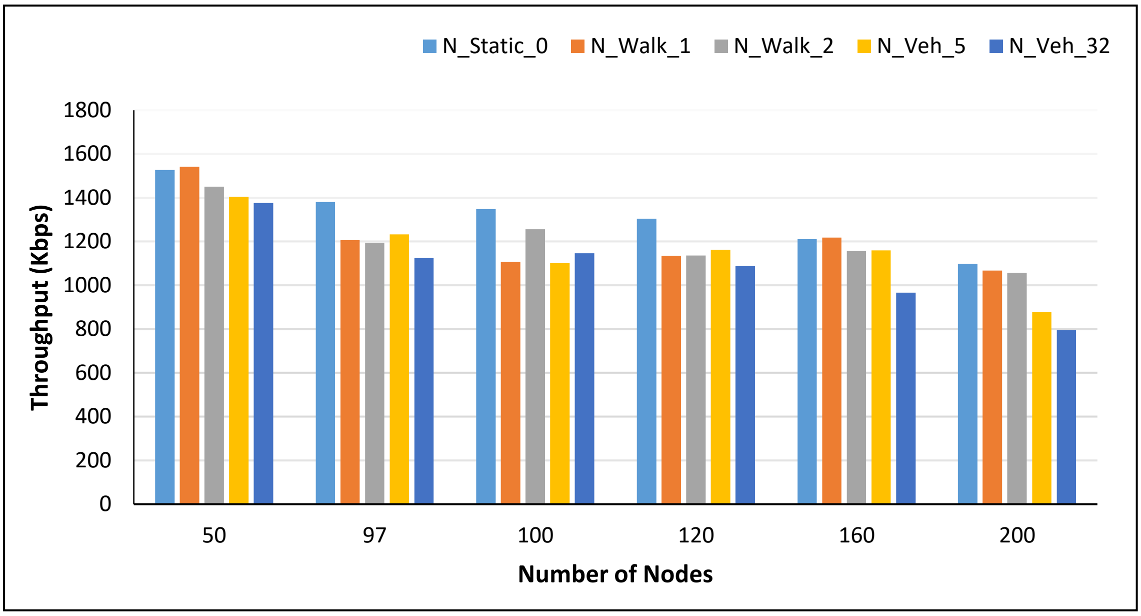


Figure 6.8: Throughput of node mobility

6.7.2 Average Delay

In Figure 6.9, it can be seen that increasing the number of nodes significantly changed the average delay. The peak delay was at the highest mobility speed rate and maximum number of nodes in the disaster recovery area. Since nodes in the disaster recovery area were mobile, when the source node wanted to send a packet to the next neighbour, the neighbour node could suddenly leave the source node coverage range. At static and low movement speeds (representing people walking), the proposed GWRS began with a low delay, which slowly increased when the movement speed of nodes increased. The density of nodes in the disaster area with a high movement of speed (32 m/s) increased the average delay.

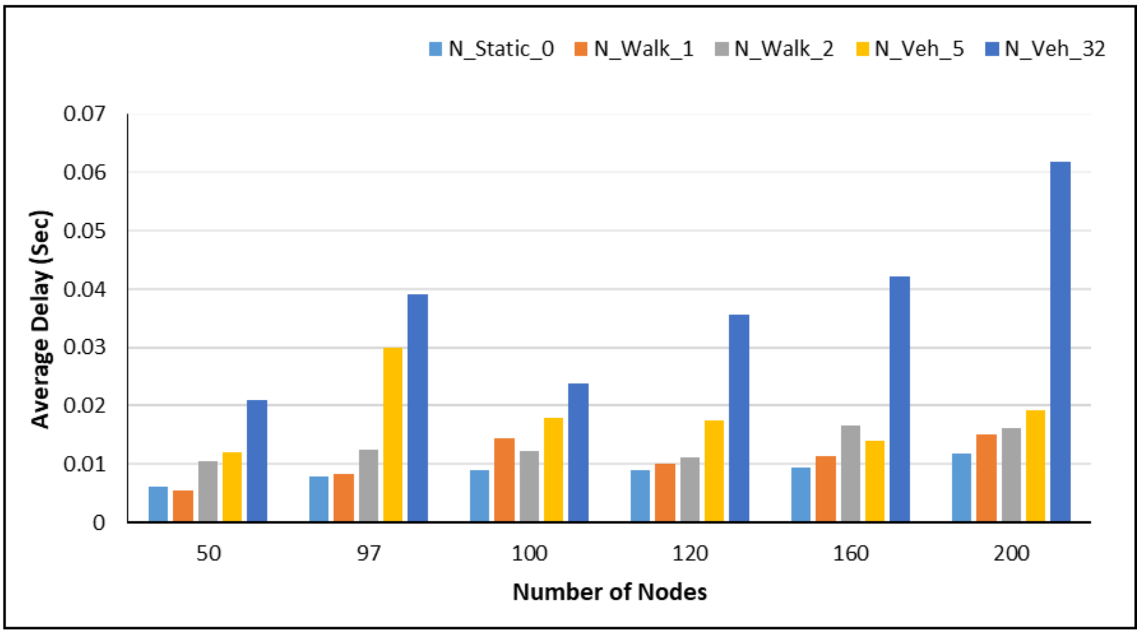


Figure 6.9 Average packet delay

6.7.3 Packet Drop and Packet Delivery Ratio

Performance analysis was continued by determining the packet drop ratio. From the graph shown in Figure 6.10, it can be seen that with a static mobility, as the number of MNs increased, the packet drop ratio also increased. The same pattern also applied to a mobility speed of 32 m/s, which represented people in vehicles in the disaster recovery area. However, no gradual increase was found for the minimum and maximum speed of people walking or for the lowest speed of people in vehicles. The bar chart shows a fluctuation graph by way of nodes starting to move slowly in the area.

The effect of this finding can be seen in relation to the results of packet delivery ratio in Figure 6.11. When there were 50 nodes in the disaster recovery area and people were standing in the same place without moving, the maximum packet delivery ratio was reached. The lowest packet delivery ratio was seen when there were 200 nodes in the area and speed was increased to the extreme vehicle speed. This happened because when the number of nodes increase, there are more destinations to which the GWRS routing scheme must deliver the packet. Packet delivery dropped to the lowest as mobility speed surged to the maximum rate.

In addition, as graphs show fluctuation in packet delay, the graph of packet delivery ratios also shows the variation of results for mobility speeds 1 m/s, 2 m/s and 5 m/s. With each variation of node density, excluding 200 nodes, delivery of packets became intermittent and fluctuated, led by vehicles with a speed of 5 m/s, followed by people walking at a speed of 1 m/s. At a density of 200 nodes, the contrast between these speeds was only 2.7%. Walking people were left behind. Walking people with a speed of 2 m/s started with the lowest and then remained intermediate from a density of 120 nodes.

