Jafar

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Honours Final Project Report

Project Title: **"What effect would density and node mobility have on the performance of reactive MANET routing protocols AODV and DSR and proactive routing protocol DSDV when simulated using NS2 under varied network conditions"**

BSc (Hons) Networking & Systems Support

Project Supervisor: Dimitrios Liarokapis
Second Marker: Richard Foley

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"Except where explicitly stated all work in this report, including the appendices, is my own"

Signed: ____________________________ **Date:**

Abstract

Mobile ad hoc networks operate in a decentralised manner with mobile nodes acting as both a host and router in order to accomplish routing in a wireless multi-hop environment. Various protocols have been proposed to deal with the unique problems encountered for mobile ad hoc routing where the connections are formed arbitrarily and node movement within the topology is dynamic. (Corson, Macker 1999)

Each protocol performs routing in a different manner and depending on the class of the protocol routes will either be sourced on demand or sourced prior to nodes signaling intent to transmit and stored within a table. Testing of the protocols is necessary in order to identify how efficiently a protocol will perform. The results of which are critical in understanding the applications for use of a protocol and how the protocol will react under certain circumstances of network variations. Simulation is one of the methods used for evaluating protocol performance and is the method identified for use for the experiments within this project. (Kurkowski, Camp & Colagrosso 2005)

This project aims to conduct simulation experiments on MANET protocols AODV, DSR and DSDV to test their performance over varied network characteristics. The variations introduced include the node density where the topology will include dense and sparse network conditions and node mobility where mobile nodes will move randomly using variations in pause times. These variations will test the protocols ability to route data and deliver packets based on the metrics; data packet delivery ratio, end-to-end delay, normalised protocol overhead, throughput and number of packets dropped.
(V, Aithal & ChandraSekaran 2006, Garousi 2005a, Divecha et al. 2007, Yamamura, Nakashima & Fukushima 2008b)

The NS2 simulator was used for this project as this software was identified to be the most popular choice for similar research on MANET topics (Dow et al. 2005). NS2 version 2.34 which was the latest version at the time of this research project was utilised for the experimental studies undertaken for this project.

Through analysis of simulation results it was determined that reactive protocols function optimally in the MANET environment as compared to pro-active protocols. It was further identified that AODV offers a greater performance for networks beyond 50 nodes and scales well in comparison to DSR which performs best in small networks. DSR was found to offer the best performance in terms of packet delivery for networks experiencing high mobility rates and AODV was found to offer the least end to end delay time and drop the least number of packets.

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1.0 Introduction

1.1 Background

1.1.1 Wireless Communications and Popularity

Since the creation and deployment of the ALOHAnet wireless packet radio network in the 1970's (Abramson 1985), wireless technology has advanced and usage has significantly grown. Statistics on wireless trends show exponential growth in this market area as documented in the CTIA Semi-Annual Wireless Industry Survey (CTIA-The Wireless Association 2008), various growth areas are reported including estimated data on wireless subscribers which shows an increase of 19.3 million taken from June 2007 to June 2008 with minutes used for the first half of 2008 exceeding 1.1 trillion. Worldwide wireless growth continues to climb, (Thomson Reuters 2008 2008)comments on annual growth for 2007 taken from 'Fitch Ratings' showing growth of 17.5% with the biggest new markets emerging in Asia/Pacific accounting for approximately 27% of annual prepaid subscriber growth, primarily due to growth rates in India and China (Weaver et al. 2008).

1.1.2 Future applications & Trends

The wireless market is constantly evolving and growing in popularity due to such reasons as the mobile nature of wireless communications, ease of installation and cheaper technology, giving rise to accessibility (Vance 2007). Advancements in wireless technologies in the race to provide higher bandwidth, with developments for 4G and WiMAX technologies, provide users with similar connection speeds to that of a LAN (Local Area Network) (Chou, Chang & Wu 2008). Mobile WiMAX has a theoretical maximum data rate of 70Mbps and transmission range of 35 miles and is set to rival last mile technologies such as DSL (Digital Subscriber Line) (Garber 2008). 4G (Fourth Generation) or B3G (Beyond 3G) technologies are the next generation of emerging wireless standards and technologies, with a move towards higher data rates, advanced multimedia applications, user-oriented computing, based on digital, packet-switched IP communications. It is foreseen that 4G will encompass an array of protocols and standards in order to achieve it's goal of high throughput at lower costs (Anderson, Daim & Kim 2008a).Increased interoperability of devices through IEEE 802.11 standardisation and product testing and certification undertaken by the Wi-Fi Alliance enable the end user to connect to wireless networks easily and interconnect a range of wireless devices.

With the advancements in wireless technology, standards, data rates and transmission ranges new developments in applications for wireless technology are emerging. Ad hoc networking is one particular area of interest, however developing technologies related to this area include pervasive computing, using a mixture of sensors, embedded devices and wireless devices, pervasive computing will be the forefront of user-centred computing, various projects such as the MIT project Oxygen (MIT Laboratory for Computer Science, MIT Artificial Intelligence Laboratory

2002) herald advancements in pervasive computing technologies. Pervasive technologies are the future direction of ubiquitous computing; some uses for this technology include pervasive healthcare, smart appliances and vehicle to vehicle communications (Reddy 2006).

1.1.3 Wireless Network Topology

Networks are the infrastructure fabric that enable wireless communication between existing and future wireless technologies and are pertinent to providing the mobility sought after that make wireless so popular (Royer, Chai-Keong Toh 1999). Wireless networks can be deployed in either infrastructure mode, also referred to as a BSS (Basic Service Set); a centralised topology consisting of the wireless node communicating through a central point, such as an AP (Access Point) which is connected to a fixed or wired network. The BSS can also be extended to include multiple APs and is referred to as an ESS (Extended Basic Service Set). Finally an infrastructureless configuration can be used, known as an IBSS (Independent Basic Service Set); an ad hoc decentralised topology where nodes participate in peer to peer communication with each other without the need for a central device (Cisco Networking Academy 2004).

1.1.4 Mobile Ad Hoc Networks (Manets)

Mobile Ad Hoc Networks (MANETs) are infrastructureless and thus they enable greater mobility through the dynamic nature of arbitrary connections that are created (Royer, Chai-Keong Toh 1999).
The IETF (Internet and Engineering Task Force) set up a MANET working group to standardise IP routing protocols for mobile ad hoc routing. Protocols researched by the working group are documented as Internet-Drafts. The IETF MANET working group is currently looking to standardise one proactive and one reactive routing protocol (IETF Secretariat 2008).

RFC 2501 defines mobile ad hoc networking as "*an autonomous system of mobile nodes. The system may operate in isolation, or may have gateways to and interface with a fixed network*". It is envisioned a MANET is a dynamic, multi-hop, random network that is expected to have bandwidth-constrained links and where by incorporating routing into mobile nodes an efficient and robust network can be supported. As the advancement of wireless technologies is mostly based on the IP (Internet Protocol) suite, as in 4G technologies, routing relating to mobile hosts based on the IP protocol is referred to as "mobile IP" technology (Corson, Macker 1999).

1.1.5 MANET Benefits and Routing Overview

The benefit of MANETs is that they can be deployed in areas where there is no fixed infrastructure or due to cost or other factors such as geography of the location it would not be possible to connect to existing infrastructures. Nodes in an ad hoc network form connections with each other in order to establish a network. As nodes may not be within transmission range of one another communication in an ad hoc network is achieved by nodes acting as both a host and a router. Data thus must take multiple hops over wireless links to reach the destination node; therefore ad hoc networks can be referred to as multi-hop networks. Multi-hop networking enables the network to scale as nodes out with transmission range of one another can communicate. Nodes must have a routing mechanism in order to forward packets to destinations that are not within transmission range. Routing is dynamically configured between nodes and nodes forward packets for one another in order to achieve end to end communication. (Broch et al. 1998) (Anastasi et al. 2003)

1.1.6 Uses for MANET Deployment

Due to the flexible nature of ad hoc networks the technology could be deployed in several areas where a fixed infrastructure is not a feasible option such as commercial and academic scenarios, military applications where communications networks must be robust and could not rely on any central point that could represent possible failure of the system and in emergency/ disaster response locations where a robust communication network would also be essential (Anastasi et al. 2004).

1.1.7 MANET Routing Problems

As MANETs are a dynamic environment where topological change can be rapid and nodes rely on each other to route data due to the de-centralised architecture of ad hoc networks, efficient routing of data becomes a problem. Traditional routing protocols, which can be classified as link state or distance vector, cannot be utilised in the MANET environment. The reason for this lies in the algorithmic operational characteristics of these routing protocols, where the aim is to find an optimal path to every node existing on the network and advertise the optimal routes in order for the network to converge. As the network is typically static topology changes are not frequent, any changes that occur are advertised through network updates.
Nodes in an ad hoc network communicate over bandwidth-constrained links and generally will operate on battery power. Therefore the cost of finding and maintaining routes to every destination in the network would be too high and would also be inefficient as mobile nodes communicate with a subset of nodes within transmission range as each host provides routing in MANETs compared to infrastructure based networks where hosts communicate separately with routers located on the network. Due to node mobility the topology of a MANET will under go rapid changes, the periodic updates sent out from traditional routing protocols would not show a valid picture of the network as the changes would not be reflected immediately it would take time for the network to re-converge, this would lead to stale routes and packets being dropped.

Research work in this area has attracted great interest and various protocols have been proposed that respond to the dynamically mobile nature of MANETs based on distance vector and link state algorithms. (Boukerche 2004b, Narayan, Syrotiuk 2003)(Layuan, Chunlin & Peiyan 2007)

1.1.8 Categories of MANET Routing Protocols

Study into ad hoc protocols can be categorised as follows;

Proactive Routing Protocols (also referred to as Table Driven): - Routing information is gathered on routes to every node on the network before transmission is required and held in various tables maintained within each node in the network. Proactive protocols therefore try to identify a view of the network topology at a given time. Updates and topology changes are broadcast throughout the network periodically. Disadvantages include the storage of unused routes being held in the routing tables and bandwidth consumption due to updates and routing overhead. Due to these problems proactive routing protocols do not scale well.

Examples of proactive routing protocols include DSDV (Destination Distance Vector), GSR (Global State Routing) & FSR (Fisheye State Routing). OLSRv2 (Optical Link State Routing Version 2) protocol is the current proactive routing protocol being pursued by the IETF MANET working group, based on the traditional link state algorithm (Clausen, Dearlove & Jacquet 2008).

