

Self-organizing Mobile Medium Ad Hoc Network in NS-2

by

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Abstract

MANETs (Mobile Ad Hoc Networks) are mobile networks of wireless mobile devices capable of communicating with one another without any reliance on a fixed infrastructure. A M2ANET (Mobile Medium Ad hoc Network) is a set of mobile nodes forming a Mobile Medium and functioning as relays for facilitating communication between the users of this Mobile Medium. Movement of the nodes affects the performance of a M2ANET. We propose a scheme for controlling the movement of mobile nodes in a M2ANET based on an attraction/repulsion paradigm. The new node movement has an advantage over a random movement in keeping the nodes in an unbounded region in a sufficient density to allow for an efficient transfer of data over the Mobile Medium. Simulation results show tripling of the delivery ratio in a self-organizing M2ANET compared to a mobile network with all nodes moving randomly, in one experimental scenario.

Dedication

I would like to dedicate this work to:

My mother, Hammdah. Mummy you inspired my whole life; you are the only school that I will never graduate from. God bless you.

My father, Mohammad. There is no doubt in my mind that without your continued support and counsel I could not have achieved this level of education. Daddy you are the greatest man in my life. God bless you.

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To all those special and precious people in my life, I could not have completed this effort without their assistance and enthusiasm. Thank you all. I am very fortunate to have you in my life.

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Abbreviations

AODV	Ad-hoc On-Demand Distance Vector
CBR	Constant Bit Rate
CBQ	Class-Based Queuing
CIDR	Classless Inter-Domain Routing
DSDV	Destination Sequence Distance Vector
DSR	Dynamic Source Routing
FTP	File Transfer Protocol
LAN	Local Area Network
MAC	Media Access Control
MANET	Mobile Ad-Hoc Network
M2ANET	Mobile Medium Ad-Hoc Network
NAM	Network Animation Tool NS Network Simulator
OTcl	Object Tool Command Language
RED	Random Early Detection
RWPM	Random Way Point Model
RWM	Random Walk Model
TCL	Tool Command Language
TCP	Transmission Control Protocol
Th	Threshold
UDP	User Datagram Protocol

Chapter 1

Introduction

This chapter presents an introduction to the research in Section 1.1. Also, it covers the objectives and motivations of this research in Section 1.2. Section 1.3 specifies the project description. Finally, Section 1.4 presents the organization of the report.

1.1 Introduction

A Mobile Ad Hoc Network (MANET) is an interesting research topic in the area of wireless networks. A mobile Ad Hoc Network (MANET) is a set of mobile nodes that cooperate with each other to perform a certain task [1] [2]. Mobile devices are linked together through wireless connections without infrastructure and can change locations and configure themselves in space.

They act as routers and move dynamically and may follow an algorithm that determines the mobility pattern in the network. Mobility of mobile nodes significantly affects the performance of a MANET [8]. The main objective of this research is to develop a mobility model, which can control the movement of wireless nodes in a boundless area. More specifically, I would like to allow for the mobile nodes to move randomly and keep the nodes together over a given region, which means the nodes should not disperse. The new movement in this report will be used for experimenting with different movement patterns and comparing their impact on performance of MANET, by measuring the packet delivery ratio.

1.2 Background

In simple terms, a network is a group of two or more computers and other devices linked together by communication channels that allow sharing of information and data. Networks can be classified based on which technique is used to link devices in the network. There are two main categories of networks. These are wired and wireless [3]. Wired networks allow a number of computers or devices to connect to each other via cables that transfer data between them. They also need routers that allow for forwarding of data. Wired networks have limited mobility so they are restricted to a specific area [4] [5]. The other type of communication network is a wireless network. Wireless networks are becoming popular in the area of networking and their

techniques are improving rapidly with time. They use high-frequency radio waves rather than wires to maintain communication between a number of computers or devices. Wireless nodes may act both as hosts and routers. They can forward the packets to neighbouring nodes. Wireless networks are designed to overcome the problems of wired networks such as the limitation of mobility. Some advantages can be obtained by using wireless networks such as ease of access, increased productivity, and easy installation. There are two types of wireless networks: Infrastructure Networks and Ad Hoc Networks. Devices in infrastructure networks are always communicating indirectly through a base station. A base station is installed at a geographical location and it sends and receives radio signals. Advantages of Infrastructure networks include greater power, distance, scalability and high security [5]. Ad hoc networks are another type of wireless network. The Latin expression “ad hoc” is the English translation of “for this”. Ad hoc networks do not rely on existing infrastructure because they do not require an access point. A wireless ad-hoc network is a wireless network deployed without any infrastructure. An ad hoc network typically refers to any set of networks where all devices have equal status on a network and are free to associate with any other ad hoc network devices in link range. Each node functions as a router by forwarding data for other nodes, and so the determination of which nodes forward the data is made dynamically based on the network connectivity. This includes Wireless Mesh networks, Mobile Ad Hoc networks, and Vehicular Ad Hoc networks [7].

The Mobile Ad Hoc network (MANET) is one type of wireless ad hoc network. A MANET does not rely on a fixed infrastructure network [6]. Mobile devices in the MANET, which are called nodes, communicate with each other over wireless links and each is free to move in any direction, therefore it changes links to other devices frequently. MANET nodes cannot necessarily form direct links with all other nodes in the network. Nodes that are in each other's transmission range can communicate directly and are responsible for dynamically discovering each other. Radio propagation effects limit direct transmission range. In order to communicate between nodes that are not directly in each other's transmission range the source sends the packet to one of its neighbours, who in turn forwards it to another neighbour, until the packet reaches the destination node. In this case the main challenge in a MANET is to make each device properly route traffic to continuously stream the information [6].

A M2ANET is a particular configuration of a typical MANET proposed in [9] where mobile nodes are divided into two categories: (i) the forwarding only nodes forming the so called Mobile Medium, and (ii) the communicating nodes, mobile or otherwise, that send data and use this Mobile Medium for communication. The advantage of this M2ANET model is that the performance of such a network is based on how well the Mobile Medium can carry the messages between the communicating nodes and not based on whether all mobile nodes form a fully connected network.

1.3 Problem

A Mobile Ad Hoc network consists of a collection of wireless mobile devices. The nodes and links are important components of the dynamic topology. During the lifetime of the network, nodes are free to move around within the network and node mobility plays a very important role in mobile ad hoc network performance. Most previous simulations have been performed in bounded areas, which can maintain all the nodes in the same place. If any node moves far way it will hit the boundary and will then move into another direction but still in the same area with the other nodes. The problem is how to organize a model network while maintaining all nodes in the same area, without reliance on a fixed boundary. When nodes move too far away they should be able to detect where the other nodes are and return back.

1.4 Objectives

The research objective in this report is to model the node motion in a mobile network in a new way, that specifies the motion without a fixed boundary. The intention is to develop an appropriate simulation where mobile node movement is confined to a small area between the source node and the destination node in a M2ANET. More specifically, the goal is to simulate a network that allows for the mobile nodes to move randomly, and stay in the same region. The following question will be investigated experimentally: Is a Self-organizing Modeling motion in M2ANET better or worse than a

Random Model?

1.5 Report Organization

Chapter 1: gives an introduction and brief overview of the general composition and working terms of a wireless network. This chapter introduces the report aim and objectives of this reaserch.

Chapter 2: discusses the main concept of MANETs with information about the research on the issues faced in Ad-Hoc networks. This chapter also contains an analysis of various routing protocols in the MANET and some movement patterns in details .

Chapter 3: gives an introduction about the network simulator NS-2 as well as the features and capabilities of this simulator. This chapter discusses the component of a MANET inside the NS-2, traffic generators, and mobility. A complete setdest tool and its limitations is included.

Chapter 4: illustrates controlled node movement methods, including strategies for expected scenarios. It mainly introduces the implementation of a new movement that specifies the node movement. Finally, it describes the two scenarios used in the evaluation.

Chapter 5: presents the Self-organizing mobile medium network used to investigate the effect on network performance when changing the movement. Also some performance metrics are introduced and followed by the description of the simulation enviroment used in the experiment analysis. A compar-

ison between the Random case and the Self-organizing movement generator is presented. Finally, the results are evaluated in this chapter.

Chapter 6: final conclusion and recommendations for further research will be mentioned in this chapter.

Chapter 2

MANET

This chapter gives a brief background about MANET networks in section 2.1, including extra details of the common sample routing protocols used in MANET. These protocols are DSR and AODV, discussed in Section 2.2. Additionally, various existing mobility models for MANETs are discussed in Section 2.4. Brief information about the most commonly used model, which is a Random Waypoint Model (RWP) is included. Finally, different ways of investigating network performance are described in Section 2.5.

2.1 Mobile Ad Hoc Networks

Mobile Ad Hoc networks, or MANETs, have received considerable attention over the past 25 years. Mobile Ad Hoc networks (MANETs) are an

autonomous collection of wireless mobile nodes which dynamically exchange messages among themselves, without reliance on a fixed base station, or a wired network [9], as shown in Figure 2.1. Due to concerns such as radio power limitation and channel utilization, mobile nodes may not be able to communicate directly [9] [11]. If all the mobile nodes are within the transmission range of each other, a mobile host may be able to communicate directly with other hosts in a single-hop fashion. However, this is not true in most situations, due to short transmission range. In this case, a multi hop scenario occurs.

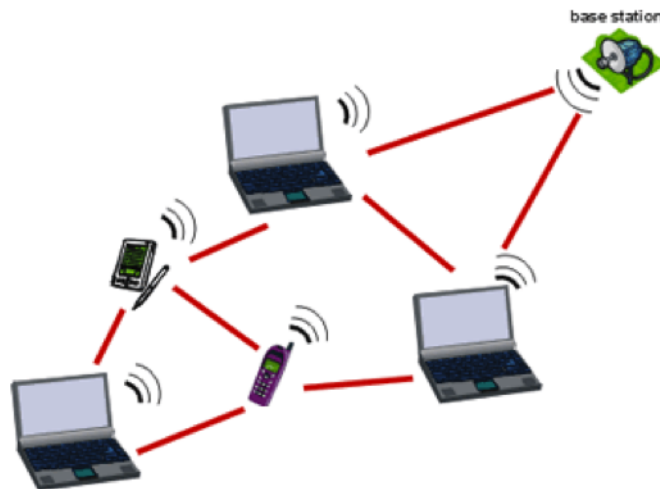


Figure 2.1: MANET [10].

Most Ad Hoc networks are multi-hop. A message from a source node must go through intermediate nodes to reach its destination [11]. All nodes cooperate in delivering messages across the network. The nodes must collect local neighbourhood information in order to make global routing decisions.

The packets sent by the source node must be relayed by several intermediate nodes before reaching the destination node. The highly growing interest of Mobile Ad Hoc Networks has been largely influenced by current wireless technology growth and demand from a number of civil and military applications. Although military applications are still considered the primary application for Ad Hoc wireless networks, commercial interest in this type of network continues to grow. Applications such as commercial, educational use, and sensor networks are just a few possible commercial examples [12] [13]. There are several technical challenges related to the Ad Hoc wireless network. In Ad Hoc wireless networks, the topology is highly dynamic and frequent changes in the topology may be difficult to predict. With the use of wireless links, the network suffers from higher loss rates, and can experience higher delays and jitter. In addition, physical security is limited due to the wireless transmission. Finally, most of the existing studies in Ad Hoc wireless networks focus on issues related to the network layer, such as routing and broadcasting [14].