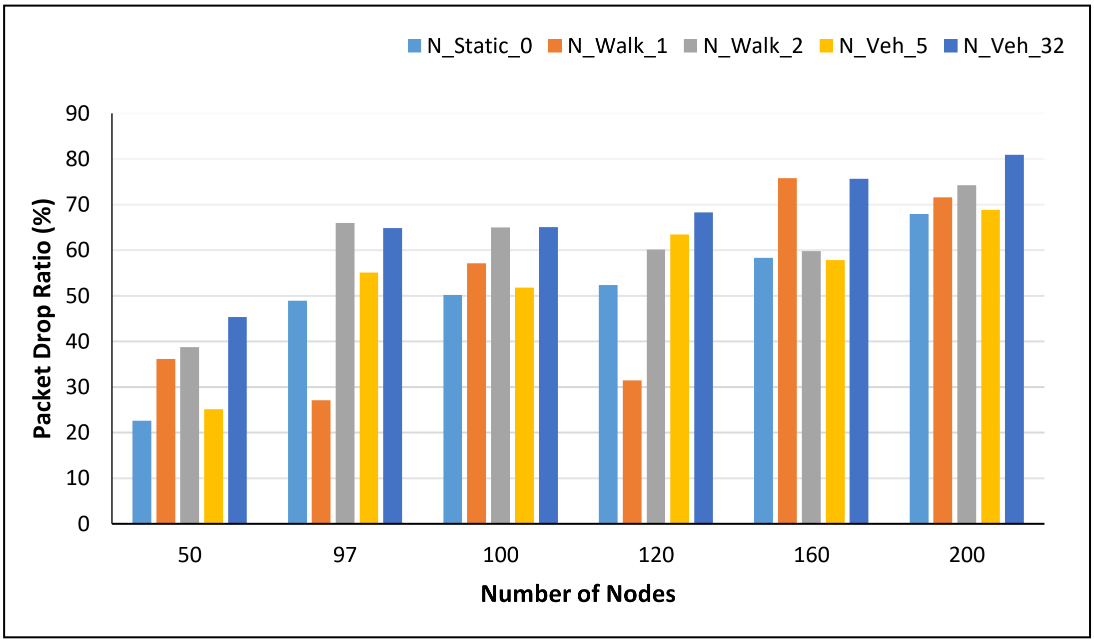


Figure 6.10: Packet drop ratio

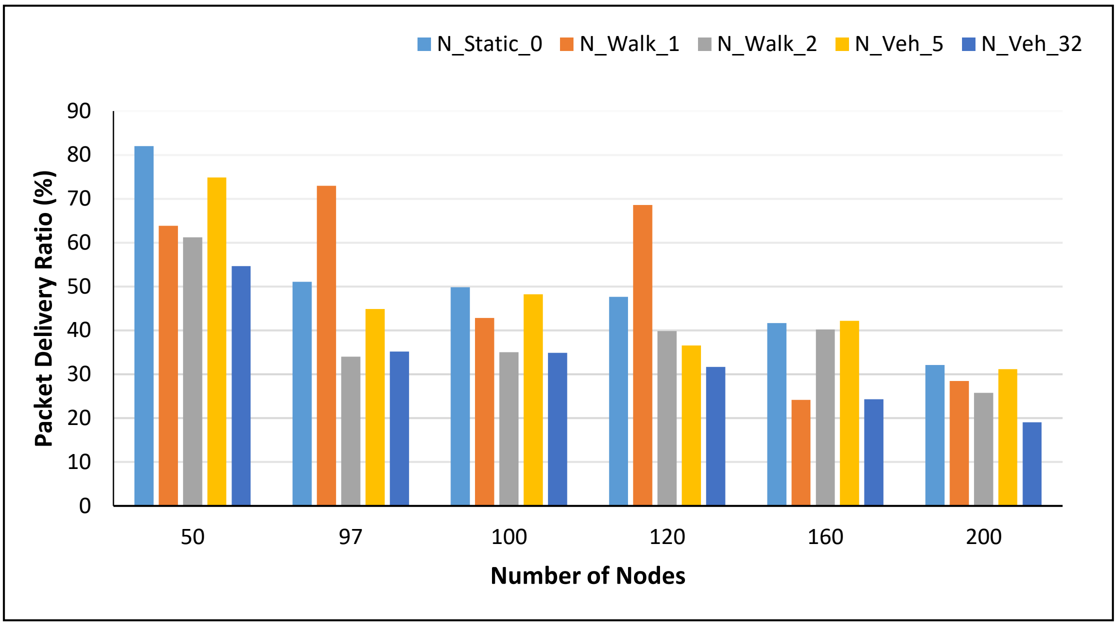


Figure 6.11: Packet delivery ratio

6.7.4 Sent Packet Rate

The chart of the sent packet rate, shown in Figure 6.12, identified the consistency of this research. Packet sent rate per second increased as the number of nodes in the disaster recovery area increased. The sent packet rate indicated the continuation to the packet delivery ratio. At a total number of 50 nodes in the area, the GWRS scheme delivered over 80% of packets, with a ratio of 18 packets per second. When people started walking, the average ratio decreased to 16 packets per second, and the number continued to drop until reaching 11 packets per second. The average packet delivery ratio across varied vehicle speeds was 65%. Since the number of nodes was small, at a certain time only several packets were communicated. Therefore, the sent packet rate was also small. The peak sent packet rate occurred with the highest node number variation and when the average speed was between 0 and 32 m/s. A density of 200 nodes showed many people wanted to communicate at the same time. The packet rate was 62 packets per second and only reduced by 9 packets at the highest node mobility speed. However, because of the limitations in sending messages during disasters and the effects of node mobility speed, the packet delivery ratio was the lowest among others. These analyses show that node mobility speed in disaster recovery area does affect MANET performance.