Reactive Routing Protocols: - Attempt to address the issues with routing overhead in proactive protocols. Reactive protocols address these issues by only storing information on active routes, thereby initiating a route request on the network when a node requires to transmit, in order to determine the route to the destination node. Some limitations to reactive protocols are that a delay occurs before transmission as the route to the destination must first be discovered through the route discovery process, also topology changes would lead to dropped packets requiring a route request to again be initiated. Some examples of reactive routing protocols are AODV (Ad hoc On-Demand Distance Vector), DSR (Dynamic Source Routing) and TORA (Temporally Ordered Routing Algorithm). DYMO (Dynamic MANET On-Demand) protocol is currently being pursued as an option for a reactive/ on-demand routing solution by the IETF (Chakeres, Perkins 2008).

Position-Based Routing Protocols: - Make use of GPS (Global Positioning System Information) in order to route data. Routing decisions are taken based on GPS location and this information is included in the packet. Use of GPS information in order to base routing decisions reduces some of the limitations of reactive and proactive routing protocols as position-based routing does not require nodes to store and maintain routing tables. LAR (Location-Aided Routing) is an example of a position-based routing protocol.

The difference between the routing protocols is the way in which routes are updated and discovered. (Trung, Benjapolakul & Duc 2007b, Abolhasan, Wysocki & Dutkiewicz 2004)

1.1.9 Why Evaluation of Routing Protocols is Useful

Evaluation of the performance of proposed routing protocols gives an insight as to how a routing protocol reacts under certain network circumstances. The results of research evaluations can be utilised to derive the best protocols to be used for various deployment scenarios and also provide an insight into areas for improvement within the protocol.

Various techniques can be used for evaluating routing protocols such as simulation, emulation and real-world experiments. Real-world experiments give a clearer picture of the behaviour of a protocol as simulation scenarios are based on assumptions which may or may not reflect those faced in the real-world and are also limited to the capabilities of the software. Simulations however can provide vital insight into the workings of protocols and are necessary as certain real-world deployments of MANETs have drawbacks such as scalability due to equipment costs and a lack of repeatability. The results of real-world experiments however can be used as a source for simulation and emulation experiments. Research work undertaken by Royer et al (Royer, Perkins 2000) on the AODV protocol gives insight into ad hoc protocol experiments where simulation scenarios were required before real-world implementation. Research into mesh and sensor networks also provides useful information that can be used for MANET research, although these networks are stationary they are both wireless multi-hop networks, wireless mesh networks are also the most mature currently deployed wireless multi-hop networks. (Kiess, Mauve 2007a)

As previously mentioned ad hoc routing protocols face various problems due to the distributed manner that ad hoc communications undertake. Gaining knowledge on the performance of routing protocols enables an understanding of their efficiency. This project proposes to investigate the performance issues relating to routing protocols AODV, DSR and DSDV. The findings of the project will provide data on their performance and behaviour and can be utilised in further research by discovering which routing protocol performs best with relation to the test scenarios.

1.2 Project Outline and Research Question

This section details the project question that is being investigated and the justification for investigation into this topic area, the type of project and the aim and objectives.

1.2.1 Project Question

"What effect would density and node mobility have on the performance of reactive MANET routing protocols AODV and DSR and proactive routing protocol DSDV when simulated using NS2 under varied network conditions"

(An experimental based project where the use of NS2 simulation software will be utilised to simulate a series of implemented network configurations to test the performance of mobile ad hoc routing protocols AODV, DSR and DSDV against a set of metrics.

The results will be analysed and the performance of each protocol will be used to identify their efficiency under varied network characteristics relating to the simulation scenarios.)

1.2.2 Hypothesis

The below hypothesis have been made by studying performance simulations based on the protocols AODV, DSR and DSDV. Sources used in determining the hypothesis are: (Saurabh Rastogi 2006, V, Aithal & ChandraSekaran 2006)

1.) DSDV will have a lower packet delivery ratio than AODV and DSR in high mobility scenarios due to the table-driven nature of the protocol, where an attempt is made by the protocol to store all routes for the network topology at a given time and whereby data is forwarded to a destination based on the routing information held in the tables. In scenarios where mobility is high the possibility of stale routes increases meaning packets will be dropped.

2.) AODV will achieve a greater packet delivery ratio than DSR in high mobility scenarios. The reason for this is that DSR utilises aggressive caching, in high mobility scenarios there are increased link breakages meaning that the probability of the cached routes utilised by DSR being stale are high. Stale routes lead to a decrease in delivery of packets, once detected the protocol is required to initiate a route request.

3.) Routing overhead for DSR , AODV and DSDV will increase as mobility increases, however DSDV will always have a higher routing overhead as compared to the reactive protocols as the protocol will require to send more updates in order to update the routing tables.

1.2.3 Justification

Variations in node mobility test a protocols ability to route packets by finding correct paths to the destination. Different mobility situations will test the mechanics of a routing protocol to determine how effectively packets are delivered and the amount of routing overhead produced. Furthermore it would be beneficial to identify how a protocols performance reacts when faced with dense and sparse topologies. Dense topologies introduce problems associated with finding paths through a large number of nodes; on the other hand dense topologies provide plenty of links in order to make a connection. Sparse topologies present the challenge of few nodes widely distributed and thus connection may be intermittent.(V, Aithal & ChandraSekaran 2006, Garousi 2005a, Divecha et al. 2007, Yamamura, Nakashima & Fukushima 2008b)

Simulations of MANETs are carried out to gain further understanding of the functionality of routing protocols. Ns2 is a widely used simulation tool for this purpose as analysed by (Dow et al. 2005) (See Appendix 7.1) and Kurkowski et al (Kurkowski, Camp & Colagrosso 2005) as it provides support for mobile ad hoc routing protocols. AODV, DSR and DSDV protocols have been chosen for the project study as these protocols are supported under the Ns2 environment (Fall, Varadhan 2008b), furthermore they are widely studied and documented which shows that they are a topic of active research in relation to mobile ad hoc network routing. Apart from many simulation studies real-world implementations of the above protocols have been carried out, some of these studies include; DSR test bed at Carnegie Melon University (Maltz, Broch & Johnson 2000) and AODV/DSDV implementation at Sydney Networks and Communications Lab (Chin et al. 2002). Testing the performance of these protocols under dense and sparse topological conditions with variations in node mobility tests the efficiency of the protocol to determine routes and route data effectively. The results of which can be utilised to identify the strengths and weaknesses of the protocols depending on protocol performance results over varied network characteristics.

1.2.4 Project Type

The proposed project is an experimental project whereby the use of software based simulation scenarios will be utilised and carried out on routing protocols AODV, DSR and DSDV. Data gathered from the test results will be used in order to review the performance of each protocol.

1.2.5 Project Aim

The research project aims to identify how MANET routing protocols perform under varied network characteristics. The aforementioned problems encountered with routing in an ad hoc environment together with the possible applications for this type of technology give rise to the importance of research into the performance of ad hoc routing protocols. Routing protocol performance will be measured by conducting a series of simulation based experiments, recording the results based on a set of identified metrics and analysing the data. The analysis of routing protocol performance will give insight into the strengths and weaknesses of the protocols based on the test scenario used.

1.2.6 Project Objectives

In order to undertake the project a number of objectives are required to be identified and carried out in relation to the research question proposed. Objectives identified for this project are as follows:

1.) Analyse wireless communications.

Ad hoc communications are a form of wireless technology therefore it is important to describe wireless communications.

Analysis of wireless communications provides further understanding of the background, use and features of these technologies. From this data insights into how these technologies have evolved and future market trends can also be identified.

2.) Explanation of the idiosyncrasies of wireless infrastructure and ad hoc communications.

By understanding the difference between infrastructure based and ad hoc wireless communications, the fundamental nature of ad hoc technologies can be explained.

3.) Define the characteristics of a mobile ad hoc network (MANET) and how routing is undertaken in a MANET environment.

As the project focus is on MANET routing protocols, understanding must first be gained on the characteristics of MANETs.

As routing in a MANET is approached differently than an infrastructure based network an insight into how routing is achieved enables an understanding of the nature of ad hoc protocol workings.

4.) Identify the general characteristics of mobile ad hoc routing protocols.

Mobile ad hoc routing protocols can be generalised into categories such as reactive and proactive, the protocols studied in this project and in the wider area of research fall into set categories based on how they operate. Due to these reasons in order to study the protocols used in this project and understand research utilised in order to gain knowledge pertaining to the project issues, the general characteristics of the categories routing protocols are based on must be understood.

5.) Investigate the characteristics of AODV, DSR and DSDV routing protocols.

AODV, DSR and DSDV are the three protocols that this project aims to test the performance of. In order for tests to be based on these protocols and to interpret test results effectively, the characteristics of how each protocol works is required to be known.

2.0 Literature Review

The literature review aims to address the key areas identified in the objectives set out in section 1.2.5. By gaining further in depth knowledge of these objectives a framework and outline of the project can be built on in order to understand the principles of wireless mobile ad hoc network communications and how the working of the protocols may affect performance depending on the simulation setup used.

2.1 Wireless Communications

The study into wireless communications aims to give an insight into how wireless technology operates and the background of wireless technology evolution.

2.1.1 Wireless Introduction

Wireless networks use radio frequency (RF) or infrared (IR) light as the medium in which to transmit data. RF covers a wider area than IR and wireless local area networks (WLANs) operate over either 2.4 gigahertz (GHz) or 5 GHz frequency bands. Wireless equipment is standardised and provided to be interoperable by two organisations which are the IEEE 802.11 committee and the Wi-Fi Alliance (Cisco Networking Academy Program Fundamentals of Wireless LANs Companion Guide 2004).The Wi-Fi alliance rigorously tests equipment to ensure it meets a required set of standards to be deemed interoperable (Wi-Fi Alliance 2009). The IEEE 802.11 specifications set a number of standards for WLANs.(Stephen 2009)

802.11 WLAN standards specify the technologies used for wireless transmission. Signalling methods specified in the 802.11 standards enable data transmission using infra red light or via radio frequency transmission.

