A FRAMEWORK FOR EVALUATING THE PERFORMANCE OF MOBILITY MODELS FOR ADHOC NETWORKS

Thesis submitted in partial fulfillment of the requirements for the award of the degree of

Masters of Engineering

In

Electronics and Communication Engineering

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(Established under the section 3 of UGC Act, 1956)

PATIALA – 147004

JULY 2015

DECLARATION

I, hereby declare that the work, which is being presented in the dissertation, entitled "A Framework for Evaluating the Performance of Mobility Models for Adhoc Networks" in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electonics and Communications submitted at Electronics and Communication Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Ms. Amanpreet Kaur (Assistant Professor),** Electronics and Communication Department and refers other research's work which are duly listed in reference section.

The matter presented in this thesis has not been submitted in any other University/Institute for the award of degree.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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ACKNOWLEDGEMENT

I would like to express my gratitude to my **Ms. Amanpreet Kaur (Assistant Professor)**, Electronics and Communication Engineering Department, Thapar University, Patiala, for their advice, kind assistance, and invaluable guidance. It has been a great honour to work under them.

I am also very thankful to **Dr. Amit Kumar Kohli, P.G. Coordinator**, Electronics and communication Engineering Department, for the motivation and inspiration that triggered me for this work.

I am greatly indebted to all of my friends who constantly encouraged me and also would like to thank all the faculty members of Electronics and Communication Engineering Department for the full support of my work. I am also thankful to the authors whose work have been consulted and quoted in this work.

Finally, I would like to thank my parents for allowing me to realize my own potential. All the support they have provided me over the years was the greatest gift anyone has ever given me.

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ABSTRACT

Recent advances in wireless area have generated a great interest in creating and utilizing ad hoc mobile networks in our day-to-day lives. A mobile ad hoc network (MANET) is a collection of wireless devices which can be configured without using any pre-existing infrastructure or central controller. The mobility and scalability are the basic parameters of MANETs. The application of MANETs comprises of emergency search-rescue operations, meetings, battlefield or disaster areas, communication between moving vehicles and/or soldiers.

There are many factors that impact the performance evaluation of such networks. These factors include the transmission range, the buffer space for message storage, the battery power, the computing power, the data traffic model and the used mobility model. A mobility model signifies the movement of the mobile nodes within the network. The simulation results obtained with unrealistic mobility models such as random models which may fail to capture movement of mobile nodes in the real world scenario such as moving vehicles as their velocity at current epoch depends on velocity at previous epoch may not correctly reflect the true performance of a protocol. Moreover, mobile nodes in random models move independent of each other but in military applications there is a specific leader whom nodes follow so spatial models comes in the picture here. The appropriate design and selection of the mobility model is essential as it supports realistic and accurate protocol simulations. Our thesis work aims to conduct a parametric study using the simulation technique to evaluate the performance of ad hoc mobile networks using different mobility models. In order to illustrate how the choice of the mobility models (random, spatial, geographic etc) impact the network performance of ad hoc protocols to be simulated, this research will perform a comparison among these models considering the performance metrics: throughput, end-to-end delay, normalized routing load and dropped packets.

Keywords: Mobility models, MANET, Routing Protocols, Performance Evaluation

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LIST OF ABBREVIATIONS

ADR	Angle Deviation Ratio
AODV	Ad-hoc On-Demand Vector
ARP	Address Resolution Protocol
AN	Airborne Network
CBR	Constant Bit Rate
CMU	Carnegie Mellon University
CMM	Column Mobility Model
CBRP	Cluster Based Routing Protocol
DSDV	Destination-Sequenced Distance Vector
DSR	Dynamic Source Routing
DDR	Distributed Dynamic Routing
DREAM	Distance Routing Algorithm For Mobility
E2E	End-to-end delay
IETF	Internet Engineering Task Force
IFq	Interface Queue
LAN	Local Area Network
LAR	Location Aided Routing
LL	Link Layer
MAC	Medium Access Control
MN	Mobile Node
MANETs	Mobile Ad-hoc NETworks
MPR	Multi Point Relay
NAM	Network Animator
NRL	Normalized Routing Load
NS	Network Simulator
OTcl	Object-oriented Tool Command Language
OLSR	Open Link State Routing

OSI	Open System Interconnection
OSPF	Open Shortest Path First
QoS	Quality of Service
RWP	Random Way Point
RPGM	Reference Point Group Mobility
RERR	Route Error
RREQ	Route Request
RREP	Route Reply
SDR	Speed Deviation Ratio
SSRWP	Steady State Random WayPoint
TTL	Time to Live
TORA	Temporally Ordered Routing Algorithm
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
WLAN	Wireless Local Area Networks
ZRP	Zone Routing Protocol

CHAPTER 1

INTRODUCTION

1.1 Introduction to Wireless networks

A computer network or data network is a telecommunication network which helps in exchanging the information from one computer to another. In computer networks, the data transfer in the form of data packets from source node to the destination node. The connection is established via cable media or wireless media. Internet is the best computer network. The network is classified into:-

- Wired Network
- Wireless Network

Wired Network uses the Ethernet wires to establish a connection between devices. It is fast, secure network. Optical cables, Twisted pair cables, Coaxial cables etc are used in the wired network as shown in fig. 1.1(a).

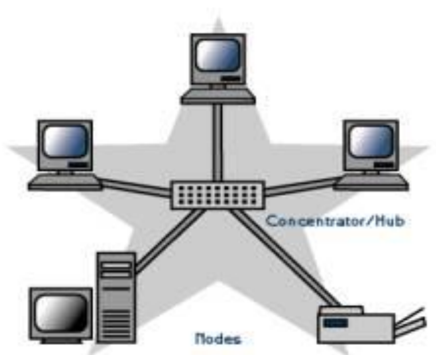

Figure 1.1 (a) Wired network

Figure 1.1 (b) Wireless Network

Wireless network can be established between the devices by using radio frequency waves rather the wires (refer fig. 1.1(b)). This network allows the devices to communicate without the network cables which increases the mobility but decreases the range [1]. The messages are transmitted and received in the air. It is a self centralized and infrastructure less system. Examples of Wireless network are MANETs, sensor networks etc. In the performance analysis of mobile nodes in wireless networks, mobility models are used.

1.2 Motivation of Thesis

A mobility model signifies the movement of the mobile nodes within the network. The simulation results obtained with unrealistic mobility models such as random models which may fail to capture movement of mobile nodes in the real world scenario such as moving vehicles as their velocity at current epoch depends on velocity at previous epoch may not correctly reflect the true performance of a protocol. Moreover, mobile nodes in random models move independent of each other but in military applications there is a specific leader whom nodes follow so spatial models comes in the picture here. The appropriate design and selection of the mobility model is essential as it supports realistic and accurate protocol simulations.

Our work mainly focuses in determining the effect of mobility model on Proactive and Reactive routing protocols for ad hoc mobile networks. In this thesis, both entity and group mobility models are used with varied number of nodes and speed of nodes to examine the behavior of the routing protocols used. DSDV, OLSR, DSR and AODV are used in our simulation as the proactive and reactive routing protocols respectively.

1.3 Thesis Layout

Our thesis report consists of six individual chapters. Chapter 2 presents a literature review of the effect of mobility models and other parameters on an ad hoc network. Chapter 3 contains a brief introduction of MANETs, its characteristics and applications. Chapter 4 contains different mobility models routing issues in MANET. Chapter 5 contains the problem statement and project goal of the thesis. Chapter 6 gives brief overview of Network Simulator. Chapter 7 presents simulation results in the NS-2 environment. Finally, conclusion and future work are drawn in Chapter 8.

CHAPTER 2

LITERATURE REVIEW

MANETs is widely used in wireless network. It is a collection of various nodes or devices of wireless mobiles which help in sending the data from one node to the other node. Each node in MANETs acts as a router. MANETs is a self–configured, self-centralized network of mobile nodes connected to the wireless links [2].

The mobility and scalability are the basic parameters of MANETs. The mobility models characterize the moving patterns of nodes or devices. The routing protocol is a challenging task and it respond to the change made at any node [3]. There are various major problem associated with routing i.e. Asymmetric links, Routing Overhead, Interference and dynamic topology.

2.1 Literature Review

Bai et al. [4] compared AODV DSDV and DSR using NS-2 simulator in Low load and low mobility scenario with various routing protocols and conclude that DSR outperform in high mobility and high load.

Manoharan [5] studied the impact of mobility models for evaluating multicast routing protocols in MANET. The author used Random waypoint models reference point models Manhattan Grid with three protocols ODMRP, AODV and ADDV using NS-2 simulator and carry out their strength weakness and applicability of protocols with mobility models.

Nand et al. [6] authors provide a simulation based performance evaluation and compare various reactive, proactive and hybrid protocols such as AODV,OLSR, ZRP based on Random waypoint mobility model only and evaluated performance parameters such as packet delivery ratio, average end to end delay with using Qualnet 4.5.

Kumar et al. [7] evaluated the performance of DSDV, AODV and DSR protocols and figured out that AODV and DSR perform better in high mobility models than DSDV the performance matrix taken by the author are network load, network size with random waypoint mobility models.

Mazhar et al. [8] compared the performance of various MANET protocols such as DSDV, AODV, DYMO, OLSR, DSR with various mobility model such as RWP, RPGM, CMM with various performance parameters such as throughput, packet delivery ratio, routing load and energy congestion using NS-2 simulator with the varying area.

Amnai et al [9] conducted a behavior study of OLSR proactive routing protocol using two traffic types multimedia (VBR) and CBR, by over various mobility models as Random Way Point, Random Direction and Mobgen Steady State. The experimental results according to the used traffic and models, the OLSR behavior are explained.

Kaushik et al. [10] analyzed the behavior of routing protocols i.e. AODV, DSDV, DSR, OLSR, TORA under the three mobility models (RPGM, CMM, RWP) and then compared the performance of protocols using NS-2 simulator which depicting the significant impact on node mobility on routing performance in terms of PDR, delay, NRL and throughput when subjected to change in numbers of nodes. The simulation results predict that reactive protocols are much better than proactive in the terms of above mentioned metrics.

Gupta et al. [11] illustrated the importance of selecting a mobility model while simulating an ad hoc network protocol. They compared the performance of AODV and DSDV over RWP, RPGM and Freeway Mobility Model on the basis of throughput.

Xie et al [12] paper represents the comprehensive study and analysis of the mobility models of AN. The analytic behavior and comparison of the existing mobility models for AN. RD, RWP and RW are the other model apart from mobility models which are specified for AN. We evaluate this model based on the adaptability of these models for AN if they are not directly designed for AN, network performance and whether the particular mobility model are realistic to capture AN mobility attribute.

Abed et.al [13] evaluated the performance of the three different routing protocols with four classes of mobility models presented in the wireless ad hoc networks. These mobility models determine the performance of routing protocol in the operating environment. The single path routing protocol (AODV, DSR, DSDV) with different mobility models and network loads are considered. The results are obtained after the stimulation in NS-2. The DSR protocol performs better with the RWPM model and fair performance with MGM model. The lowest end-to-end delay is obtained in the routing protocol. The analysis shows that the four mobility models are used with different routing protocols. For example, RWPM works better with DSR and RPGM works better with DSDV.

Quispe et. al [14] depicts that the mobile ad hoc network is a collection of wireless mobile nodes. The network is designed dynamically without a fixed infrastructure. The authors discuss which type of routing protocol in MANETs i.e. Proactive, Reactive or Geographical routing models perform in the emergency and rescue situations. The density of the nodes is calculated for AODV, DSDV and CBRP routing models in the urban areas for the rescue and the emergency operations. The simulation is done on NS-2 that is used in the study of CBRP, AODV and DSDV protocols are evaluated for ERS. The result shows that the CBRP is the best protocol among these protocols. The information lost in this protocol is very less as compared to the other routing process. The delay and mean fluctuation are also smaller in CBRP than in AODV and DSDV. In disaster areas, CBSR can work better than other routing protocols to efficiently adjust the evacuation of persons.

Singh et al. [15] represents the paper in which the comparison between the User Datagram Protocol (UDP) and Transport Control Protocol (TCP) is discussed in corresponding to the behavior of AODV, DSR and DSDV routing protocol with Random Waypoint Model, Reference Point Group Model and Manhattan Grid Model. The NS2 is used for the stimulation to obtain the results under the different conditions. The performance is calculated with the various parameters such as throughput, packet delivery ratio, and end-to-end delay. In MANET, the TCP is widely used in stimulation but its behavior is not satisfactory for the routing protocols and mobility models. The result depicts that the DSDV has very low end-to-end packet delay in all the mobility models for UDP transmission than in AODV and DSR.

There has been several works in the literature that evaluated several routing protocols but the assessment was based on random waypoint mobility models. The main disadvantage of these studies is that they are not based on real life scenarios. This is probably the main reason MANETs have not been used extensively in every day applications although they have significant advantages above traditional communication networks (cellular and infrastructure networks).

The appropriate design and selection of the mobility model is essential as it supports realistic and accurate protocol simulations. As reviewed earlier, different mobility models have different characteristics, strengths and weaknesses that can be used for modeling different scenarios. Thus, instead of adopting fixed mobility model, the researchers should conduct a thorough analysis of various mobility models before beginning their simulations.

CHAPTER 3
ROUTING IN MANETS

3.1 Key features of MANET

A mobile ad hoc network (MANET) is a collection of wireless devices which can be configured without using any pre-existing infrastructure or central controller. The key features of MANETs are as follows [3]:

- Autonomous terminals: In a MANET, each node is an autonomous terminal and can act as either a host or a router. In other words, besides performing the basic processing functionalities of a host, the nodes in a MANET can also perform switching functionalities as routers.
- Dynamic configuration: As the mobile nodes may join or leave the network at any time without any disruption, changing the network topology rapidly and unpredictably. The wireless network also consists of both bidirectional and unidirectional links. The wireless channel is also subjected to interferences by other channels and errors because of unclear physical boundary.
- Distributed control: In a MANET, there is no fixed infrastructure or central controller. The control and management of the network is distributed among the participating mobile nodes. The participating nodes have to cooperate with each other and to implement some core functionalities like security and routing.
- Low profile terminals: The mobile nodes in MANET have limited processing capabilities, small physical memory and limited power storage. Therefore, the devices require optimized algorithms and energy conservation algorithms. The attackers can easily reach the network by snooping through these low-end devices sharing a wireless channel.
- Bandwidth-constrained: The wireless links have significantly lower capacity than their wired counterparts which results in congestion that may significantly drop the throughput of the network.

- Limited physical security: Since the wireless channel is open for all, MANETs are more vulnerable to security attack than the wired networks. The boundary separating the inside network from the outside world is blurred.

3.2 Real world components of MANET

Before simulating a network, we need to understand various real world components of MANET which are broadly classified as follows:

- **Nodes:** A component which has the capabilities of transmitting, processing and receiving of information is called as node or host.
- **Architecture of the node:** Nodes or hosts are the main communication or radio devices and the internal architecture of the node is defined by the OSI network protocol stack. The OSI protocol layers are physical, data link, medium access control (MAC), network, transport, session, presentation and application layer. The implementation of the networks using simulators is similar to the real time counterparts.
- **Communication Architecture:** As the term, mobile nodes doesn't have a central entity to maintain/organize them so these nodes are independent and use wireless media for communication with other nodes, but the nodes will be able to communicate only when the other nodes lie within the radio transmission range. The physical properties of a node are transmission and reception.
- **Network:** This is the place where the nodes/hosts are present and obviously only a group of them is called as a network. Always there will be physical boundaries for every network. For example, all the cell phone service providers will have their network coverage only limited to the country that they exist. Even if they offer service outside the physical territory of their country, they borrow of the service where the mobile user is actually present. The count of the nodes will not be constant as they keep moving so nodes will be leaving and entering the network at any time.

- **Traffic:** The process of moving data from one node to another node or transfer of information from one layer to another layer (according to OSI protocol layers) is termed as traffic.
- **Mobility:** As the term MANET, has mobile in it which means the nodes are mobile and are free to move in any given direction. But the simulators follow certain types of mobility models such as linear mobility, restricted linear speed mobility and so on. In real world they don't have any specific model for their mobility but for simulators we have to use certain mobility models which are almost similar to different mobility patterns of the real world.

3.3 MANET Applications

MANETs are ideally suited for many applications, as stated previously. What follows is but a brief sampling and description of a few promising applications [16, 17]. There are many other possible applications, and as experience with MANETs increases and the technologies mature and improve, the number of applications and the frequency of actual deployments will undoubtedly increase.

- **Disaster relief:** It often happens that after a major natural disaster the infrastructure (taken here to mean all infrastructure in general and communications infrastructure in particular) of the devastated area is destroyed or rendered inoperable. A recent example is the devastation in New Orleans and other parts of the Gulf of Mexico coast of the United States in 2005 due to hurricane Katrina. It may also happen that the affected area had a poor or non-existent infrastructure to begin with, such as many of the areas affected by the recent Indian Ocean tsunami in 2005. Rescue efforts could greatly benefit by setting up temporary MANETs whose nodes are individual rescue units, both on land and in the air.
- **Surveillance:** Aerial and land vehicles/personnel tasked with keeping watch over some swath of territory, such as the southern border of the United States or parts of Afghanistan or Iraq, can greatly benefit from being able to coordinate their actions in a more integrated form than is possible with conventional forms of communication. In a MANET context, what one node sees all nodes also see, in essence allowing the force to act as a unified, coherent whole. The concept of

surveillance is not restricted to detecting intruders; it also extends to detecting or monitoring other threats or situations, such as forest fires. The surveillance nodes can be aerial drones, land robots, individuals, and simple wireless sensor nodes.

- **Military:** Soldiers or vehicles operating in hostile territory cannot afford to depend on any kind of pre-existing infrastructure for communications. A MANET can provide a coherent view of the situation to all those involved, and allow those in charge to coordinate the actions of their forces in a more effective manner than would otherwise be possible. Multimedia capabilities typically provided by today's portable computers could enhance the overall level of situational awareness and make any miscommunications less likely.
- **Exploration:** Robotic or manned vehicles sent to other planets could constitute a MANET for coordinated exploration of a given area of terrain. A large interesting feature found by a node could be communicated to the other nodes, in order to have additional nodes (with potentially more suited equipment) investigate the feature. Similarly, a node could alert other nodes of some sort of dangerous condition it has encountered, such as quicksand or slippery ground, or ask for assistance if need be.
- **Air Traffic Control:** The control of aircraft approaching and departing airports could be enhanced by MANETs. The nodes would be the aircraft and the ground control stations. All kinds of relevant information, such as fuel state, could be exchanged in addition to position, velocity, altitude, and identification. Multimedia information could also be exchanged, and all the airplanes could have selfawareness of their neighbors. Aircraft further away from the airport than is common today could also become aware of the general situation by also becoming part of the network (by being within transmission range of airplanes closer to the airport). Since the aircraft are equipped with precise equipment to pinpoint their spatial location and velocity, and their general movements follow some general rules and patterns, this is an ideal application for the LAR scheme to enhance the "main" routing protocol.
- **Wireless Sensor Networks:** The number of situations in which MANETs can be used for sensing activities is very large. There are many situations in which a

rapid sensor deployment capability in hostile or hard to reach territory is very desirable, such as in military tracking of vehicles or personnel. Civil defense and the military alike can greatly benefit from sensor networks to detect biological or chemical attack. Animal studies can make use of networks of sensors that do not inhibit the behavior of the animals in the wild. Geological and other natural activities in remote areas or too dangerous to humans, such as forest fires, monitoring of physical phenomena harmful to people, such as radiation or volcanic eruptions, are just a few more examples of applications that can effectively be carried out by sensor networks.

3.4 Advantages of MANET

MANET posses following advantages due to its mobility and infrastructure-less structure:

- **Fast establishment**: MANET doesn't require proper installation or network of wires. It can easily be created and destroyed so it is easily adaptable.
- **Dynamic topologies**: In MANET, nodes can enter or leave the network haphazardly.
- **Fault tolerance**: Whenever there is failure of connection between nodes alternate paths may be provided for routing.
- **Connectivity**: In MANET, nodes can easily communicate with other nodes present within the transmission range to forward data packet. There is no need of centralized links and gateways for communication.
- **Mobility**: MANET supports mobility i.e. wireless mobile nodes can move in different directions that may increase complexity. So, routing algorithms must be designed to handle this complexity level.
- **Cost**: Cost of establishment of MANET is quite less because infrastructure is not required.
- **Spectrum reuse**: In MANETs, there is a possibility of spectrum reuse due to small communication links.