2.2 A Routing Protocol

MANETs employ the traditional TCP/IP structure to provide end-to-end communication between nodes. However, due to their mobility and the limited resource in wireless networks, each layer in the TCP/IP model require redefinition or modifications to function efficiently in MANETs [21] . One interesting research area in MANET is routing. Routing is the process of

moving a packet of data from source to destination. Routing is usually performed by a dedicated device called a router. A mobile ad-hoc network (MANET) is a self-configuring network of mobile routers (and associated hosts), connected by wireless links with the nodes in the network constantly moving. Every node in the MANET can assist in the routing of packets in the network. They follow the dynamic topology where nodes may join and leave the network at any time, and the multi-hop routing may keep changing as nodes join and depart from the network. Routing is a fundamental issue in Mobile Ad Hoc Network (MANET). In MANET, nodes can communicate directly with other nodes if they enter each other's communication range. Conversely, each node participates in routing by forwarding data to another node until the packets being sent reach their destinations [21] [22]. For example: in Figure 2.2 in an Ad Hoc network consists of three wireless mobile hosts. Node 3 is not within the range of node 1's wireless transmitter, (indicated by the circle around node 1), and vice versa. If node 1 and node 3 wish to exchange packets, they must enlist the services of node 2 to forward packets for them, since node 2 is within the range of overlap between node 1 and node 3 [22] .

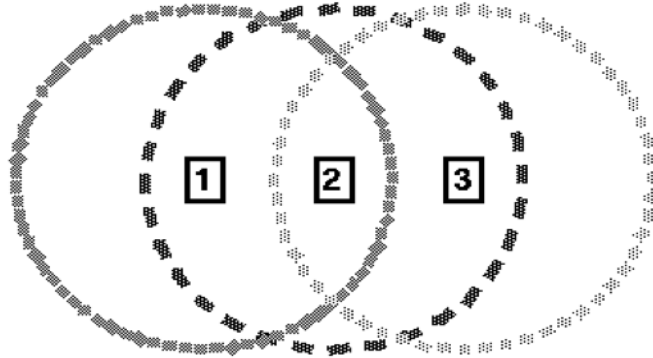


Figure 2.2: A network with 1, 2 and 3 hosts [22].

Furthermore, new nodes may unexpectedly join the network, or existing nodes may leave or be turned off. Ad Hoc routing protocols must minimize the time required to converge after these topology changes. A low convergence time is more critical in Ad Hoc networks because temporary routing loops can result in packets being transmitted in circles, further consuming valuable bandwidth. There are numerous different routing protocols presently proposed for Ad Hoc networks. Ad Hoc networks must deal with frequent changes in topology. Routing protocols in ad hoc wireless networks fall into either Table Driven Routing Protocols (proactive) or On-Demand Routing Protocols (reactive). In proactive routing schemes every node continuously maintains complete routing information of the network. This is achieved by flooding the network periodically with network status informa-

tion to find any possible changes in network topology. Every node in this routing protocol maintains information of only active paths to the destination nodes. A route search is needed for every new destination, therefore the communication overhead is reduced at the expense of delay to search the route. Rapidly changing wireless network topology may break active routes and cause subsequent route searches. In reactive routing, a route to a specific destination is computed on demand, that is only when needed. To efficiently use resources in controlling large dynamic networks, hierarchical routing, including cluster based and dominating set based, is normally used [18] [19]. Categories for Ad Hoc On-demand Distance Vector Routing are: Dynamic Source Routing Protocol, Temporally Ordered Routing Algorithm, Associativity Based Routing and Signal Stability Routing.

2.2.1 Destination-Sequenced Distance-Vector Routing (DSDV)

DSDV packets are routed between nodes of an ad hoc network using routing tables stored at each node. Each routing table, at each node, contains a list of the addresses of every other node in the network. Along with each node's address, the table contains the address of the next hop for a packet to take in order to reach the node [22], as shown in Figure 2.3. One disadvantage of DSDV is that it constantly uses energy and bandwidth through a regular update for the routing file. This is due to new sequence numbers being

generated along with the changes in topology. Therefore DSDV is unsuitable in a highly dynamic or large-scale network scenario [23].

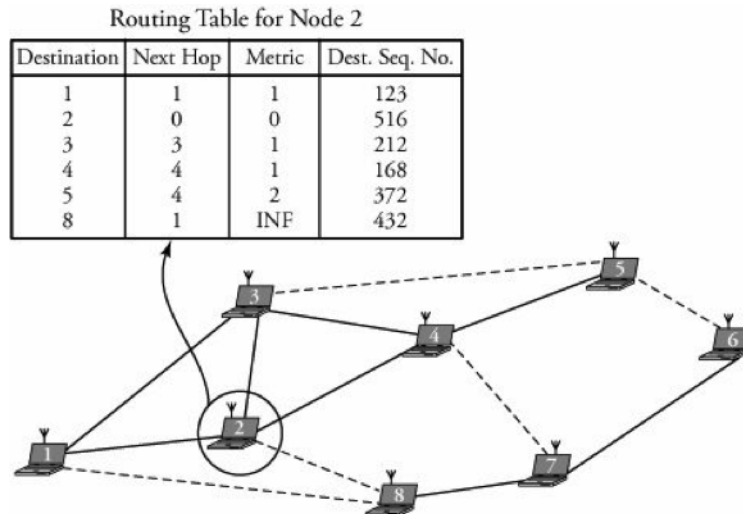


Figure 2.3: Routing Table for Node 2 [23].

2.2.2 Dynamic Source Routing (DSR)

Dynamic Source Routing (DSR) is a routing protocol for MANET, in that it forms a route on-demand when transmitting packets between nodes, in an ad-hoc network. If nodes want to communicate with other nodes to which they have unknown routes, every node in this routing protocol will be able to communicate by maintaining information of only active routes to the destination node. In the DSR communication, the route path to the destination will be discovered after the source node sends the first packet [23]. The routing process of DSR can be implemented in two phases: the first phase is

route discovery, and the second is route maintenance. In the Route discovery phase, the mechanism which is sending the node, obtains a route to destination as in Figure 2.4 (a). In the Route maintenance phase, as in Figure 2.4 (b), as in Figure 2.4 (c) the mechanism which is sending the node detects that the network topology has changed and its route to destination is no longer valid [24].

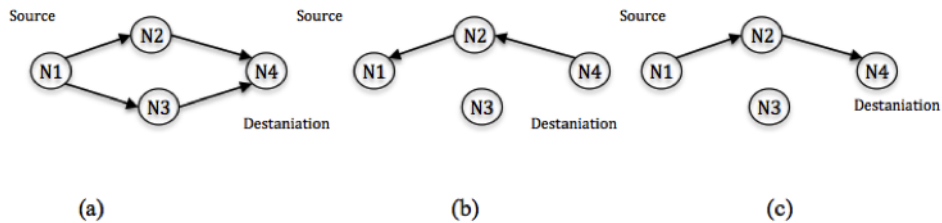


Figure 2.4: Example of Route Discovery and Data Delivery in DSR: (a) Route Request; (b) Route Reply; and (c) Data Delivery.

2.2.3 Ad Hoc On-Demand Distance Vector (AODV)

The second routing protocol for mobile Ad Hoc networks is AODV. AODV is a reactive routing protocol that only establishes a route to a destination on demand. AODV includes route discovery and route maintenance. In the AODV protocol, when a node needs to start a connection it broadcasts a request for a connection. Other AODV nodes forward this message and record the node that they heard it from. Then, they establish a reverse

route to the source node. When a node receives such a message and already has a route to the destination node, it sends a message backwards through a temporary route to the requesting node. The source node then begins using the route that has the least number of hops through other nodes [26]. When a link fails, a routing error is passed back to a source node, and the process repeats. AODV minimizes the number of broadcasts by creating routes on-demand. AODV uses only symmetrical links because the route reply packet follows the reverse path of the route request packet. Both DSR and AODV are routing protocols for MANET but each employs different techniques that significantly affect the network's performance [24]. DSR and AODV can be compared and evaluated based on various metrics, such as the packet delivery ratio, normalized MAC load, normalized routing load, and average end-to-end delay by altering the number of sources, rate of speed, and pause time [26]. However, the main difference between DSR and AODV arises in the source routing feature. The source routing is a mechanism in which the sender identifies the route (from the source to destination) in the packet's header, so that the intermediate node can be identified by the address on the way to the destination node [27]. In conclusion, there are some characteristics that tend to favor the AODV protocol. One of them is that AODV shares many prominent features of DSR, such as on-demand route discovery, route maintenance, and hop-by-hop routing of Destination Sequence Distance Vector (DSDV) algorithms. Therefore, MANET takes advantage of obtaining the routes on-demand and uses the AODV protocol

[24].

Some of the advantages of AODV Routing Protocol are listed below [26] [27].

- AODV has better performance than DSR in higher-mobility scenarios.
- AODV provides quick convergence when the networks topology is changed.
- AODV provides higher reliability of data delivery.

Some of the disadvantages of AODV Routing Protocol are listed below [26] [27].

- AODV requires more time to establish a connection.
- AODV has heavy overhead control over the network.
- AODV does not have an efficient route maintenance technique.

To choose the routing protocol one must take into consideration the objective. Depending on the network applications, the objective could be maximization of data throughput, or minimization of delivery delay, or power consumption.

2.3 Mobility Models

Many mobility models are designed in order to simulate the real world scenarios better for MANET applications. A mobility model tries to mimic the movement of real mobile nodes that change the speed and direction with

time. Currently there are two types of mobility models used in simulation of MANETs [28] [29]: trace and synthetic. A trace is where actual node movements have been experienced and observed in real life systems. In this type of model, accurate information can be captured when the simulations include a large number of mobile nodes over a long observation period of time. However, it is difficult for new network environments (e.g. Ad Hoc networks) to be modelled, if traces have not yet been created. In this type of situation it is necessary to use synthetic models. When no traces are available, synthetic mobility models are used. The syntactic models often replicated the movements of mobile nodes realistically in Ad Hoc networks [28]. In synthetic mobility models, the categorization of models is mainly based on the description of the mobility patterns in Ad Hoc networks [29]: individual mobile movements and group mobile movements. Based on specific mobility characteristics, the mobility models can be classified into four categories: A Model with Temporal Dependency, A Model with Spatial Dependency, A Model with Geographic Restriction, and Random models [29]. In the mobility model with Temporal Dependency the movement of mobile nodes is affected by its movement history. A node's current movement is affected by past movement such as in the Gauss Markov Model and the Smooth Random Mobility model. In mobility models with Spatial Dependency the mobile nodes tend to travel into a group and are connected to each other. The movement of a node is affected by the surrounding nodes as it occurs in group mobility, such as in the Reference point Group Model. Another class

is mobility models with Geographic Restriction. In these, the mobile node movement is limited to certain geographical area such as streets or freeways, as in the Pathway Mobility Model and the Obstacle Mobility Model. In Random Mobility Models, the mobile nodes move randomly without limitations. Below more explanation is given about Random Model used in NS-2 simulation.