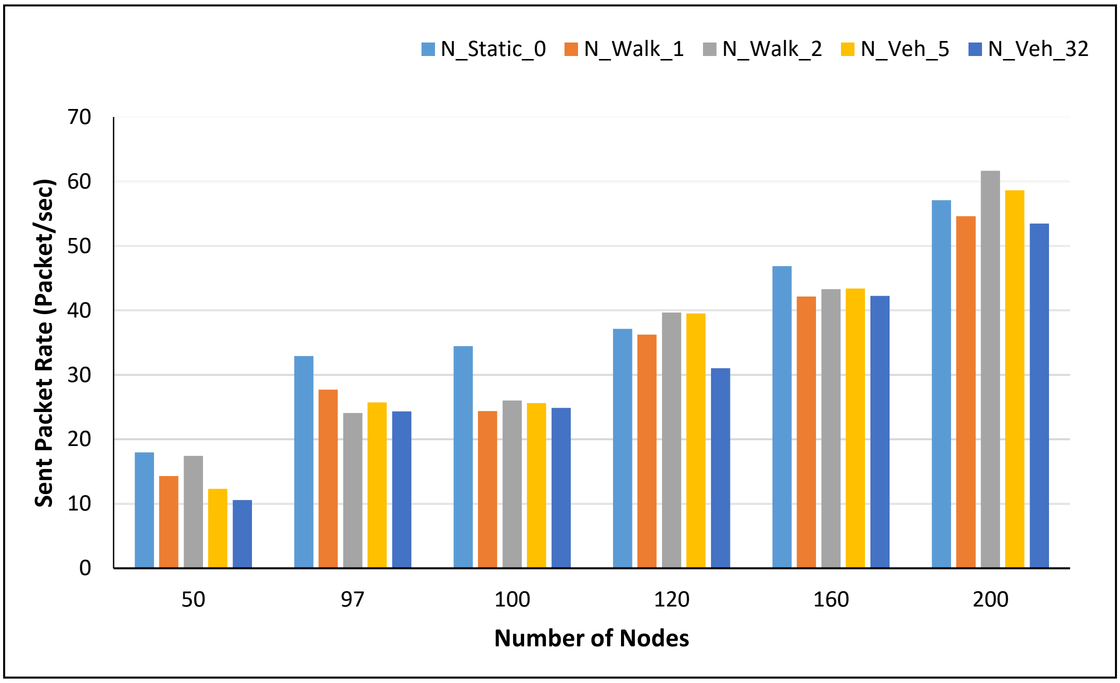


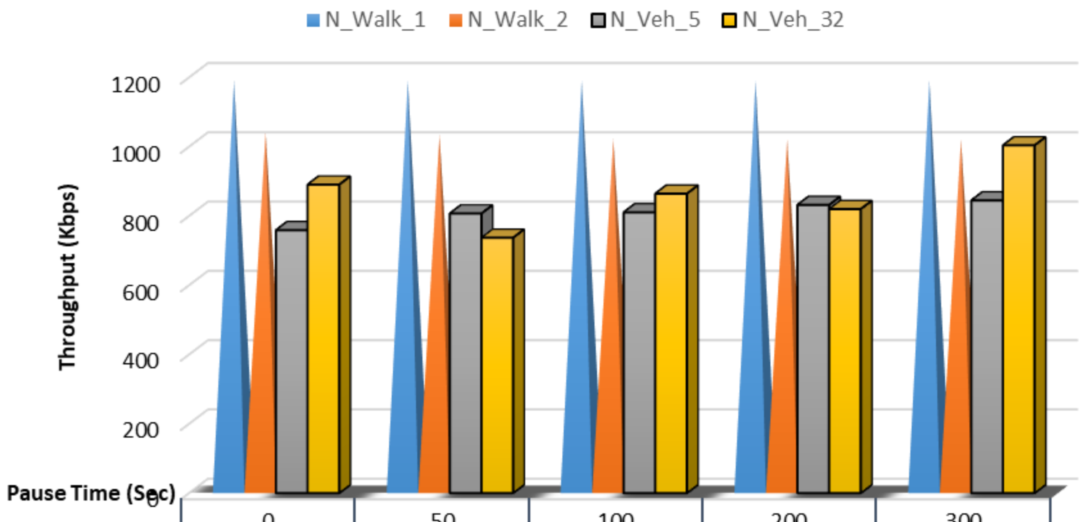
Figure 6.12: Sent packet rate

6.8 Pause Time

The study of the effects of node mobility in disaster recovery areas in this chapter identified that the movement of nodes with different velocities affects the performance of MANETs in disaster recovery areas. This study continued by analysing the speed of MNs and pause time. According to the random waypoint mobility model, pause time occurs when MNs stay in one place for a random amount of time and then move to a new chosen place [111]. As described in Section 6.6 at the beginning of this chapter, this thesis represented pause time through nodes in the disaster recovery area that stopped for a while at one destination before choosing the next nearest neighbour because the route to the final node was obstructed by an obstacle. The results of pause time were compared to evaluate the performance of the GWRS scheme. Sarmah et al. [110] conducted a comprehensive performance analysis of AODV, DSR, DSDV and OLSR by varying mobility, speed and network load. To further analyse using the same varying mobility parameters, the proposed GWRS scheme was compared with those schemes. The GWRS scheme performed significantly better than AODV, DSR, DSDV and OLSR.

6.8.1 Throughput

In this thesis, a MANET in a disaster recovery area was used as a case study to evaluate GWRS scheme performance. Pause time was incorporated by means of nodes stopping at certain places before determining their next direction and then moving until they reached their final destination. This process was repeated.



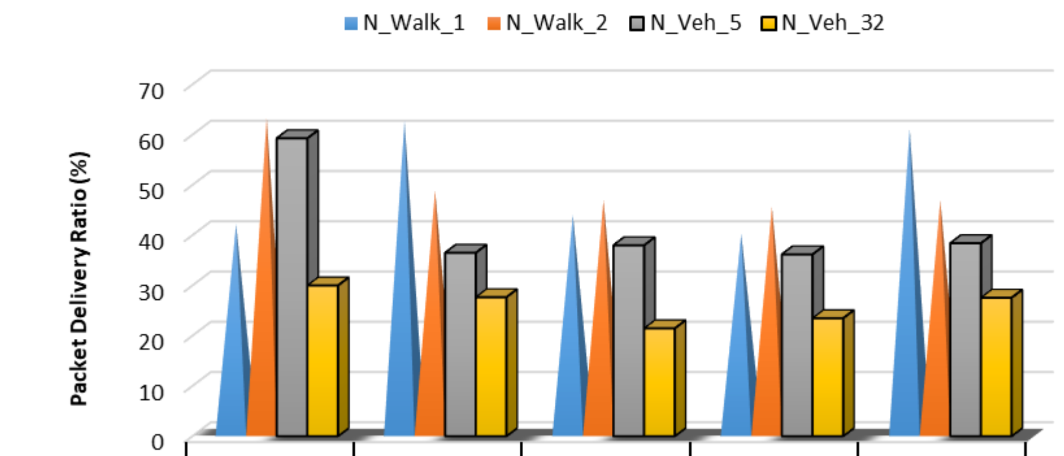
Pause Time (Sec)	0	50	100	200	300
N_Walk_1	1180.043	1180.924	1181.172	1180.562	1181.323
N_Walk_2	1030.533	1023.09	1010.538	1009.609	1009.155
N_Veh_5	759.0961	807.221	810.485	832.0263	845.0084
N_Veh_32	890.5678	737.1468	864.4087	820.0046	1003.93

Figure 6.13: Throughput versus Pause time

The bar chart in Figure 6.13 shows the throughput performance of two groups. The pyramid shape represents walking people, while the rectangle box represents people in vehicles. Walking people showed the highest throughput for all variations of pause time. The results indicated that when node mobility speed was reduced, throughput significantly increased. However, as mobility speeds rose, throughput performance decreased. In cases of higher mobility, the GWRS scheme found it difficult to locate the next hop because all nodes in the area were moving fast. Despite that, when the results were compared to those reported in [110], GWRS still performed better.

6.8.2 Packet Delivery Ratio

The bar chart in Figure 6.14 represents packet delivery ratio. The results obtained from the figure show that people in vehicles travelling at maximum speed had less packet delivery. Although the pause time increased, which gave enough time for nodes to perform well in choosing the next hop, the ratio did not reach 30%. As node mobility speed decreased to 5 m/s, packet delivery increased from 36% to 59%. For walking people, as node mobility speed decreased and pause time increased, performance fluctuated. People walking at maximum speed with a pause time of 0 had only 62% packet delivery. Performance decreased gradually as pause time increased.