3.5 Limitations of MANET

Although mobile ad-hoc networking is the need of hour but there are various limitations associated with them:

- **Bandwidth constraint**: The capacity of wireless link is less than their wired counterparts. For example, wireless LAN has capacity of 2 Mbps whereas wired LAN has capacity in powers of Gbps.
- **Processing capability**: Routing and data transmission processes normally consumes a lot of power of mobile devices.
- **Energy constraints**: Mobile devices have limited battery power backup. Their limited energy can't be used in employing cryptographic techniques for security and battery saving algorithms should be used instead.
- **High latency**: Mobile nodes remain in inactive state when they don't send data packets and come in latent state while sending state from dormant or inactive state which will increase delay.
- **Security**: MANET suffers from various vulnerabilities that can be exploited by due an attacker for harming the network and its resources.

3.6 Routing in MANETs

The routing procedure for MANETs is designed over the conventional algorithm. Therefore, to determine the routing principles in MANETs, it is necessary to review the traditional algorithms for routing i.e. Distance Vector, Link state and Source Routing protocol.

- **Distance Vector**

In distance vector routing protocol, each router acknowledge its neighbors about the routing table. Corresponding to each path, the receiving router pick neighbor advertising the local cost, then add this advertising entry into the routing table for the re advertisement. Eg. Routing Information Protocol (RIP) [18].

- **Link State Routing**

In Link State routing protocol, each router maintain the partial mapping of the topology. When the network link changes from one state to the other state, it notifies a link state advertisement and it is broadcast in the entire network. The link state routing protocol is more reliable, easier to debug and less bandwidth intensive than the distance vector routing protocol. The demerits of this routing protocol are its high complexity and more consumption of memory resources. Examples of link state routing protocol is OSPF [19] and Intermediate System-to-Intermediate System (IS-IS).

- **Flooding**

Flooding is used in broadcasting the packets. In flooding protocol, packets are broadcasted to all the neighbors in the network by any node. When the packets are received by the nodes then it rebroadcast in the network. The node re-transmit the packet exactly once. This phenomenon continues until the packet is received by the nodes in the network. High network resources are needed in this flooding technique which results in the high packet delivery ratio.

- **Source Routing**

In Source Routing Technique, the transmitter (which transmits the packet or message) will specify the route that it should follow in the network. Source routing technique is classified into two types i.e. strict and loose. In strict source routing technique, the transmitter specifies the proper route to the packet or message that it should follow in the network. In loose source routing technique, the transmitter only specify the few hops that will help the packet to reach its destination. In this source routing technique, every node have the knowledge of the nodes present in the network and this is possible only by maintaining the routing table.

3.7 Problems in routing with Mobile Ad hoc Networks

- **Routing Overhead:** In wireless ad hoc networks, the location of the nodes is changed within network. Due to which some stale routes are generated in the routing table which leads to unnecessary routing overhead.
- **Interference:** It is one of the major problems in the mobile ad hoc networks. As the nodes in the network are not stationery due to which the links get interfere with each other and the inference between the links will corrupt the transmission.
- **Dynamic Topology:** The network topology of mobile ad hoc network is not stationery and nodes are also mobile due to it the characteristics of the network changes. The changes are noticed by the routing tables which are maintained by

the nodes in the network. After every 30sec the changes are updated in the routing table. The frequency of the updating is very low for the mobile ad hoc network.

3.8 Routing Protocols and its Characteristics

In mobile ad hoc network the route between the nodes is created by the MANETs protocol. The problems present in the ad hoc network and the performance are analyzed by IETF MANET working group. The nodes that are present in the mobile ad hoc network decide the route on which the packet must transfer between the devices by using the mobile ad hoc routing protocols. The nodes find their route in the network topology though they are not familiar with it.

The nodes present in the network inform their presence to its neighboring nodes and then the neighbor announce its broadcast so that every node knows about its neighboring node and route to reach them. Various routing protocols and routing algorithms are used i.e. distance vector, link state etc. to determine the route from source node to the destination node [20]. The wired network routing protocol is not use in combination with the wireless network due to the limitations in the wireless network. The various routing protocols are used to overcome the challenges in the network. The characteristics of the routing protocol are discussed below-:

- **Distributed:** The routing protocol are fully distributed because centralized routing in wired networks results in high control overhead and single point of failure.
- **Adaptive:** It should be adaptive to frequent topology and changes due to high node mobility in MANETs.
- **Faster route computation:** Computation and maintenance of routes should involve minimum number of nodes i.e. hop count is minimum.
- **Loop-free:** The route should be free from loops and stale routes.
- **Optimal utilization:** It optimally uses scarce resources in MANET such as bandwidth, memory, computing power and battery power.
- **QoS:** It must provide a level of QoS as required in real time applications of MANETs, and should offer support for time-sensitive traffic.

3.9 Classification of Routing Protocols

The routing protocols are classified as below [20]:

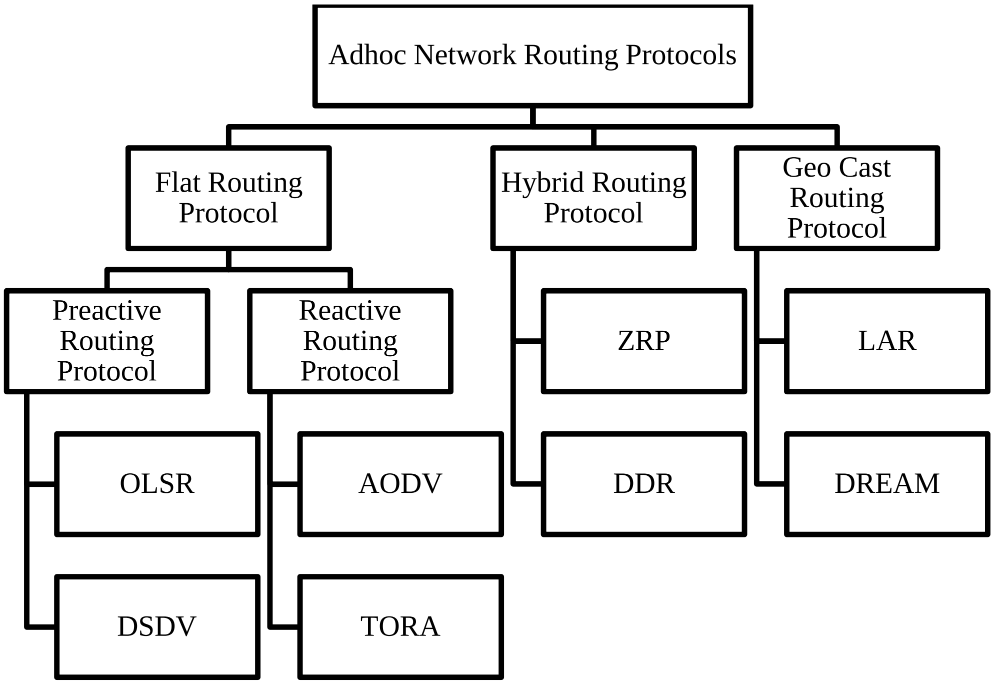

Figure 3.1 Classification of Ad hoc Network Routing Protocols

- **Proactive Routing Protocol**

The Proactive Routing Protocol or Table driven Routing Protocol is a type of routing protocol the address of destination are obtained by distributing the routing table to all the neighboring nodes. Some examples are OLSR [21], DSDV [22] etc.

- **Reactive Routing Protocol**

The reactive routing protocol or On-demand routing protocol is a type routing protocol in which the path from source node to the destination depend on the Query-Reply Topology. In a reactive routing protocol approach, when the sender want to send the message at the particular time then it determines the route. Some examples are AODV [23], TORA etc.

- **Hybrid Routing Protocol**

The Hybrid Routing Protocol is a combination of Reactive and Proactive Routing Protocol. It maintains the routing tables as in proactive routing protocols and determine the routes for the far nodes as in reactive routing protocol. There are many protocols available in hybrid routing protocol in MANETS that are globally reactive and locally proactive in nature. Some examples of hybrid routing protocol are ZRP (Zone Routing Protocol) [24], DDR (Distributed Dynamic Routing Protocol).

- **Geocast Routing Protocol**

Global Positioning System (GPS) is the major evolution in the communication system. The GPS provides the location and the timing of a node. The node in this routing protocol doesn't maintain any record about the neighboring nodes as it is aware about its destination [25]. There are various protocols associated with geographical restriction routing protocol i.e. DREAM, LAR etc.

3.10 Destination Sequenced Distance Vector (DSDV) Protocol

The DSDV Routing Protocol is enhanced version of Bellman-Ford Routing Algorithm. It is a type of Proactive Routing Protocol [22, 26]. In this routing protocol, every node has its own routing table with new sequence number and attribute. Every node maintains its routing table and corresponding to this table node broadcast the message or packet to the other nodes present in the network. The data exchange between the nearby base station can also be done by this routing protocol.

3.10.1 Protocol Operation and activities

The routing table is maintained by the nodes in the network which help in transfer of packets and connect the base stations in the network. Each node has the knowledge of network before moving to the next node. All the available destination and number of hops required to reach the destination are contained in the routing table. The record basically consists of the available links between the nodes, distance i.e. number of hops, sequence number etc. The nodes send this maintained record to the neighboring node so that it can update its record. Each single entry in the routing table that is maintained by the node is allocated a sequence number and these sequence number are allocated by the destination node so that the new route to the destination from the current node is distinguished by the state routes. Thus, this will help in avoiding the formation of route loops.

When the packets are sent from one node to the other node in the network the routing information is also broadcasted at that time and the routing table is updated by the nodes.

Every node periodically updates the information of its routing table to its neighbor node. The information of the routing table is broadcasted so frequently that the entries in the table changes very quickly. This phenomenon is performed to get the less number of hops to reach the packet from source node to the destination node. The node can exchange its data to the node that is not directly connected with the help of the updated routing table.

The data that is broadcasted in the network should contain some information for the new route i.e.

- The sequence number of transmitter
- The destination address where the data will transfer
- The hop count required to reach the destination.
- Destination Sequence number.

The routing table of the source node may also contain the hardware address, network IP address of the source node [26]. The sequence number of the source node and the new destination are required for the transfer of packet. The routing table of all the nodes is updated by new destination sequence number which helps in managing the routing entry for the source node.

When the route information is received from the routing table, the destination node increment the sequence number before receiving the transmitted packet as the packet has to travel to one or more hop to reach the destination. The most important factor that should be taken care of between transmitting the packets to the nodes is the time. The time should be properly set while transmitting the packets so that the packets don't collide with each other and the broken links don't occur. If the broken links occur, the measured factor is assigned an infinity value and they are detected by layer2 protocol.

3.10.2 Example of DSDV

Consider a mobile network with 8 nodes. Initially, routing table at node C is shown in Table 3.1 which is created from information received from other nodes. As node A moves its location nearer to node G and D, the link between node A and B is broken and infinity metric assigned at routing table of B for node A. Node B will advertise this updated information to its neighbors. Similarly, nodes G and D also broadcast information about A to its neighbors. Node C will receive updated information from its neighbor and routing table will look like Table 3.2.

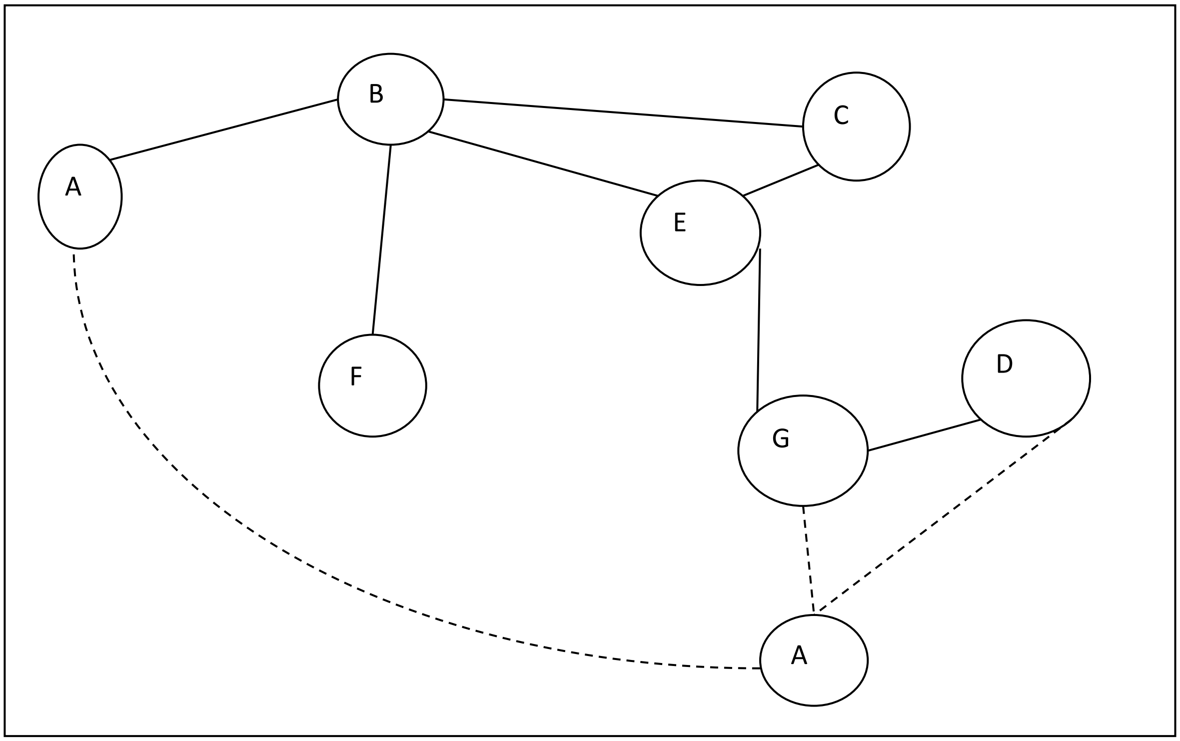

Figure 3.2 Movement of node A in MANET

Table 3.1 Routing Table at node C

Destination	Next Hop	Metric	Sequence No.
A	B	2	S100-A
B	B	1	S102-B
C	C	0	S104-C
D	G	3	S106-D
E	E	1	S106-E
F	B	2	S108-F
G	E	2	S110-G

Table 3.2 Routing Table at node C after movement of node A

Destination	Next Hop	Metric	Sequence No.
A	G	3	S200-A
B	B	1	S102-B
C	C	0	S104-C
D	G	3	S106-D
E	E	1	S106-E
F	B	2	S108-F
G	E	2	S110-G

3.10.3 Advantages of DSDV

- Loop free paths are available in DSDV protocol.
- DSDV reduces the Count to infinity problem.
- Incremental updates avoid the extra traffic instead of full damp updates.
- The best path is maintained by DSDV. It is called path selection.

3.10.4 Limitations of DSDV

- The unnecessary advertisement of routing information causes the wastage of bandwidth when there is no change in network topology.
- Multipath and multi task routing is not performed by DSDV.
- To find the value of time delay is a difficult task for the route advertisement.
- In the network every node maintains the routing table for advertisement of routes. But the maintenance of routing table for larger network is very difficult, as it will consume more bandwidth.

3.11 Optimized Link State Routing Protocol (OLSR)

OLSR is a Proactive Routing Protocol that is based on the link state routing protocol for large and dense networks [21, 27]. It relies on the Multipoint Relays (MPR) concept for reducing number of broadcasts. In contrast to pure flooding, few routes are selected for broadcasting the messages. Each selected routes defines small set of neighbors to reduce broadcast messages.

In OLSR route discovery procedures, MPRs behave as intermediate routers [21]. The working of OLSR operation is divided into three parts:

- Packet forwarding: It provides information about neighbors to routers in an optimized way using MPRs.
- Neighbor sensing: In neighbor sensing, the status of the neighbor links have the three phases i.e. unidirectional, bidirectional and MPR. Routers distribute the local information to each node present in the network.
- Topology discovery: The topology discovery is used for determining the network topology which is used in creating routing tables and shortest path to every node.

OLSR used four types of messages i.e. Hello message (HM), Topology Control(TC) message, Host and Network Association (HNA) message and Multiple Interface and Declaration(MID) message [21].

- The Hello message is used for detecting the list of neighbors and their link status.
- The topology control message is used for declaring network topology that contains MPR ID and MPR selector set.
- The Host and network association message is used for declaring host and network information associated with it.
- Multiple interface and declaration message is used for declaring multiple interfaces.

On the basis of HELLO message each node selects its MPRs. The nodes maintain the two sets of nodes, MPR set and MPR selector set. The MPR set is a minimal subset of one hop neighbors that covers all two hop neighbors. The MPRs selector set is created from its one hop neighbor which has selected it as MPR nodes. A neighbor table is constructed which stores the one-hop neighbor , link status, list of two-hop neighbors accessible from the one-hop neighbor and a sequence number specifying the most recent MPR set.

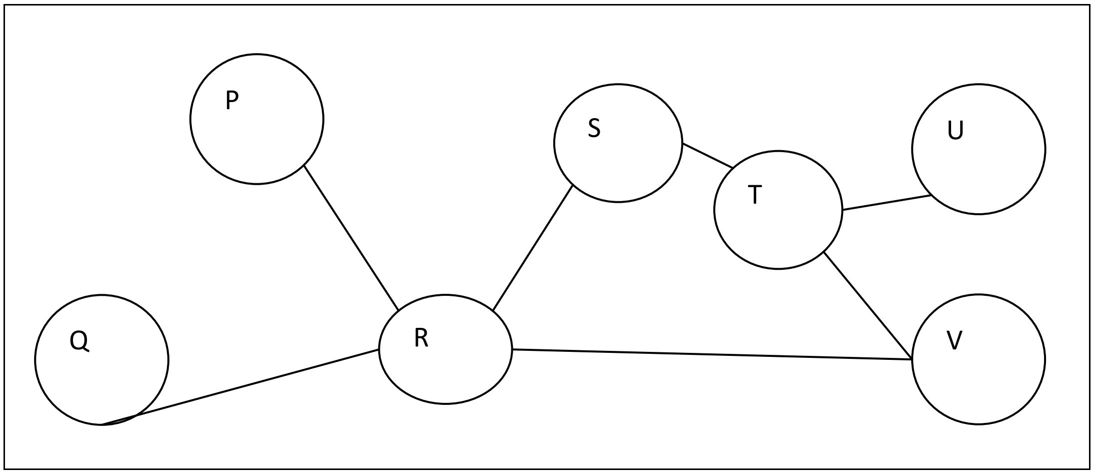

Figure 3.3 Example of OLSR routing protocol

Table 3.3 MPR sets and MPR selector sets in OLSR Example

Router ID	MPR set	MPR Selector set
P	R	NULL
Q	R	NULL
R	S	P,Q,S
S	T,R	T,R
T	S	U,V,S
U	T	NULL
V	T,R	NULL

3.11.1 Merits of OLSR

- It reduces the control overhead and minimizes the broadcast traffic.
- Routes to all the nodes are always available.

3.11.2 Demerits of OLSR

- Routing delays at MPR nodes.
- Every route involves transmission through MPR node so path chosen may not be always shortest.
- Large bandwidth required to compute optimized path.

3.12 Dynamic Source Routing (DSR)

DSR is a Reactive Routing Protocol based on the source routing in which routing information is maintained and updated at mobile nodes [28]. It is suitable for wireless mesh networks and relatively small network (5-10 hops away).