Three signalling technologies are available for 2.4GHz radio transmissions which are: Frequency Hopping Spread Spectrum (FHSS), Direct Sequence Spread Spectrum (DSSS) and Orthogonal Frequency-Division Multiplexing (OFDM). These modulation techniques allow for data transmission over the RF spectrum and are defined as standards to use by the IEEE which are broken into different specifications known as 802.11a, 802.11b and 802.11g. Radio transmissions over 5GHz frequencies make use of one type of signalling technology OFDM. 802.11a works with OFDM modulation over the 5GHz frequency band and provides data rates up to 54Mbps. 802.11b and 802.11g both use DSSS modulation and work over the 2.4GHz frequency band, 802.11b provides data rates up to 11Mbps and 802.11g provides data rates up to 54Mbps. (Cisco Networking Academy Program Fundamentals of Wireless LANs Companion Guide 2004)

2.1.2 Evolution

ALOHAnet

Wireless networks are becoming increasingly popular, research interest in this area initially started with the creation and deployment of the first packet radio network ALOHAnet at the University of Hawaii. ALOHA was a single-hop system that made use of a packet broadcasting technique and was deployed in the 1970's. (Kiess, Mauve 2007b), (Abramson 1985)

The aim of the Aloha System project which was started in 1968 was to find alternatives to wired computing techniques. The project discovered new methods for random access communications and implemented these techniques with the creation of the network. Data is transmitted by way of a packet switching technique similar to that used by ARPANET (Advanced Research Projects Agency Network). (Kuo 1974)

PRNET

DARPA (Defence Advance Research Projects Agency) setup a multi-hop Packet Radio NETwork (PRNET) consisting of 50 nodes in 1973 based on the knowledge gained from the ALOHA System project. PRNET was the first network with mobile wireless nodes and MANET routing protocols are still based on the mechanics of this research. The project deployment ran for around ten years and was replaced by the SURvivable Adaptive Networks (SURAN) project. (Kiess, Mauve 2007a)

SURAN

SURAN was setup in 1983 to research network technologies capable of providing robust communication in a dynamic environment. PRNET showed packet radio (PR) networking was possible, the SURAN project aimed to find solutions to the problems of dynamic mobile networking. The program completed in the 1990's developed a number of routing network and link-layer algorithms, incorporated in the SURAN Protocol suite (SURAP), which addressed the issues relating to providing robust mobile communications. SURAP algorithms lead to developments in areas such as; link adaptivity, where monitoring and selection of channel conditions and transmission control can be achieved; channel access & scheduling; end-to-end delay protocols that focus on packet delivery and various routing algorithms focusing on adaptivity, security and management. A framework was developed based on these developments; the network was simulated and also deployed in a real test bed at a low cost. (Beyer 1990)

As communication technologies evolved rapidly in the 1990s with notebook computers and the use of RF and infrared technologies, the term ad hoc networks was adopted by the IEEE to describe a set of mobile nodes which communicated in an infrastructureless manner. Interest into ad hoc networks grew both in military and non military context. The military continued with projects into ad hoc networks with the development of two projects known as Global Mobile

Information Systems (GloMo) and Near-Term Digital Radio (NTDR). GloMo was focussed on providing office based Ethernet multimedia networking via handheld devices with anytime, anywhere communication capabilities. GloMo made use of CSMA/CA and TDMA and from this project a number of routing and control schemes were developed. NTDR focussed on the use of clustering and link-state routing methods deployed in a two-tier hierarchy of ad hoc routing which was self organising. NTDR is used by the US Army and is the only non proto-typical ad hoc network in use in the real world. Research into ad hoc networks has lead to routing protocol standards being adopted by the IETF and active research into a number of possible standards undertaken by the MANET working group of the IETF. (Ramanathan, Redi 2002)

2.1.3 Popularity

Wireless technologies offer user mobility and provide an opportunity for networks to be deployed and accessed in areas where this would have previously been impossible with wired networks. Due to these reasons and the support for new technologies wireless has become a popular medium.

The increase in use of wireless technologies as mentioned earlier and detailed in the CTIA Semi-Annual Wireless Industry Survey (CTIA-The Wireless Association 2008) showing a rise in subscribers to 19.3 million from June 2007 to June 2008 and the use of more than 1.1 trillion minutes for the first half of 2008, give a clear indication of the popularity of wireless technologies. The survey also shows an annual rise of 4.1% of direct wireless carrier employment. The rate of wireless growth continues to climb as commented on in (Thomson Reuters 2008 2008) detailing a growth rate of 17.5% for 2007 taken from ‘Fitch Ratings’. As previously mentioned the strongest expansion in global markets comes from Asia/Pacific accounting for 27% annual prepaid subscriber growth with the biggest rise in uptake from India and China. (Weaver et al. 2008).

Fitch Ratings’ “Global Wireless Review” reports on a number of global statistics taken from 72 operators over 27 countries for 2007. The report on individual countries annual growth rate reported Western Europe to have an increase in wireless growth from 6% (2006) to 8% (2007); United States and Canada had a growth rate of 10%; Latin America’s growth rate was 22%; Asia/Pacific 23%; Germany 13% and Italy 11%. Asia/Pacific’s consistent rise in wireless growth rate is primarily due to India where the subscriber base was found to be the fastest growing with a growth rate of 72% and Indonesia with a growth rate of 37%. China also contributes greatly to these figures with the largest subscriber increase at a rate of 68 million for 2007, India and Indonesia experienced an active subscriber rate of 23%. This leads to Asia/Pacific capturing 46% of the world’s subscribers and 52% of the world’s total new subscribers as such Asia/Pacific had the strongest prepaid subscriber growth rate for 2007 with a rate of 27%.

United States and Canada had a rate of 23% prepaid growth for 2007 followed by Latin America with a rate of 22%.The decrease in tariff rates and better service plans are two reasons pointed out for the contribution to the rate of wireless growth. (Weaver et al. 2008)

These figures illustrate that use of wireless technology is set to evolve and will continue to grow. As new technologies become available and more accessible and the price of technology falls, the uptake of new and existing technologies looks set to rise.

2.1.4 Future trends

Wireless technologies are evolving to offer increased data rates, reliability and access at lower costs. The move towards 4G technologies and IP based communications such as Mobile IP will provide the faster data rates sought after and access to a range of new applications for wireless devices (Chou, Chang & Wu 2008), (Anderson, Daim & Kim 2008b).

New standards such as 802.11i will address security issues and 802.11e will provide for Qos (quality of service) support for delay sensitive applications such as voice and video (Cisco Networking Academy Program Fundamentals of Wireless LANs Companion Guide 2004). 802.11n is a proposed new physical layer standard that may reach throughputs beyond 200Mbps and provide a greater transmission range over current 802.11a/b/g standards; 802.11n will make use of spatial division multiplexing (SDM). (Paul, Ogunfunmi 2008)

2.2 Infrastructure and Wireless Communication

This section aims to give an overview of infrastructure based routing and the various wireless topologies.

2.2.1 Conventional infrastructure routing

Infrastructure based routing consists of a wired medium between nodes. The wired medium could be a variety of media including, UTP (Unshielded Twisted Pair) cable, STP (Shielded Twisted Pair) cable, coaxial or fibre optic cables. The most common media used is twisted pair Ethernet. Ethernet defines the transmission and distance run properties of a cable. Nodes can be wired directly together as in a peer-to-peer setup or can be connected to a central point by which all transmission will travel through such as a router, hub or switch. In order for communication to be possible over multiple hops routing protocols must be used. These can be divided into two categories:

1. Distance Vector

Maintains routing tables and bases routing decisions on the metric hop count. The distance “hop count” and direction “vector” is computed for reaching every node on the network. The best path calculation is done based on the Bellman-Ford Algorithm. Periodic beacons are transmitted to all neighbouring nodes. The updating of routing table data based on a neighbours routing table update packet is referred to as routing by rumour.

2. Link-State

Link-state protocols work on the Shortest Path First (SPF) algorithm. The shortest path to a destination is computed by applying the SPF algorithm against the link state database which holds routing information for the network. A shortest path first (SPF) tree is built based on the result of the calculation. Link state protocols send routing updates only when a change has occurred and periodic updates are sent out after a longer time interval of 30 minutes.

Link state protocols overcome the problems associated with distance vector based protocols and as such they are able to respond quickly to change and scale well. (Cisco Networking Academy Program CCNA 1 and 2 Companion Guide 2005)

2.2.2 Media Access Control

Media access control (MAC) is divided into two categories for an infrastructure based network, these are 1.) Deterministic ; 2.) Nondeterministic. MAC protocols work at layer 2 of the OSI (Open Systems Interconnect) model the data-link layer. MAC protocols determine how the media is accessed for communication purposes in a shared environment. The shared environment is referred to as the collision domain as collisions take place within the boundaries of the shared environment as all devices have access to a shared medium and any node can transmit at any time. The following describes infrastructure based MAC methods and protocols.

1.) Deterministic MAC

Deterministic protocols determine who will transmit at any given time, the method is based on the idea that devices take turns to communicate and thus when one device is communicating no other device is permitted to communicate over the shared media. Examples of deterministic protocols are Token Ring and FDDI (Fibre Distributed Data Interface). Token ring communication implements a token passing scheme by which only the device holding the token can communicate, when it is finished it passes the token on to the next device that wants to communicate. The token circles the ring and devices wishing to communicate take possession of the token, proceed with communication and then pass the token on after which another device may take possession of the token and communicate. Using this method collisions do not occur as only one device can communicate at any given time.

2.) Nondeterministic MAC

Devices in a nondeterministic network communicate on a first come first served (fcfs) basis. Nodes listen to the media, by sensing the carrier nodes can determine if the media is quiet or busy, if the shared media is sensed to be quiet the node wishing to transmit attempts to send out their transmission over the media else they wait until the media is sensed to be quiet. As many nodes can be attached to a network and belong to the same collision domain a collision may occur if two nodes transmit at the same time, in this case both transmission would fail. Nodes attached to the network sense the collision causing a back off algorithm to compute requiring each node to wait a set random amount of time before attempting re-transmission after the timer expires. The nodes involved in the collision do not have priority when to transmit data.

The protocol used for nondeterministic data transmission is CSMA/CD (Carrier Sense Multiple Access/ Collision Detection) and is used over LAN technologies such as Ethernet. (Cisco Networking Academy Program CCNA 1 and 2 Companion Guide 2005)

These methods differ from that used for wireless MAC data transmission, wireless networks make use of a method known as CSMA/CA (Carrier Sense Multiple Access/ Collision Avoidance), described in detail in section 2.3.4. A different MAC method is required for wireless transmission as unlike in a fixed infrastructure wireless devices are unable to sense collisions (collision detection) and thus employ the technique of collision avoidance.

2.2.3 Wireless Topology

Wireless topologies differ from wired LANs, instead of being wired to a central point such as a hub, switch or router, wireless nodes communicate with a central point known as an access point (AP). The AP is usually interfaced with the wired network and nodes in communication range of an AP are said to be within a cell.

A Basic Service Set (BSS) consists of node communication with a single AP covering a single cell area as illustrated in Diagram 1. An Extended Service Set (ESS) consists of two or more BSS that can communicate by means of connection to a common distribution system, which can be wired or wireless as shown in Diagram 2. Nodes can move between cells by the process of roaming, clients do not lose connectivity during the signal crossover from one cell to another the AP will hand over the client to the AP residing in the next cell.