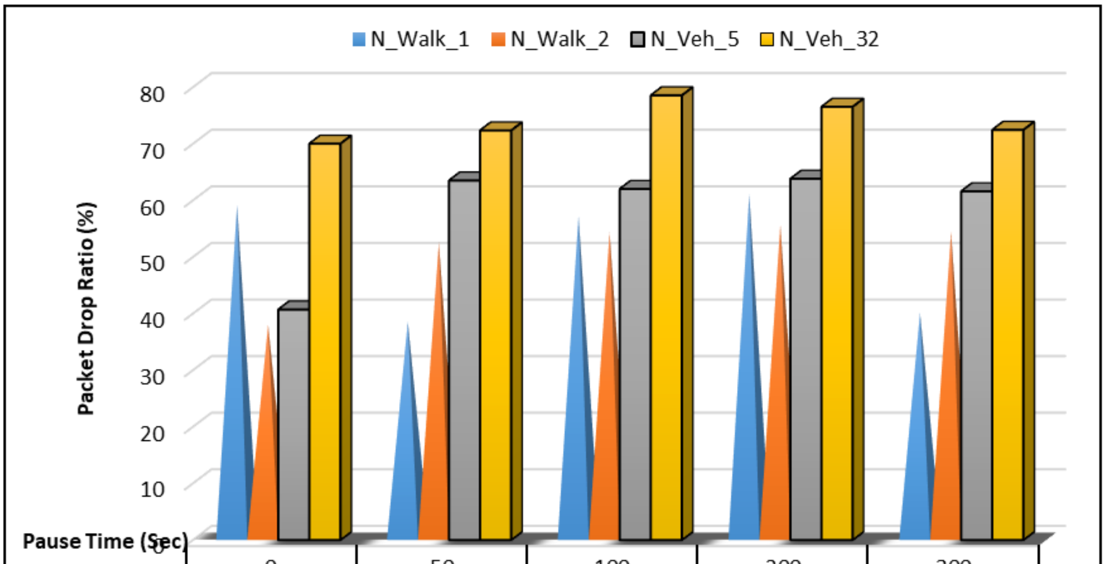


Pause Time (Sec)	0	50	100	200	300
N_Walk_1	41.46	62.06	43.34	39.55	60.51
N_Walk_2	62.6	48.19	46.29	44.97	46.21
N_Veh_5	59.27	36.48	37.98	36.17	38.39
N_Veh_32	29.98	27.64	21.44	23.46	27.54

Figure 6.14: Packet delivery ratio versus Pause time

6.8.3 Packet Drop Ratio

Figure 6.15 shows that nodes at maximum speed with various pause times constantly dropped the packet to the highest value. Nodes travelling at the minimum speed performed best because only 39% of packets were dropped at the maximum pause time of 300 s. When pause time was 0, which meant nodes were moving without break, nodes representing people walking at maximum speed performed best, with only a 37% packet drop ratio. This shows that a node speed of 2 m/s without pause time can reduce packet drop rates. However, obstacles will usually be found in the disaster recovery area, which makes nodes stop at one place for a time before continuing to find other available routes. Therefore, to achieve the best performance when facing an obstacle in a disaster recovery area, nodes should move slowly to avoid packet drop.

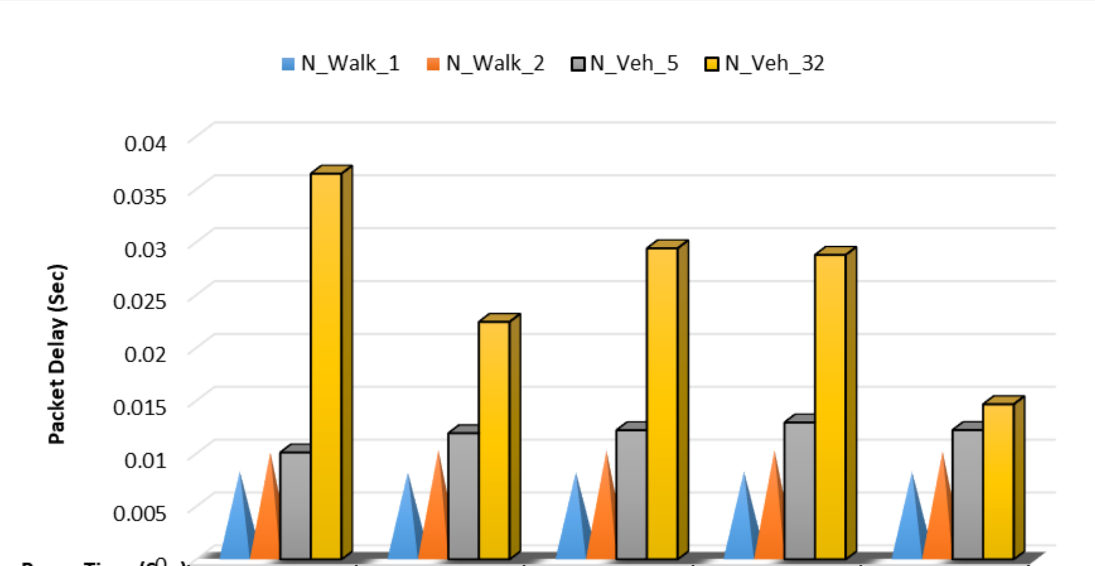


Pause Time (Sec)	0	50	100	200	300
N_Walk_1	58.54	37.93	56.66	60.45	39.49
N_Walk_2	37.4	51.88	53.71	55.03	53.79
N_Veh_5	40.72	63.52	62.02	63.83	61.61
N_Veh_32	70.02	72.36	78.56	76.54	72.46

Figure 6.15: Packet drop ratio versus Pause time

6.8.4 Average Delay

In Figure 6.16 it can be seen that all nodes with a mobility speed that represented people walking had lower packet delays with various pause times. As discussed in Section 6.8.3, nodes that moved slowly in disaster recovery areas performed better. Packet delay for nodes that moved in vehicles at the minimum speed of 5 m/s slightly increased but there was not a huge difference for nodes representing walking people that moved at a maximum speed of 2 m/s. People in vehicles at the maximum speed had the maximum delay. Surprisingly, these groups of people had less packet delay when the pause time was increased to a maximum of 300 s. There was only a 0.002 s difference for nodes with a mobility speed of 5 m/s. From Figure 6.16, it can be concluded that when node mobility reached the maximum speed, packet delay was higher if the node was moving without stop. The longer pause time benefitted nodes moving at high velocities.