The two phases for routing in DSR protocol are:

- **Route Discovery:** It finds an optimum path between source node and destination node. RREP message is generated by the destination node only. It first searches for route to source node in route cache. If not found, then destination node will follow the route record of RREQ packet in reverse order and copy it in RREP packet. The destination node responds to the RREQ packet by sending the RREP packet to the node. The figure given below shows the propagation of RREQ packet and the route taken for RREP packet. The RREQ message is shown by bold line and the RREP is denoted by dashed line in the fig. 3.4. Flowchart is shown in fig 3.5

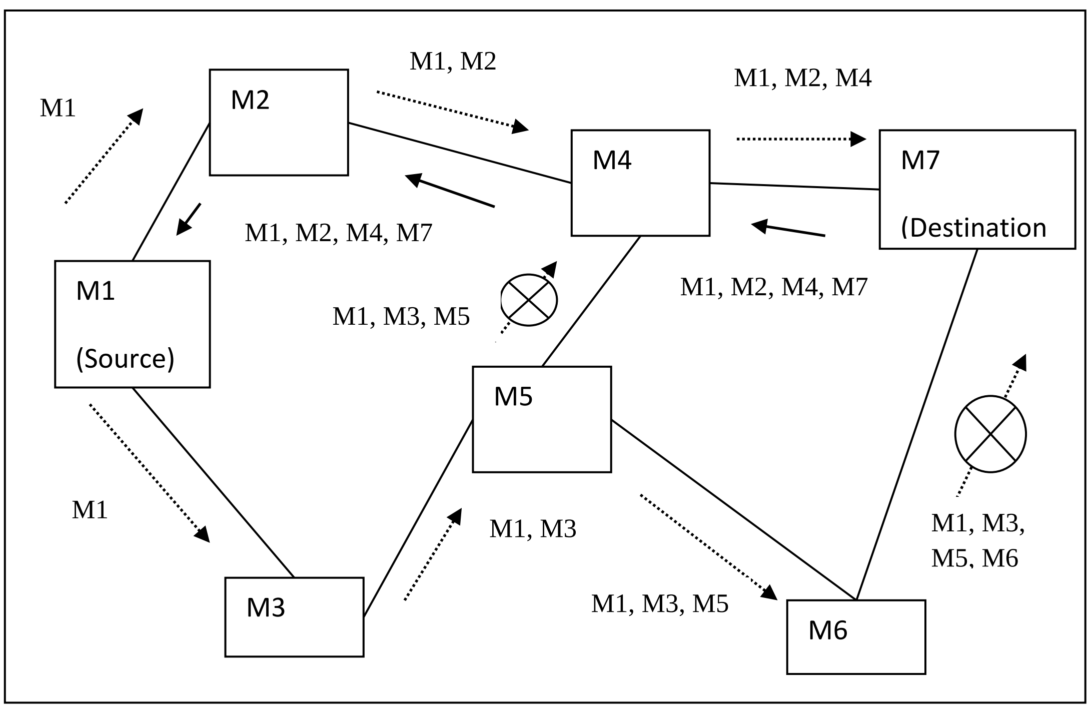

Figure 3.4 DSR Route Discovery

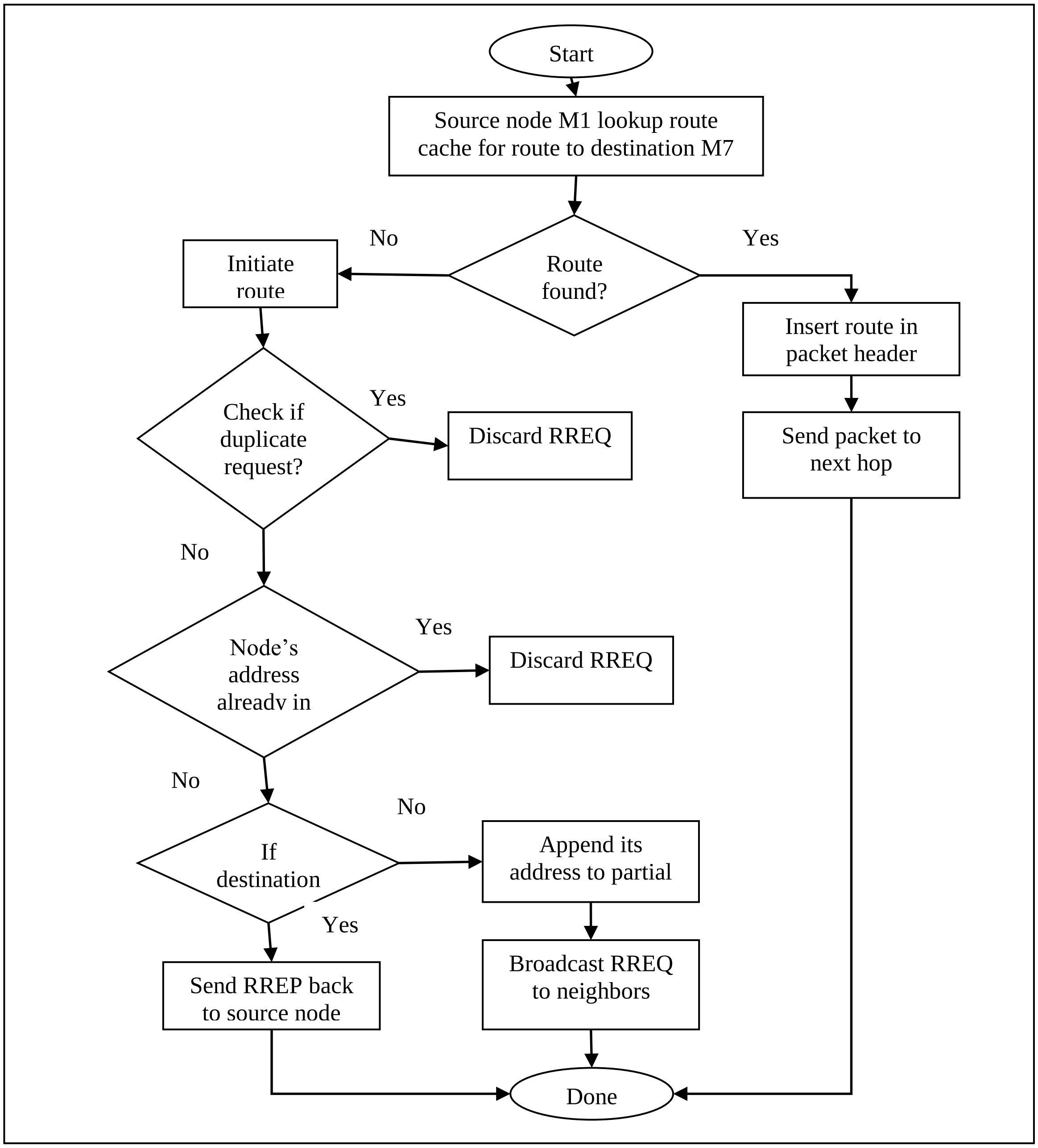

Figure 3.5 Flow Chart of DSR

- **Route Maintenance:** It starts when the route is in use and RERR packets are send to the source node to start another route discovery process .The information about the broken links is updated in route cache of a node and all the nodes that contain that hop are removed.

3.13 Ad hoc On Demand Distance Vector (AODV) Routing Protocol

AODV means Ad hoc On Demand Distance Vector Routing Protocol. It is mainly used in ad hoc networks and in other wireless ad hoc networks also [23]. It is a type of reactive routing protocol. AODV establishes the unicast route and its extension AOMDV establishes the multicast routes. The sequence number is used in the AODV for maintaining the freshness of the routes. The routing table is maintained and it contains the information of the destination nodes from every source node. If the route is not used by the source node for a certain period of time then the node is removed from the table. The routing table keeps the destination route till the source node uses it. All the mobile nodes can communicate with their neighboring nodes to forward the packets to the nodes which are not directly connected to them. AODV consist of the following basic messages [23]:

- HELLO message: The HELLO messages are broadcasted to neighboring nodes to check whether the neighboring node is in communicating range or not. These are like local advertisements for showing their continued presence in the network. If HELLO messages are not received from a particular node within a specified time then it is assumed that the neighboring node has moved away and the link to this node is marked as "broken".
- RREQ: When the source node needs a route to the destination node then it will broadcast a RREQ message with IP address, route request ID and sequence number of the source and destination to all the nodes in the network. The RERQ ID and IP address are used to recognize all the request and sequence number are used to examine the freshness of the packet. The expanding ring technique is used while broadcasting these messages. The Time to live (TTL) value in RREQ defines the number

  hops through which the message should be forwarded and in the first transmission its value is set to a predefined value. If the further re-transmission is needed the value of TTL is increased. The packet format for the RREQ message is given below.

Type	Flags	Reserved	Hop Count
RREQ ID			
Destination IP Address			
Destination Sequence Number			
Originator IP Address			
Originator Sequence Number			

Figure 3.6 Route Request Packet Format

The field of the packet format are defined as:

1. Type field: The value of this field is set to 1 for RREQ packet.
2. Flags: There are various flags present in this field i.e. join flag, repair flag, destination only flag and unknown sequence number flag.
   - Join Flag (J flag) and Repair flag (R flag) are reserved for the multicast.
   - Destination only flag if set to 1, then only destination respond to the RREQ message otherwise the intermediate node will respond.
   - Unknown Sequence number flag if set to 1, then the destination sequence number is not known at the time creating RREQ packet.
3. Route Request ID (RREQ ID): This identifier in combination with IP address of source node uniquely identifies the RREQ packet.
4. Destinations IP address: This field specifies the unique IP address of the destination node.
5. Destination Sequence Number: This field specifies the most recent sequence number received by the source node to reach the destination in the past.
6. Originator IP address: The field specifies the IP address at which RREQ message is broadcast.
7. Originator Sequence Number: In this field the present sequence number of the source node which is incremented every time source node sends any message in the network.

- Route Reply (RREP) Message: The RREP message is broadcasted in response of RREQ to the source node. When source node broadcast the RREQ to the destination node to find the route if the route is found then the RREP is send as acknowledgment. The intermediate nodes that are present between the source node and the destination node establish a path when RREP message is sent. If the number of RREP from the destination node to the source node is more than one then the path which consists of less hop count will be considered and the transfer of packet will start to the destination. If the link between the source node and destination node is broken, Route Error (RERR) message is sent to the source node. After receiving the RERR message if it still needs a path or route then the route is discovered again. The packet format of RREP is given as below:

Type	Flags	Reserved	Hop Count
Destination IP Address			
Destination Sequence Number			
Originator IP Address			
Lifetime			

Figure 3.7 RREP Packet Format

The fields of the packet format are defined as:

1. Type field: The value of this field is set to 2 for RREP packet.
2. Flags: There are two flags present in this field i.e. Repair flag and acknowledgement flag.
    - Repair Flag(R flag) : This flag is reserved for multicasting.
    - Acknowledgment flag (A flag): This flag is set to send the reply of RREP message when there is danger of unidirectional links.
    - Reserved: This flag is reserved.
3. Hop Count: This flag specify the number hops present between the source node and the destination node.
4. Destination IP Address as in RREQ packet

5. Destination Sequence Number: The sequence number associated with destination for a particular route.
6. Originator IP Address of source node as in RREQ packet
7. Lifetime: It is the time period in milliseconds for which route is considered to be valid by the nodes receiving this RREP.

3.13.1 AODV Operation

Whenever the node wants to transmit the data to another node which is not its immediate neighbor, source node begin the process of locating the route and send RREQ message to neighboring nodes and the latter one after receiving the RREQ renew the information regarding source node and in routing table create a backward link to source node [29].

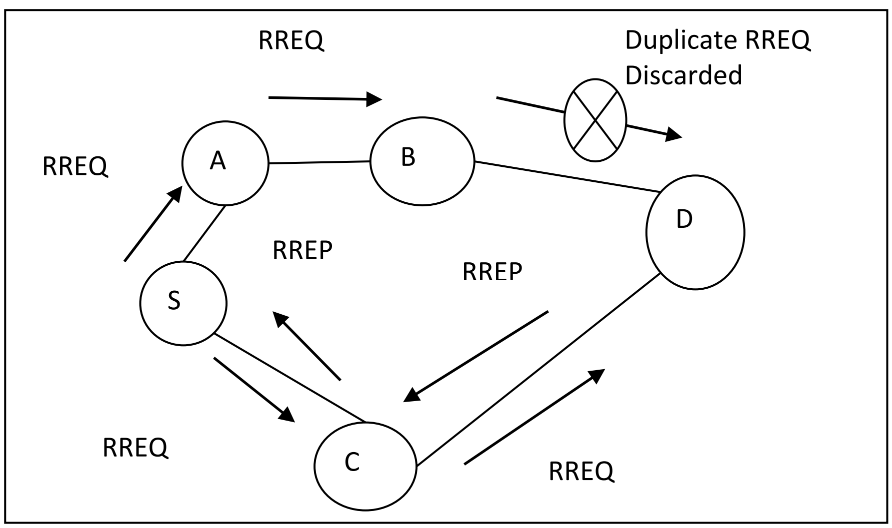

Figure 3.8 AODV Route Discovery

Further it checks if it has already received the same RREQ, then the RREQ is discarded. If the RREQ is received by the intermediate node which do not have the direction of path to the destination then it is re broadcasted to the neighbor nodes. After the destination node or with intermediate node which knows about the way to final node, RREP is propelled back. RREP travel the same track as that of RREQ. Intermediate nodes create a forward path to destination in routing tables. When there is link failure or breaks occur then RERR message is propagated. As shown in fig 3.8, source node S broadcasts RREQ to its neighbor A and C which further broadcasts it to B and E. When RREQ reaches destination D, RREP is unicasted back to source. The flowchart is given in fig 3.9.

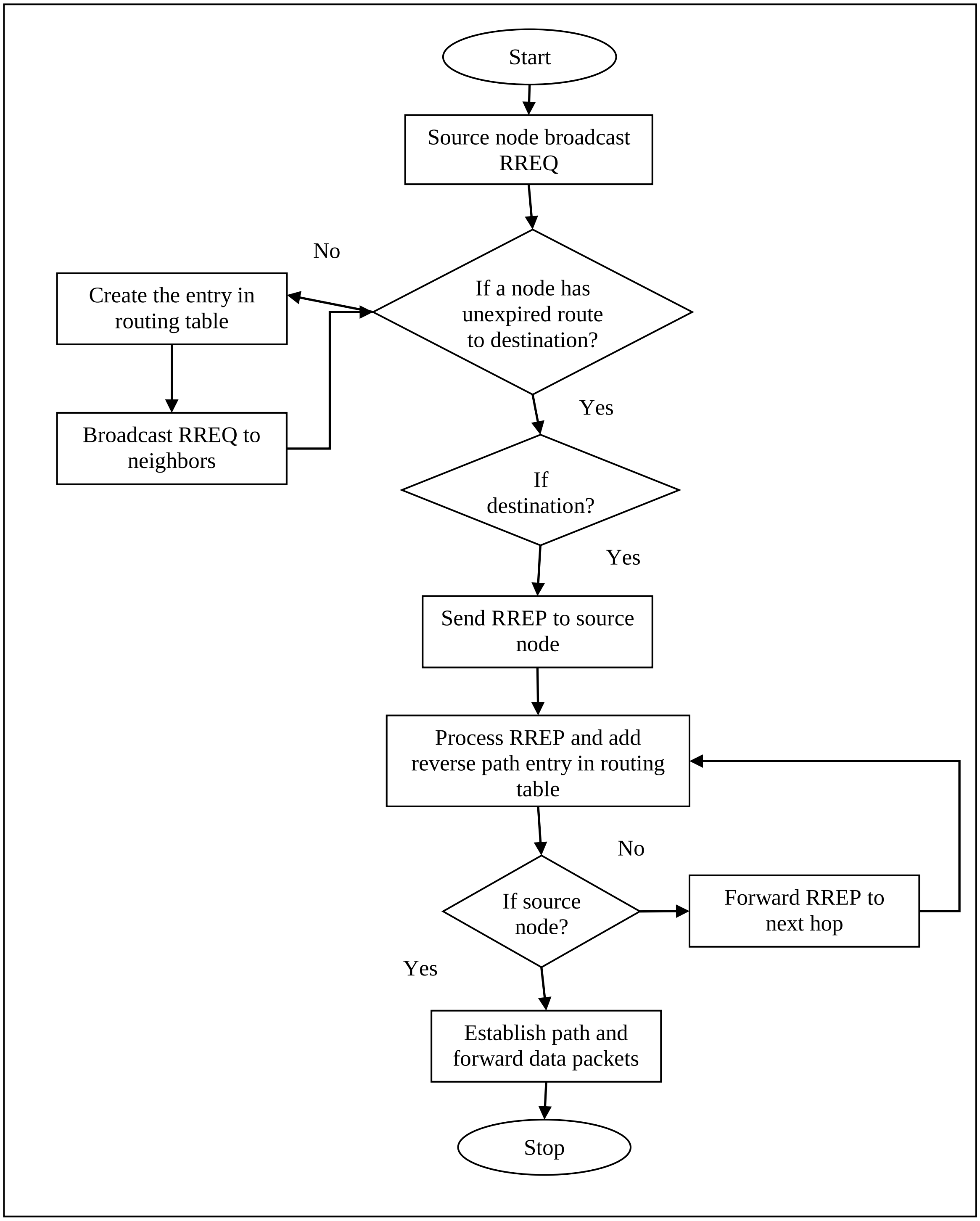

Figure 3.9 Flow Chart of AODV

CHAPTER 4
MOBILITY MODELS

4.1 Classification of Mobility Models

The mobility models are cast to define the movement pattern of mobile nodes. It describes the location, velocity and acceleration change over time of mobile nodes. The brief description of mobility models is explained in this section. The fig. 3 describe the categories of the mobility models which came into existence and are used in Mobile Ad hoc Networks. There are several classes based on the characteristics of the mobility models [30].

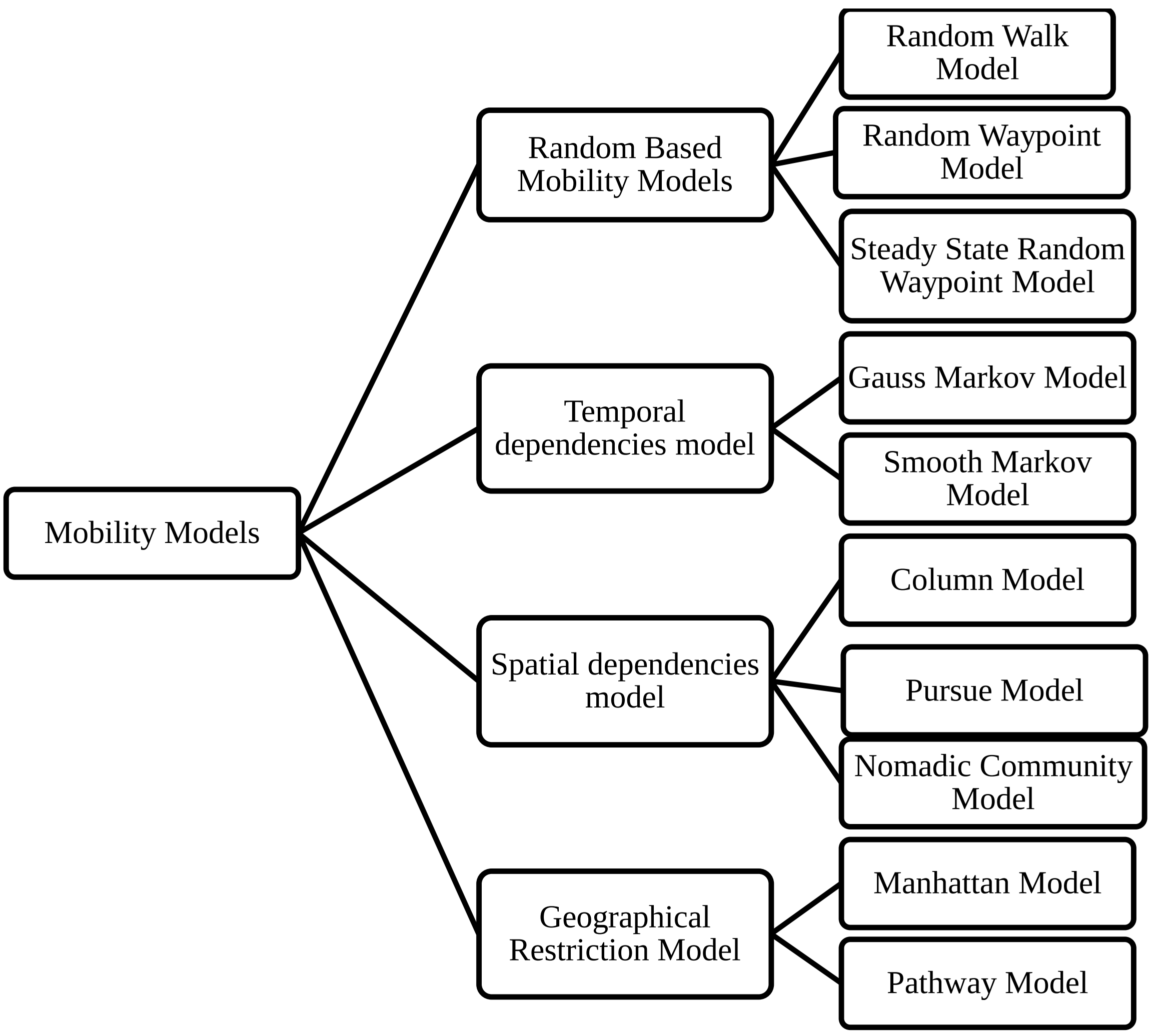

Figure 4.1 Classification of Mobility Models

4.1.1 Random Mobility Model

In this model, the mobile nodes are allowed to move freely within the specified area without any restriction. The destination of the packet, speed and direction of nodes are selected randomly independent of other nodes in the network. Examples of the random models are Random walk model, Random Waypoint model etc.