Ad-Hoc routing is also referred to as an independent basic service set (IBSS), nodes connect to each other directly in a random manner without planning as illustrated in Diagram 3. Communication out with the IBSS is achieved by nodes acting as a gateway or router. This can be implemented using simply wireless connections or a node can be attached to a fixed network and act as a single gateway for the other nodes. (Cisco Networking Academy Program Fundamentals of Wireless LANs Companion Guide 2004)

Examples of wireless architectures with reference from (Cisco Networking Academy Program Fundamentals of Wireless LANs Companion Guide 2004):

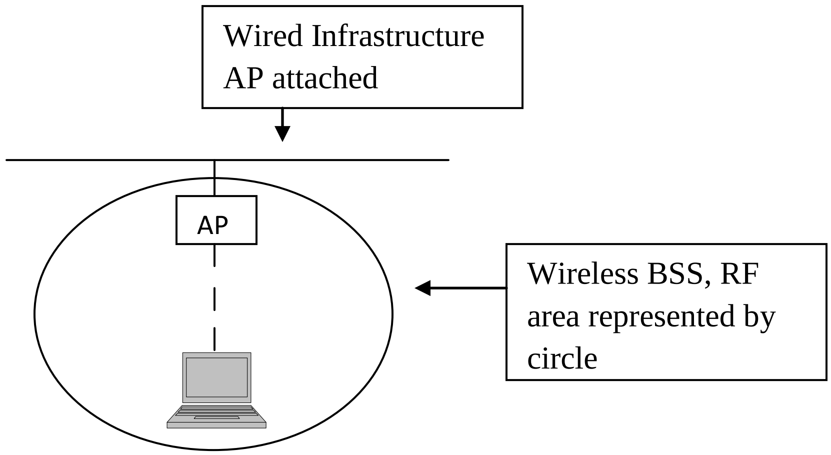


Diagram 1: Basic Service Set (BSS)

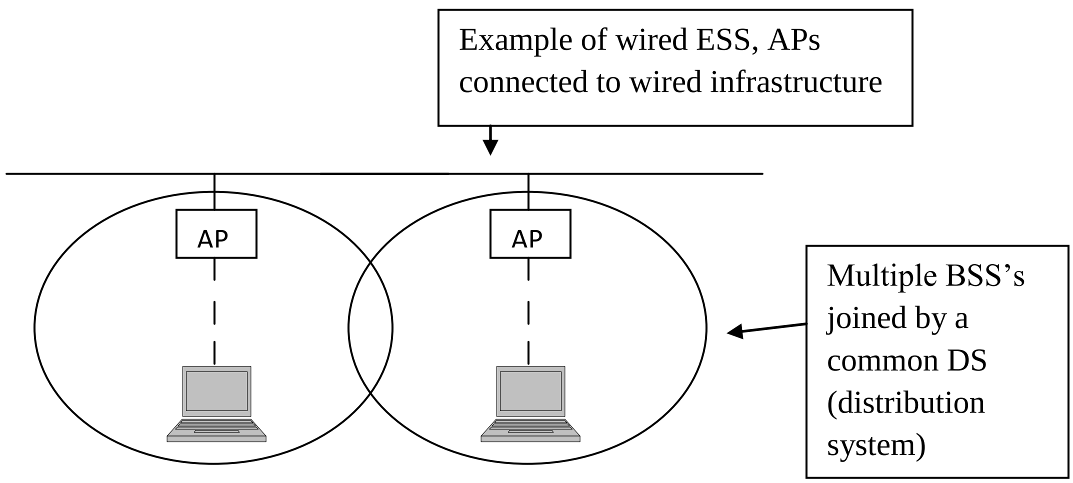


Diagram 2: Extended Service Set (ESS)

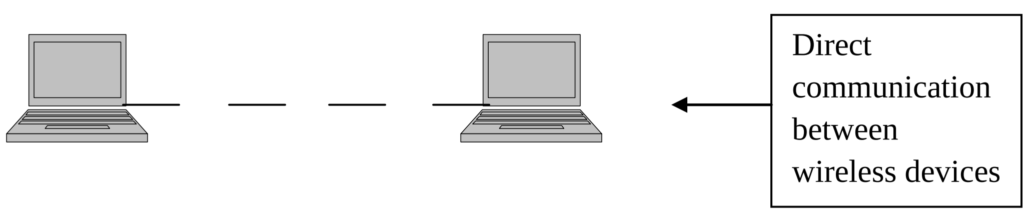


Diagram 3: Independent Basic Service Set (IBSS)

2.3 Characteristics and Routing Functions of MANETs

This section aims to identify the characteristics of MANETs and an overview of the routing functionality.

2.3.1 Definition of MANET

A mobile ad hoc network is envisioned to be a dynamic, multi-hop, random environment therefore routing protocols must be able to cope with the unique demands of a MANET environment and often will have to route data effectively over bandwidth constrained links. The goal of MANETs foresees that mobile networks will operate as autonomous wireless domains that will usually be in the form of a stub network which in turn connects at some point to a fixed network. Devices on a MANET will usually have a limited power supply therefore a routing protocol must also not require high power consumption in order to operate effectively. Wireless technological advancements are being created around the IP (Internet Protocol) suite, as seen with the development of 4G technologies, as such routing in a mobile host environment based on IP is referred to as "mobile IP". (Corson, Macker 1999)

2.3.2 Characteristics of MANETs

MANETs consist of a variety of challenges based on the nature of the network environment. A number of characteristics can be summarised as stated in RFC 2501:

1. Dynamic Topologies

The arbitrary connections that make up a MANET topology lead to dynamic, random movements. Routing protocols must be able to cope with this environment to route data effectively.

2. Bandwidth-Constrained

Nodes in a MANET make use of wireless RF communication which has a lower capacity the wired communications. A number of factors reduce the throughput further than the theoretical maximum such as noise, fading, congestion due to use of a multiple access shared medium and interference.

3. Energy Constrained Operation

Mobile nodes generally rely on battery power which has a limited time span before running out. Power conservation is a primary design objective for protocols operating on MANETs in order for nodes to have a sufficient life span.

4. Limited Physical Security

Wireless networks are more vulnerable to attacks as communication occurs over the air waves meaning attackers can eavesdrop on communications and carry out attacks such as spoofing and denial of service. MANETs have an advantage in that the decentralised architecture results in no effect to the network as a whole when a node is affected by an attack, the attack is isolated to the node and the network can continue to operate. (Corson, Macker 1999), (Latiff, Fisal 2003), (Naski 2004)

2.3.3 MANET Operation and Routing

Trung et al (Trung, Benjapolakul & Duc 2007b) and Royer et al (Royer, Chai-Keong Toh 1999) refer to Mobile ad hoc Networks as a network which operates in an infrastructureless, decentralised manner, where there is no established central point of communication. The network consists of a group of mobile nodes that communicate arbitrarily forming a dynamic topology.

The infrastructureless nature of MANETs thus provides mobility; nodes do not require to be fixed to a specific location and no infrastructure requirements are needed for deployment of the mobile ad hoc network. This makes MANETs ideal for deployment in disaster locations or for military use as mentioned in (Giuseppe Anastasi, Marco Conti,Enrico Gregori, 2004) as in these scenarios the use of existing infrastructure based communications may not be possible due to geographical location or an option if it is damaged. The decentralised manner of communication provides greater mobility and fault tolerance as there is no single point of failure on the network and nodes are not tied down within certain boundaries of communication to a single central point, for example a wireless node communicating in a BSS relies on the AP as the central point of communication and can only communicate with the network as long as the node stays within the wireless range of the AP.

Broch et al (Broch et al. 1998) and Anastasi et al (Anastasi et al. 2003) explain mobile nodes in a MANET form connections with one another creating a network. Communication through the network is achieved by the nodes acting as both a host and a router in order to communicate with nodes out with transmission range.

Data may take multiple hops over wireless links to reach the destination node hence MANETs are also referred to as multi-hop networks.

Each node must undertake the functionality of being a host and router in order for communication to be possible between nodes out with transmission range of each other. Due to this mixed functionality communication is possible via the intermediate nodes wireless links. A node acting as a router will forward packets to a destination for another node and if a node is the host, other nodes will form the connection and act as routers in order for communication to be successful. The purpose of nodes undertaking this dual role to efficiently communicate is expressed in RFC 2501 which states a vision of MANETs as being able "*to support robust and efficient operation in mobile wireless networks by incorporating routing functionality into mobile nodes*".(Corson, Macker 1999)

In order for the network to scale a network must be able to provide multi-hop functionality. As (Broch et al. 1998, Anastasi et al. 2003) further advise multi-hop networks enable the network to scale as this functionality allows nodes that are not within transmission range of each other to communicate. A routing mechanism is required for multi-hop networks for communication to be possible. In a MANET environment routing is dynamically configured between the nodes. End-to-end communication is achieved by the nodes forwarding packets for each other.

Many routing protocols have been proposed to deal with routing in a MANET environment. With the future of wireless communication primarily being based on IP (Internet Protocol) technologies the IETF (Internet and Engineering Task Force) established a MANET working group in order to standardise IP routing protocols for static and dynamic MANETs. The protocols researched by the working group are published as Internet-Drafts. Informational data on mobile ad hoc networking is published in RFC 2501 by the working group. The MANET working group aims to standardise one reactive MANET protocol (RMP) and one proactive (PMP) MANET protocol as well as developing a forwarding protocol that floods data to all MANET nodes by means of multicast. (IETF Secretariat 2008)

2.3.4 MAC Layer Function

Transmission is controlled in wireless networks via the MAC layer. The IEEE 802.11 specification includes an access method called distributed coordination function (DCF) which is based on the carrier sense multiple access/collision avoidance (CSMA/CA) protocol. When a node wishes to transmit DCF senses the medium to see whether it is free or not.

The node must sense no activity for a time period referred to as distributed inter frame space (DIFS) before it can attempt to transmit. If the medium is busy the node must wait for a specified time known as the back off time before it can try again. The back off timer decreases to zero when the medium is sensed to be idle and a time period greater the DIFS has elapsed. If two nodes transmit at the same time a collision occurs, nodes on a wireless network cannot hear a collision, in order to overcome this positive acknowledgements are sent when a packet is received. A node receiving the frame waits for a time period known as the short inter frame space (SIFS) before sending an acknowledgement. SIFS time periods are shorter than DIFS time periods. If an ACK (acknowledgement) is not received by the source an error is presumed to have occurred and the packet is retransmitted. An ACK is not sent by the receiving station if a cyclical redundancy check CRC found the packet to be corrupted, in this case the station remains idle for an extended inter frame space (EIFS) interval, after this period has elapsed the back off algorithm is initiated. (Giuseppe Anastasi, Marco Conti,Enrico Gregori, 2004)

An example of basic DCF access is illustrated in the below diagram created with reference from Stallings (Stallings 2004).