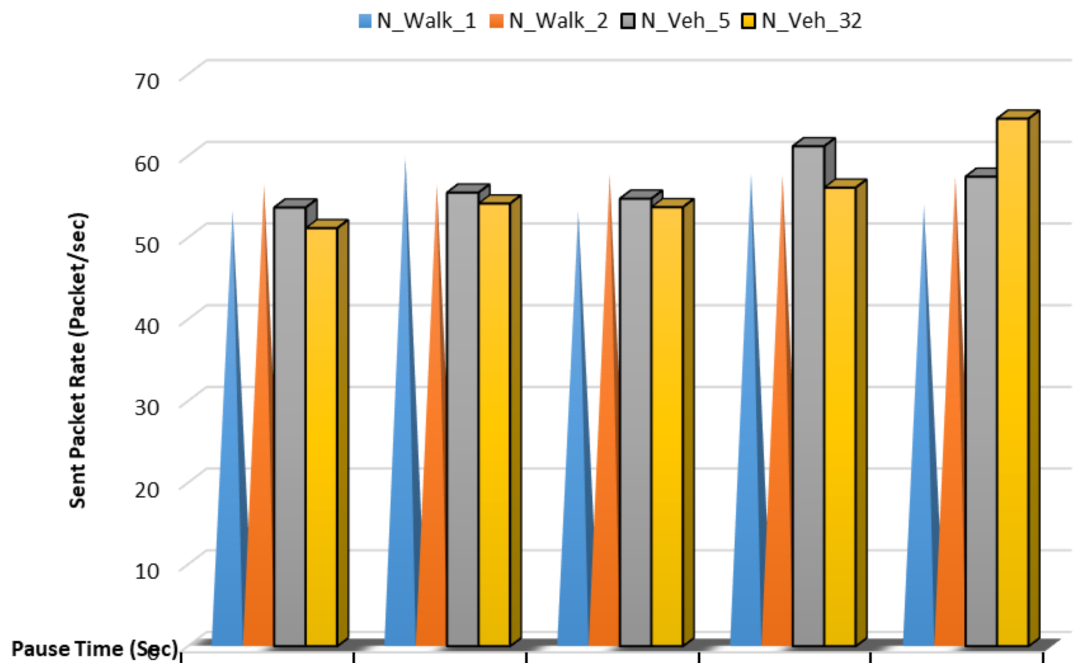


Pause Time (Sec)	0	50	100	200	300
N_Walk_1	0.007964	0.007862	0.007896	0.007947	0.00794
N_Walk_2	0.009801	0.00999	0.009916	0.009962	0.009867
N_Veh_5	0.010101	0.01192	0.012205	0.012936	0.012219
N_Veh_32	0.036468	0.022453	0.029412	0.028784	0.014663

Figure 6.16: Packet delay versus Pause time

6.8.5 Sent Packet Rate

Figure 6.17 represents the sent packet rate for nodes with different mobility speeds and pause times. The results show the effects of pause time, which represented an obstacle to the node that was constantly moving in the disaster recovery area. It clearly shows that the sent packet rate is almost the same for nodes moving at different velocities, although nodes had varying pause times. The graph shows that the sent packet rate for groups of people with vehicles gradually rose when the pause time was larger than 50 s. Overall, the sent packet rate was above 52 packets per second for all different pause time. Based on this finding and the packet delivery results in Section 6.8.2, nodes that stopped at a certain place for a while achieved a better packet sent rate.



	0	50	100	200	300
N_Walk_1	52.85	59.39	52.81	57.45	53.55
N_Walk_2	56.07	56.05	57.33	57.2	57.04
N_Veh_5	53.7	55.53	54.78	61.2	57.47
N_Veh_32	51.17	54.19	53.74	56.13	64.57

Figure 6.17: Sent packet rate versus Pause time

6.9 Summary

In this chapter, a performance analysis was performed to investigate the effects of MANET node mobility in disaster recovery areas. In previous chapters, the performance of the proposed GWRS scheme was analysed. This chapter identified the significant effects of node mobility speed in disaster recovery areas on the performance of GWRS.

The objective was to determine a suitable mobility pattern for this simulation that could mimic the movement of real victims in a disaster recovery area. The specifications that were considered were node speed, direction, position and the way nodes moved within the area. Despite that fact that MANETs commonly use the random waypoint mobility model, this model was chosen because it can represent the motion of nodes that can move with a random speed at any time in any direction in the set area. In addition, this model was used because of its ease and wide availability. Before nodes changed direction or speed, a pre-set pause time was considered. Nodes randomly chose speed and the next destination within range before the time duration expired. The same process was repeated until the message arrived at the destination. Pause time in this simulation represented obstacles in the way of victims in the disaster recovery area. Upon facing an obstacle, the node stopped for a certain duration (between 1 and 300 s), determined by the complexity of the obstacle. Each node in the simulation area was set as mobile. The nodes represented three groups of people within the disaster recovery area: first, people who remained seated in the same place; second, people walking with a minimum speed of 1 m/s and maximum speed of 2 m/s; and third, people in a vehicle with minimum speed of 5 m/s and maximum speed of 32 m/s. The simulation of the disaster scenario was based on the natural disaster in the Loja City area, which resulted in public communication network failure and involved a density of 50 to 200 people.

The effect of node mobility in disaster recovery was investigated by the simulation that used various mobility speeds, as stated above. Network performance was measured in term of throughput, average delay, packet drop ratio and sent packet rate. The results were compared to previous work that measured AODV, DSDV, DSR and OLSR schemes with varying mobility, speed and node density. DSR performed best among the four protocols at speeds from 20 m/s to maximum, with throughput between 120 and 140 Kbps. AODV performed best, with a peak throughput of 167.5 Kbps with 80 nodes. However, these schemes could not sustain performance when the network load was higher than 80.

This is a significant positive reason why the proposed GWRS scheme is a solution to the problem of managing large networks during disasters. Obstacles are usually found in disaster recovery areas, which make nodes stop in one place for a certain time before continuing to find other routes available. It can be concluded that to achieve the best performance, the best act when facing an obstacle in a disaster recovery area is to move slowly to avoid packet drop. When node mobility reaches maximum speed, packet delay will be higher if nodes are moving without stop. A longer pause time will benefit the node that is moving at a high velocity.

Node mobility does influence the performance of GWRS schemes used in MANETs in disaster recovery. This conclusion is consistent with all the results obtained in this simulation. The implications for network planning and deployment are discussed in Chapter 7.

Chapter 7

Implications for Network Planning and Deployment

7.1 Introduction

The issues influencing MANET performance in network disaster recovery were studied and analysed in Chapters 3–6. A primary objective of this thesis was to develop a communication network that was isolated in the disaster area. Inaccessible mobile devices in the area can form a dynamic MANET, in which some nodes can receive Internet coverage through alternative disaster recovery technologies such as using cellular networks on wheels, nodes configured as gateways. To achieve this objective, recommendations can be drawn from the results in this thesis regarding better design and cost-effective planning for deploying communication networks in disaster recovery.

Deploying a MANET in a disaster area to improve the failed communication network is right, suitable and reliable. MANETs do not require infrastructure and are easy to deploy, which is the reason why MANETs are recommended as a solution after natural disasters. Each mobile node in a MANET is independent and can act as a relay to other nodes.

Nodes in a MANET can communicate with each other depending on their coverage area. The technologies commonly used for communication in ad hoc networking is wi-fi defined according to 802.11 standards.

A group of mobile wireless nodes can spontaneously form an Internet protocol (IP) based network. However, because nodes can enter and leave the network, IP addresses are not permanently owned by the nodes. The IP address assigned to a node when it enters the network will be released when the node leaves the network. Nodes which are the destination of other packets are configured with an IP address set as a default gateway. The configuration is considered because a MANET cannot stand alone. The default gateway has a connection to an external network, such as the Internet. The results of Chapters 4 and 5 showed that the deployment of MANETs must consider the method of packet transmission. The routing method when nodes send a packet from source to destination affects MANET performance. The method by which gateways manage packet load and how nodes choose a gateway as a relay to the Internet affects the network. This thesis presented a method for improving MANET performance. The scheme proposed in Chapters 4 and 5 is suitable to deploy in any group-based network.