2.4 Random Model

In Random Mobility models, the mobile nodes move randomly without limitations and independently of other nodes. Nodes move in a randomly chosen direction and randomly selected velocity. This kind of model has been used in many simulation studies. Frequently used mobility models are Random Waypoint, Random Direction, and Random Walk.

2.4.1 Random Waypoint Mobility Model

The node movements in Random Waypoint Models are random and independent of each other. They use pause time between changing direction and velocity. The nodes start at randomly chosen positions, pause for some time, and then start moving in a uniformly distributed speed between [minSpeed, maxSpeed]. After arriving at the destination again, a node waits for the same period of time before moving to a new place [28] [30]. Mobile nodes in RWPM are randomly located at certain positions [30]. Normally they

stay for a certain period of time, known as a pause time, before moving toward the destination. After the pause time passes, a mobile node randomly chooses a destination within an allocated simulation area. The minimum and maximum velocities of a node are chosen, hence a mobile node moves toward a destination with a particular constant velocity, which is uniformly distributed, between the minimum and maximum velocities. When a destination is reached, a mobile node pauses for a specific time before repeating the random process. Because the movement patterns of mobile nodes are difficult to obtain, synthetic mobility models such as RWPM are used to show the behavior of mobile models [29] [30], as shown in Figure 2.5.

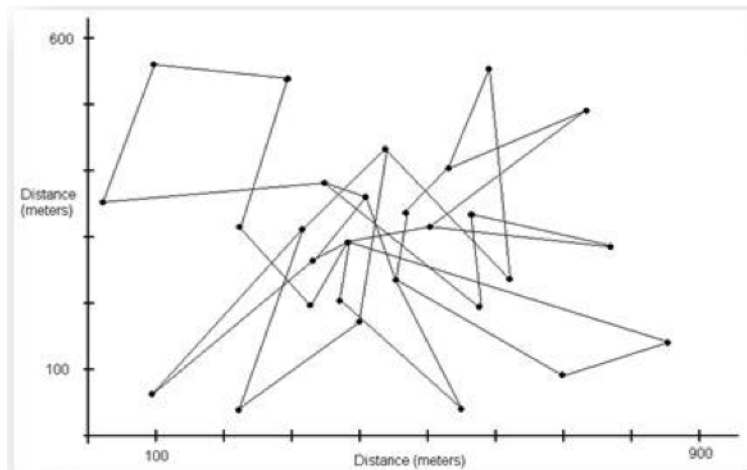


Figure 2.5: Traveling Pattern of an Mobile Node Using 2-D Random Way Mobility Model [30].

2.4.2 Random Walk Mobility Model

In the Random Walk model, the nodes choose their location, velocity and direction at each time randomly. We can think of the Random Walk model as the specific Random Waypoint model with zero pause time. The velocity has to be contained within minimum speed and maximum speed values. A node changes direction and speed at each time interval T [9]. In real life, mobile nodes move randomly in an unpredictable manner [12] [13]. This is the reason why RWM was developed—solely to meet this behavior. From the location of a mobile node, it randomly chooses both velocity and direction, and then randomly moves toward a new destination. Minimum and maximum velocities are determined hence, whether in constant time interval or distance, a constant velocity is chosen between the determined range of velocities. At the boundary of the simulation area a mobile node bounces at a certain angle, which is created by the current direction, as shown in Figure 2.6.

This model is considered to have a sure probability in 1-D or 2-D surfaces because a mobile node always returns to its original location. It does not depend on the past history of both velocity and location. This model can generate unrealistic movements of mobile nodes because of sudden stops and change of direction, caused by the mobile nodes.

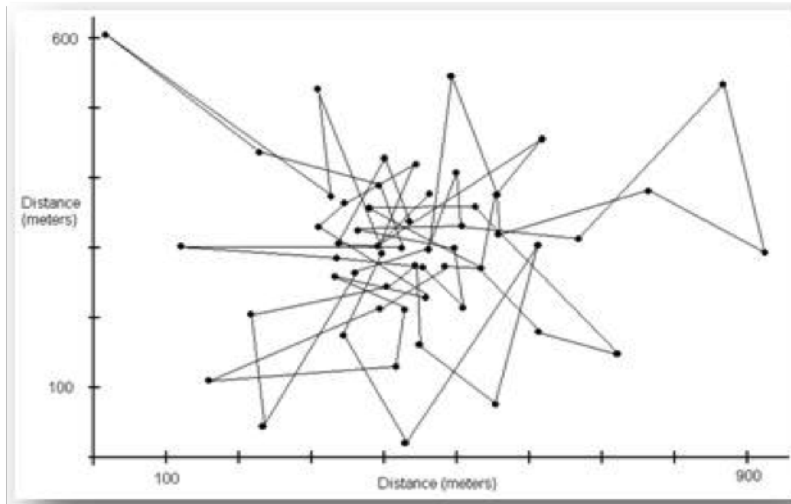


Figure 2.6: Traveling Pattern of an Mobile Node Using 2-D Random Walk Mobility Model [30].

2.4.3 Random Direction Mobility Model

In the Random Direction model, the nodes travel with chosen velocity and direction randomly until they reach the boundary. When a node hits the boundary it pauses for a time T and changes direction, and then starts moving toward the boundaries again, and so on [30].

2.4.4 Boundless Simulation Area Mobility Model

In this model a relationship exists between the previous direction and velocity of a node to its current direction and velocity. There are functions to determine the new velocity, direction, and hence position. All these are updated after a fixed time interval. If a node reaches the boundary of a sim-

ulation area then, instead of reflecting back from it, it continues travelling and reappears from the opposite side of the area[30].

Chapter 3

Network Simulation

Chapter 3 discusses the Network Simulator-2 as it is the simulator used for this research in Section 3.1. Section 3.2 describes the main concepts of the network simulator NS-2 including features and capabilities. It presents different aspects related to NS-2, such as limitations, and the Setdest command of NS-2 in Sections 3.3 and 3.4.

3.1 Overview

The network simulator 2 NS-2 is a popular and powerful simulation environment, and the number of NS-2 users has increased greatly in recent years. NS (version- 2.35) is an object oriented, discrete event driven network simulator written in C++ and OTcl, targeted at networking research. It implements

network protocols such as TCP and UDP. This simulation can be used for wired as well as wireless networks, such as wireless LANs, Mobile Ad hoc networks (MANETs), and Sensor networks. NS-2 provides users with a way of specifying such network protocols and simulating their corresponding behaviors. In general, as a wireless network facilitates mobility among the nodes, it provides the ability for a mobile node to move at a certain time from its current location to a desired destination, at a constant speed.

NS-2 provides a network animation tool (NAM) that visualizes the network simulation, and packet trace data. Visualization helps to understand the complex behavior of network simulation, and helps to develop better protocol and debugging. The NAM trace file contains information, which includes the topology set up, nodes, links, queues, node connectivity, and packet trace information. Additionally, X graph is a plotting graph also provided by NS-2. Moreover, NS-2 has preprocessing components for traffic and topology generators, as well as components which perform a simple trace analysis, such as in an AWK program or a Perl program which can be used to analyze a text-based trace. Therefore, NS-2 can provide insight into the operations and interactions of networking protocols [14] [15].

3.2 NS-2 Features

The first NS2 consists of two programming languages, which are C++ and Object-oriented Tool Command Language (OTcl). These are two powerful

languages. The C++ defines the internal mechanism of the simulation objects such as network component objects and the event scheduler in order to reduce packet and event processing time. NS-2 is an object-oriented Tcl (OTcl) script interpreter that has a simulation event scheduler, network component object libraries, and network setup (plumbing) module libraries. To setup and run a network simulation, the user has to program with OTcl script language to initiate an event scheduler, set up the network topology using the network objects and informs traffic sources to start and stop transmitting packets through the event scheduler. OTcl script is executed by NS-2. An Object Tool Command Language interpreter is used to implement user's command scripts. It is used to control the simulation scenario where the network structure and the topology are defined, and schedule the events.

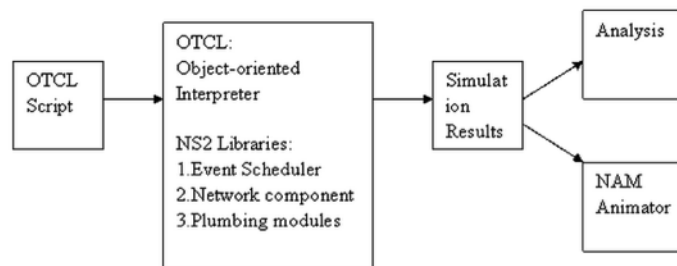


Figure 3.1: Simplified users view of NS-2 [33].

As a result, the open source programming model in NS-2 enables it to add new scripts efficiently. NS-2 is a valuable tool for network researchers through its provision of a common simulation platform, which makes protocol engineering simple and provides an insight into the operations and interactions

of networking protocols. NS-2 is utilized for three broad reasons in research: selecting a mechanism or protocol variant, investigating the performance of composite networks, and exploring unanticipated connections of various protocols. Wireless mobile ad-hoc networks have no physical connections, and no fixed topology due to the mobility of nodes, interference, multi path propagation and path loss. In NS-2, results can be quickly obtained when testing more ideas in smaller time frame repeatability, which helps in debugging. The main disadvantage, however, is that real systems are too complex to model. For these ad-hoc networks, dynamic routing protocol is required for proper functioning. There are many routing protocols developed for handling the mobility in wireless networks. Therefore, the goal of this project is to come up with different movement methods to overcome the limitations in these routing protocols [32]. NS2 provides users with an executable command NS-2 which takes on input arguments, and the name of a Tcl simulation scripting file. In most cases, a simulation trace file is created, and is used to plot a graph and/or to create an animation as in Figure 3.1.

3.3 NS-2 Limitations

Some of NS-2 limitations are listed below [32].

- NS-2 does not support some protocols, for example Classless Inter Domain Routing (CIDR).
- Support for Variable Bit Rate (VBR) is not provided in NS-2 where

VBR is used for audio/video streaming in real networks.

- Although NS-2 supports different delays like propagation, queuing, and transmission, it does not support processing delay.
- NS-2 has limited functions when simulating a large network; it is slow.

3.4 The Setdest Tool

Mobile Ad Hoc Networks include a large number of nodes. They are moving at a certain time to a specific coordinate, from its current location at a specific constant speed. NS-2 simulation has the ability to provide tools used to generate node movement. A utility called Setdest is supplied with the simulator. It was developed in C++ to address the mobility simulation issues in NS-2. The Setdest utility is a tool used to generate the positions of nodes and their moving speed and moving directions, by first generating the nodes in the specified boundary and then using the Random Waypoint Mobility models algorithm to create random movements for the mobile nodes [18]. Setdest uses the following parameters: Setdest version number, node number, pause time, maximum speed of the movement, simulation time, x coordinate, and y coordinate. It has two versions. The syntax is:

```
setdest -v 1 -n numnodes -ppt -M maxspeed -t simtime -x maxx -y maxy.
```

The first version excluded minimum speed. For this the node uses random speed that can be too small for a node to reach its destination. This was not helpful in providing a true simulation scenario. In the second version v 2 of Setdest this problem was fixed by adding the option to set a minimum speed, along with some other features. This piece of the code is called a Setdest command. With the help of Setdest utility, we can simulate movement within the NS-2 simulator. The Random Waypoint (RWP) mobility model addresses this issue in NS-2. In Random Waypoint mobility, each node chooses a random destination and moves towards it with a random velocity chosen from $[0, V_{max}]$. After reaching the destination, the node stops for a duration defined by the pause time parameter. After this duration, it again chooses a random destination and repeats the whole process again until the simulation ends [18]. The output of both versions will be exactly the same in terms of the structure, but there will be differences in the information that allows NS-2 to read the file and to execute the simulation as needed. The Setdest utility generated file must be called by NS-2 to get the simulation to run with the random movement, based on the Setdest utility, using the Waypoint Mobility model.