- **Random Walk Model**

It is a memory less mobility model which doesn't retain any knowledge of past location and speed of nodes [31]. It is also referred as the "Brownian Motion" that mimics the behavior of mobile nodes moving in an unexpected way. Each node randomly chooses new direction and speed from pre-selected ranges (speedmin , speedmax)and (0,2∏) respectively after a fixed interval of time, say t and distance travelled , say d. The memory less property of this model generates the unrealistic movements and sharp turns**.**

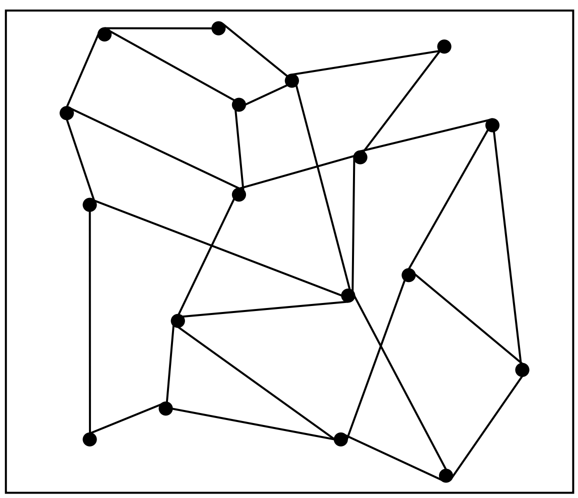

Figure 4.2 Movement patterns of mobile nodes using Random Walk Model

- **Random Way Point Model (RWP)**

The RWP Model is first defined by Johnson and Maltz [31]. It is mainly implemented by Network Simulator such as ns2 [21]. Corresponding to each movement in this model, the mobile nodes choose a position within the specified area and move towards it with the speed distributed in the range [V_{min}, V_{max}]. Here, V_{min} is the minimum allowable velocity for each mobile node and V_{max} is the maximum allowable velocity for each mobile node .

The mobile node stops for the specified time called the pause time denoted by T_{pause} after it reaches the current destination and then repeat the same procedure.

This model is mostly used in MANETS. It is also called the memory less model because it doesn't have any record of the past location and speed values. There are various parameters on which this model depends i.e. speed, direction and destination of the node. The fig 4 shows the random way point model.

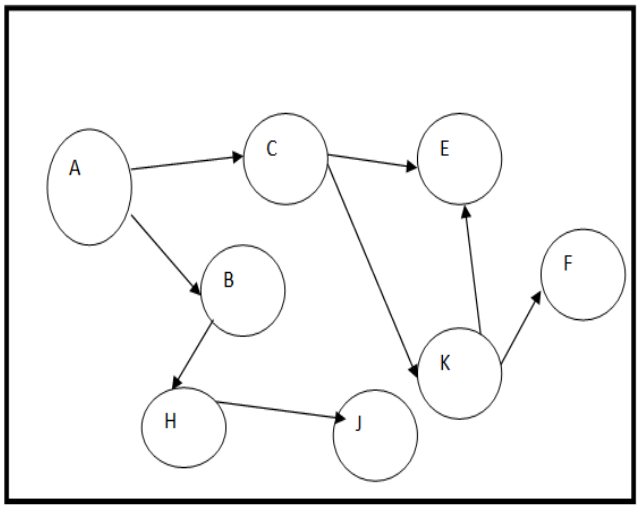

Figure 4.3 Random Waypoint Model

- **Random Way Point Model (RWP)**

Steady State Random Waypoint Model (SSRWP) [32] is a modified Random Waypoint Mobility Model is used in the ns2 [33]. On the stimulation area, a random point is picked by the node and a random speed is taken to reach at that point. When it arrives at the node, a random pause time is chosen. This process is repeated till the stimulation ends. According to the Random Waypoint Model, the SSRWP initially selects the initial position of the nodes, position speed and pause time so that no time is required in the beginning of the stimulation for the distribution of position and speed. The approach has two demerits i.e. The discarding of the data makes it inefficient and the sequence of discarded data is very difficult to evaluate. The RWP is the most important mobility model used in adhoc network simulation.

4.1.2 Temporal Dependencies Mobility Model

The mobility of the nodes depends on the acceleration, velocity and direction. The previous velocity of the mobile node is related to the current node. So at different time slots, the velocity of the mobile nodes is correlated. This characteristic of the Mobile node is called Temporal Dependencies of velocity.

- **Gauss Markov Mobility Model**

Liang and Haas introduced the Gauss Markov Mobility model [34]. In this mobility model, we assume that the velocity of mobile node is correlated with time. The temporal dependency plays an important role in Gauss Markov Mobility Model in determining the mobility behavior. The following equation of Gauss Markov Mobility in two dimensional field are as follows [34]:

$$\overline{V}_t = \overline{\alpha} \circ \overline{V}_{t-1} + (1-\overline{\alpha}) \circ \overline{\upsilon} + \overline{\sigma} \circ \sqrt{1-\overline{\alpha}^2} \circ \overline{W}_{t-1}$$

Where $\bar{V}_t = [v_t^x , v_t^y]^T$ and $\bar{V}_{t-1} = [v_{t-1}^x , v_{t-1}^y]^T$ are the velocity vector at time t and t-1. The uncorrelated random Gaussian process is represented as $\overline{W}_{t-1} = [W_{t-1}^x , W_{t-1}^y]^T$ with zero mean and variance σ^2, $\alpha=[\alpha^x, \alpha^y]^T$, $\bar{\upsilon}=[\upsilon^x, \upsilon^y]^T$ and $\bar{\sigma}=[\sigma^x, \sigma^y]^T$ which represent the memory level, asymptotic mean and asymptotic standard deviation. The above equation can be written in the more simplified way in dimensional form-

$$\begin{cases} v_t^x = \alpha v_{t-1}^x + (1-\alpha)\upsilon^x + \sigma^x \sqrt{1-\alpha^2}\, w_{t-1}^x \\ v_t^y = \alpha v_{t-1}^y + (1-\alpha)\upsilon^y + \sigma^x \sqrt{1-\alpha^2}\, w_{t-1}^y \end{cases}$$

Here α represent the randomness of the Gauss Markov process. For the memory less channel the value of $\alpha = 0$ then the above equation can be written as-

$$\begin{cases} v_t^x = \upsilon^x + \sigma^x w_{t-1}^x \\ v_t^y = \upsilon^y + \sigma^x w_{t-1}^y \end{cases}$$

Here the velocity of the mobile node is determined at time slot t by the fixed drift velocity $\bar{\upsilon} = [v_t^x , v_t^y]^T$, $\overline{W}_{t-1} = [W_{t-1}^x , W_{t-1}^y]^T$.

- **Smooth Mobility Model**

In Smooth Model, the velocity of the node over the time slot is considered [35]. This model is also memory less in nature as it doesn't store any information of past. Bettstetter proposed this smooth model, the sudden change in speed and direction of node is considered.

Let us consider the speed at which nodes tend to move be $[V_{pref}^{1}, V_{pref}^{2} \dots V_{pref}^{n}]$. The probability distribution of velocity nodes is given as- the probability of speed is high in the set of preferred speed, while $[0, V_{max}]$ is considered as the uniform distribution . For example if the preferred speed set is assumed to be $[0, 0.5V_{max}, V_{max}]$ then the probability distribution is

$$
\Pr_V(v) = \begin{cases} \Pr(v=0)\delta(v) & v=0 \\ \Pr(v=0.5V_{max})\delta(v-0.5V_{max}) & v=0.5V_{max} \\ \Pr(v=V_{max})\delta(v-V_{max}) & v=V_{max} \\ \dfrac{1-\Pr(v=0)-\Pr(v=0.5V_{max})-\Pr(v=V_{max})}{V_{max}} & 0<V_{max}<1 \\ 0 & otherwise \end{cases}
$$

where $P_r(v=0) + P_r(v=0.5V_{max}) + P_r(v=V_{max}) < 1$

The Smooth Random Model is considered Poisson process when the frequency of the speed changes. By incrementing the current speed to the target speed the speed of the mobile node changes by acceleration or deaccerlation the speed a(t). The probability distribution function of the uniformly distributed accerlation and deaccerlation $[0, a_{max}]$ or $[a_{min}, 0]$ is

$$
\Pr_a(a) = \begin{cases} \dfrac{1}{a_{max}} & \text{for acceleration } 0 < a \le a_{max} \\ \dfrac{1}{a_{min}} & \text{for deceleration } a_{min} \le a < 0 \\ 0 & otherwise \end{cases}
$$

4.1.3 Spatial Dependencies Model

The mobility models in which the mobile nodes travel in a correlated manner are referred as Spatial Dependencies Models.

- **Column Mobility Model**

In this Mobility Model, the set of mobile nodes move in the fixed direction [36]. It is used in destroying the mines of military by using the searching and scanning activity. The MN j at time slot t updates the reference point RP_j^t. The reference point RP_j^t is achieved by summing the advanced vector α_j^t and the previous reference point RP_j^{t-1}. The Reference point is given as-

$$\mathrm{R}P_j^t = \alpha_j^t + \mathrm{R}P_j^{t-1}$$

In order to move the reference grid associated with node j, α_j is used as the advanced vector at time t. The new position of node is deviated by random vector W_j^t from reference point. Formally,

$$P_t^j = \mathrm{R}P_j^t + W_j^t$$

The mobile nodes flipped by 180 degree when it travels outside the simulation field boundary in the movement direction.

- **Pursue Mobility Model**

In Pursue Mobility Model, the mobile nodes track the particular target. This model is helpful for the police officers to catch the criminals. The equation for this model consist of single update equation for new position of each MN [37]:

New_position=old_position+accerlation(target- old_position) + random vector

Where the accerlation (target-old_position) defines the information of MNs on their movement are pursued and random vector is the random offset for each MN. The entity mobility model helps in finding the value of random vector eg. Random Walk Model, the amount of randomness of the MN is limited so that the maintained effective tracking of MN is pursued. To calculate the next position of the MN various factors are needed i.e . current position of a MN, a random vector and acceleration function.

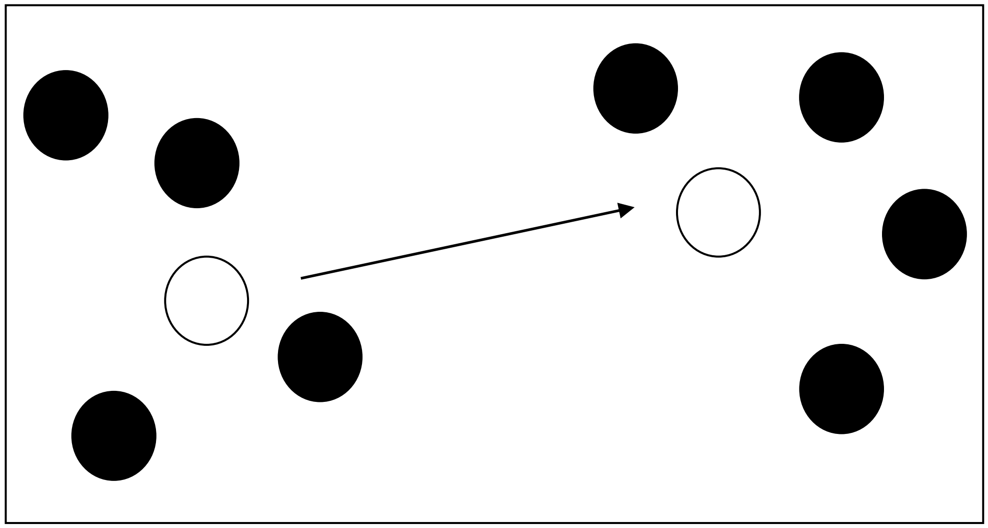

Figure 4.4 Five mobile nodes moving in Pursue Mobility Model

In this example given above, the Pursue Mobility Model is used in the movement of Five MNs. The black shaded nodes are the pursued nodes and the blank node is the current pursuing node.

- **Nomadic Mobility Model**

This model stimulates the movement of mobile nodes collectively from one place to another as in ancient nomadic societies [37]. When the group or community of MNs moves in random ways, they maintain their individual personal spaces. For example consider a group of friends organized a trip to Manali. The group together move from one location to another, the friends move individually around a particular location. Entity mobility model is used by every MN in nomadic community mobility model to move around the reference point. If the reference point changes, then the reference point decides the area where all the MNs in the group move.

The mobility of mobile nodes around the reference point is defined by the parameters of entity mobility model. The common reference point is shared by all the MNs in a group in this mobility model.

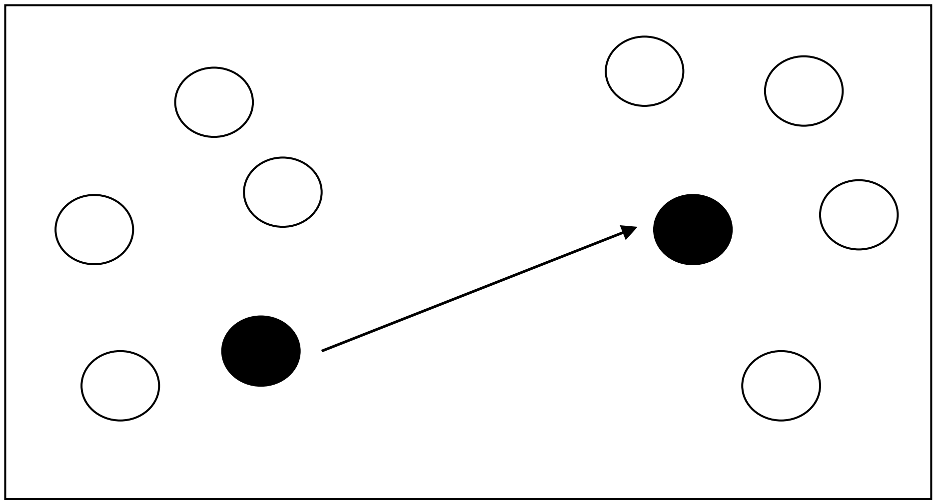

Figure 4.5 Movement of five MNs using Nomadic Community Model

In this example illustrated above the group of five MNs are moving in Nomadic Community Mobility Model. The reference point is shown by black shaded hole that move from one location to another.

4.1.4 Geographical Models

In this model, the mobile nodes cannot move freely without any restrictions. They are bounded by buildings, streets or freeways. In this model, the performance of the mobile nodes is evaluated using various models such as pathway mobility model etc.

- **Manhattan Grid (MG) Mobility model**

This model stimulates the movement patterns of mobile nodes on street defined by maps. It is mainly used in urban areas and basically composed of horizontal and vertical streets.

Maps are used in this model also as in freeway model [38]. The map is designed with the number of horizontal and vertical streets. Corresponding to this mapping each street has two lanes for each direction (north and south direction for the vertical street and east and west direction for the horizontal street). The mobile nodes are confined to move along the vertical and horizontal street forming the grid like structure. While moving in the horizontal and vertical direction if the mobile nodes get intersected, then it can turn left, right or go straight. The probability distribution of moving on same street is 0.5, probability of turning left is 0.25 and that of right is 0.25.

The velocity of the node at a time slot is dependent on the velocity of the previous node. The inter-node and intra- node are same as in freeway model. This model also has high spatial dependencies and high temporal dependencies. Geographical restriction model is imposed by this model too. The only difference between MG model and Freeway model is that this model gives freedom to the nodes to move in any direction while get intersected in the lane.

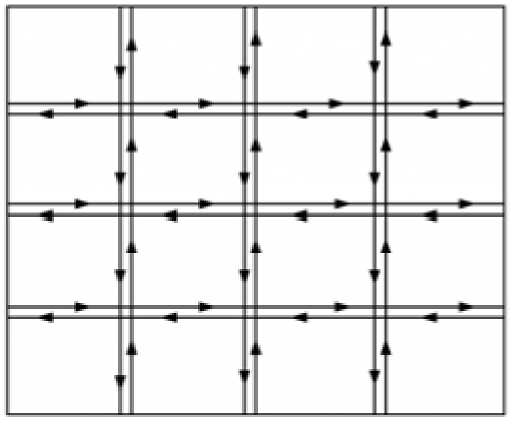

Figure 4.6 Manhattan Mobility model

- **Pathway Mobility Model**

Pathway is a type of Geographical Restriction Model [39]. In this mobility model, the movement of node is restricted to the pathway in the map. In the stimulator field, the pathway map is predefined. The map in the pathway mobility model are generated randomly and carefully based on the real city map. In the graph, the building of the city is represented by vertices and the streets are represented by edges.

Initially, in the graph the nodes are randomly placed on the edges. Corresponding to each node, the destination is chosen randomly and the shortest path will be followed by the node to reach the destination along the edges. The nodes wait for certain time period called Pause time (T_{pause}) and for the next movement the new destination is chosen.

In the example shown above, the buildings i.e. E-block, F-block, Tan block etc. are taken as the vertices of the graph and the path connecting these buildings are taken as the edges of the graph.

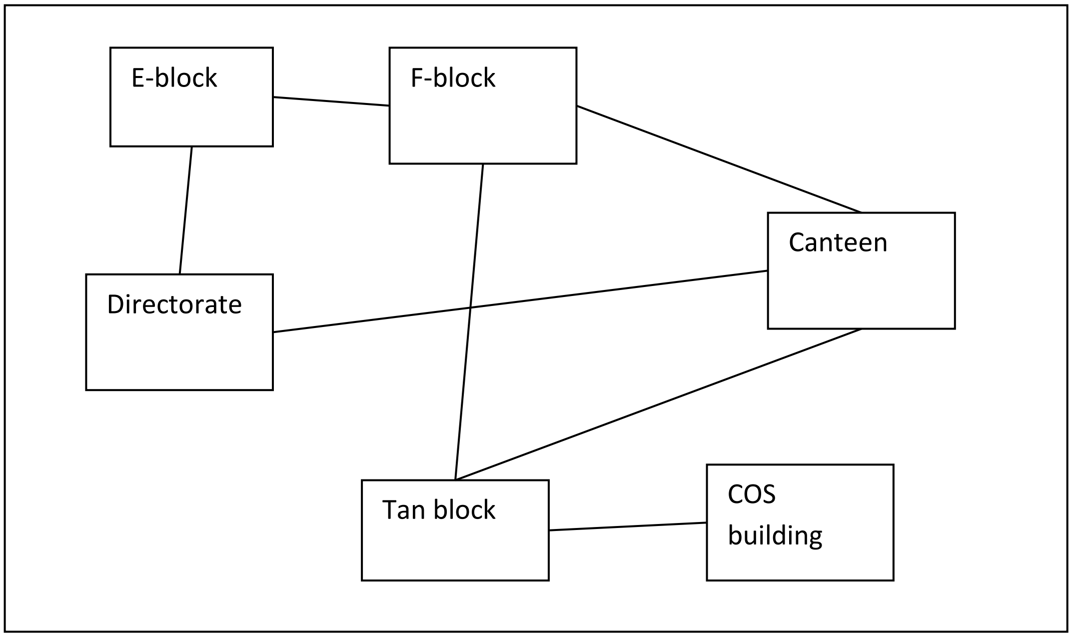

Figure 4.7 Pathway Graph of TU Campus

CHAPTER 5

PROBLEM STATEMENT AND OBJECTIVES

5.1 Problem Statement

Many routing protocols investigated under various assumptions in the literature are unable to capture actual mobile adhoc network characteristics. This motivates the need to investigate performance of MANET under various routing protocols and mobility models that are closely related to real life scenarios. Random models widely used in literature fail to capture movement of mobile nodes in the real world scenario such as moving vehicles or pedestrians as their velocity at current epoch depends on velocity at previous epoch. Mobile nodes in random models move independent of each other but in military applications there is a specific leader whom nodes follow so spatial models comes in the picture here [40]. In order to illustrate how the choice of the mobility models (random, spatial, geographic etc) impact the network performance of ad hoc protocols to be simulated, this research will perform a comparison among these models considering the performance metrics: throughput, end-to-end delay, normalized routing load and dropped packets. Offering more insight into these mobility models will help researcher to decide which mobility model is suitable for a particular application scenario.