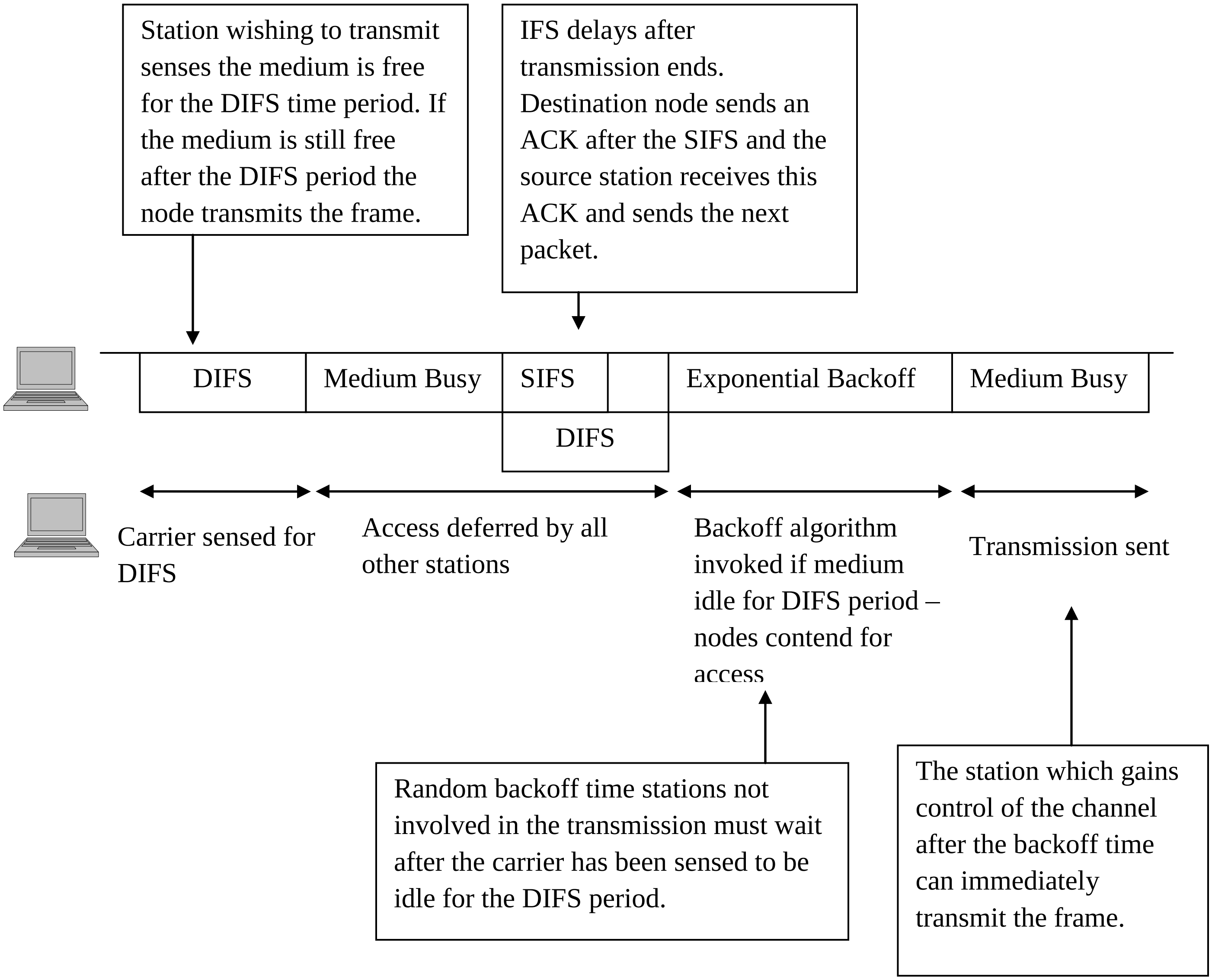


Diagram 4: Basic DCF Operation

In order to further reduce the possibilities of a collision occurring request to send (RTS) and clear to send (CTS) packets can be used where the sender uses RTS to indicate its intent to transmit and the destination device uses CTS to respond to the RTS packet before a data frame is transmitted. The sender will transmit the data frame on receipt of the CTS frame and the destination node will send an ACK packet to signify that the data has been received. RTS/CTS is useful in overcoming the problem of hidden nodes in wireless networks. A hidden node is a node that is out of transmission range of another node and therefore collisions can occur when both nodes attempt to transmit at the same time.

The RTS signal is received by all nodes within range of the source and CTS is received by all nodes within range of the destination node. All stations refrain from transmission on receiving the RTS or CTS. RTS/CTS is an optional MAC feature. DCF is a contention based algorithm used directly by asynchronous ordinary WLAN traffic. Another wireless MAC layer access method is available known as PCF. PCF (Point Coordination Function) is another access method that provides contention-free access by using a centralised point coordinator to issue polls. PCF which is implemented on top of DCF in the MAC layer uses PIFS (Point coordinator function interframe space). The PIFS is a midlength IFS and therefore is shorter the DIFS but larger than the SIFS. This means that asynchronous traffic is not able to gain control of the medium if a point coordinator wants to transmit polls. PCF is therefore useful for controlling time sensitive traffic and allows all other traffic to contend for the medium using the DFS method. In order to ensure a point coordinator does not keep control of the medium stopping asynchronous traffic from gaining access a superframe is used in which the point coordinator can issue polls at the start and then must remain idle for the remainder of the superframe allowing asynchronous traffic to contend for access. As the PCF scheme uses a centralised controller (AP) to issue polls and MANETS are a decentralised architecture the DCF scheme is used in MANETS. (Stallings 2004)

The hidden and exposed node problem is an issue in wireless transmissions and therefore MANETs. A hidden node scenario arises when two nodes are out with transmission range of each other and therefore cannot sense the carrier resulting in data errors at the receiver when both nodes transmit at the same time. As mentioned previously the RTS/CTS feature helps to overcome this problem. However with the use of RTS/CTS the neighbouring node is locked from transmitting as the CTS signal from the neighbouring sending station is sensed. As collisions occur at the receiver only, it would not affect communication if the node was able to transmit; instead the node is locked from transmitting to other nodes within its range. An exposed node scenario occurs when wireless nodes out with the range of each other transmit to a node that is within range to both nodes at the same time. The hidden and exposed node problem is illustrated below in Diagrams 4 and 5. (Bharghavan et al. 1994)

The hidden node problem occurs when nodes are out with transmission range from one another and are therefore unaware of each others presence as node A wishes to transmit node C is the hidden node as node C is hidden from node A and neither are aware of each others presence.

In Diagram 4 the nodes affected are node A and node C, node B is not affected by the hidden node phenomena as it is within range of both nodes A and C. In the case of Diagram 4 node A is transmitting to node B, nodes A and B and B and C are within range of one another, nodes A and C are out with range of one another and are therefore unaware of each others presence and as such cannot sense each others signal. Collisions could occur of both node A and C attempted to transmit with node B as neither would be aware of the others communication are they are not within range. The RTS (request to send) and CTS (clear to send) signals are used to provide a mechanism to overcome this problem.

As node A wishes to transmit to node B, node A sends an RTS signal which is received by node B. Node C does not hear this signal as it is out with the range of node A. Node B replies to node A with a CTS signal on receipt of the RTS signal. Node C is within range of node B and hears the CTS signal therefore the CTS packet send by node B is received by nodes C and A.

Node C is therefore aware that a transmission is taking place even although it is not in range of Node A which is the node initiating the transmission. On hearing the CTS signal node C will defer from transmitting. This means that node C cannot transmit to other nodes that could be within transmission range of node C but are out with transmission range of nodes A and B, even although in this case the transmission from node C is viable as it does not interfere with the transmission of node A and B. Node C is the hidden node in that node C although aware that node B is transmitting cannot transmit to other nodes out with the range of nodes A and B which would not affect their transmission. (Bharghavan et al. 1994)

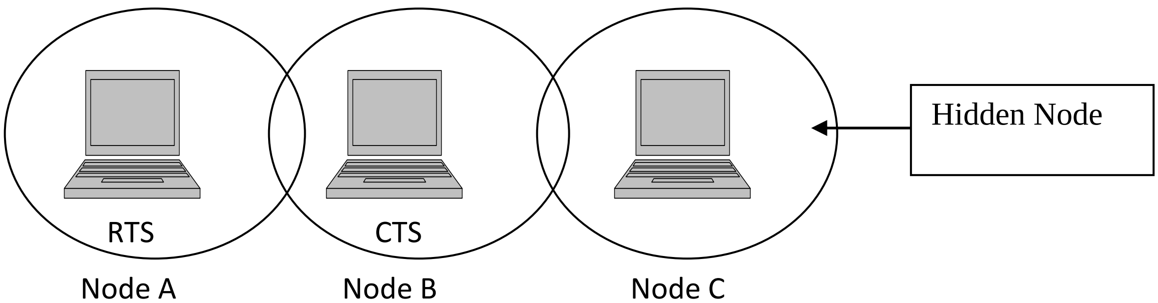


Diagram 4: Hidden Node Scenario

Diagram 5 shows an exposed node scenario and shows nodes A and B are within range of each other, nodes B and C are within range of each other and nodes C and D are within range of each other. Node D is out with the range of nodes A and B and node C is out with the range of node A. In this case node B wishes to transmit to node A and sends an RTS signal to which node A replies with a CTS signal. Node C which is in range of node B hears the RTS signal but is however out with transmission range of node A and does not hear the CTS signal meaning node C could transmit causing a collision with node B. Node C is therefore the exposed node in this scenario in that it cannot hear the transmission of node A and is unaware that node A and B are communicating as such if node A transmits to node B a collision will occur. Nodes become either hidden or exposed nodes depending on the location of the node with the other nodes on the network and depending on communication pattern experienced by the network. (Bharghavan et al. 1994)

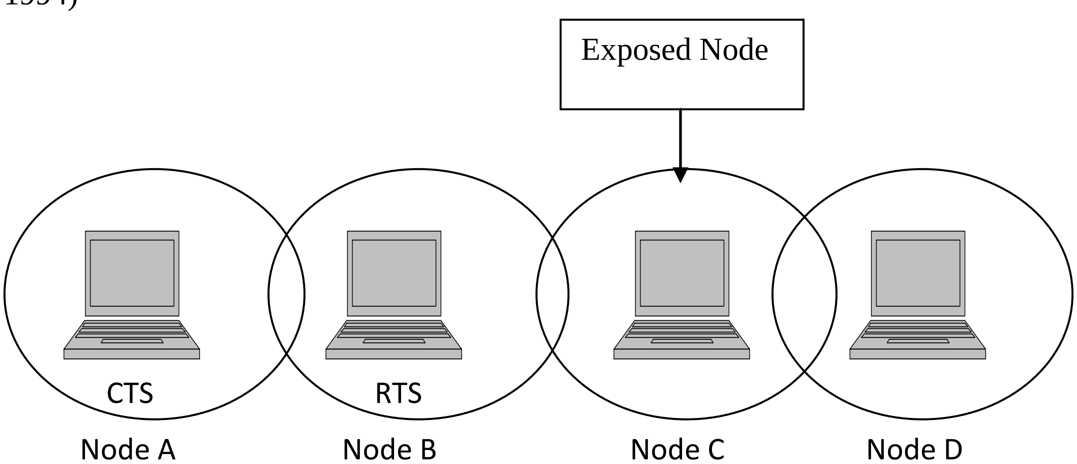


Diagram 5: Exposed Node Scenario

2.3.5 Uses

MANET technology provides flexibility as no fixed infrastructure is required to enable deployment. Due to this factor various uses for application of MANETs have been identified including commercial, academic, rescue and military applications. Commercial and academic applications could include deployment in building areas where it is too costly or not possible to install fixed infrastructure or for one off events such as conferences. Military and rescue operations require a robust network and cannot rely on a central point that could represent a single point of failure (Giuseppe Anastasi, Marco Conti,Enrico Gregori, 2004).