3.5 Setdest Command

With the help of Setdest utility and Setdest command we can simulate movement within the NS-2 simulator. The Random Waypoint (RWP) mobility

model addresses this issue in NS-2. This tool is used to generate positions of nodes, their moving parameters, and their directions automatically by performing a command in TCL in NS-2. It generates movement patterns according to random waypoint mobility. The initial node positions are generated by this command in a two-dimensional region: The following is an example:

```
$ns_ at 60.000000 "$node(2) setdest x-coordinate y-coordinate  
velocity"
```

Setdest command:

```
$ns_ at 0.100000 "$node(0) setdest 450.0000 50.0000 1000.0000"
```

This line specifies that at time 0.100000s, node0 starts to move from its current location towards the destination (450,50) at a speed of 1000m/s. A dynamic simulation model or an adaptive simulation model represents a system as it changes over time. The elements of a model of this type may shift their properties or attributes during the simulation. One form of simulation based on dynamic simulation models is an interactive simulation where users can intervene during the runtime [34]. In this report, Setdest command entry is required rather than Setdest generator, since the nodes movements for some scenario cases will be dynamically controlled according to the node's throughput.

3.6 Trace File

Text-based packet tracing in NS-2 can be activated by informing the program to trace packets (where NS-2 Simulator is a store and the trace file is a store for the tracing text). This line below is used to inform NS-2 to trace packets.

```
$ns trace-all $file.
```

When a simulation for network is starting, a tracing file is created to collect the detail of traversing packets.

```
+ 0.110419 1 2 tcp 1040 ----- 2 1.0 4.0 6 13
```

```
- 0.110431 1 2 tcp 1040 ----- 2 1.0 4.0 5 12
```

The above trace file simulation script is executed by typing:

`ns myfirstns.tcl`. Twelve columns make up a complete trace line, also shown above. Four possible event types can occur for a packet. These correspond to: r (received), + (enqueued), -(dequeued), and d (dropped). Time field denotes the time events occur. Field 3 is the starting node, and Field 4 is the terminating node of the link at which the event takes place. Field 5 is the packet type, and Field 6 is the packet size. Fields 7 and 8 are a series of indication ags noting abnormal behaviorss. Output "-" denotes no ag. Next is a packet flow ID. Field 9 marks the source, and Field 10 is the destination address, in the form of node.port. NS also specifies a packet sequence number in the second last field. This ensures correct packet

assembly at the destination node. A packet unique ID is recorded in the last field keeping track of all packets. Once the trace file is obtained it is useful to process the network data from the NS-2 simulation, and analyse the performance by extracting a subset of the data of interest and further analyzing it. For example, the number of packets received with a specific link can be computed by extracting only the columns and fields associated to that link, from the trace file. Two of the most popular languages that facilitate this process are AWK and Perl. The basic structures and usage of these languages are described in Chapter 5.

Chapter 4

Self-organizing Mobile Medium Ad hoc Network

This chapter introduces the Mobile Medium Network in Section 4.1. Also the strategy for self-organizing in M2ANET for both attraction and repulsion motion is described in Section 4.2. Section 4.3 explains the methodology used in order to implement new movement in ns-2 simulation. Finally in Section 4.4 we generate the random motion which is used for the analysis and evaluation, and present results for these two motions.

4.1 Introduction

A Mobile Ad Hoc Network (MANET) is a set of mobile devices that cooperate with each other by exchanging messages and forwarding data [31] [32]. Mobile devices are linked together through wireless connections without infrastructure and can change locations and reconfigure network connections as shown in Figure 4.1 . During the lifetime of the network, nodes are free to move around within the network and node mobility plays a very important role in mobile ad hoc network performance. Mobility of mobile nodes significantly affects the performance of a MANET [7].

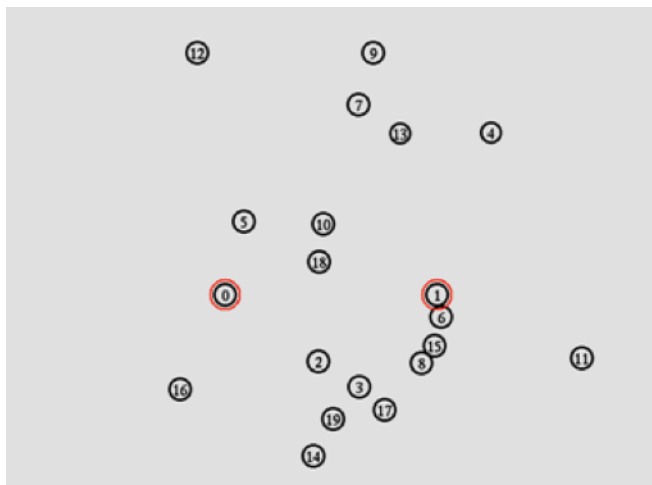


Figure 4.1: NS-2 Simulation Screen of a MANET.

A M2ANET is a particular configuration of a typical MANET proposed in [9] where mobile nodes are divided into two categories: (i) the forwarding only nodes forming the so called Mobile Medium, and (ii) the communicating

nodes, mobile or otherwise, that send data and use this Mobile Medium for communication. The advantage of this M2ANET model is that the performance of such a network is based on how well the Mobile Medium can carry the messages between the communicating nodes and not based on whether all mobile nodes form a fully connected network. An example of a M2ANET is a cloud of nodes released over an area of interest facilitating communication in this area. Recently, a number of projects that match the M2ANET model have been announced; they include Google Loon stratospheric balloons [37] and Facebook high altitude solar power planes [38] for providing Internet services to remote areas, and the Swarming Micro Air Vehicle Network (SMAVNET) project where remote controlled planes are used for creating an emergency network [39]. Controlling the movement of all forwarding nodes forming a Mobile Medium is a problem in deploying M2ANETS in real world scenarios like emergency or disaster recovery. While movement of each node is most easily directed independently there is a need for keeping the nodes in relative proximity to maintain their connectivity one with another. In practical terms the nodes may move on closed paths (e.g. circular), or at random. With randomly selected trajectories maintaining the nodes in one area becomes a problem. The problem is simple to handle in MANET simulation: simulators typically allow setting the simulation area defined as a bounded region which guarantees that the nodes do not disperse any further. If any node tries to move too far away it hits the boundary and then moves in another direction but still in the same area together with the other nodes.

The same cannot be said about the real world scenarios.

In this report we propose a solution for controlling the Mobile Medium nodes for M2ANET deployments in an unbounded region. The mechanism is based on an attraction/repulsion paradigm for controlling the movement of mobile nodes in a region without boundaries while providing means for maintaining all nodes in the same area. In principle, when a node moves too far away from other nodes it should detect the separation and turn back. While the decision making in our simulation is based on the actual distance between the nodes, in a practical deployment the same can be done based on the radio signal strength.

4.2 Proposed Strategies

One of the most incredible sights in nature happens when animals form a group and move together in a flock. How exactly do these individuals do it? A group, such as a herd of land animals or flock of birds, consists of individuals but exhibits some characteristics of team collaboration in the population. While it seems that the group is under a centralized control, in reality what is observed is an aggregated behavioral performance of independent individuals, each of which is acting on the basis of its own local perception [40].

Similar principles can be applied to controlling node movement in our self-organizing M2ANET. The objective of the proposed approach is to control the collective movement of locally interacting nodes similar to the behavior

observed in flocks of birds or swarms of insects. Our goal is to keep randomly moving nodes (similar to RWP model) in a limited area without imposing a hard constraint of an external boundary. Our approach is based on an attraction principle to keep the nodes together in a flock (we use the name flock or a cloud when referring to a number of mobile nodes moving together) and on a repulsion mechanism to keep them sufficiently far apart so that they cover a large area. Though the actual simulation we conducted is based on the distance calculation, in practice the attraction/repulsion principles can be implemented based on the received signal strength at each node.

4.2.1 Attraction

The main deficiency of the RWP model for controlling the movement of nodes in a MANET is that, aside from the border effect [1], the nodes tend to fill the entire available space. If there is a boundary limiting the node movement, as in the case of most simulation environments, NS-2 included, the nodes tend to disperse and the average distance between the nodes is determined by the available area and the number of nodes in the network. The situation becomes worse in an environment with no boundaries where nodes would disperse completely and lose any connectivity over time.

Attraction between the nodes, when used in addition to the RWP model, can remedy this problem. In our proposed approach, nodes normally move following the RWP model, but when the distance to the nearest neighbor becomes too large they turn towards the nearest neighbor rather than choosing

a random direction, as shown in Figure 4.2.

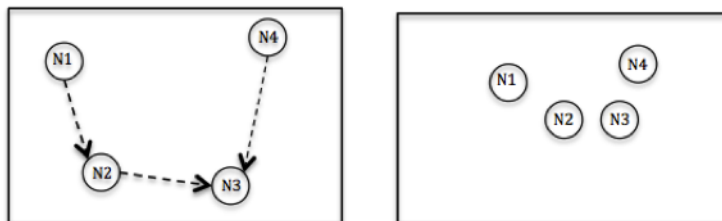


Figure 4.2: Attraction Keeps Nodes in a Flock.

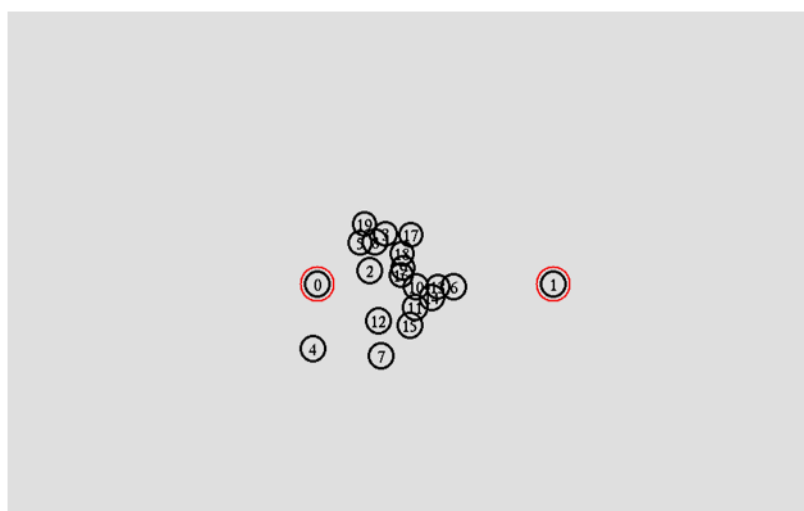


Figure 4.3: NS-2 Simulation Screen of a Attraction.