5.2 Objectives of the thesis

Several mobility models will be studied, analyzed, and implemented. Then node movement scenario will be generated and animated. The network simulator ns-2 is used to illustrate the performance of the ad hoc network under these scenarios. An analyzer will be implemented in order to analyze the output of the simulation (i.e. analyze the trace file). It will use the throughput, end-to-end delay, normalized routing load and dropped packets as metrics to obtain the performance of the network. The aim of our thesis is to:

- Analyze possible environment where MANET can be used.
- Study different types of MANET routing protocols: OLSR, DSDV, DSR and AODV.

- Model the devices, geographical zone, mobility, traffic pattern, etc. into NS-2 files.
- Discuss which figures of merit are important in the modeled system to decide which the best protocol to use is.
- Create the awk script that describes the whole simulation process and the variables to sweep and run it.
- Analyze the results with awk scripts.
- Check if the results are coherent with the theoretical expectations. If not, explain why or check for mistakes and repeat the process.
- In concluding part, we interpret the simulation results as well as theoretical study which will help researchers working in this area.

5.3 Performance Metrics

In this work, four important performance metrics are used to figure out and examine in contrast the behavior of the routing protocols. Metrics for performance used in our work includes:

- **Throughput:** It is defined as the number of packets correctly received by the destination node. It is measured in kbps.
- **Normalized routing load:** It is defined as the fraction of routing packet per data packet that successfully reached the destination node. Ideally, it should be less for better performance of the network. Normalized routing load can be calculated as [41]:

$$\text{Normalized routing load} = \frac{\textit{Total number of routing packets sent}}{\textit{Total number of data Packets recived}}$$

- **Average end-to-end delay:** End-to-end delay measures the time the packets generated by the initiator takes to reach their destination. Average end-to-end delay is the overall end-to-end delay for all the packets received. It is calculated by subtracting the total time taken in receiving all the packets at the destination from the total time taken to send those packets from the source and dividing them with the number of packets received. The lower the end-to-end delay better is the behavior of the protocol. Mathematically we can represent it as [41]:

$$\text{Average-end-to-end delay} = \frac{\sum_1^n (Packets\ received - packets\ send)}{\sum_1^n packets\ received}$$

- **Dropped Packets:** It is the difference of packets received from packets sent in the network.

CHAPTER 6

NETWORK SIMULATOR

6.1 Network Simulator (NS2)

NS is a discrete event network simulator developed at University of California at Berkeley, USA in 1989 in cooperation with other organizations. It is now a VINT project that is supported by DARPA. NS is an on-going research project not a finalized tool for managing all kinds of network model. The users must ensure that their network model simulation should be bug-free and the community has to share the innovations with all.

This network simulator was targeted for network research and provides support for simulating protocols on conventional wired networks and wireless networks. NS-2 is written in C++ and a scripting language called OTcl (Object Tcl) is used for simulation [33].

6.2 Research Methodology

A complete network simulation requires an OTcl script for configuring the network, a traffic pattern for describing data traffic, a mobility pattern for describing node movement and necessary files for describing coordinates for obstacles and pathways if required. There is a need to trace the mobility model, the data traffic used for routing, media access control (MAC) or application level for post-simulation analysis into trace files. As a result, simulation results are further stored in trace files for analysis.

Trace file can be parsed using the *awk* scripts and the results obtained can be analyzed using spreadsheets for plotting graphs. XGraph and TraceGraph can be used to automate the data parsing but they require some technical proficiency in order to extract the data meaningfully. Figure 6.1 below shows the flow of events for simulating routing protocols in NS-2.

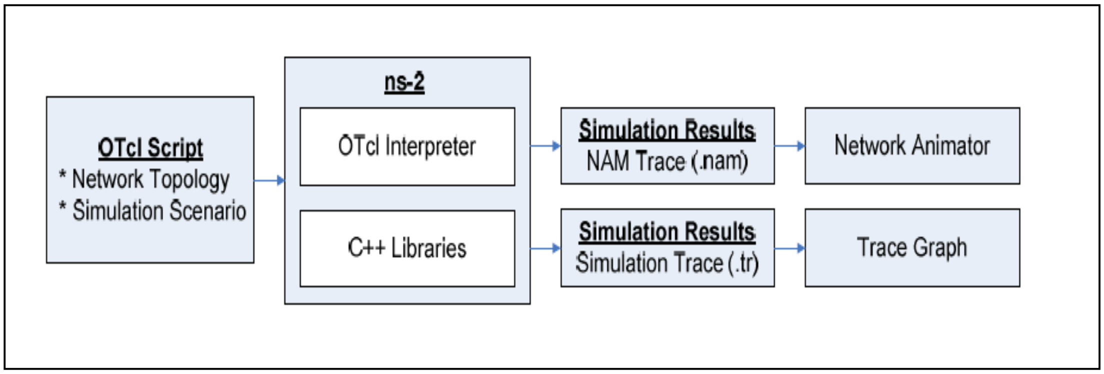

Figure 6.1 Research Methodology for running MANET protocols in NS-2

6.3 Mobile Node Model

The network model for wireless networks consists of the class *MobileNode* at its core derived from base class *Node*. It also consists of additional supporting features as shown in fig. 6.2. The *Node* object is responsible for providing various mobility features like periodic updation of position, node movement, maintaining topological boundaries, etc. It also contains a network protocol stack which is connected to a shared wireless channel and comprised of a link layer, an Address Resolution Protocol, an interface priority queue, a media access control layer, a network interface, all are connected to a shared wireless channel.

- **Link Layer:** The link layer (LL) provides functionalities like queuing and LL retransmission. The LL object implements different data link protocols like Automatic Repeat Request (ARQ). The LL object also supports piggybacking by integrating sending and receiving functionalities in single module. The LL for mobile node is connected to an ARP module for IP address to MAC address mapping. All the outgoing packets into the transmission channel are sent to the LL by the Routing Agent which transmits packets further to the IFq. The MAC layer forwards all incoming packets to the LL which is then handed off to the node_entry_ point.

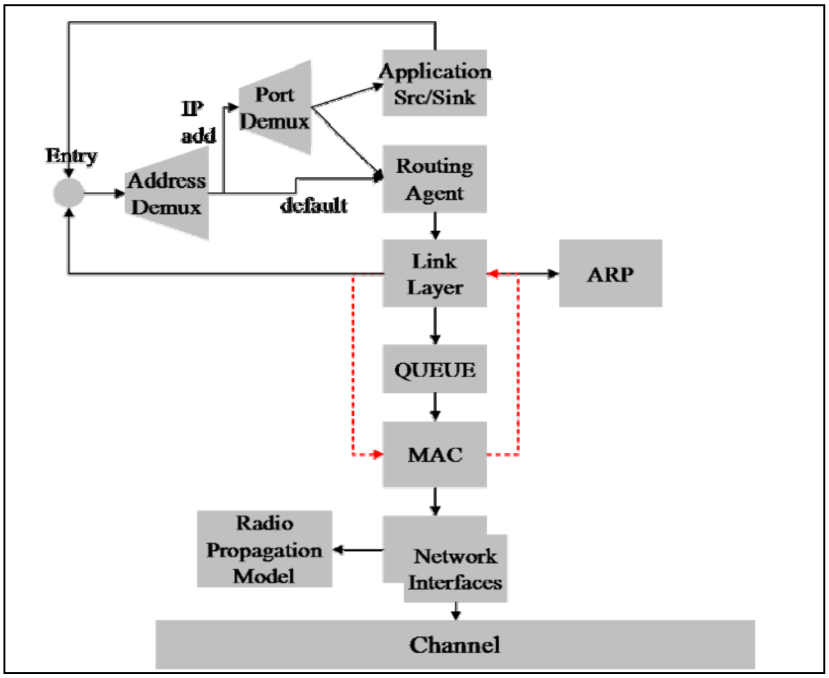

Figure 6.2 Wireless node model in NS-2 [33]

- **Address Resolution Protocol (ARP):** The ARP module has to receive queries from the LL. If the ARP already contains the MAC address mapping for destination node, it is inserted into the MAC header of the packet. Otherwise ARP module broadcasts an ARP query message, and caches the packet temporarily. Once the MAC address of next hop is known, the packet is inserted into the IFq.
- **Interface Queue (IFq):** The Interface queue is based on priority queue, which gives high priority to message control packets such as RREQ, RREP than data packets and control packets will be inserted at the front of the queue.
- **Media Access Control (MAC) Layer:** The MAC layer provides functions like carrier sense, collision detection, collision avoidance, etc. These functionalities are implemented in single MAC object as it affects both the sending and receiving sides.
- **Physical (PHY) Network Interface Layer:** The PHY Network Interface layer is used as a hardware interface by mobile node for accessing the transmission channel. This interface is prone to collisions and the radio propagation model is responsible for receiving packets that are transmitted by other node interfaces to

the wireless channel. The interface also stamps some meta-data such as transmission power, wavelength etc for each transmitted packet.

- **Radio Propagation Model:** These models predict the receiving signal power of every packet. This power is compared with threshold value at the physical layer. If the received signal power is below the threshold level, the packet is dropped by the MAC layer otherwise forwarded to another layer. NS-2 fully support various inbuilt radio propagation models like free space model for closer distances, two-ray ground reflection model for distant locations, and the shadowing model includes fading. The simulations for this thesis are based on two-ray ground reflection model without any fading considerations.
- **Antenna Model:** The mobile nodes are by default configured with an omni-directional antenna with unity gain.
- **Routing Agents:** All packets destined for the mobile node are routed directly by the address demultiplexer to its port de-multiplexer. The port de-multiplexer hands the packets to the respective destination agents.

6.4 Traffic Generation

In NS-2, two different types of traffic files can be generated i.e. constant bit rate (CBR) traffic or transmission control protocol (TCP) traffic [42]. In our thesis, we used CBR as the source of data traffic as it is more suitable for real time traffic and presents a more stringent demand on the network. Both CBR and TCP traffic can be generated using OTCL scripts “cbrgen.tcl” available in the NS2 directory. Various configuration parameters that can be initialized are size of generated packets, number of nodes, sending rate, interval between packets, maximum number of packets to send, maximum number of connections to be used etc. Random seeds are used for generation of random variables for source-destination pair to improve the scripts’ randomness. The connection loading starts at a specific time and lasts till simulation ends. The data rate directly reflects the actual load, a shorter interval means more data packets are generated and vice versa.

6.5 Scenario Generation

NS2 generates only RWP mobility model using setdest. The BonnMotion is java based software which was developed by Waal at the Institute of Computer Science, University of Bonn, Germany to create and analyze other mobility models [43]. The mobility movement scripts can be easily ported over to NS2 using "NSFile" application and other network simulation tools such as QualNet which can be further integrated into a TCL. Apart from the movements of the nodes in a certain scenario, BonnMotion also defines the size of the scenario, the number of nodes, their speed, the duration of the simulation and how many seconds we want to skip in order to avoid the transitory period of the movement of the nodes. Apart from this, default parameters we can also change some parameters for each mobility model such as the pause time in RWP or the number of nodes in each region. BonnMotion also provides tools which are also used in this research to analyze a certain scenario and obtain statistics of it. There are two ways of analyzing either by calculating over all statistics averaged over the entire simulation run or by calculating progressive statistics for certain points in time.

Bonnmotion is responsible for the random properties of the positions and movements of the nodes, and for the traffic NS-2 random variables are used. In order to make a fair comparison between protocols, the random seeds for the position and movements of the nodes as well as the ones for the connection parameters must not change till all the protocols are tested. This way, each protocol is tested under a scenario with exactly the same conditions. For this, in NS-2 the seed value must not be 0, because this means that each time the script runs with a different value.

Bonnmotion is the responsible to generate all movements commands in tcl according to the mobility model chosen. When they are generated, the movement patterns present a transitory period so we have to be careful to skip this first seconds since they do not present the properties of the mobility model wanted. CBR traffic under UDP accurately compares different protocols whereas TCP has a slow start mechanism that can influence the overall results.

6.6 OTcl

It is an object oriented tool command language which is interpreted and dynamic programming language. It is highly expandable and fully compatible with C language. An OTcl script starts an event scheduler and configures the network topology by using different network objects. In OTcl script, traffic sources are signalled to start or stop transmitting packets.

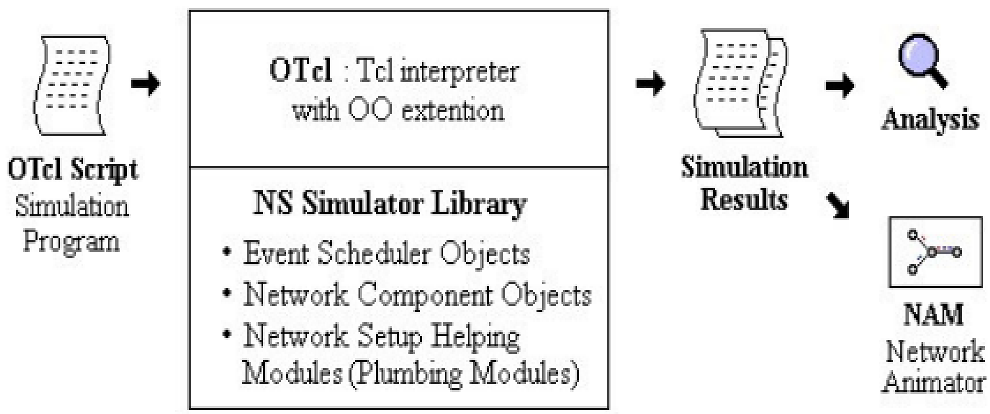

Figure 6.3 User's View of NS-2

6.7 The Network Animation (NAM)

The simulation results obtained by running the OTcl file generates text based trace files and NAM files which can be send as an input to a graphical display tool called Network Animator (NAM). It is an animation tool used for viewing network simulation traces. NAM tool is started as:

```
$nam <file.nam >
```

In ns-2 script:

```
Proc finish{} {
exec nam file.nam
exit
}
```

The network simulator will display the network topology inside the animation area of the NAM tool.

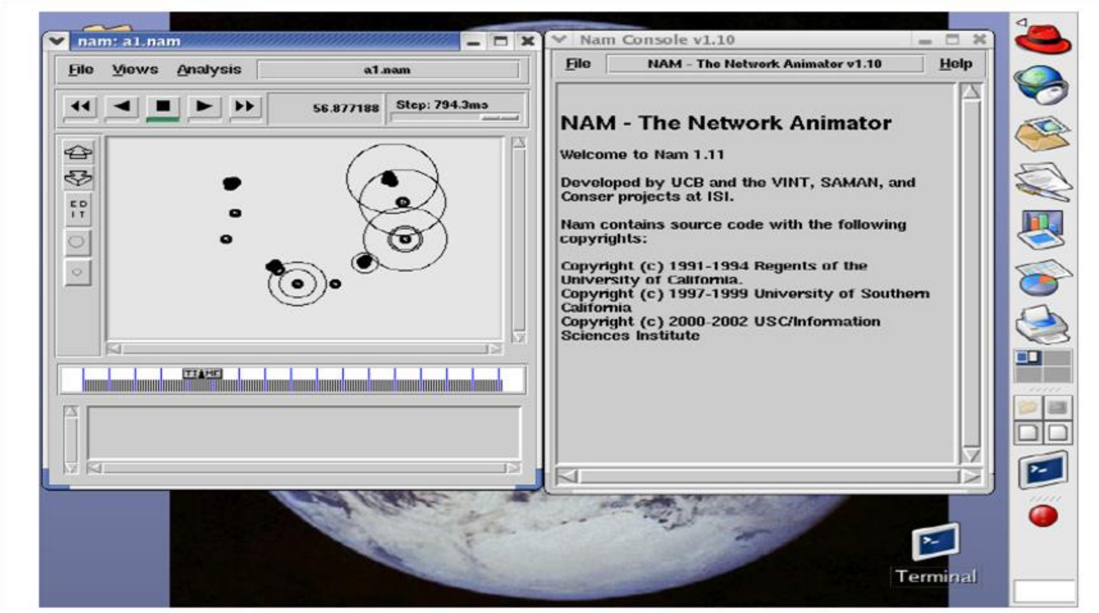

Figure 6.4 NAM Tool

6.8 Trace File Formats in Wireless Networks

Trace file is a text-based output that the user can get from a simulation. It records the relevant information of discrete events that occurred during the entire simulation run. The first letter of flags signifies the property of each column and two letters designates the flag type:

N: Node Property

I: IP Level Packet Information

H: Next Hop Information

M: MAC Level Packet Information

P: Packet Specific Information

Table 6.1 Trace File Format [44]

Event	Abbreviation	Flag	Value
Wireless Event	s: Send r: Receive d: Drop f: Forward	-t	Time (* For Global Setting)
		-Ni	Node ID
		-Nx	Node X Coordinate
		-Ny	Node Y Coordinate
		-Nz	Node Z Coordinate
		-Ne	Node Energy Level
		-Nl	Network trace Level (AGT, RTR, MAC, etc.)
		-Nw	Drop Reason
		-Hs	Hop source node ID
		-Hd	Hop destination Node ID, -1, -2
		-Ma	Duration
		-Ms	Source Ethernet Address
		-Md	Destination Ethernet Address
		-Mt	Ethernet Type
		-P	Packet Type (arp, dsr, imep, tora, etc.)
		-Pn	Packet Type (cbr, tcp)

6.9 AWK Language [45]

AWK is a scripting programming language. It is named with the initials of three authors. Its main use is elicitation of data. Text File processing is done with it. The illustration of AWK program is:

Begin

{ print

“HELLO WORLD!”

}

The syntax to use awk is:

awk –f “[program file]” [flags] [files]

program file : awk program file.

Files: text file from where data to be fetched.

CHAPTER 7
SIMULATION ENVIRONMENT

7.1 Simulation setup

In our simulation, a framework for evaluating the performance of adhoc network routing protocols: OLSR and DSDV under proactive protocols and DSR and AODV under reactive protocols has been developed. The impact of popular mobility models such as steady state random waypoint under random models, column and pursue under spatial models and Manhattan grid under geographic models has been investigated in detail with varying number of mobile nodes and their speed of movement.

Traffic sources in our communication model are CBR. We generated different movement scenario files for each mobility model. Several communication scenario files were generated for different numbers of nodes and speed of nodes. Communication model and simulation parameters are given in table 7.1 and 7.2 respectively. Each simulation run includes one communication scenario file, one movement scenario file, protocol to be simulated and tcl script. The same communication model is used for both group mobility model and non-group mobility models according to the number of nodes and speed of nodes to be simulated. Trace file was generated for each simulation run and awk script was used to get the results of the simulation. The protocol's performance was evaluated and shown according to the average results of simulations.

We have skipped initial 3600 seconds for allowing system to stable. Each set of experiment is repeated 5 times to record an accurate set of readings. Performance metrics for each protocol are evaluated separately to visualize behavior of single protocol under different mobility models.