RFC 2501 advises with the increased and technological advancements of wireless mobile computing that there are present applications that could make use of this technology as well as future requirements. RFC 2501 identifies various commercial and industrial applications for MANET technology including that of the military and rescue operations as well as future technologies such as "wearable" computing equipment. (Corson, Macker 1999)

2.3.6 Advantages

With technological advancements in mobile and nomadic computing the use of mobile ad hoc networks provides an array of advantages. MANETs allow communication to be possible and networks setup in areas that previously would provide obstacles and where installation of communication networks might not be possible. This is primarily due to MANETs providing the platform for wireless communication via mobile devices. The use of wireless communication allows for deployment of a network where there is no fixed infrastructure, this may be due to cost or geographical location or in scenarios such as disaster areas where the existing infrastructure has been damaged.

There are many applications for this type of technology and emerging technologies such as vehicle to vehicle to communications show there are a number of applications and advantages to mobile ad hoc communications.

2.3.7 Disadvantages

MANETs operate on a decentralised architecture depending on the nodes themselves to route data, the operating environment is dynamic and topological change can be rapid. This poses a problem for routing protocols as traditional solutions that exist and are implemented for infrastructure based networks, which are typically static, cannot be used for mobile ad hoc networks which are envisioned to be dynamic.

These aforementioned issues previously highlighted in this paper mean that in order for a mobile ad hoc network to work new routing protocols that address the unique issues relating to the MANET environment must be engineered.

Routing protocols for a MANET environment will also have to take into consideration issues pertaining to available bandwidth and power supply. Wireless mobile devices generally operate on battery power; the routing protocol must be able to work efficiently while producing the least overhead possible and without excessive use of CPU and memory. Communicating over bandwidth-constrained links mean that the cost of finding and maintaining routes must be kept minimum with the routing protocol being able to adapt to rapid and dynamic changes. If routing overhead was high this data would swamp the communication channels and hinder effective communication.

Mobile hosts communicate with a subset of nodes compared to an infrastructure network where hosts communicate with separate routers, therefore the cost of finding and maintaining routes to all destinations as is the case with traditional routing protocols, would be inefficient and too high a cost for MANETs.

The problem of stale routes occurs when there are topological changes and the network has not been able to re-converge to route data to the destination via a correct path. This in turn leads to packets being dropped. The topology of a MANET could experience rapid changes due to node mobility; periodic updates sent from traditional routing protocols would not give a valid picture of the network as it would take time for the network to re-converge.

Finding solutions to these problems have attracted great interest and research works into various protocols that can respond to the dynamic nature of MANETs have produced a variety of different protocols. The protocols proposed are based on link state and distance vector algorithms and fall into a number of categories depending on how they source and maintain routes.

(Boukerche 2004b, Narayan, Syrotiuk 2003)(Layuan, Chunlin & Peiyan 2007)

2.3.8 MANET Challenges

Royer et al (Royer, Chai-Keong Toh 1999) advise of a number of challenges facing ad hoc networks which include:

1. Multicast

2. Qos Support

3. Power Aware Routing

4. Location Aware Routing

1. Multicast – Mobile ad hoc routing is dynamic therefore a multicast protocol must be able to route data efficiently in a mobile environment and deal with leave/join requests. Multicast protocols typically work over infrastructure networks where a distribution tree can be created from the source to the user and the data is streamed to the user for as long as the user wants it.

Join requests join a user to a group and leave requests take the user off the receiving list. Mobility would prove an issue for functionality especially with streaming media.

2. Qos (quality of service) – The mobile dynamic nature of ad hoc networks will have an impact on Qos, the more the dynamics of the network change the more the affect this will have on Qos. Wireless technologies pose various factors that affect Qos such as signal interference, hidden and exposed node problems and channel fading. These inherent factors together with the dynamics of a mobile ad hoc network mean that Qos is an issue.

3. Power Aware Routing - Nodes within a MANET will generally run on battery power thus any way this can be conserved will be of benefit to the network. Routing protocols which can conserve energy and make routing decisions based on power metrics will help towards increasing the lifetime of nodes and paths.

4. Location Aided Routing – Routing based on global positioning system (GPS) information is useful as it saves on periodic beaconing and hello messages in order to find out locations of neighbours. Routing protocols based on positioning information currently exist and research into location aided protocols continues to study and improve on this type of routing.

Other challenges facing MANETs as identified in (Penttinen) include:

1.) Security

The decentralised operation of ad hoc networks pose security issues as there is no central point of administration or certification authority. Wireless networks are more vulnerable to attack as the communication channel is over the airwaves and is not limited inside a building thus it is easier for an attacker to eavesdrop and initiate an attack. Military and emergency service networks are better secured than civilian networks in that the devices connected belong to the same organisation where as civilian networks have the downside which comes from the very nature of wireless networks in that any device can join or leave the network at any time thus users of the network could be anyone and the network must determine if the node is trusted or not. This is usually done by encryption of data and the use of keys which are used for secure data forwarding. Ad hoc networks however provide further security issues in that if a node was compromised it could transmit false routing information resulting in the breakdown of the network. Solutions using keys are being researched to overcome issues pertaining to ad hoc networks.

2.) Scalability

Applications that are being envisaged to make use of ad hoc networks such as the idea of ubiquitous computing would see a network of thousands of nodes. It is unclear how far ad hoc networks could scale. As with any network, ad hoc networks suffer from scaling issues such as efficiently finding routes and maintaining routing information along with dealing with the mass amount of requests that would be placed on the network. These issues generally result in latency, packets being dropped, system hangs and a huge amount of pressure on memory and CPU resources as well as network bandwidth. Ad hoc networks suffer with capacity as the network grows throughput decreases.

Physical layer and protocol enhancements which would make use of smart antennas and could reduce protocol overhead are the areas being researched to overcome some of these issues.

Resources on an ad hoc network are valuable and if wasted by profuse control traffic from protocol overhead as the network grows the network would be inoperable. Scalability issues are a main concern not just for ad hoc networks but for networking in general.

2.3.9 Future Directions of MANETs

Study into the future implementation of ad hoc networks and pervasive ubiquitous computing has shown that these technologies and applications will require increased bandwidth and capacity requiring the use of higher frequencies resulting from improved re-use of the spatial spectrum. The use of a mesh architecture has proven successful for deployment of ad hoc networks. Due to these findings and the requirement to conserve energy future ad hoc technologies are shifting away from using a single long form of wireless signal to using short signals in a mesh architecture. Research is being conducted into the use of mesh multi-hop based networks as a solution to allow for future implementation of ad hoc networks, this is a shift from using 3G architectures.

As technology evolves the devices will be capable of smarter functions whilst reducing in size and cost allowing for new applications for ad hoc networks such as connecting smart appliances to the Internet. Ad hoc networks are beneficial for deployment in military scenarios and as such future research is also being conducted on large scale dense deployments that also make use of multi-media applications and ultimately will give rise to higher capacity multi-media networked systems. Last mile solutions that are based on ad hoc mesh based networks is also another area being looked at for ad hoc deployment. Ad hoc networks will prove to be the next step in wireless networking allowing for anytime, anywhere access this kind of ubiquitous computing could see ad hoc mobile routing nodes being used to send data from space, provide traffic updates by monitoring traffic and communicating via vehicles and sending video footage to airborne routing nodes of events. (Ramanathan, Redi 2002)

Due to the number of challenges with ad hoc networks for which solutions much be found before large scale deployment could be envisioned it is more likely that use for this technology will initially be as an extension to LAN technologies. With progression of ad hoc networks the use of this technology for 4G technology deployment would allow the anytime, anywhere communications that the future is demanding. The idea that routing and communication is all handled by the device itself could create an era of a shift away from ISPs to local based routing handled by the devices and device manufacturers and end users. The applications and deployment scenarios for ad hoc networks have captured many researchers' imaginations and are the basis for research projects that will find solutions to future wireless networking and with this a new era of networking and the application deployment will be created. (Penttinen)

2.4 MANET Routing Protocol Categories

The routing protocols used within this study fall into two categories either being proactive or reactive routing protocols. As the protocols used are based on these two categories the study below focuses on reactive and proactive definitions.

2.4.1 Proactive Routing Protocols

Proactive routing protocols can be classified as either link state or distance vector. Each type has a different method for maintaining routing tables. Link state protocols periodically flood the network in order to build a picture of the network. Distance vector protocols periodically broadcast updates out to all neighbours and base routing decisions on the distance to a destination node.(Pan-long Yang, Chang Tian & Yong Yu 2005)

Proactive routing protocols also referred to as table driven protocols maintain routes to all nodes in the network and store the data within various tables. This is different than on demand protocols where a route to a specific destination is stored; table driven protocols thus store a route entry in the routing table for each host residing on the network. Proactive protocols require to periodically determine the state of the network in order to keep a valid view of the network topology. If a broken link or new node is detected the changes are broadcast throughout the network until each node has the same view of the topology, when this state is reached the network is said to have converged. Proactive protocols face problems when network mobility is high mainly due to stale routes within the routing tables leading to packets being dropped. Stale routes occur when a route status has changed to down but the node has not yet received an update advising of the change and still considers the route valid. The node will therefore attempt to route data to the destination via an invalid route. Proactive protocols work well in networks where mobility is low as the route to all destinations is known which reduces the delay for sending packets. (Boukerche 2004a)

Proactive routing protocols do not scale well due to the large amount of overhead produced for the updating of routing tables as this uses a lot of bandwidth and in MANETs links are bandwidth constrained. OLSR has been designed to scale further by reducing the number of nodes that can rebroadcast information in order to keep some control over the degree of network overhead. Other proactive protocols such as Distance Routing Effect Algorithm for Mobility (DREAM) use geographical positioning (GPS) location information which reduces the amount of overhead and may enable this protocol to scale better. Some examples of the various proactive protocols available include; DSDV which was amongst the initial protocols developed (Khan et al. 2008). Destination Sequence Distance Vector (DSDV) is an example of a proactive routing distance vector based protocol.