4.2.2 Repulsion

While the attraction mechanism would be sufficient for a set of randomly moving nodes to form a flock (or a cloud) and remain connected and stay over

a limited area without imposition of a hard boundary, the network coverage could be improved with an added mechanism, also based on watching the distance to the nearest neighbor. The coverage of a M2ANET is where the Mobile Medium nodes are, so keeping the nodes apart assures a larger area of coverage by preventing the nodes from congregating in only one place, as shown in Figure 4.3 In our proposed approach, nodes normally move following the RWP model, but when the distance to the nearest neighbor becomes too small they move away from the nearest neighbor rather than choosing a random direction, as shown in Figure 4.4.

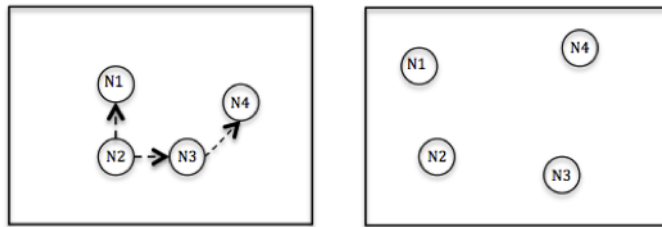


Figure 4.4: Repulsion Prevents the Nodes from Collapsing into one Point.

4.3 Implementation for Self-organizing

Nodes normally follow RWP model movement patterns, with the next move direction determined by parameters stored locally at each node. Attraction and repulsion mechanisms can be implemented based on the received signal strength at each node. We could assume that each node periodically sends

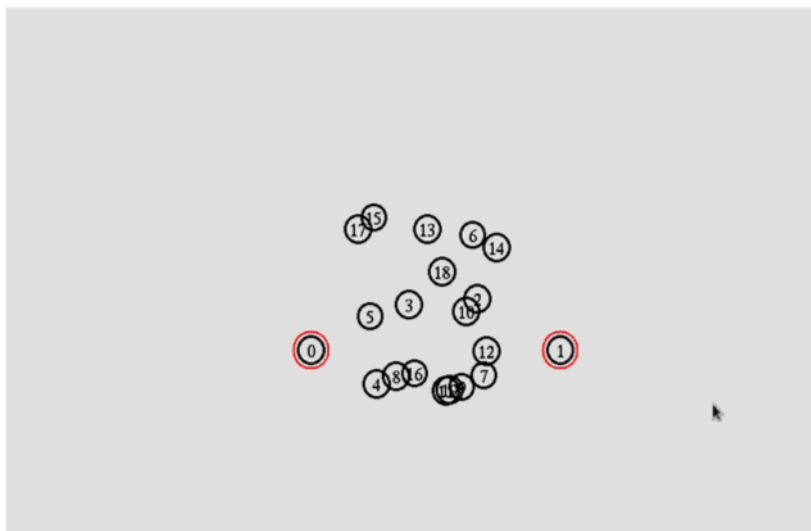


Figure 4.5: NS-2 Simulation Screen of a Repulsion.

a beacon signal (possibly as a part of a functioning routing mechanism like DSDV [13]). The received signal strength determines the identity and possibly the direction towards, the nearest neighbor. Alternatively, the direction towards the nearest neighbor could be determined by querying the nearest neighbour for the location information (assuming it has a GPS).

In a NS-2 simulation, nodes move piecewise linearly with each movement of a node specified with the `setdest` command [42]. In our simulation experiments we use the distance between the current node and its nearest neighbor D , and define two thresholds: $Th1$ to mark when nodes are too far apart, and $Th2$ when nodes are too close. The next move is specified:

- i. towards the nearest node, when $D > Th1$,

- ii. away from the nearest node, when $D < Th2$, and
- iii. otherwise, in a random direction.

The distance covered is chosen randomly (in cases (i) and (ii), uniform distribution $U(0,D)$), but within the bounds of the simulated area, as shown in Figure 4.5.

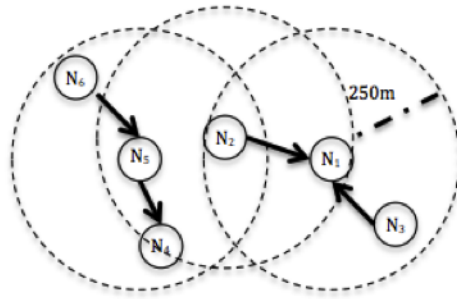


Figure 4.6: Self-organizing Mobile Medium Ad hoc Network.

At the beginning of the simulation, mobile nodes are randomly distributed in a small region in the center of the simulation area. Nodes are then allowed to move randomly. In the simulator each node first calculates its distance to all the other nodes. Based on the distance to the nearest node and the two thresholds $Th1$ and $Th2$ the node moves randomly or applies the attraction or repulsion mechanism as shown in Figure 4.6.

4.4 Implementation for Random Model

The Random movement scenario was implemented to be used as a base case in comparison with the self organizing movement. This scenario used random motion is generated dynamically during the NS-2 simulation. It was created using 80 nodes moving with a constant speed of 10 m/s. The interval time for updating the movement direction was 2s. The topology boundary was defined as 1000 x 1000 m, with the source node at $X = 100$ m, and $Y = 500$ m. The destination node was at $X = 400$ m, and $Y = 500$ m. The area between the source and destination nodes was 300 m by 300 m. The intermediate nodes were distributed randomly in the area between the source and destination. By executing a Setdest command with a new destination randomly selected within the topology boundary after each interval time, the intermediate node can change direction randomly, and move over the whole simulation area without restrictions. In other words, during the simulation, the mobile node can change direction randomly, every two seconds, with no restrictions to keep them away from the simulation boundary.

Chapter 5

Investigation of the Self-organizing Mobile Medium Ad hoc Network

In this chapter, we tested the performance of network simulation using a variety of tools, including the standard deviation tests and the delivery ratio calculations. We have used the standard deviation to complete the investigation of node distribution in a network. Performance metrics are discussed in Section 5.1 and are followed by the description of the simulation environment of the experiment in Section 5.2, including extra details about node configuration and traffic connection set up for our analysis. Section 5.3 presents the way we measured the network performance in the experiment. Section 5.4 includes all the analysis and evaluations of the research results. Furthermore,

a comparison between the Random case and the Self-organizing movement generator is presented.

5.1 Network Performance Metrics

There are many mobility metrics which can be used to observe the mobility behavior. These metrics have been carefully chosen to give an idea of the behavior and reliability of the network simulations. Some performance metrics that are commonly used are listed below [4].

5.1.1 Delivery Ratio

Similar to throughput, the delivery ratio is calculated as the percentage of the transmitted data packets that is successfully received. It is an important metric, which can be used to measure network performance. Typically, the delivery ratio is calculated as the percent of packets received to the packets transmitted. This is the metric used in this investigation:

$$DR = \text{Numberofpacketsreceived}/\text{Numberofpacketssent}, \quad (5.1)$$

5.2 Node Distribution Performance Metric

A node distribution performance metric is a method or a test to give a better understanding of node movement behaviour. A statistical parameter can be

used to measure distribution of nodes in a sub-region. The standard deviation is one of the popular statistical methods which can be used to measure the distribution of the node X coordinates and the Y coordinates. Standard deviation is a measure of dispersion and is widely used. Low standard deviation indicates low spread, or clustering. High standard deviation indicates a wide ranging spread. The mathematical formula to calculate standard deviation of node X coordinates, is:

$$S = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n}} \quad (5.2)$$

where x_i is a node coordinate, \bar{x} is the average and n is the number of samples.

5.3 Simulation Environment

Each case of the network consists of a different number of nodes roaming in a bounded 1000 x 1000 meters area. The transmission range is 250m. The data rate is 1 Mbps. Every packet has a size of 512 bytes. The buffer size at each node is 50 packets. Data packets are generated following a constant bit rate (CBR) process. The experiments will transmit packets from one source to one destination for each case in 900 seconds, and measure the effective delivery ratio with increasing simulation area and node density.

5.3.1 Basic Simulation Parameters of TCL Script

NS-2 contains parameters and variables that help change the network scenario and settings and control the simulation process. Each case shares the same parameters for our investigation with the exception of the number of nodes and the technique. The simulation parameters are listed in Table 5.1.

Table 5.1: The basic settings of NS-2 simulation.

Parameters	
Channel Type	Channel/Wireless channel
Network Interface Type	Phy/WirelessPhy
Mac Type	Mac 802 11
Radio-Propagation Type	Propagation, Two-ray ground
Interface Queue Type	Queue/Drop Tail
Link Layer Type	Link Layer Type
Antenna	Antenna/Omni Antenna
Maximum Packet in ifq	50
Routing Protocols	AODV

NS-2 contains parameters and variables that help change the network scenario and settings and control the simulation process, which are linked in Table 5.2.

5.3.2 Experiment Set up for Traffic Connection

For this experiment, the traffic connection is between the source and destination, which are two stationary nodes having other mobile nodes between

Table 5.2: Experiment set up.

Parameters	
Simulation Time	900 Sec
Node Movement Area	1000 X 1000
Number of Mobile Nodes	10, 20, 30, 40, 60, 80
Number of Source nodes and position	One node at x=100, y=500
Number of Destination nodes and position	One node at x=400, y=500
Traffic Type	(UDP) CBR
Packet Size	512 B
Number of Simulation runs per experiment	3,10

or around them. We measure delivery ratio, i.e. how many packets are transmitted from the source and how many packets are received at the destinations. Below is the Tcl code that sets up the CBR traffic connection between node (0) and node (1).

```

set udp_(0) [new Agent/UDP]
$ns_ attach-agent $node_(0) $udp_(0)
set null0 [new Agent/UDP]
$ns_ attach-agent $node_(1) $null0
set cbr_(0) [new Application/Traffic/CBR]
$cbr_(0) set packetSize_ 512
$cbr_(0) set interval_ 0.01
$cbr_(0) attach-agent $udp_(0)
$ns_ connect $udp_(0) $null0
$ns_ at 0.0 "$cbr_(0) start"

```

5.4 Measuring Performance in the Simulation Experiment

The aim of this experiment is to compare the effectiveness of the self-organizing movement generator in terms of the Random Model movement pattern of the Setdest command. There are two scenarios in this experiment. The scenario used the trace file of the Random Model, which is generated dynamically during the NS-2 simulation, as discussed in Chapter 4. The second scenario used the trace file of the Self-organizing movement, which is generated by the Tcl program. These two files contain the data for both scenarios to do the evaluation. Network simulation is used to examine the differences in network performance caused by different movement patterns. It is required to compute the packets that are received at the destination node, to do the evaluation. The packet delivery will be the performance metric for this experiment. The number of packets received from the NS-2 trace file can be counted by using the following AWK and grep scripts: AWK script was used to count the receiving packets from the trace file; for example, counting the sending packets from the source node (0). To include all sending data from the trace file named out.tr in the send-out file, the command below is run:

```
awk /s -t/ wireless-out.tr> send-out
```

To include from the sending-out file only the packets that are sent from node (0) in a separated file named out-0, we run the command below:

```
awk $9 == 0 sending-out > out-0
```

(Field 9 marks the source node in the trace file. This will be discussed in more detail in Chapter 3). To count the cbr packets in out-0:

```
cat out-0 |grep cbr| wc
```

The same technique was used for the receiving packets at the destination node. Microsoft Excel sheet is used to create tables and graphs for the results in this experiment.