Table 7.1 Communication model parameters

Parameter	**Value**
Source	CBR
Maximum connections	8
Data packet size	512 bytes

Sending rate	4 packets/seconds

Table 7.2 Simulation parameters

Parameter	**Value**
Simulation time	200 Sec
Simulation area	1000m x 1000m
Antenna	Omni antenna
Mobility Model	SSRWP, MG, Column, Pursue
Maximum packet interface queue	250
Routing protocol	OLSR, DSDV, DSR, AODV
Transport Layer	UDP
Number of seconds to skip	3600

Table 7.3 Varying number of nodes

No. of nodes	15, 20, 25, 30
Maximum number of connections	2, 5, 10, 15
Speed (m/s)	5

Table 7.4 Varying speed of nodes

Speed (m/s)	2, 5, 10, 15
Number of nodes	30
Maximum number of connections	15

Table 7.5 Parameters for different mobility models

Mobility Model	Parameter	Value
Steady State Random Way Point Mobility model (SSRWPM)	Mean speed	2, 5, 10, 15
	Speed delta	0
	Pause mean	0
	Pause delta	0
Column	Maximum speed	2, 5, 10, 15
	Minimum Speed	1, 4, 8, 13
	Number of groups (Varies with size of network)	3,6, 9, 15
	Reference Point Separation	10
	Maximum distance to group center	2.5
	Maximum Pause Time	60
Manhattan Grid	Maximum speed	2, 5, 10, 15
	Minimum speed	1, 3, 8, 13
	Number of blocks between paths vertically	4
	Number of blocks between paths horizontally	4
	Turn Probability	0.5
	Speed Change Probability	0.2
	Pause Probability	0.0
	Speed Standard Deviation	0.2
	Maximum Pause	120
Pursue	Maximum speed	2, 5, 10, 15
	Minimum speed	1, 3, 8, 13
	Aggressiveness	1
	Pursue Randomness Magnitude	0.5

7.2 Simulation Results of Routing Protocols with varying number of nodes

7.2.1 Simulation Results of OLSR with different mobility models

Fig. 7.1-7.4 presents performance of OLSR with varying number of nodes. As seen in fig. 7.1, throughput under MG is 175.63 kbps and Pursue is 174.58 kbps which is 17% more than SSRWP and approx. 11.79 % more than column with number of nodes as 25.

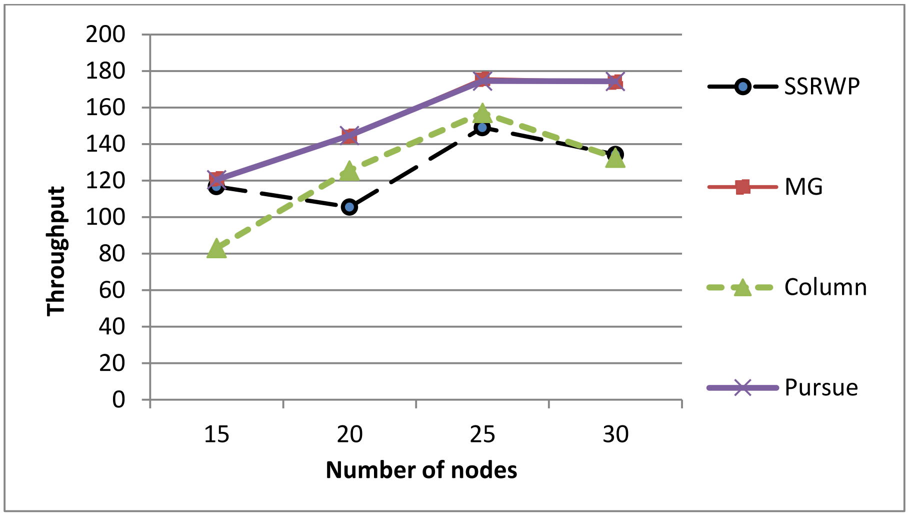

Figure 7.1 Throughput vs Number of nodes for OLSR

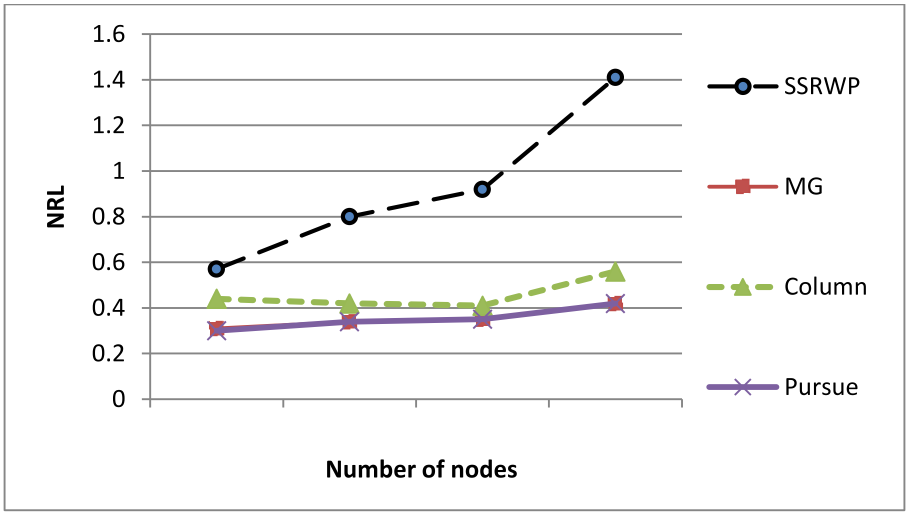

Figure 7.2 NRL vs Number of nodes for OLSR

As number of nodes increases from 15 to 25, throughput for MG, Column and Pursue increases and further increase in number of nodes to 30, decreases throughput. Decrease in throughput is more in SSRWP and Column than MG and Purse. The best results in terms of throughput are obtained from MG. NRL for SSRWP is high and it increases from 0.57 to 1.41, as the number of nodes increases from 15 to 30. Similarly, E2E delay increases from 22.73 ms to 168.87 ms. All the other three models are scalable to large networks as routing loads and average E2E delay doesn't increases much with increasing network size. When there are 20 nodes in the network, NRL for Column Model is 55% less, NRL for Pursue Model is 61% less and NRL for MG Model is 63% less as compared to SSWRP. As shown in the fig. 7.2 and fig. 7.3, MG and Pursue Models are well suited in terms of NRL and dropped packets with 98% or more packet delivery.

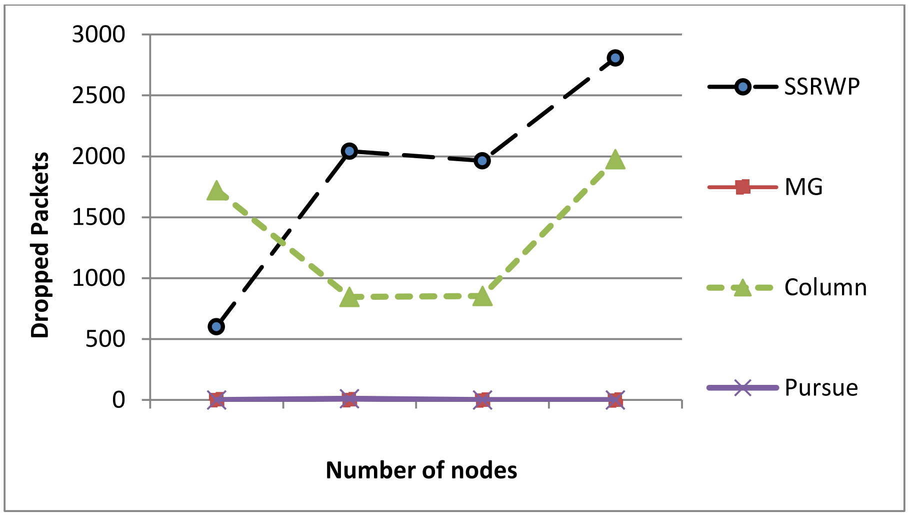

Figure 7.3 Dropped packets vs Number of nodes for OLSR

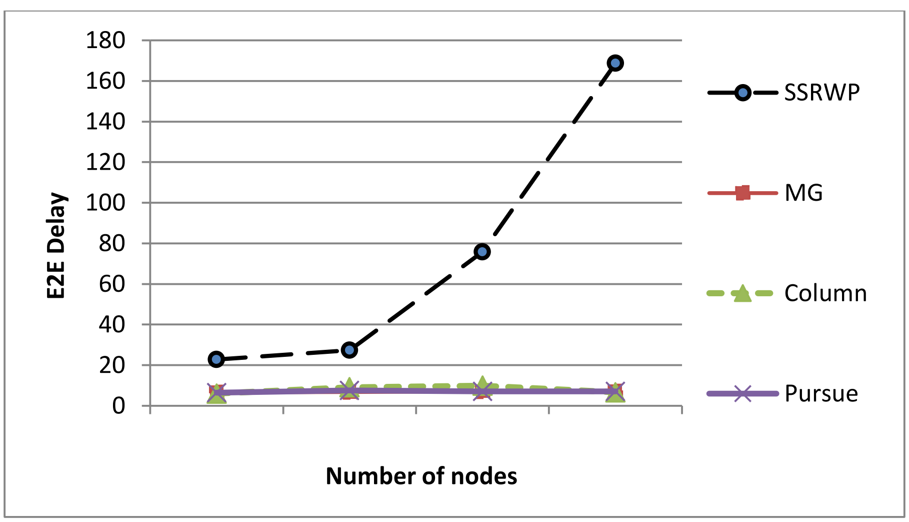

Figure 7.4 Average E2E delay vs Number of nodes for OLSR

7.2.2 Simulation Results of DSDV with different mobility models

Fig. 7.5 - 7.8 presents the performance of DSDV with node density varying from 15 to 30. The Throughput for DSDV under SSRWP is very less approximately 62.99% as compared to OLSR and other models show the similar results to OLSR. NRL for DSDV is quite less as compared to OLSR approximately 70.65% less. MG and Pursue Models for DSDV Protocol perform better in terms of NRL, throughput and E2E delay.

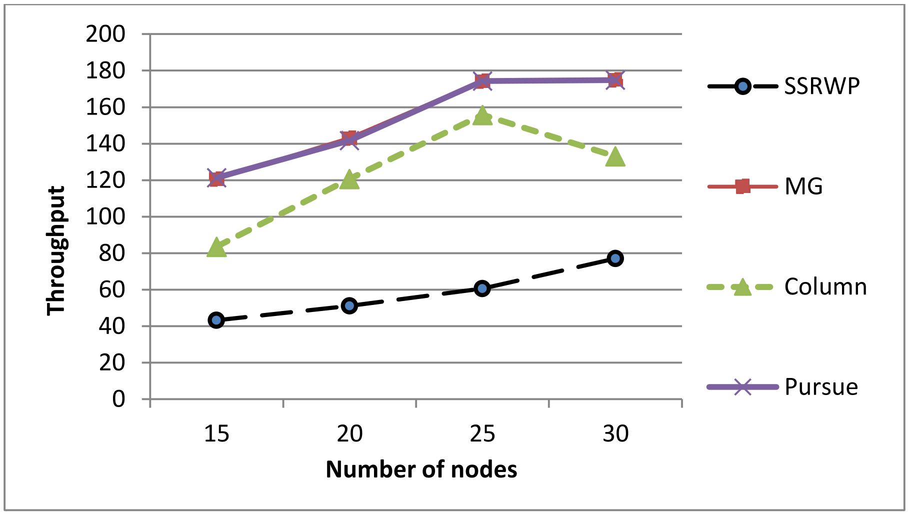

Figure 7.5 Throughput vs Number of nodes for DSDV

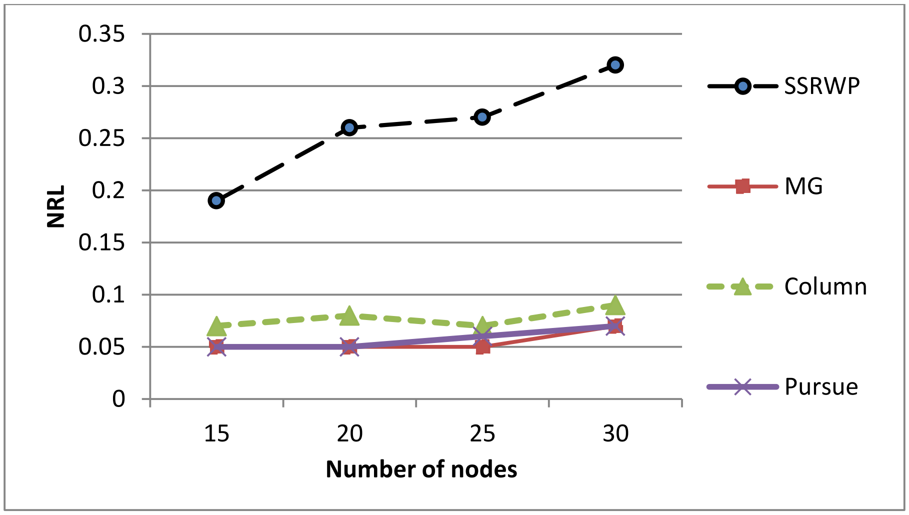

Figure 7.6 NRL vs Number of nodes for DSDV

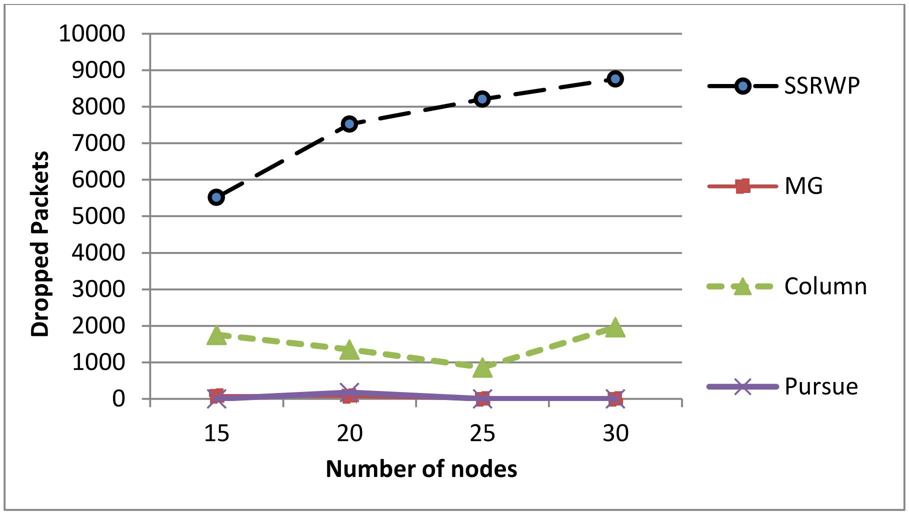

Figure 7.7 Dropped Packets vs Number of nodes for DSDV

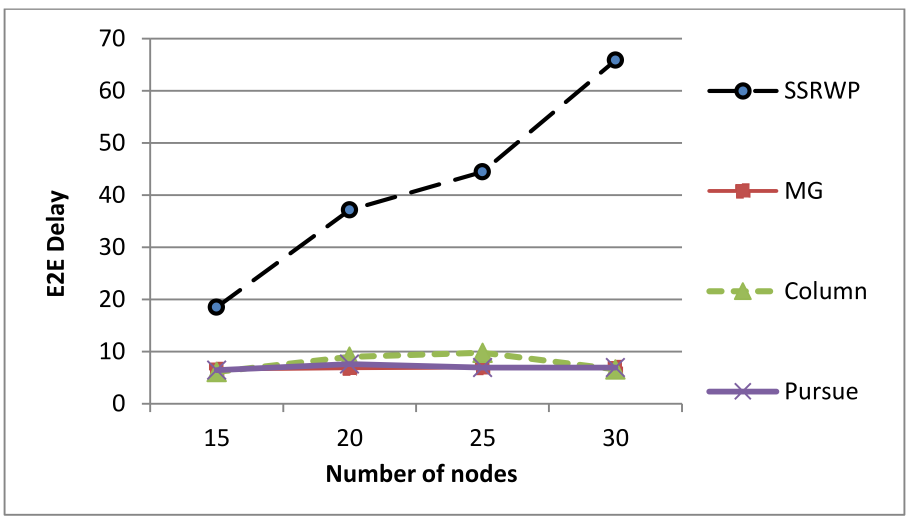

Figure 7.8 Average E2E Delay vs Number of nodes for DSDV

7.2.3 Simulation Results of DSR with different mobility models

DSR being the Reactive Routing Protocol is suitable for small networks under the SSRWP model with throughput 120.34 kbps as the size of network reaches 30. Throughput drops by 13.92% as shown in fig. 7.9. The Reactive Routing Protocol initiate the route discovery message so routing overhead is comparatively high than proactive routing protocol as shown in fig 7.10. NRL for the SSRWP performs worst and MG performs best in terms of E2E delay as shown in fig 7.12.

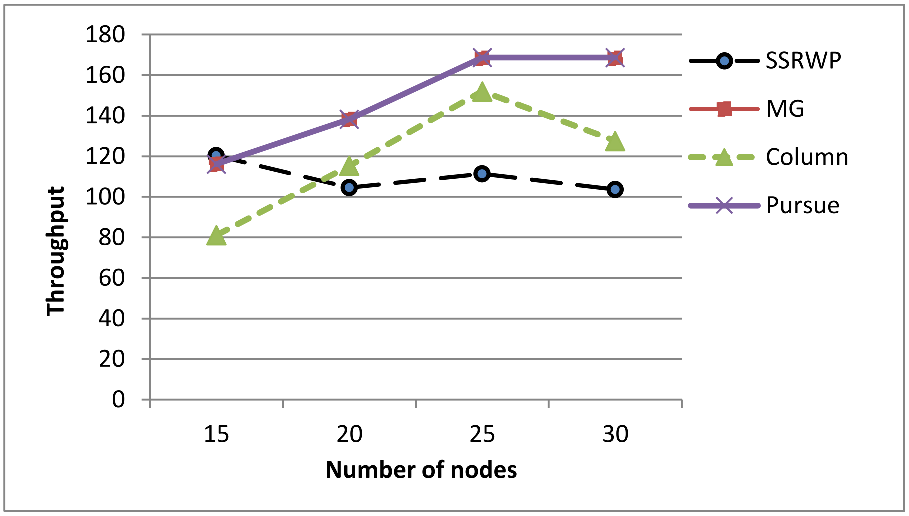

Figure 7.9 Throughput vs Number of nodes for DSR

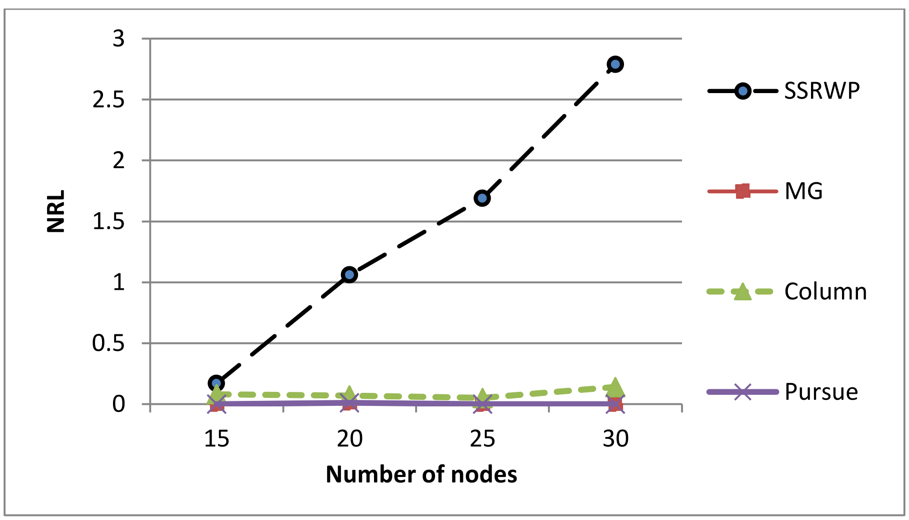

Figure 7.10 NRL vs Number of nodes for DSR

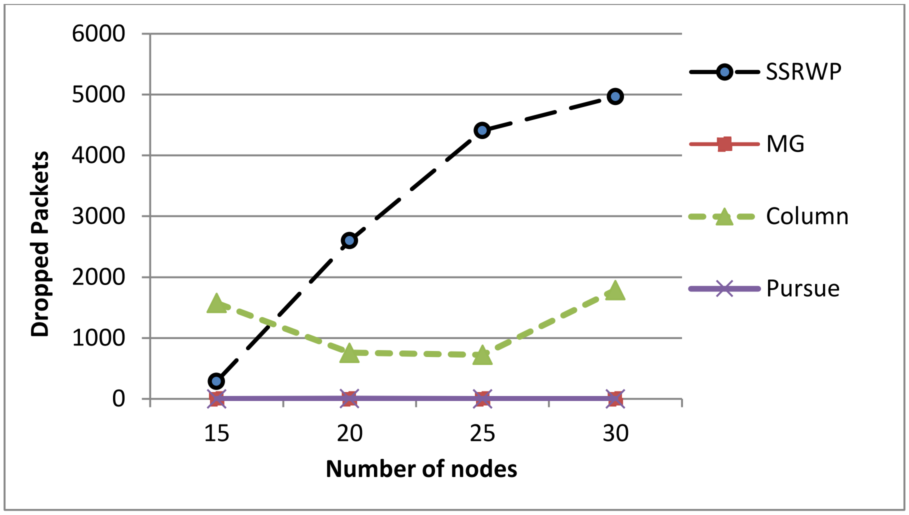

Figure 7.11 Dropped Packets vs Number of nodes for DSR

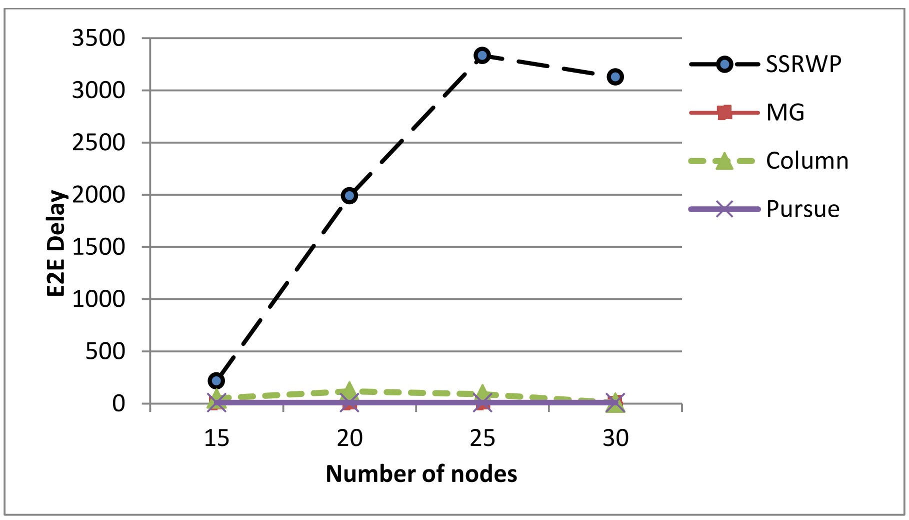

Figure 7.12 Average E2E Delay vs Number of nodes for DSR

7.2.4 Simulation Results of AODV with different mobility models

Fig. 7.13 -7.16 depicts the performance of AODV with varying network size. As compared to all the three protocols, throughput of AODV under all the four mobility model is high.