7.2 An evolutionary path for adopting IEEE 802.11

Figure 7.1 shows an evolutionary path for adopting and deploying wireless technology in this thesis. At the bottom left shows first generation and low performance speed of the wireless technology. However Wi-Fi technologies express perfection from year to year. Until at the top right, sixth generation in the future enhance wireless technology to higher speed and coverage. As for today, the fifth generation 802.11ac has offers maximum bandwidth at 1Gbps compared to the conventional generation 802.11 and 802.11b was only 2Mbps and 11Mbps respectively. For reliable communication in emergency scenarios such as disaster recovery, the conventional wireless network 802.11b is suits the requirement [112] to provide good Quality of Service.

IEEE generation for 802.11g/a and 802.11n offer moderate speed performance which is 54Mbps and 600Mbps. It is commonly used as a hotspot at homes, offices and coffee house for Internet access. However, 802.11g is more compatible and cheaper compared to 802.11a. On the other hand, as latest generation before 802.11ac, 802.11n improved network throughput of 802.11g and 802.11a in respect of maximum speed and transmission capabilities.

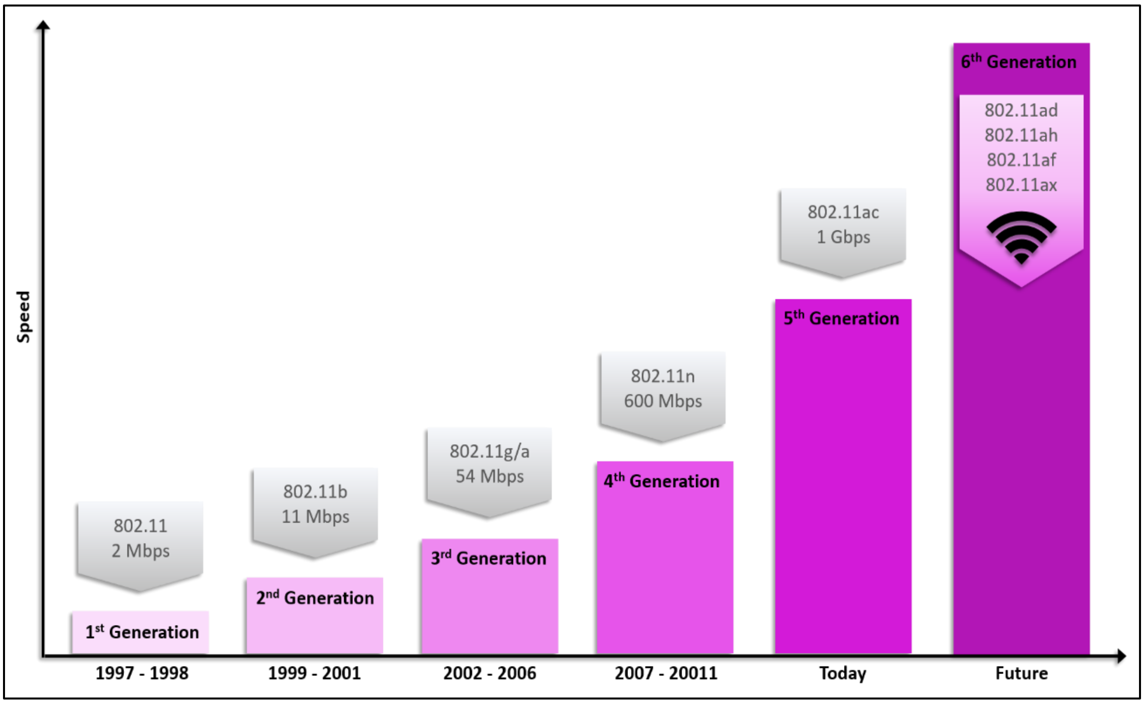


Figure 7.1: Evolutionary path for IEEE 802.11

7.3 Deployment of MANETs in Disaster Recovery

The deployment of wireless network for MANET in disaster recovery scenarios is a challenge as high data rates is required for communication. Reliable communication infrastructure is crucial to communicate with the victims in the disaster recovery area. Based on research study on the previous work, this thesis has chosen second generation of wireless network protocol which is 802.11b to be used in the simulation. This thesis has examined the effects of people moving around in a disaster area with different velocity. Analysis results from Chapter 6 shows that mobility has a significant effect on the Wi-Fi link throughput. Particularly when the density of nodes is increased.

7.3.1 Dense Network Scenario

When disaster happens, it is a complex challenge for disaster relief communications. Communication infastructures such as cellular tower may completely have destroyed. Condition become severe when it involves the high density of victims in the area. In Chapter 4, the thesis has investigated the effect of the node which is node represent as a victim in disaster recovery area. It was shown that as the number of victims increased in the area, communication throughput was reducing. However, in some cases, there are nodes which have high number of neighbours while others have less because nodes not travel over the whole area. The effects were graph shows different throughput such as for node with velocity of people walking and people in vehicle, the graph was up and down when the node density increases. While Figure 6.9 shows node with high velocity has huge impact to the average delay results when node density was maximum.

7.3.2 Large Network Scenario

This thesis has focused on analysing the effects of GWRSs on MANET performance, using the natural disaster in Loja City, Ecuador, as a scenario. Nodes in a disaster area are expected to move around with different velocities. This thesis considered node mobility parameters to mimic the movement of people during disaster recovery. It is a challenging task for a network engineer to deploy communication in network disaster recovery. The network engineer must determine the optimal number of nodes, the optimal velocity of the nodes in the disaster area and a suitable location for the gateway to achieve the desired performance and coverage. The results presented in Chapter 5 showed that the ratio of the number of gateways to the number of nodes should be balanced to avoid packet delay and packet loss because communication plays a crucial role after disaster strikes. The analysis in this thesis used the actual ratio of the number of people involved in the disaster in Loja City.

7.3.3 High Node Mobility

In Chapter 6, this thesis studied the minimum and maximum velocity of people moving in a disaster. This measurement involved extensive consideration of; (1) people who do not move anywhere, (2) people walking with minimum and maximum velocity, (3) people in cars with minimum and maximum speed, and (4) people suddenly stopping at a certain place for a period of time.

Another contribution of this thesis was to analyse the effect of node mobility on MANET performance in disaster recovery areas. This thesis investigated the issues and challenges in disaster recovery, such as: (a) obstacles, (b) nodes unexpectedly joining or leaving the network, and (c) signal propagation. Based on the analysis obtained from the simulation results, node mobility affects network performance. This thesis can be a reference to assist network engineers in planning and deploying network recovery in disaster areas. When deploying communication networks in a disaster situation, the network engineer must consider installing optimal networking devices that can support high performance.

7.3.4 Summary of Findings

Tables (7.1 to 7.4) summarise the empirical results of MANET performances presented in Chapters 4 to 6. The number of Gateways was set to 3, 10, and 32 for low, medium, and high network scenarios, respectively. Likewise, the number of nodes was set to 50, 120, and 200 considered as low, medium, and high network scenarios, correspondingly. However, the velocity of nodes was set to 1, 5, and 32 (m/s) for low, medium, and high network scenarios, respectively.