5.5 Analysis and Results

Four sets of simulation experiments were conducted: one set with all forwarding Mobile Medium nodes moving randomly, and three sets with the forwarding nodes moving based on the attraction/repulsion principle using three different threshold levels:

- i. Low threshold: Th1 = 60, Th2 = 30.
- ii. Medium threshold: Th1 = 120, Th2 = 60.
- iii. High threshold: Th1 = 200, Th2 = 120.

5.5.1 Network Delivery Ratio

In each experiment data regarding the node location and the delivery ratio was collected. The main goal of a self-organizing M2ANET is to avoid node

dispersion and to provide enhanced communication over the area covered by the Mobile Medium (forwarding nodes).

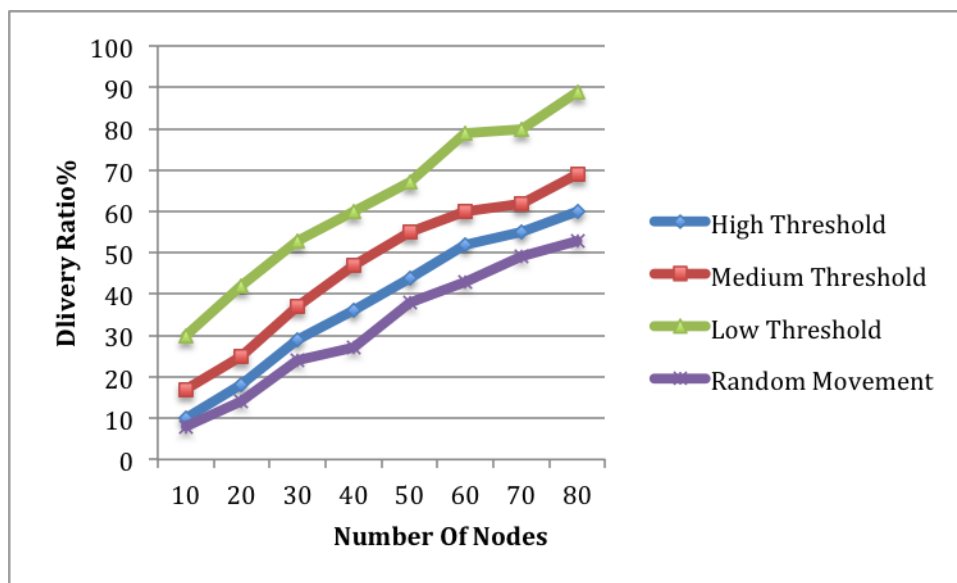


Figure 5.1: Delivery Ratio for Random Movement and Self-organizing M2ANET Movement with Three Different Thresholds.

Figure 5.1 shows the comparison between the delivery ratios in a self-organizing M2ANET versus a M2ANET, with Mobile Medium nodes moving randomly over the entire simulation area. The graph shows that decreasing the threshold values, and thus keeping the Mobile Medium nodes closer together, improves the delivery ratio. In our experiments all self-organizing networks do better than a network with nodes moving totally randomly. The improvement is most significant for experiments with a small number of nodes: in a M2ANET with only 10 nodes in an area 1000m by 1000 m, the delivery ratio of 9 percent for a random movement scenario was improved threefold to almost 30

percent in a self-organizing M2ANET when a low threshold settings of $Th1 = 60$, $Th2 = 30$ were used. The improved performance, shown in Figure 5.1, is due to keeping the nodes closer together, which increases a likelihood of forming a route from the source to the destination.

5.5.1.1 Comparing the Self-organizing Movement at High, Medium and Low Thresholds for Different Simulation Times.

In this scenario, the performance of three different thresholds was compared with respect to their packet delivery ratio measurement. The number of nodes connected in a network was 80. Simulation time was varied from 100 sec to 900 sec and the final delivery ratio was calculated at the end of each simulation run. The experiment was run 5 times. The average result was used to plot the graph shown in Figure 5.2.

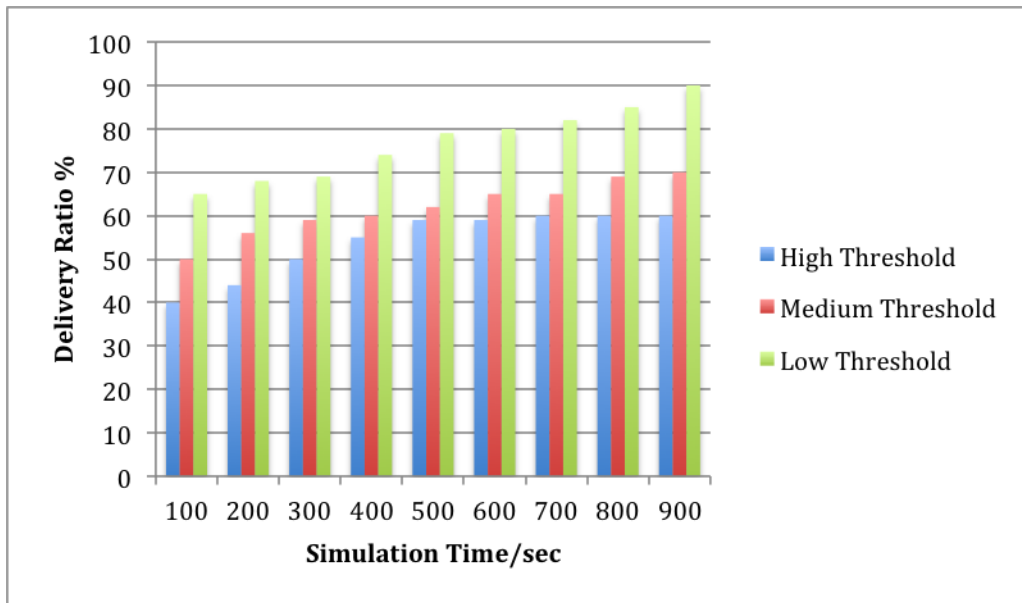


Figure 5.2: Delivery Ratio for Self-organizing M2ANET with Three Different Thresholds at The Different Simulation Times.

Packet Delivery Ratio was calculated by the ratio of numbers of packets transmitted by source node to the number of packets received by destination node. Figure 5.2 shows that the value for the low threshold is 30 percent higher than high threshold when 80 nodes are present in the network with long simulation time. From the above study, the packet delivery ratio, increases over time for low, medium and high threshold, up to 500 seconds of simulation time when it saturates and becomes constant for the high threshold experiment.

5.5.1.2 Comparing the Random Movement and Self-organizing M2ANET Movement for Low Threshold for Different Simulation Times

In this scenario, the performance of random movement compared with the Self-organizing M2ANET at a low threshold in respect to their packet delivery ratio measurement. The number of nodes was 80 connected in a network with varying simulation time 100, 200, 300, 400, 500, 600, 700, 800 and 900 sec. The experiment was run 5 times. The average result was as shown in Figure 5.3.

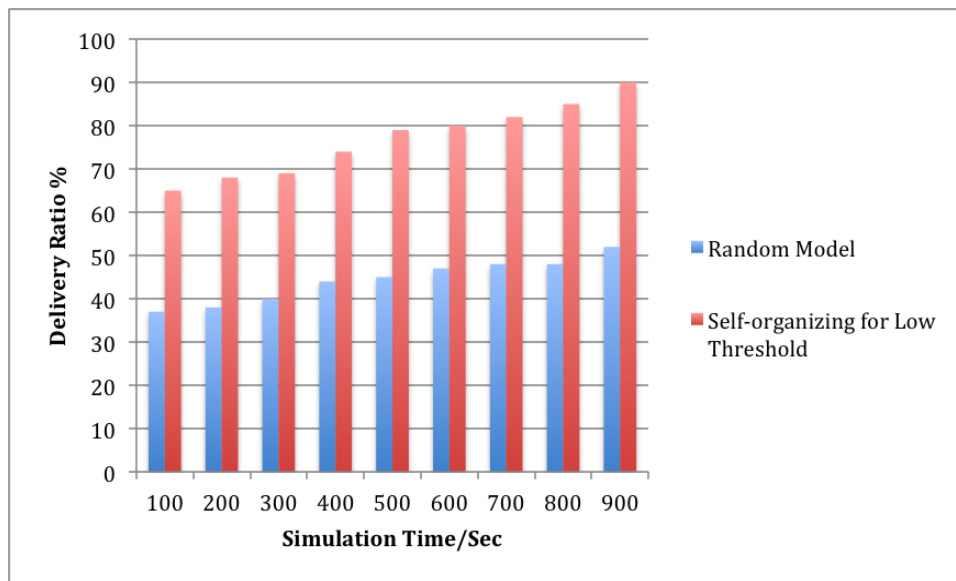


Figure 5.3: Delivery Ratio for Random Movement and Self-organizing M2ANET Movement within Low Threshold.

Figure 5.3 depicts the result that the value of delivery ratio for Self-organizing

M2ANET movement is significantly higher than random movement at 80 nodes in the network with different simulation time. From the above study, in view of the packet delivery ratio, reliability of low threshold is 30 percent greater than the random movement with the ADOV routing protocol.

5.5.2 Node Movement Behavior

Topologically, the purpose of the attraction/repulsion mechanism is to keep the nodes together while allowing them to move independently. To measure the togetherness of the nodes we collected samples of node coordinates (every 10s) over the duration of each experiment, and calculated the standard deviation of all X coordinates, for all the samples.

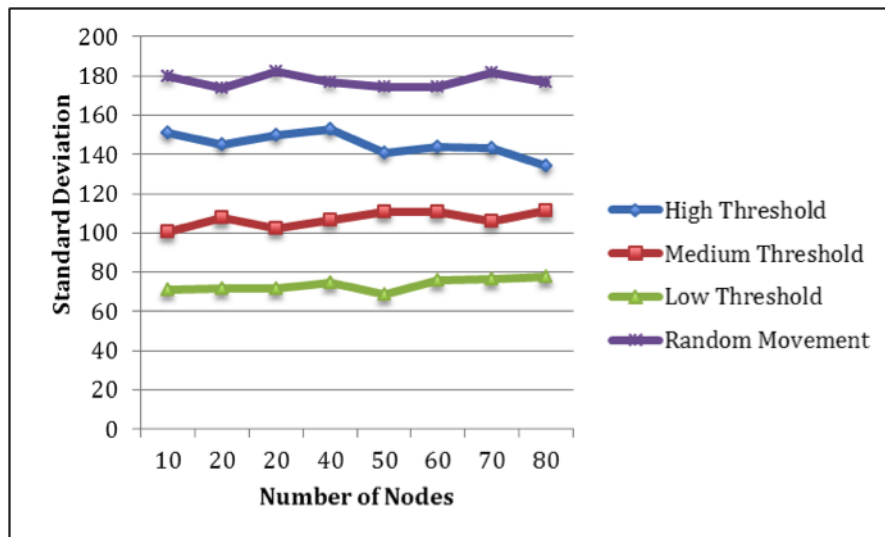


Figure 5.4: Standard Deviation for Random Movement and Self-organizing M2ANET Movement with Three Different Thresholds.