NRL of AODV i.e. 0.33 under SSRWP is slightly more than DSR 0.17 with 15 nodes but as the size of network increases from 15 to 30, AODV outperforms DSR and NRL in AODV drops from 2.79 to 1.82 as depicted in fig. 7.13. NRL for MG and Pursue Model increase from 0.03 to 0.06 as size increases from 15 to 30 nodes. Fig. 7.14 clearly shows that least number of packets is dropped for AODV than all other three protocols.

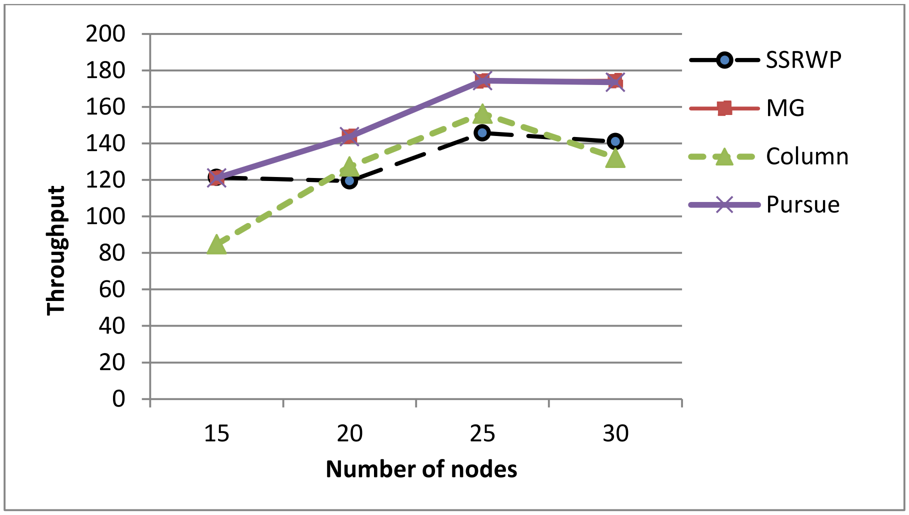

Figure 7.13 Throughput vs Number of nodes for AODV

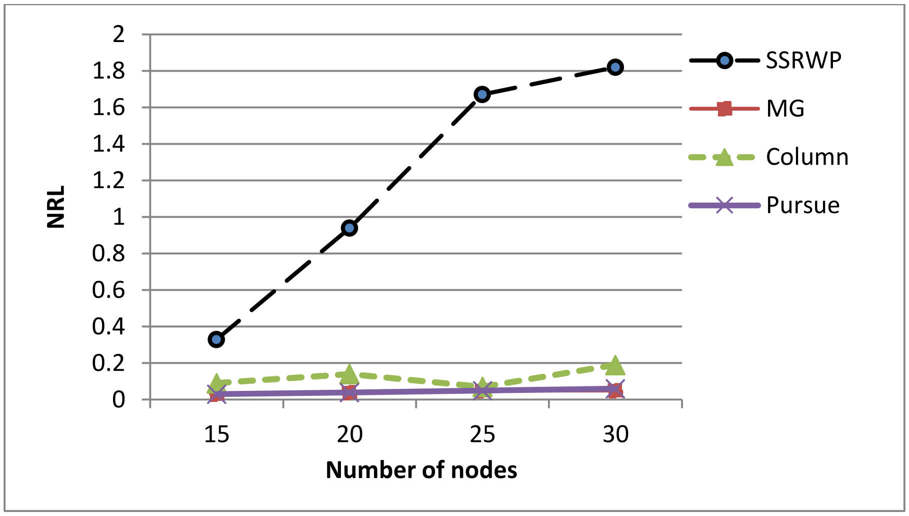

Figure 7.14 NRL vs Number of nodes for AODV

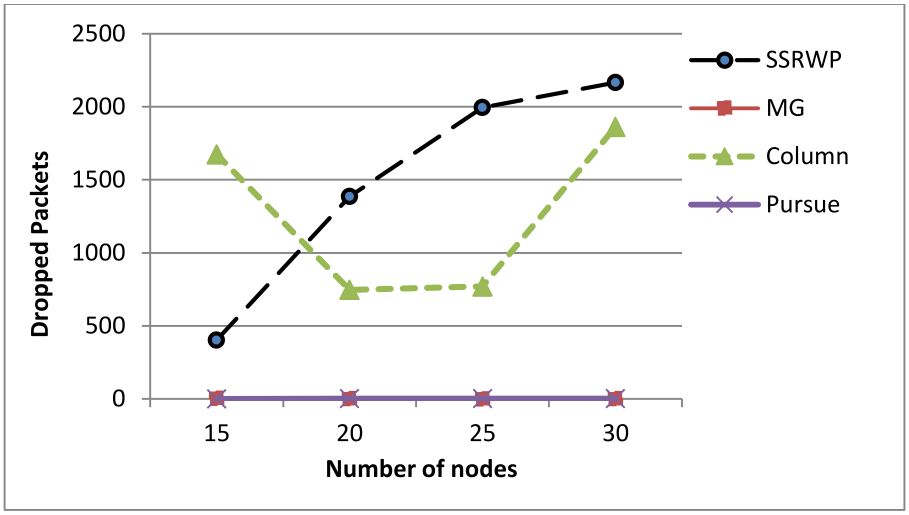

Figure 7.15 Dropped Packets vs Number of nodes for AODV

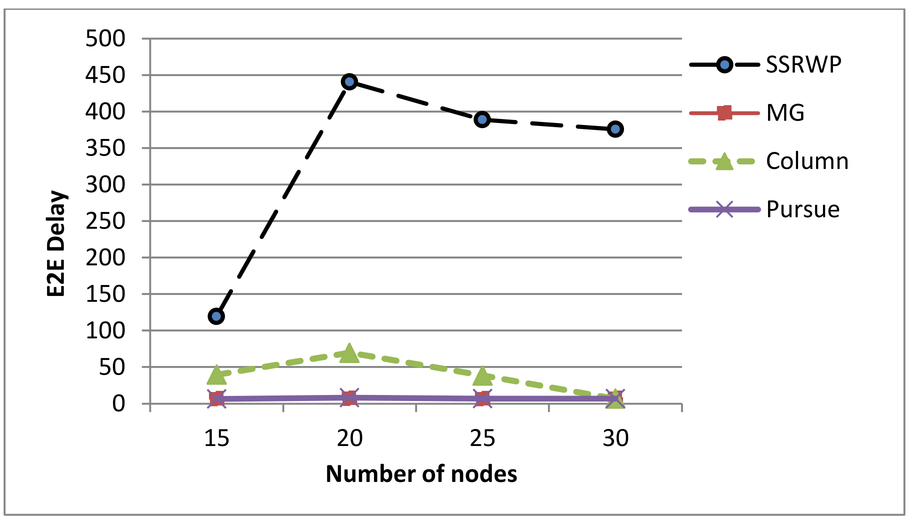

Figure 7.16 Average E2E delay vs Number of nodes for AODV

7.3 Simulation Results of Routing Protocols with varying speed of nodes

7.3.1 Simulation Results of OLSR with different mobility models

Fig. 7.17-7.20 depicts the behavior of OLSR with varying node mobility from 2 m/s to 15 m/s. SSRWP, MG and Pursue Mobility Models show approximately similar throughput 174kbps under the low mobility but as the speed increases MG and Pursue Model outperforms SSRWP. Column Model performs worst with 102.58 kbps throughput. There is high difference between NRL, dropped packet and E2E delay of SSRWP and other models as shown in fig. 7.17- 7.19.

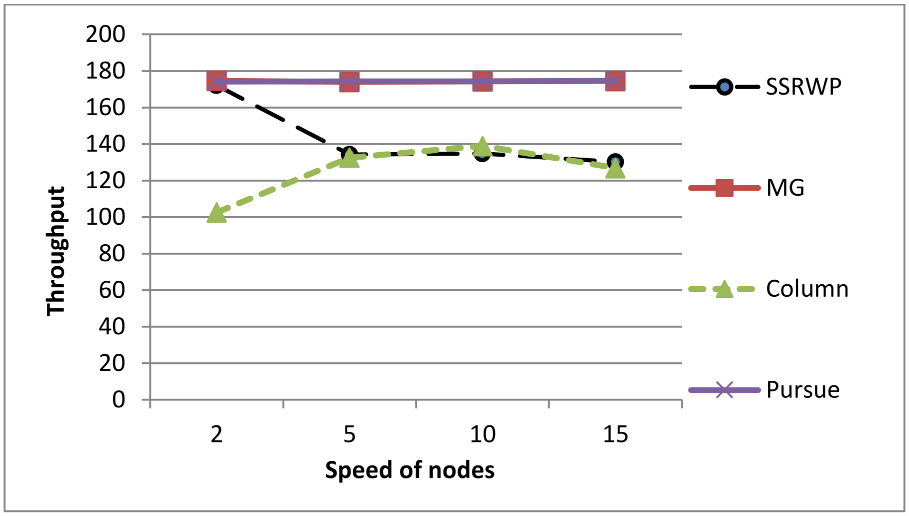

Figure 7.17 Throughput vs Speed of nodes for OLSR

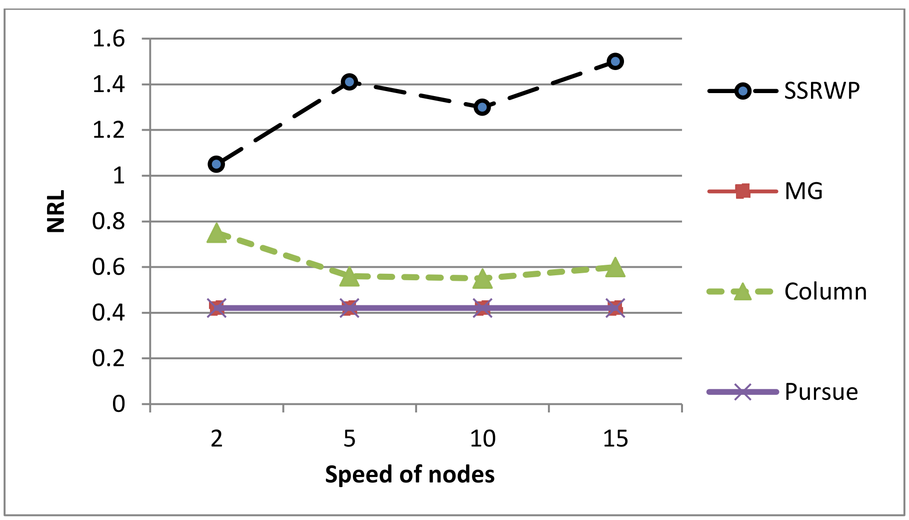

Figure 7.18 NRL vs Speed of nodes for OLSR

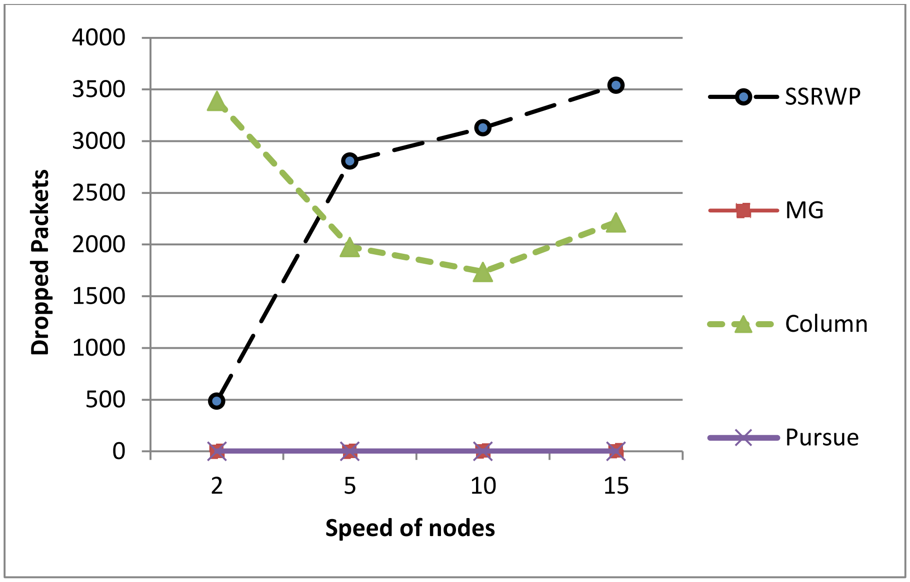

Figure 7.19 Dropped Packets vs Speed of nodes for OLSR

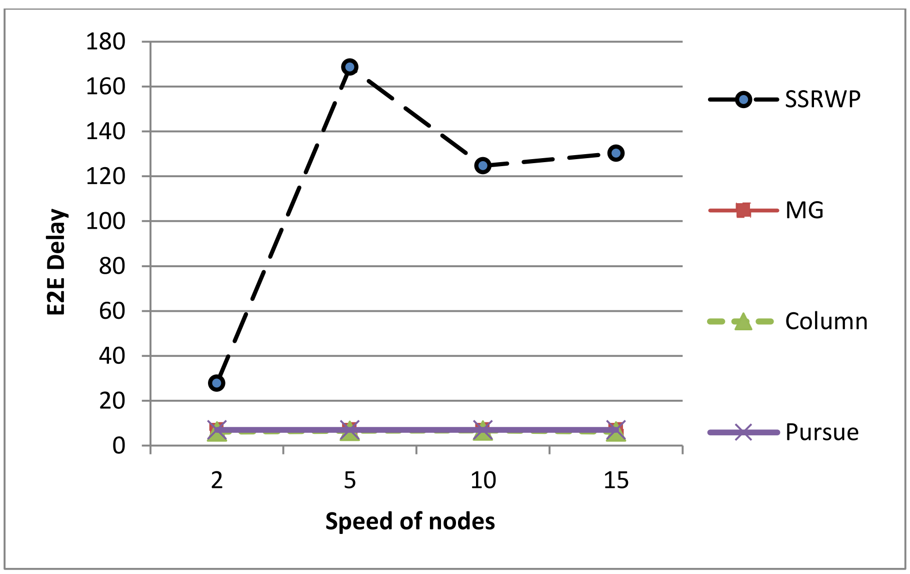

Figure 7.20 Average E2E delay vs Speed of nodes for OLSR

7.3.2 Simulation Results of DSDV with different mobility models

The throughput of DSDV decreases from 123.88 kbps to 63.38 kbps under SSRWP whereas in Column increases from 102.77 kbps to 126.81 kbps as in MG and Column

Model, throughput almost remains constant. DSDV shows highest NRL and E2E delay under SSRWP and lowest under MG as presented in fig. 7.22 - 7.24.