Examples of proactive routing protocols based on the link state algorithm are Global State Routing (GSR), Source-Tree Adaptive Routing (STAR), Hierarchical State Routing (HSR), Optimised Link State Routing (OLSR and Topology Broadcast Reverse Path Forwarding Routing (TBRPF). (Abolhasan, Wysocki & Dutkiewicz 2004)

As mentioned previously OLSRv2 (Optical Link State Routing Version 2) protocol is the current proactive routing protocol being pursued by the IETF MANET working group, based on the traditional link state algorithm (Clausen, Dearlove & Jacquet 2008).

2.4.2 Reactive Routing Protocols

Reactive or on demand based protocols source a route to a destination only when it is required unlike proactive routing protocols that aim to source routes to all destinations in the network. The method of sourcing a route when it is needed cuts down on the overhead that proactive protocols experience enabling reactive protocols to scale better (Abolhasan, Wysocki & Dutkiewicz 2004). In situations where a route is temporary reactive protocols prevent the situation of storing a number of stale routes (Boukerche 2004a).

Reactive protocols use a route discovery process where route request (RREQ) packets are broadcast on the network when a node wishes to find the route to a destination node. The route to a destination node is sent back to the source node via link reversal or by flooding in a route reply (RREP) message. Depending on how the protocol routes data, it will either be classed as a source routing protocol or a hop-by-hop routing protocol. Source routing protocols store the full address information for the route from the source to a destination. Intermediate nodes can therefore forward packets to a destination without the need to source routes or hold up to date routing information as the information of the entire source to destination path is contained within the packet. Source routing protocols such as the Dynamic Source Routing (DSR) protocol don’t send periodic beaconing messages as by using the compete path within the message nodes do not need to maintain connectivity with their neighbours. Source routing protocols do not scale well due to the overhead required to keep track of a large number of nodes between a source and destination, the more nodes and the higher the mobility the higher the possibility is of broken links. Hop-by-hop routing protocols perform better in a dynamic environment as each node performs routing. The packet transmitted contains the destination address and the address of the next hop. When traversing intermediate nodes, the nodes check their routing tables for an entry towards the destination and forward packets based on the routing decisions they make.

Packet overhead is kept down and nodes can respond to network changes to enable the packet to be forwarded to the destination resulting in fewer route recalculations. In order for routing to be successful nodes must maintain active routes this is usually achieved by periodic beaconing messages sent to neighbouring nodes. Both categories of routing protocols will perform similar when faced with a worse case scenario as both category type source routes on demand. Ad Hoc On-Demand Distance Vector (AODV) routing protocol is an example of a hop-by-hop reactive routing protocol and Dynamic Source Routing (DSR) protocol is an example of a source routing reactive protocol. Other examples of reactive protocols include Routing On-Demand Acyclic Multi-Path (ROAM), Temporally Ordered Routing Algorithm (TORA), Light-Weight Mobile Routing (LMR), Location-Aided Routing (LAR) and Ant-Colony-Based Routing (ARA). (Abolhasan, Wysocki & Dutkiewicz 2004)

As previously mentioned the IETF is pursuing DYMO as a MANET solution. (Chakeres, Perkins 2008)

2.5 Characteristics of AODV, DSR and DSDV Routing Protocols

This study focuses on the three MANET routing protocols AODV, DSDV and DSR. Each of these protocols is described in further detail within this section.

2.5.1 Ad hoc On-Demand Distance Vector (AODV) Routing

AODV is a reactive routing protocol based on distance vector routing. It uses destination sequence numbers to ensure loop free paths for every route entry which avoids the “counting to infinity” problem associated with traditional distance vector routing protocols based on the Bellman- Ford algorithm. Nodes use the sequence number of packets to determine how fresh the information contained with the message is from the source node. AODV message formats are sent via the user datagram protocol (UDP) and consist of route requests (RREQs), route replies (RREPs) and route errors (RERRs). Route requests (RREQs) are initiated when a node requires a route to a new destination. RREQs are broadcast by the node requiring the destination route information. Once a RREQ reaches the destination node or an intermediate node that has knowledge of the route to the destination, a route reply (RREP) can be sent back to the source node that generated the RREQ, containing the routing information. Route replies (RREPs) are sent in the form of unicast transmission back to the source node. The destination sequence number is used by an intermediate node to determine the appropriate routing information of a valid fresh route to the destination node. RREP data must travel along a path in order to be received by the originating source node of the RREQ.

Each node that receives the RREQ caches a route back to the source node thus creating a path back to the source node that initiated the RREQ. AODV stores and maintains routes in a routing table including temporary reverse path routes created when nodes receive RREQs. Route error (RERR) messages are sent when a node detects a change in the link state of active routes. The node detecting the broken link sends a RERR message to neighbouring nodes included in a “precursor list” which may use the node with the broken link as a next hop. A precursor list is created during the process of generating a RREP message. (Perkins, Belding-Royer & Das 2003)

A RREQ is sent by way of a new route discovery process when a node receives a RERR. (Naski 2004)

AODV shares similarities with DSR and DSDV. DSR’s route discovery process broadcasts RREQ messages as is the procedure for AODV, the difference being DSR’s RREQ records the node addresses it transverses where as AODV records the sequence number. Both DSR and AODV source routes on demand. Route maintenance is similar in the both protocols as when an upstream node of a host detects a link breakage a RERR message is sent by the node detecting the change to all active neighbours. (Boukerche 2004a)

AODV and DSDV both make use of periodic beaconing as in the transmission of hello messages as well as the use of sequence numbers in order to base routing decisions on (Abolhasan, Wysocki & Dutkiewicz 2004). AODV uses hop-by-hop routing as does DSDV. (Naski 2004)

2.5.2 Dynamic Source Routing (DSR) Protocol

DSR is a reactive protocol and sources routes in an on demand basis. DSR uses source routing which means source nodes incorporate the full route from source to destination within a packet (Aissani et al. 2007). Intermediate nodes do not carry out routing decisions, they forward packets based on the routing information provided in a packet called a "source route" (Boukerche 2004a). As the full address of each hop in a route from source to destination is included within all packets the protocol will not be sufficient for large networks due to the overhead that would be produced. (Abolhasan, Wysocki & Dutkiewicz 2004)

DSR can store multiple routes to a destination and route selection and control can be managed by the sender allowing for load balancing to increase network performance. No periodic updates are required by the protocol keeping overhead to a minimum.

DSR guarantees loop freedom and recovers rapidly when there is a change in the network due to multiple route support. Due to low overhead and rapid recovery the protocol can perform well with high mobility rates. The protocol has been designed to support a mobile ad hoc network of up to 200 nodes. DSR comprises of two main mechanisms which enable route discovery and maintenance. The two mechanisms are "Route Discovery" and "Route Maintenance". Route discovery is the process initiated when a source node requires a route to a destination address. Route discovery is used when a source node does not know the route to a destination. In DSR nodes use a "route cache" to store routing data, a node will first look in the cache for a route to a destination if no route is found then the route discovery process must be used. A node initiates a route discovery by broadcasting a route request (RREQ) to all nodes within transmission range. RREQs contain information on the source "initiator", destination "target" and a unique request identification. A listing of all intermediate node addresses which the RREQ transverses are also contained within the RREQ packet. The destination target node returns a route reply (RREP) to the source node that initiated the RREQ, on receipt of the RREP the source node caches the routing information. The target node sending the RREP first checks its route cache for a route to the source that initiated the RREQ. If no route is found in the cache the target destination node must initiate a route discovery process to find a route back to the source node. In order to stop the number of route discoveries from escalating the RREP, sent by the target node, is piggybacked onto the RREQ sent to the source node. The source node initiating a route discovery stores a copy of the original unsent packet in a "Send Buffer". Packets are organized by the time they entered the send buffer and are discarded after the "SendBufferTimeout" expires or in a first in first out (FIFO) basis. If the RREQ is received by an intermediate node, the node appends its address information to the RREQ packet and re-broadcasts the RREQ. RREQs are dropped by nodes if it sees its own address listed in the route record or if the node has recently received a RREQ with the same request ID and target destination address.

Nodes hold a "Route Request Table" which contains information on RREQs allowing a node to decide to drop or process the RREQ packet. Route maintenance is the procedure where a source node detects a link break between the source and destination nodes for the route information held for a destination.

As DSR makes use of multiple route entries to destinations the protocol can select another route to the destination from the routing table. If no other route to the destination exists the source node will invoke the route discovery procedure. Nodes using source route information to send or forward packets must ensure the link to the next hop is active. Active links can be identified by acknowledgement packets which can be sent independently or piggybacked onto another packet. Links that do not return an acknowledgment packet are considered to be “broken”, the node that requested the acknowledgment packet sends out a route error (RERR) message and removes the address of the node from the route cache.

The RERR message is sent back to the source node (Aissani et al. 2007). The source node then checks the route cache for alternate routes that it may have learned and retransmits the data via the new route if one is found. If no new route is found the route discovery process is initiated. (Johnson, Hu & Maltz 2007)

In small to medium sized networks DSR may outperform AODV and DSDV due to the ability of the protocol to store multiple routes in a route cache which is checked before data transmission for active routes. As DSDV and AODV both send periodic beaconing messages and DSR does not, DSR has the advantage of producing less overhead, conserving both bandwidth and battery power. (Abolhasan, Wysocki & Dutkiewicz 2004)

2.5.3 Destination Sequence Distance Vector (DSDV) Routing Protocol

DSDV is based on an enhanced version of the distance vector Bellman-Ford algorithm (Khan et al. 2008) and uses a hop-by-hop routing strategy as well as a periodic beaconing method for updating routing information (Garousi 2005a).

Routes are stored to every destination in the network with updates of the routing table sent incrementally or by way of a full dump of the entire routing table. Incremental updates are sent when the node perceives change within the network to be minimal. In order to prevent routing loops updates are transmitted with an increment to the sequence number tag, this also addresses the counting to infinity problem (Khan et al. 2008). The sequence number of the source node is compared and the most recent data is added to the routing table, if sequence numbers are identical the route with the best path based on other metrics such as cost is chosen. (Lejun Chi et al. 2006), (Garousi 2005b)

Mobile hosts store information regarding a nodes age or sequence number, set of current neighbours and routing table entries for every other host on the network. Sequence numbers are used to prevent routing loops and to indicate how recent the route entry is. (Geetha, Aithal & ChandraSekaran 2006), (Boukerche 2004a)

If a node detects a broken link it advertises the route to the destination of the broken link with an infinite metric and increases the sequence number to a greater value than that previously held for the destination.