Figure 5.4 shows a measure (standard deviation of X coordinates of all mobile nodes, sampled every 10 seconds) of the spread of all the nodes in four sets of experiments. The results show that the lower the threshold the tighter the flock (cloud) formed by the mobile nodes. Also, the nodes of the proposed self-organizing M2ANET stayed closer together than they normally would if all the nodes just moved randomly over the 1000m by 1000 m simulation area.

5.5.2.1 Random Movement Scenario

As we defined before, we used the Random movement as the base case to generate the new movement in our experiment. In the first set of experiments, we ran the simulation at two different area settings: large area (5000 m by 5000 m), and small area (1000 m by 1000 m). For each area, we simulated a network with a different number of mobile nodes: 10, 20, 30, 40, 50, 60, 70, and 80. Each experiment was repeated three times and the average result measured the togetherness of the nodes. We collected samples of nodes (every 10s) over the duration of each experiment, and calculated the standard deviation of all X coordinates, for all the samples that were recorded.

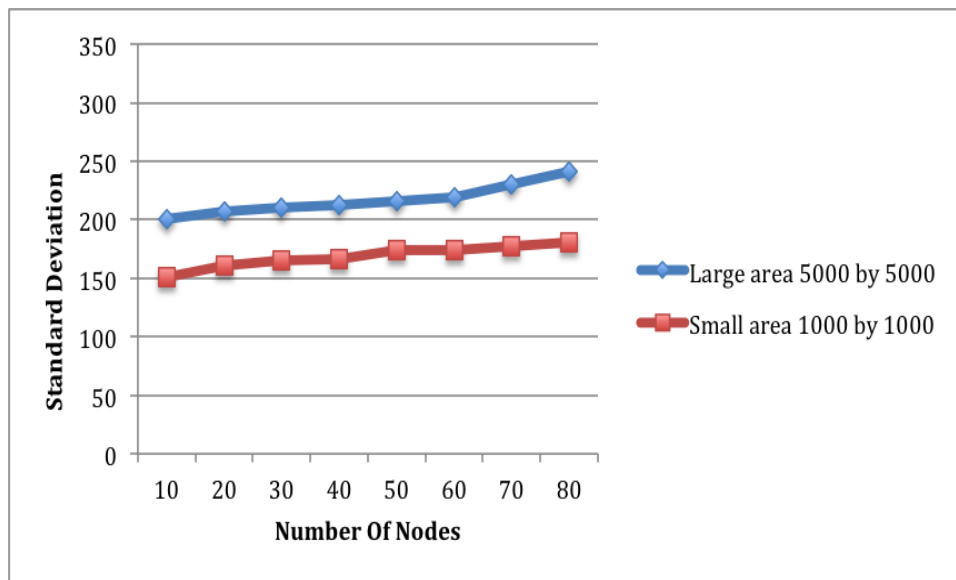


Figure 5.5: Standard Deviation of X-coordinates of all Mobile Nodes, Sampled every 10 Seconds for Random Movement.

Figure 5.5 shows the results from the Random scenario experiment, which shows two different curves that indicate the standard deviation at two different areas. Furthermore, it appears that the standard deviation starts to increase slightly with high node density. On the other hand, the standard deviation is higher within the large area which is (5000 m by 5000 m), compared with the small area which is (1000m by 1000 m).

5.5.2.2 Self-organizing M2ANET Movement Scenario

For this experiment nodes were observed to move along a repulsion and attraction strategy. Again standard deviation was calculated at each node density for Self-organizing M2ANET at low threshold $Th1 = 60$, $Th2 = 30$ in two different simulation areas, for a Self-organizing Mobile Medium Ad hoc Movement with low threshold, as discussed in Chapter 4.

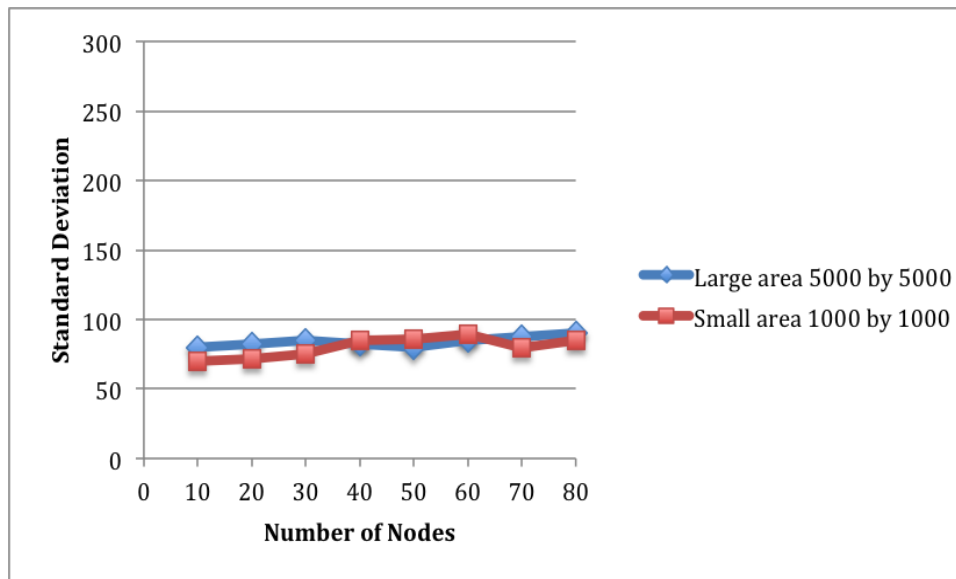


Figure 5.6: Standard Deviation of X-coordinates of all Mobile Nodes, Sampled every 10 Seconds for Self-organizing Mobile Medium Ad hoc Movement.

Figure 5.6 shows two different curves that indicate the standard deviation of registered node positions for X-axis at different simulation areas. More precisely, in the Self-organizing Mobile Medium Ad hoc Movement scenario, nodes moved within different areas 1000m by 1000 m, and 5000 m by 5000

m, but the curve was almost the same. The results for Self-organizing Mobile Medium Ad hoc Movement also show that the standard deviation is very similar for different numbers of nodes. Furthermore, comparing Figure 5.5 and Figure 5.6, we observe the standard deviation for both Random movement and Self-organizing Mobile Medium Ad hoc Movement is not affected by the number of nodes. On the other hand we observed the standard deviation in the case of self-organizing Mobile Medium Ad hoc Movement decreased by 70 percent, compared with the Random Movement. In Self-organizing Mobile Medium Ad hoc Movement the nodes disperse less in the area between source and destination node.

5.5.3 Comparing the Self-organizing M2ANET Movement and Random Movement Scenario at a Small Simulation area

Based on the initial experiments, we decided to investigate further the performance of the mobile network with the Self-organizing Mobile Medium Ad hoc Movement of the nodes. We increased the number of simulation runs to 5 to observe how the Self-organizing Mobile Medium Ad hoc Movement affects the standard deviation over a long period of time.

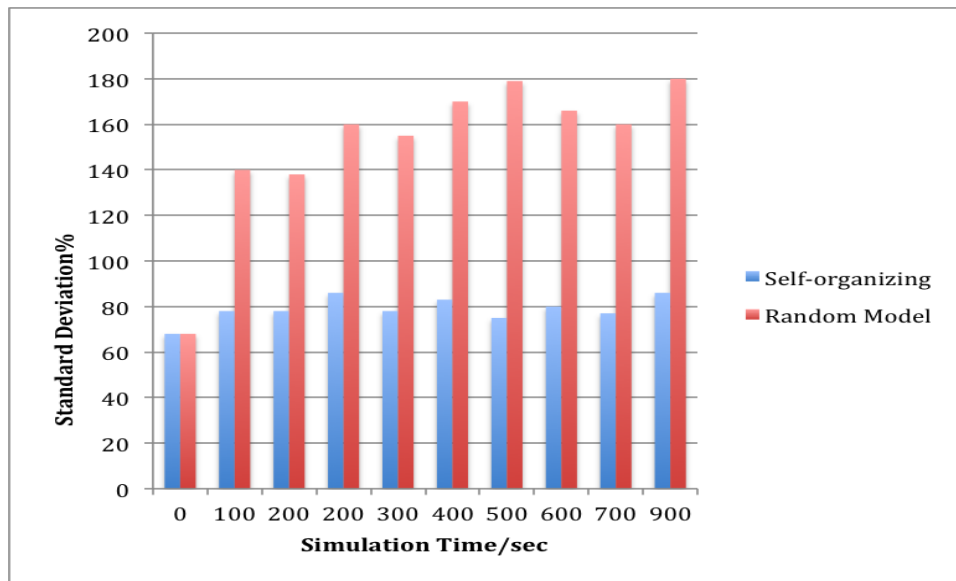


Figure 5.7: Random Model and the Self-organizing M2ANET Movement at Small Area (1000 m by 1000 m).

Figure 5.7 illustrates the difference in the standard deviation at the X axis when using the Random movement and the Self-organizing M2ANET Movement. It shows that most of the time the standard deviation for Self-organizing M2ANET movement is less than the Random movement. However the standard deviation seems unaffected by simulation time.

5.5.4 Comparing the Self-organizing M2ANET Movement and Random Movement Scenario at a Large Simulation Area

For this scenario, we observed the standard deviation for X- axis for Self-organizing Mobile Medium Ad hoc movement and Random movement, in the large area (5000 m by 5000 m) for 80 nodes during different simulation times.

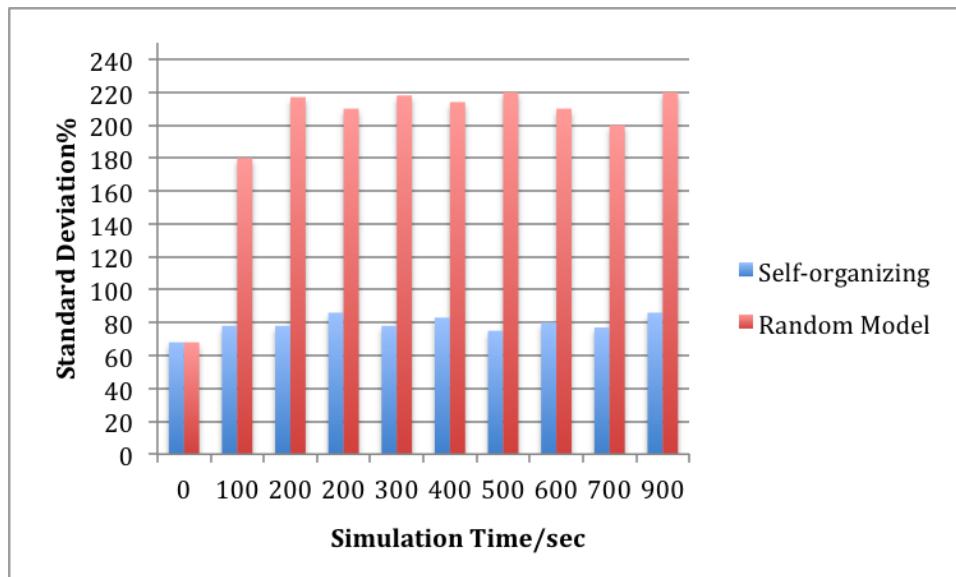


Figure 5.8: Random Model and the Self-organizing M2ANET Movement at Large Area (5000 m by 5000 m)

Figure 5.8 shows the standard deviation for Random and Self-organizing M2ANET movement. In the case of Self-organizing Mobile Medium Ad hoc Movement, the standard deviation was less than 75 m. This time we observed

a lower standard deviation for the Self-organizing model recorded in most of the experiments. This results indicates that with Self-organizing M2ANET movement the nodes were closer together within the Mobile Medium.