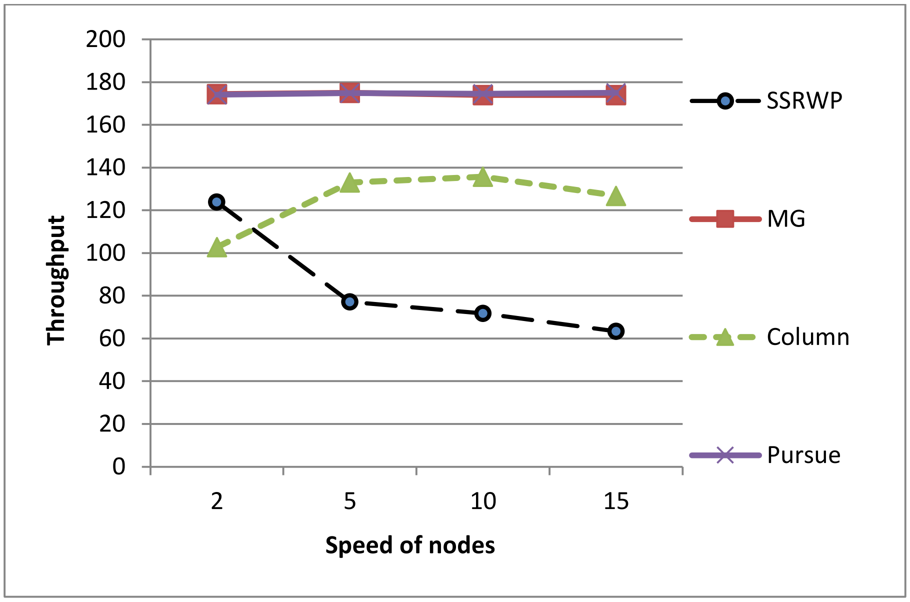

Figure 7.21 Throughput vs Speed of nodes for DSDV

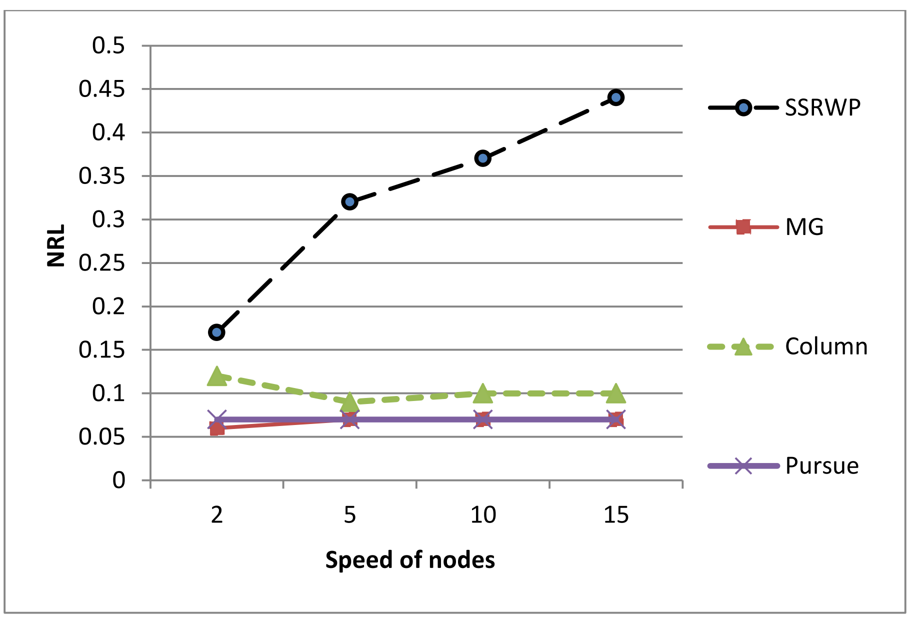

Figure 7.22 NRL vs Speed of nodes for OLSR

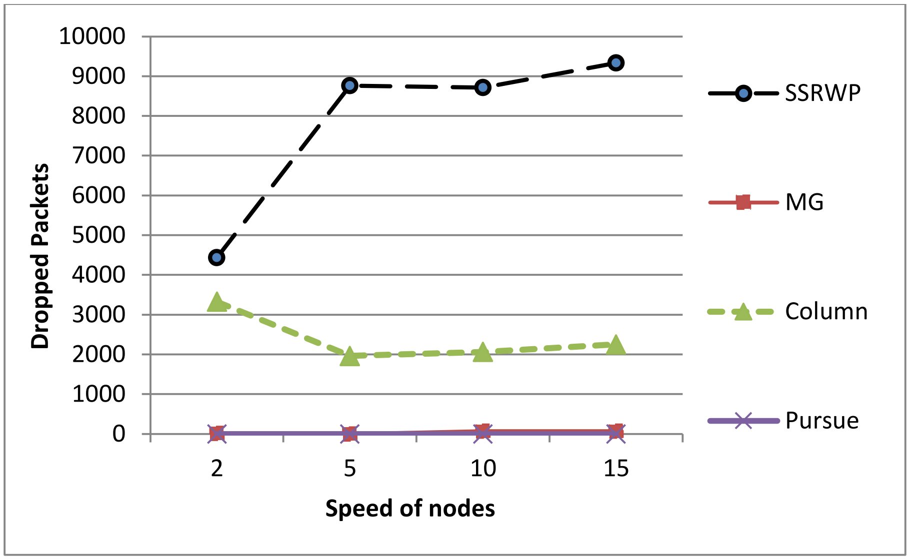

Figure 7.23 Dropped Packets v/s Speed of nodes for OLSR

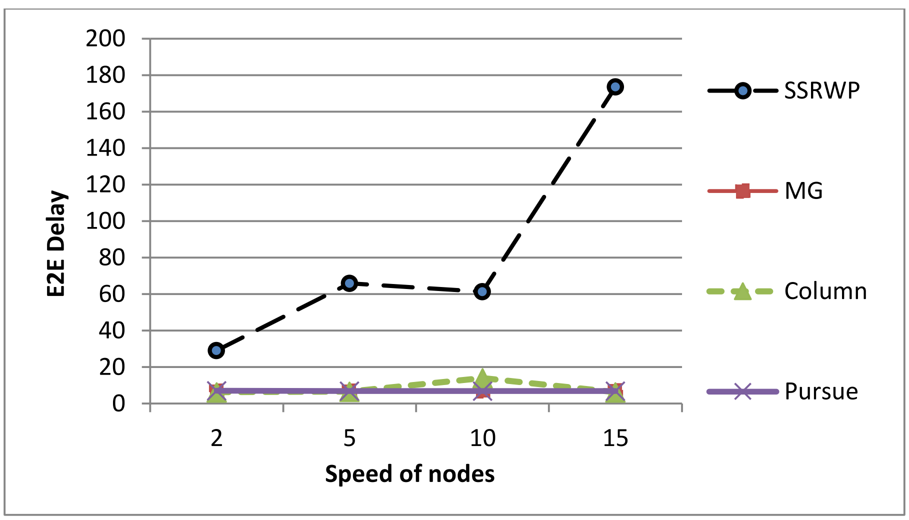

Figure 7.24 Average E2E delay v/s Speed of nodes for DSDV

7.3.3 Simulation Results of DSR with different mobility models

The performance of DSR in fig. 7.25 - 7.28 with respect to the mobility model is shown in DSR under the Pursue Mobility Model ensures 100% delivery of data packets (refer fig. 7.27). As the speed changes from 2ms to 5ms, the NRL sharply increases from 0.17 to 2.79 as shown in fig. 7.26.

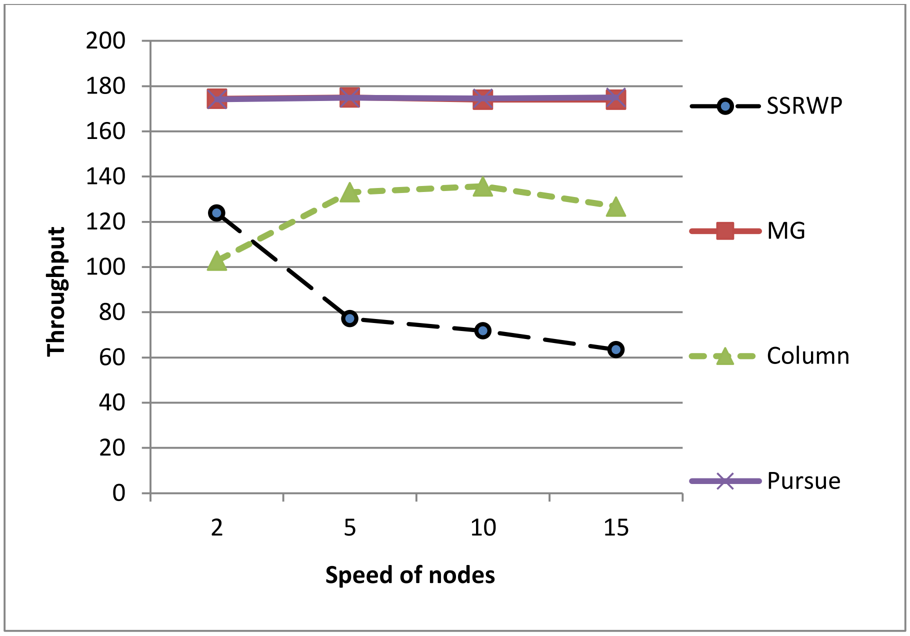

Figure 7.25 Throughput vs Speed of nodes for DSR

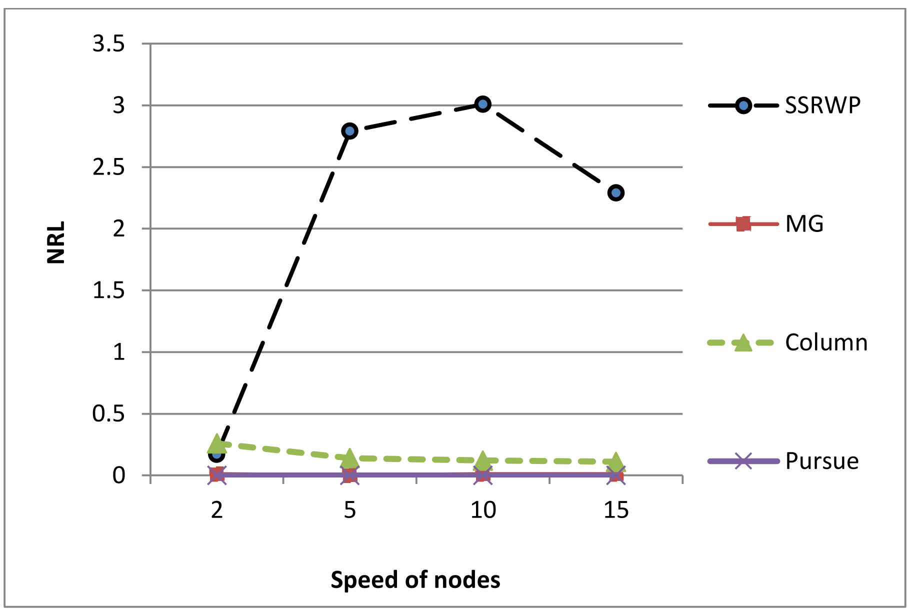

Figure 7.26 NRL vs Speed of nodes for DSR

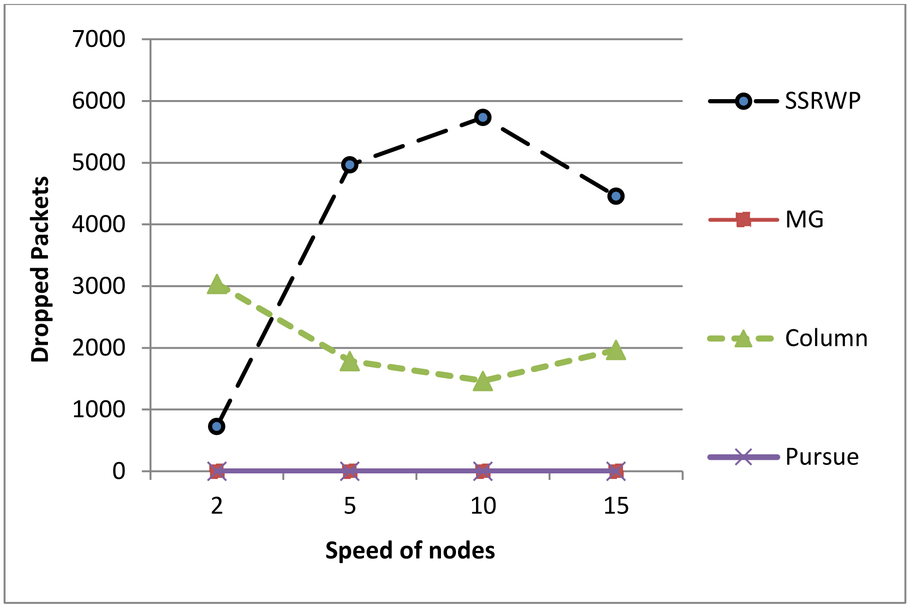

Figure 7.27 Dropped Packets vs Speed of nodes for DSR

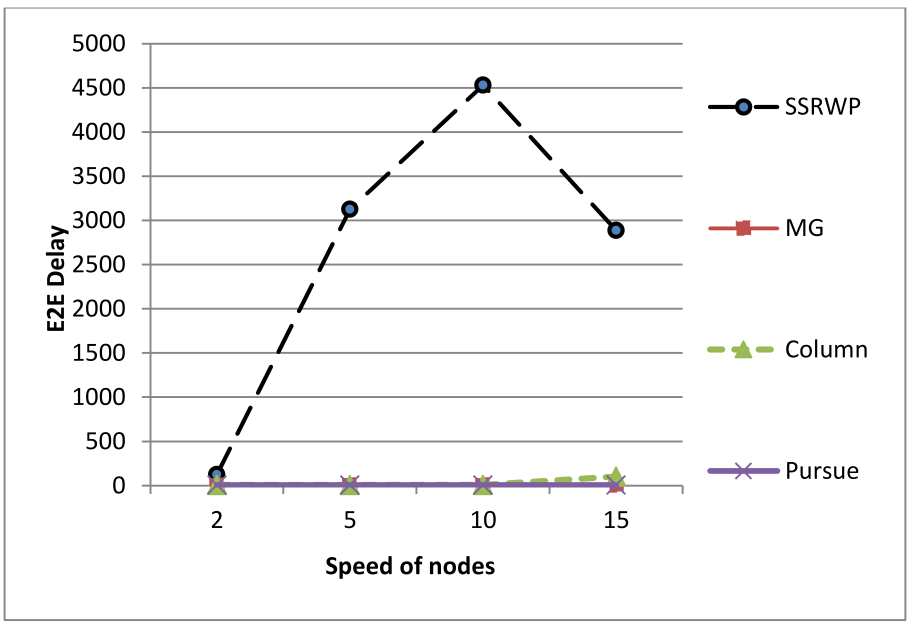

Figure 7.28 Average E2E delay vs Speed of nodes for DSR

7.3.4 Simulation Results of AODV with different mobility models

Fig 7.30 gives effect of changing speed of nodes on throughput of AODV. It performs similar to DSR. Throughput is highest in AODV. The NRL in AODV is slightly higher than DSR for all mobility values as shown in fig. 7.31.

Average E2E delay for MG, Pursue and Column Model is comparable upto speed 10 m/s. Initially, delay for SSRWP is less 35 ms but it sharply rises to 375.84 ms when speed becomes 5 m/s.

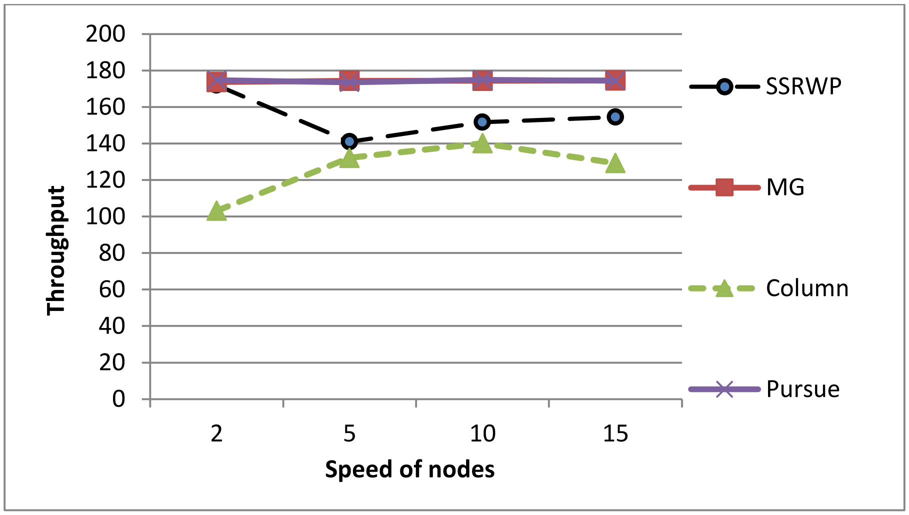

Figure 7.29 Throughput vs Speed of nodes for AODV

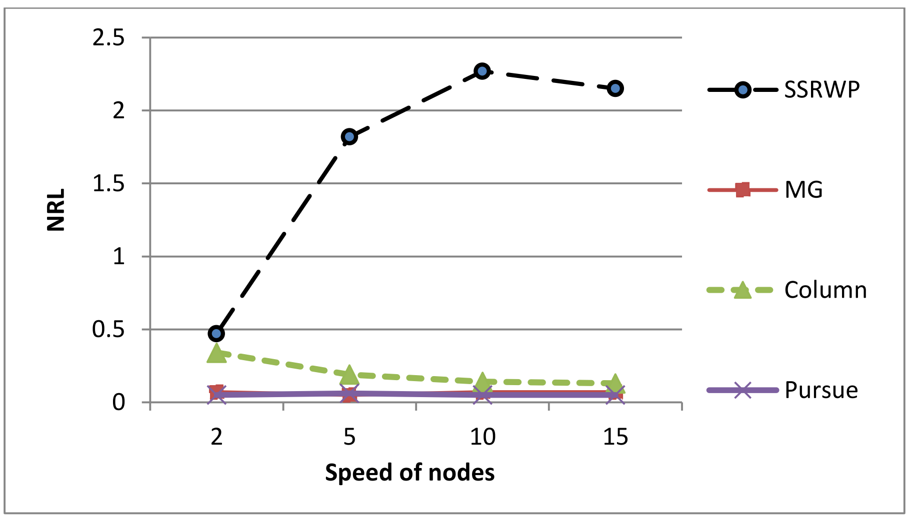

Figure 7.30 NRL vs Speed of nodes for AODV

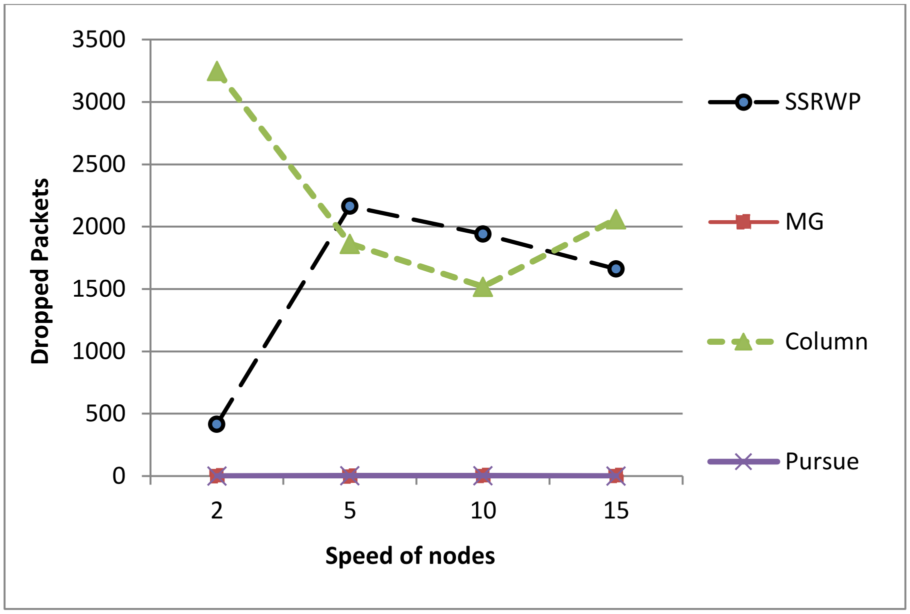

Figure 7.31 Dropped Packet vs Speed of nodes for AODV

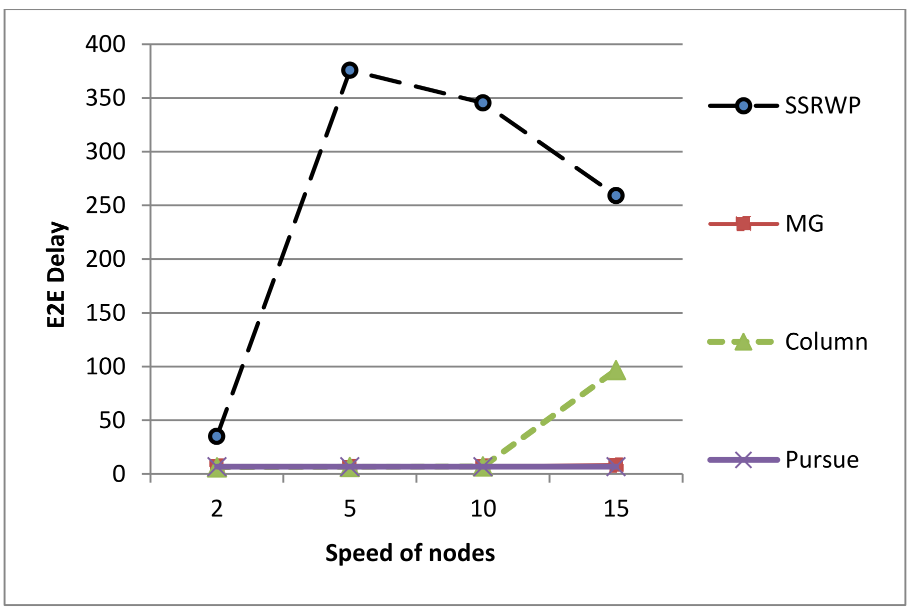

Figure 7.32 Average E2E delay vs Speed of nodes for AODV

CHAPTER 8

CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

In this thesis, we presented a comprehensive review of various routing protocols and mobility models in MANET. We have evaluated the performance of OLSR, DSDV, DSR and AODV in the presence of mobility models. The impact of popular mobility models such as Steady State Random Waypoint under random models, Column and Pursue under Spatial Models and Manhattan Grid under Geographical Models has been investigated in details with varying number of mobile nodes and their speed of movement.

The different mobility models were considered to represent the real characteristics of the MANET operating environment. It has been observed that AODV performs best in terms of throughput and DSR is only suitable for small networks. In large networks the network performance degrades with DSR. Routing overhead of Proactive Protocols is less as compared to Reactive Protocols. Manhattan Grid Mobility Model performs best with both varying network size and node mobility in terms of throughput, throughput, packet dropped, NRL and E2E delay. SSRWP, MG and Pursue Mobility Model are highly suitable for networks with low mobility whereas for high mobility, MG and Pursue Mobility Models gives better result. The degradation in performance under Steady State random Waypoint Mobility Model is more as speed increases.

8.2 Future Scope

A possible line of research would extend the simulation analysis to a broader range of mobility models under varying propagation loss models and MAC protocols. CBR packets have been used as a traffic source through the course of this study. It would be useful to analyze MANET performance under different traffic patterns such as those generated by Transmission Control Protocol. One of the future directions of research can be extending above set of the experiments by taking into consideration large scale unorganized disasters where obstacles play a vital role while determining routes. The existing mobility models can be further enhanced to develop more complex and realistic models.

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