Table 7.1 presented when the number of nodes is 50, 3 gateways are sufficient to be placed in the disaster recovery area because it does not give much difference in throughput even though the number of gateways increased. However, when nodes density growths, number of gateways need to increase in ensuring better MANET performance of packet throughput. Therefore, as for network planning, the estimated number of victims in the disaster area is needed to determine how many gateways are required to install. Yet, in some cases, when the number of nodes in disaster recovery area is less, nodes could not find the neighbours because the neighbours' node was not in the node's coverage range. To send a packet until it arrives at the destination, the node must find a neighbour within node coverage range. Otherwise, the packet delay will increase and lead to packet drop after a certain time. In network planning and deployment perspective, to solve this problem, advanced technology must be used which offer wide and stable coverage for the mobile devices.

Table 7.1: Percentage Performances of Gateway

Change in performances (%)				
Number of Gateway		Low (<=3)	Medium (4-10)	(High 11-20)
Throughput	50 nodes	74	76	74
	120 nodes	40	67	64
	200 nodes	49	50	51
Average Delay	50 nodes	0.8	1.1	1.7
	120 nodes	0.8	1.0	1.5
	200 nodes	2.8	2.6	1.7
Packet Drop	50 nodes	35	44	23
	120 nodes	39	33	29
	200 nodes	54	37	27
Packet Delivery	50 nodes	65	56	77
	120 nodes	61	67	71
	200 nodes	46	63	73

In Table 7.2 as presented in Chapter 5, percentage performances show proposed scheme has offer better performances compared to conventional routing scheme AODV and DSDV. Packet throughput of the proposed scheme was well performing in any number of nodes. AODV and DSDV used conventional techniques which give high congestion in the network. That was the reasons packet throughput is low even though the density of nodes is low.

Table 7.2: Percentage Performances of Routing

Change in Performances (%)				
Number of Nodes		**Low (<=50)**	**Medium (51-120)**	**High (121-200)**
Throughput	Proposed	73	59	38
	DSDV	6	6	5
	AODV	6	5	5
Average Delay	Proposed	1	1	3
	DSDV	6	17	25
	AODV	11	29	43
Packet Drop	Proposed	26	31	39
	DSDV	38	43	46
	AODV	37	42	46
Packet Delivery	Proposed	80	75	69
	DSDV	79	71	54
	AODV	80	72	56

The Velocity of nodes as shown in Table 7.3 can help the process of planning and network deployment when disaster occur. The table demonstrate when victims move in maximum velocity and with high density in the disaster area, packet drop was up to 81% and packet delivery was only 19%. Therefore, suggestion from this research is victims must choose low speed to send a message. Victims must be educated about this technique to make sure message send is arrives to the destinations, as in disaster recovery situation communication was very important.

Table 7.3: Percentage Performances of Velocity of Nodes

Change in Performances (%)				
Number of Nodes		**Low (<=50)**	**Medium (51-120)**	**High (121-200)**
Throughput	N_Static_0	76	65	55
	N_Walk_2	73	57	53
	N_Veh_32	69	54	40
Average Delay	N_Static_0	0.6	0.9	1.2
	N_Walk_2	1.0	1.1	1.6
	N_Veh_32	2.1	3.6	6.2
Packet Drop	N_Static_0	23	52	68
	N_Walk_2	39	60	74
	N_Veh_32	45	68	81
Packet Delivery	N_Static_0	82	48	32
	N_Walk_2	61	40	26
	N_Veh_32	55	32	19

Table 7.4: Percentage Performances of Pause Time

Change in Performances (%)				
Velocity of Nodes (m/s)		**Low (1)**	**Medium (2-5)**	**High (6-32)**
Throughput	Pause Time 50	59	40	37
	Pause Time 200	59	42	41
	Pause Time 300	59	42	50
Average Delay	Pause Time 50	0.8	1.2	2.2
	Pause Time 200	0.8	1.3	2.9
	Pause Time 300	0.8	1.2	1.5
Packet Drop	Pause Time 50	38	64	72
	Pause Time 200	60	64	77
	Pause Time 300	39	62	72
Packet Delivery	Pause Time 50	62	36	28
	Pause Time 200	40	36	23
	Pause Time 300	61	38	28

Table 7.4 presented performances changes as pause time increases. If nodes move at maximum velocity, to send a message and keep the packet throughput high, nodes must stop for a while. The longest node stops which represent as victims with mobile devices stop at a certain place, the higher reliability in MANET performances. On the other hand, when node moving slowly in the area it does not give any effect if nodes take minimum or maximum pause time. However, it is obviously different in packet throughput performances when node speed is high, the performances is improving when pause time increased.

7.4 Future Research Directions and Recommendations

This thesis has provided contributions for efficient gateway and routing selection schemes in disaster recovery environment. The aim was to answer the research questions "What are the factors that influences MANET performance in the disaster recovery area?" and "How MANET performance can be enhanced to achieve better network performance in disaster recovery scenarios?". This section outlines some research issues that could help further investigation for future extension of this research.

7.4.1 Evaluate Performances Using Other Mobility Models

While the effects of node mobility and node pause time were investigated in Chapter 6, there are some issues that still need to be considered. An analyse of the performance of the GWRS scheme using other mobility models which has more realistic characteristics of modeling disaster area, such as disaster area mobility model [113] and Reference-point-group.

7.4.2 A Simulation Tools

To embeds the different mobility models, a suitable simulation tools must be studied to comply with the development of different mobility models. Using same case studies but different tools might give different results. Therefore, a dedicated simulation tools that support to embeds different mobility models must be well analysed before the simulation tools is chosen. The deployment of the inexpensive of proposed GWRS scheme to eliminate congestion and the complexity of route discovery also can be enhanced to suit with another environment such as for Internet of things, Wireless sensor network and D2D in the future

7.4.3 Applying Network Lifetime

To provide reliable communication between nodes in MANETs, the route establishment process should have more reliable links. Reliable links will depend on the remaining battery life of the node. Therefore, network lifetime will be another important performance metric to optimise.

7.4.4 Applying Voronoi Diagram

For detailed investigation of communication network performance in disaster scenarios, the performance of node connectivity when avoiding obstacles using Voronoi diagrams must be simulated and analysed. However, Voronoi diagrams do not provide the shortest path algorithm. Thus, this approach can be combined with the proposed GWRS scheme for efficient route discovery in a similar network approach.

7.5 Summary

This chapter has presented guidelines for deploying MANET in disaster recovery area. These guidelines have been derived from the analysis of results presented in Chapter 4 until Chapter 6. Several possible extensions for this research have also been suggested. This research has shown that selection gateway schemes, routing protocols and node mobility play an important role in improving network performance. This research realised the importance of network features in disaster recovery that must be accounted for. The analysis in this research considered high mobility, varying node density and varying pause time. To summarise the results obtained: an analysis of MANET performance in network disaster recovery that examines GWRSs is a useful contribution.

Recommendations for future developments of this research are outlined. It includes evaluate performances using different mobility model which more realistic for disaster recovery scenario, a dedicated simulation tools that support the mobility models must be studied to choose the right tools, applying network lifetime as one of the performance metrics since battery life is another crucial issue in disaster recovery situation. Applying Voronoi diagram into GWRS scheme that incorporate with different mobility model is also suggested as future work. Summary developments of this research are outlined in the next chapter.