Chapter 6

Conclusions and Recommendations

6.1 Conclusion

In MANET, mobile nodes are moving randomly without any centralized administration. A node movement control paradigm for a self-organizing MANET network is proposed and extensively tested using NS2 simulator. The new approach for moving the mobile nodes is particularly attractive for M2ANETs where the goal is to create a Mobile Medium out of mobile forwarding nodes, and use this Mobile Medium to facilitate data communication between other users. The new mobility control mechanism is based on an attraction/repulsion principle. In the proposed approach the Mobile Medium nodes normally move randomly, but they turn back when they get too far

from their neighbors. This mechanism keeps all the nodes in a flock, with the flock (or cloud) density controlled by two thresholds, thus allowing the M2ANET designer to control the performance of the Mobile Medium: the lower the attraction/repulsion thresholds, the closer the nodes of the Mobile Medium remain, and the higher the delivery ration of the resulting M2ANET network. Extensive simulation tests with mobile networks consisting of 10 to 80 nodes showed a consistent improvement of a delivery ratio in a M2ANET. The improvement is most significant for experiments with a small number of nodes: in a M2ANET with only 10 nodes in an area 1000 by 1000 meters. The low delivery ratio of 9%, for a random movement, was improved three fold to 30% when the new Self -organizing paradigm was used.

6.2 Recommendations for Future Research

MANET is a rather interesting concept in computer communications. This report tested the Self-organizing movement strategies using only the AODV routing protocol, therefore using other Ad Hoc routing protocols could be investigated. In terms of efficiency, CBRs performance can be improved through further research on modifications. The scenarios we experimented with were based on using the location of the nearest node to decide on the type for the next move: random, moving away, or going back. Further research could investigate a network where the next move is determined by the average position of a number of nodes in the vicinity of a node. Also more

research on the security issues in MANETs may need to be undertaken to make the environment more reliable.

Bibliography

- [1] Alghamdi, R. (2012). Movement Generator for Mobile Network Simulation. Master's report in Computer Science, University of New Brunswick, Fredericton, Canada.
- [2] Ray, S. (2003). Realistic Mobility for MANET Simulation. Master's thesis, The University of British Columbia.
- [3] Vantage Technology Consulting Group. (2012). Data Networking Systems Wired VS. Wireless Report. Antelope Valley Community College.
- [4] Alshehri, A. (2013). Simulating Dynamic Node Movements for MANET in NS-2. Masters report in Computer Science, University of New Brunswick, Fredericton, Canada.
- [5] Hong, X., Gerla, M., Pei, G., Chiang, C-C. (1999). a Group Mobility Model for Ad Hoc Wireless Networks. MSWIM99 Proceeding of the 2nd ACM international workshop on Modeling, analysis and simulation of wireless and mobile systems, (pp.53-60). New York, NY: ACM. doi: 10.1145/313237.313248.

- [6] Goldenberg, D. K., Lin, J., Morse, A. S., Rosen, B. E., Yang, Y. R. (2004, May). Towards mobility as a network control primitive. In Proceedings of the 5th ACM international symposium on Mobile ad hoc networking and computing, 163-174.
- [7] Wireless Ad hoc Network, Wikipedia, the free encyclopedia. Retrieved on June 5, 2013 [http://en.wikipedia.org/wiki/Wireless ad hoc network](http://en.wikipedia.org/wiki/Wireless_ad_hoc_network)
- [8] Bei, F., Helmy, A. (2004). A survey of mobility models in wireless Ad hoc Networks. California: University of California, USA.
- [9] DeDourek, J., Pochee, P. (2011). M2ANET: a Mobile Medium Ad Hoc Network, Wireless Sensor Networks: Theory and Practice, WSN 2011, Paris, France, pp. 1-4.
- [10] Tschudin, C., Gunningberg, P., Lundgren, H., Nordström, E. (2005). Lessons from experimental MANET research. Ad Hoc Networks, 3(2), 221-233.
- [11] Ko, YoungBae, Nitin H. Vaidya. "LocationAided Routing (LAR) in mobile ad hoc networks.
- [12] Erciyes, K., Dagdeviren, O., Deniz Cokuslu, D. "Modeling and simulation of mobile ad hoc networks." Mobile ad hoc networks: current status and future trends.
- [13] Perkins, C. E., Bhagwat, P. (1994). Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers. ACM

SIGCOMM Computer Communication Review, Oxford university press, 24(4), pp. 234-244.

- [14] Krupp, B., Hou, L. (2011). Ns2 Setdest Acceleration Enhancement. EEC 787 Final Project Mid Report. Retrieved on June 5, 2013 from: <http://academic.csuohio.edu/yuc/mobile/>.
- [15] Wang, Y., Yue, O. C. (2012). A tutorial of 802.11 implementation in ns-2. Cornell University Library. Retrieved on July 5, 2013 from: <http://arxiv.org/abs/1202.3576>.
- [16] Lin, T. (2004). Mobile Ad-hoc Network Routing Protocols: Methodologies and applications (Doctoral dissertation, Virginia Polytechnic Institute and State University).
- [17] Xinmei Z., (2009). MANET In Urban Environment. Masters thesis of Computer Science, University of New Brunswick, Fredericton.
- [18] Lin, G., Noubir, G., Rajaraman, R. (2004). Mobility Models for Ad Hoc Network Simulation. INFOCOM 2004. Twenty-third Annual Joint Conference of the IEEE Computer and Communications Societies, Vol.1. doi: 10.1109/INFCOM.2004.1354517.
- [19] Asker Zada, S. (2010). Ad Hoc Networks: Performance evaluation of proactive, reactive and hybrid routing protocols in ns2 (Doctoral dissertation, University West, Trollhättan, Sweden). Retrieved from: <http://arxiv.org/pdf/1205.2678.pdf>.

- [20] Wang, Y., Yue, O. C. (2012). A tutorial of 802.11 implementation in NS-2. Cornell University Library <http://arxiv.org/abs/1202.3576>.
- [21] Abolhasan, M., Wysocki, T., Dutliewicz, E. (2003). A review of routing protocols for mobile ad hoc networks. Telecommunication and Information Research Institute, University of Wollongong. Australia.
- [22] Johnson, D., Maltz, D., (1996). Dynamic Source Routing in Ad Hoc Wireless Networks. Computer Science Department, Carnegie Mellon University.
- [23] Shrivastava, A. et al. Overview of Routing Protocols in MANETs and Enhancements in Reactive Protocols. Department of Computer Science, Lamar University, Beaumont TX 77710.
- [24] Misra, R., Mandal, C.R. (2005). Performance Comparison of AODV/DSR On-demand Routing Protocols for Ad Hoc Networks in Constrained Situation.
- [25] Johnson, D., Maltz, D., (1996). Dynamic Source Routing in Ad Hoc Wireless Networks. Computer Science Department, Carnegie Mellon University.
- [26] Misra, R., Mandal, C.R. (2005). Performance Comparison of AODV/DSR On-demand Routing Protocols for Ad Hoc Networks in Constrained Situation.

- [27] Murthy, S., Garcia-Luna-Aceves, J. J. (1996). An Efficient Routing Protocol for Wireless Networks. University of California, Santa Cruz. Mobile Networks and Applications.
- [28] Bai, F., Helmy, A. (2004). A Survey of Mobility Modeling and Analysis in Wireless Ad Hoc Networks, A Survey of Mobility Models in Wireless Adhoc Networks (pp. 2-32). Kluwer academic Publishers, University of Southern California, U.S.A.
- [29] Bettstetter, C. , Wagner, C. The Spatial Node Distribution of the Random Waypoint Mobility Model, in Proc. German Workshop on Mobile Ad-Hoc Networks (WMAN), Ulm, Germany, GI Lecture Notes in Informatics, no. P-11, pp. 41-58, Mar 25-26, 2002.
- [30] Camp, T., Boleng, J., Davies, V. (2002). A survey of mobility models for ad hoc network research. Wireless Communications and Mobile Computing: Special Issue on Mobile Ad Hoc Networking: Research, Trends and Applications, 2(5).
- [31] Liu, K. (2004). Network Simulator 2: Introduction. Department of Computer Science, SUNY Binghamton. Retrieved on July 8, 2013 from: <http://www.cs.binghamton.edu/~kliu/cs580t/ns2pre.pdf>.
- [32] Hortelano, J., Ncher, M., Cano, J. C., Calafate, C., Manzoni, Evaluating the goodness of MANETs performance results obtained with the ns-2 simulator. In Proceedings of the 2nd international conference

on Performance evaluation methodologies and tools. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering).

- [33] Hong, X., Gerla, M., Pei, G., Chiang, C. C. A group mobility model for ad hoc wireless networks. In Proceedings of the 2nd ACM international workshop on Modeling, analysis and simulation of wireless and mobile systems, New York, NY.
- [34] Ishibashi, B., Boutaba, R. (2005). Topology and Mobility Consideration in Mobile Ad Hoc Networks. School of Computer Science, University of Waterloo.
- [35] Samal, S. (2003). Mobility Pattern Aware Routing in Mobile Ad Hoc Networks. Masters Thesis in Computing Science, May. Virginia University, Blacksburg, Virginia.
- [36] Basagni, S., Conti, M., Giordano, S., Stojmenovic, I. (Eds.). (2004). Mobile Ad Hoc Networking. New York: Wiley-IEEE Press.
- [37] Hodson, Hal , "Google's Project Loon to float the internet on balloons", New Scientist, October 2013.
- [38] Brustein, J. Facebooks Flying Internet Service, Brought to You by Drones, Bloomberg Businessweek, March 4, 2014.

- [39] Jimenez Pacheco, A., Bouhired, D., Gasser, Y., Zufferey, J.-C. Implementation of a Wireless Mesh Network of Ultra Light MAVs with Dynamic Routing.
- [40] Dorigo, M., Maniezzo, V., Coloni, A. (1996). The Ant System: Optimization by a colony of cooperating agents. *Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on*, 26 (1), pp. 29-41.
- [41] Wunsch II, D., Pyeatt, L., Kim, T. (2006). Introduction to MIT Object Tool Command Language (OTCL): Part I. Department of Electrical Computer Engineering, University of Missouri-Rolla, USA.
- [42] Ekram, H., Issariyakul, T. (2009). Introduction to Network Simulator NS2, Springer.
- [43] Perkins, C. E., Bhagwat, P. (1994). Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers. *ACM SIGCOMM Computer Communication Review*, Oxford University Press, 24(4), pp. 234-244.
- [44] Aschenbruck, N. E. Padilla, G. P. Martini, A survey on mobility models for performance analysis in tactical mobile networks, *Journal of Telecommunications and Information Technology*, v2, 2008, pp. 54-61.
- [45] Ekram, H., Issariyakul, T. (2009). Introduction to Network Simulator NS2, Springer.

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Nada Alsalmi, J. DeDourek and P. Pochech, Self-organizing Mobile Medium Ad hoc Network, The Fourth International Conference on Mobile Services, Resources, and Users MOBILITY 2014, July 20 - 24, 2014 - Paris, France.