Chapter 8

Conclusion

This thesis focused on MANET performance in disaster recovery areas. The rise of the Internet has changed the way people communicate and live. Connecting devices wirelessly to the Internet makes living effortless and life without the Internet would not be possible. However, a breakdown of network communication caused by a natural disaster can leave people isolated from the world. The natural disasters that strike many places nowadays and the failure of telecommunication infrastructures are motivations to improve network communication during disaster recovery.

A MANET is a mobile ad hoc network that can play an important role after a disaster occurs because a MANET can be set up in disaster area within a few hours [114] without relying on any network system. This makes MANETs one of the best solutions when network communication fails. All nodes in a MANET are mobile devices that move around with different velocities in the disaster area. To forward a packet from source to destination, each neighbour node will act as a relay in forwarding the packet until it arrives at the destination. Nodes that receive external coverage will act as gateways to allow other MANET nodes to send packets to an external network, such as the Internet.

To evaluate the performance of MANETs in disaster recovery scenarios, computer simulation methodology was adopted. This performance evaluation methodology was found to be appropriate for the analysis in this research. Computer simulations were used to generalise the measurement results and estimate performance. This thesis made three original contributions, which are presented in Chapters 4–6. These contributions are highlighted below:

A gateway is a mobile device in a MANET area that has connectivity to an external network. Each gateway has a pre-set threshold queue size. However, the queue will quickly fill when there is a high node density that wants to send messages to the external network. To overcome this problem, this thesis developed an enhancement of gateway selection schemes (Chapter 4) to balance the traffic load between gateways. Two scenarios were simulated. The first scenario used general environment parameters. The second scenario was expanded to represent the environment of the disaster in Loja City, Ecuador. Scheme performance was evaluated using the OMNET++ simulation tool with an inetmanet framework.

Performance metrics, such as mean throughput, packet end-to-end delay, packet drop ratio and packet sent rate were used in the evaluation. Parameters were varied for every simulation run. Performance analysis showed that an efficient gateway selection scheme was needed to manage load balancing between gateways. In addition, the results fluctuated when the number of gateways was small and the node density in the area was high.

To improve MANET performance in disaster recovery, Chapter 5 introduced the issues of routing selection schemes, focusing on a disaster recovery scenario. The network topology in a disaster recovery area continually changes as people move around with their mobile devices. Traditional AODV and DSDV routing protocols perform a broadcasting algorithm for route discovery (Chapter 3), which leads to network flooding and complexity in route selection. In disaster recovery scenarios, when victims attempt to connect to the Internet at the same time without an efficient routing selection scheme, there will be an elevation of traffic flow in the network and of the difficulty of route selection. The proposed routing selection scheme led to a substantial improvement in MANET performance compared to AODV and DSDV routing schemes. It was observed that, although the node density in the disaster recovery area was high and topology changed rapidly because of node mobility, the proposed scheme performed better in terms of packet throughput, packet end-to-end delay, packet drop, and packet sent rate.

Chapter 6 investigated the effects of node mobility in disaster recovery areas. The behaviour of nodes was investigated by simulations. It was observed that in a disaster scenario, mobile devices can be highly mobile because of an alarm response and attempts to escape from the disaster area. Simulation results showed that node speed makes it difficult to maintain communication in disaster recovery areas because neighbour nodes can suddenly disappear or change their location randomly. This thesis simulated the GWRS scheme using varied node speeds in each simulation to distinguish the behaviour of nodes representing static people, walking people and people in vehicles during disaster recovery. The results indicated that GWRS provided a high throughput in the case of high node density and varying node speed. However, packet delay and packet drop ratio rose for people in vehicles travelling at maximum velocity. The network throughput of people walking and pausing for a certain period because of an obstacle on the route reached almost more than 1 Mbps, even in different node densities. For people in vehicles travelling at maximum speed, even though the average packet delay was higher compared to that for a low speed person in a vehicle and people walking, the throughput still reached more than 0.7 Mbps. It shows that the GWRS scheme can provide high bandwidth in disaster recovery scenarios. Overall, heterogeneous velocity of nodes in disaster area have a specific impact on the MANET performances.

Appendix A

OMNET++

A.1 OMNET++ simulation environment

Omnet++ is an object-oriented discrete event simulator written in C++. It is an open source software package designed for performance modeling tasks in network communication. In network research, a various of simulation tools have been widely used. Omnet++ is one of the simulation tools that has several frameworks that can be used depending on the scenario that researcher wants to build. One can build from small modules to the complex modules. Simple model can be combined with other models to create the simulation. OMNet++ has provided model framework with different problem domain such as Inet, Inetmanet, Mobility, Mixim, NesT, OverSim, etc. Inetmanet are classified as framework in OMNET++ that support wireless networks without infrastructure such as MANET. The same framework also provide support for wireless networks with infrastructure.

A.2 Common modules

Nodes:

Nodes in a MANET. Nodes in MANET is a host in a wireless network without infrastructure.

Inet.nodes.gwrs.GWRSRouter;

Inet.nodes.inet.AdhocHost

Inet.nodes.wireless.AccessPoint is represents an access-point from Internet on cellular.

World: Module for packet being distributed within range. Through ChannelControl the simulation can set the value for carrier Frequency, Maximum range, number of Channel and etc.

Inet.world.radio.ChannelControl

Inet.world.scenario.ScenarioManager;

WirelessNode receive messages (radio transmissions) via direct sending, so its radioIn gate is marked with **directIn**.

```
gwrs WirelessNode {
   gates:
       input radioIn directIn;
}
```

Protocols and other devices:

Inet.networklayer.manetrouting.base.BaseRouting;

Inet.networklayer.autorouting.ipv4.IPv4NetworkConfigurator;

Inet.networklayer.ipv4.RoutingTableRecorder;

Inet.mobility.IMobility

*Inet.mobility.models.**: to define nodes mobility

Example:

Host[*].mobilityType = "RandomWPMobility"

Host.mobility.speed = 2mps*

A.3 Strenghts and weaknessess

The core strengths of OMNeT++ is a flexible simulation framework. Components of nodes communicate can be easily mapped and simulated. Models in OMNeT++ are independent and never patched by models [115]. OMNeT++ has GUI which users can zooming into component level during running the simulation. The state of each component is also can be display. Packet transmissions between nodes is shown on the GUI while a simulation is running. OMNeT++ also has Tkenv that support interactive execution for simulation environment, which allows one to observe the progress of simulation while change the parameters.

OMNeT++ has an extensive library support. Build a compound module in OMNeT++ would be similar as users build a real network element such as mobile devices, wireless access point, switches, router, etc. Users can choose the interface and organized the source code with layer involved. The Internet Protocols (IP) Addresses was assigned by default alike real machine which have common IP for each interface.

As an open source software package, users can make modification in the source code to suit users needs. Depending on capacity of the computer virtual memory that users used, OMNeT++ have an ability to simulate large scale network topologies. In documentation, OMNeT++ always has up-to-date manual with well written book. It also has a clear guide and tutorials for quick introduction. Besides, it supports the diversity of operating systems (OSs) such as Linux and MS Windows.

Despite possessing strengths, OMNeT++ has several limitations. Firstly, even though it has capacity to run large scale network, it took high memory consumption and long simulation run times. Second, to develop simulation model users need to configure in a text file to combine the different applications. Simulation development in OMNeT++ requires more than just drag and drop components on a workspace.

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