Nodes receiving the update with the infinite metric send the update to all neighbouring nodes and so forth until the change reaches all nodes throughout the network. (Khan et al. 2008), (Garousi 2005b)

The sequence number must be incremented in order for an update to be considered valid and is set to an odd number for updates signifying a broken link, even numbers represent valid routes. (Naski 2004)

Due to the overhead produced by storing and maintaining information regarding routes to all nodes throughout the network DSDV will not scale well. In high mobility situations stale routes within the routing tables will hinder performance and lead to dropped packets and slow convergence. (Khan et al. 2008)

2.6 Conclusion

The literature review identified the unique aspects of a MANET environment through research of various journal, web and book articles as per the objectives set out in section1.2.6. These unique aspects present in a MANET environment are due to the dynamic nature of the topology. As the medium is wireless, bandwidth is constrained and for the purpose of a MANET all nodes must act as both a router and host. (Corson, Macker 1999)

Section 2.1 identified the popularity of wireless communications and thus as this industry grows and develops it can be derived that future networks will rely heavily on wireless solutions to meet the needs for this technology. Future uses for this technology as explored in section 2.3.9 such as vehicle to vehicle and sensor networks as well as military applications and the move towards a ubiquitous networked environment illustrate that there will be a heavy presence of wireless networking in the future. Due to this reason research into aspects of wireless networking is vital in order for the technology to progress and for improvements to be made. (Ramanathan, Redi 2002)

In order for ubiquitous networking to become a reality wireless networks must become smarter and the routing protocols must be able to cope with the dynamic environment that will be a natural aspect of MANETs. Changes such as dealing with varied node numbers and aspects of mobility would be prominent factors and this report aims to identify the performance characteristics of MANET routing protocols AODV, DSDV and DSR in relation to these factors.

The wireless media used by MANETs is clearly identified to have different characteristics compared with traditional wired networks as explained in section 2.2. Wireless networks make use of the RF spectrum in order to communicate and require different methods to sense the carrier and detect errors.

Due to this the ways in which the network and the routing protocols function is different and face different problems such as the hidden and exposed node phenomena and path maintenance as explained is section 2.3 (Bharghavan et al. 1994).

MANETs face problems with having to find and locate paths to destination nodes as the network topology changes. Other constraints such as the available bandwidth will also affect mobile node communication. Section 2.3 illustrates the need for mobile nodes to perform the functions of a router and a host. As there is no central point to control communication each node must take the responsibility of routing the data and acting on topology change (Corson, Macker 1999). Each routing protocol studied in this project report has a different means of performing these routing tasks, thus by simulating each in a MANET environment the performance can be compared and judged in relation to the method used by every one of the routing protocols.

Section 2.4 provides an overview of the categories MANET routing protocols fall under based on how they route data such as reactive or proactive. Different methods exist, but for this project reactive and proactive protocols AODV, DSDV and DSR were chosen based on interest within the research community. Each method comprises of a different procedure used to route data and as this project entails both proactive and reactive protocols a comparison can be made as to the effectiveness of each based on different network scenarios.

The more detailed overview of each routing protocol used in this study given for AODV, DSDVand DSR in section 2.5 shows the different unique mechanisms used by each protocol to provide routing in a MANET environment. Although each protocol uses different methods similarity can be made between them such as the use of routing tables by DSR and DSDV and the sequence numbers and periodic hello messages used by DSDV and AODV. The routing methods used by each of the protocols can be tested by the different MANET scenario conditions set out within this project in order to test efficiency under dense and sparse networks and also how the protocol reacts to varied mobility parameters. By simulating these protocols under varied network conditions it can be identified which method works best for certain scenarios. Changes in the number of nodes and mobility of nodes will be a constant factor in MANET environments where the mobile node could be on a vehicle, plane, part of wearable computing attire or a mix of all of these as in a military or disaster environment. Research into the performance of MANET routing protocols provides key facts that can be used for network deployment and development. Knowing this information is helpful to network administrators when choosing a routing protocol to meet the needs of their MANET environment. Further developments can also be made to routing protocols based on the output of simulation results in order to improve performance.

As outlined in section 1.1.9 and in (Royer, Perkins 2000) simulation is the primary method of analysing MANET routing protocols due to constraints in employing real life test beds such as cost and availability.

Although real life test beds are used for evaluating MANET routing protocols the drawback is repeatability of tests. In a simulation environment cost and resources required are minimum and repeatability of test scenarios is straight forward.

This project is experimental research which focuses on determining the performance of routing protocols AODV, DSDV and DSR through use of simulation software encompassing varied network parameters which would be present in a MANET environment. Thus comparison can be made between the routing protocols and the behavioural characteristics can be determined through the results of the simulations undertaken. Further understanding can be gained from these results which prove beneficial in finding out which routing mechanism works best depending on the network parameters. The simulation software environment chosen is NS2 as per Appendix 7.1 as this is the most popular simulation software for MANET studies.

3.0 Methods

3.1 Primary Research Methods

The methods section outlines the simulation environment and the metrics used to undertake the experiment.

3.1.1 Simulation Software Environment

An array of simulation software packages are available for testing the performance of protocols over network scenarios, the software package this project will utilize is NS2.

The reason for this choice is that NS2 is the most popular used software simulation package for analyzing protocol performance. Surveys undertaken on papers published by the IEEE and ACM give figures to show the popularity of NS2. Kurkowski et al surveyed ACM MobiHoc papers from the period of 2000 until 2005, these findings conclude that NS2 was used 43.8% of the time a percentage figure showing higher usage than any of the other simulation software packages considered in the survey results. The survey of MobiHoc papers also showed that 75.5% of papers used simulation in order to test and derive results for research (Kurkowski, Camp & Colagrosso 2005). Analysis from (Dow et al. 2005)show Ns2 being the most popular used simulation tool equating to 39% (see Appendix 7.1) use compared to other simulation protocols, taken from an analysis of IEEE reports from the period 1998 until 2003.

NS2 is a discrete event simulator which supports simulation of mobile ad hoc networks and protocols. AODV, DSDV and DSR are mobile ad hoc protocols supported under the NS2 environment (Fall, Varadhan 2008b).Due to the above reasons NS2 is foreseen as the correct choice of simulation software to undertake the project experiments. NS2 runs on the Linux OS (operating System) environment, Fedora which is a version of a Linux OS will be used on the PC in order to run NS2. The versions of the software used are NS2 Version 2.34 and Fedora version 8.0.

The Monarch research group at Carnegie Mellon University (CMU) developed the mobility extension for NS2 in order to support multi-hop wireless networks. The mobility extension includes models to simulate the physical, data link and medium access control (MAC) layers. The MAC layer protocol used is the distributed coordination function (DCF) of IEEE 802.11 for wireless LANs. DCF creates virtual carrier sensing and channel reservation by using request to send (RTS) and clear to send (CTS) packets along with acknowledgment ACK packets to signal when a transmission has been received. Packets are sent on the network using physical carrier sensing, an unslotted CSMA/CA (carrier sense multiple access/collision avoidance) technique is used in order to sense when the network is free to transmit data. The radio model used is similar to the Lucent Wave LAN direct sequence spread spectrum commercial shared media radio interface. The radio model has a nominal bit rate of 2Mb/sec together with a nominal radio range of 250 meters. (Saurabh Rastogi 2006, Boukerche 2004a).

The radio model uses Friis Space Attenuation at near distances where line of site is present between the transmitter and receiver and Two Ray Ground reflection model for far distance which uses line of site and ground reflection. (Fall, Varadhan 2008b) The antenna used is omni-directional (Fall, Varadhan 2008b) meaning that transmission is radiated equally in a pattern of 360 degrees. (Cisco Networking Academy Program Fundamentals of Wireless LANs Companion Guide 2004)

NS2 requires a number of parameters to be entered in order to generate the topology of the network to simulate. The parameters required include number of nodes, pause time, speed, simulation time, area x and y coordinates, type of traffic and amount of traffic. The input parameters can be varied in order to test various aspects of a routing protocol. Mobility of the nodes is initiated randomly based on the parameters and mobility model used. (Lakshmi, Sankaranarayanan 2006)

The simulation process as described in (Lakshmi, Sankaranarayanan 2006) advises that the scenario file which contains the node mobility pattern and the communication file which conveys the network traffic are both use in order to generate a simulation. The output from the simulation results in a trace file being generated. The trace file contains information from the simulation based on the parameters previously configured. The parameters contained within the trace file are analysed to provide data based on metrics. (Lakshmi, Sankaranarayanan 2006)

3.1.2 Traffic Model

Each group will use a CBR (constant bit rate) traffic source and a fixed packet size of 512 bytes sending at a rate of 5 packet initiations per second (5in/s). Use of CBR traffic for simulation purposes is used throughout many simulation studies such as in (Das, Perkins & Royer 2000) and (Garousi 2005a) as such CBR traffic will be used for this study. C. Mbarushimana et al explain CBR connections are useful in simulating applications such as voice and video whereby a continuous transfer of data and bandwidth must be available for the length of the connection time with a predictable response time. As CBR traffic is transmitted at a constant bit rate the performance of the routing protocol can be analysed in routing data.

A constant packet size of 512 bytes was selected as this is also a common choice within the research community as can be seen in various simulation studies for MANET protocols such as (Anastasi et al. 2003), (V, Aithal & ChandraSekaran 2006), (Zakrzewska, Koszalka & Pozniak-Koszalka 2008, Gao Fang et al. 2007), these references also utilise CBR traffic. S-J, Lee et al (Lee et al. 2003) advise that packets with a payload smaller than 512 bytes are not sufficient for testing routing protocols that append source route information to the data packet.

TCP (Transmission Control Protocol) is not used within this study as explained in (Trung, Benjapolakul & Duc 2007a) the use of TCP would contribute additional overhead to the network and would alter transmission times of packets.

3.1.3 Mobility Model

Various mobility models are available in order to base simulation studies on mobility patterns. The most popular mobility model of choice within the research community is the Random Waypoint Mobility Model, this is illustrated in (Stuart Kurkowski, Tracy Camp & William Navidi 2006) where a survey of MANET research papers from 2000 – 2005 showed 64 % of these papers utitlised the Random Waypoint Mobility Model (RWM).

The Random Waypoint Mobility Model creates random realistic mobility patterns based on metrics such as speed which is how fast a node moves towards a destination and pause time that determines how long a node stays stationary between changing directions. Mobile nodes (MNs) move randomly between points within a chosen simulation area. (Tracy Camp, Jeff Boleng,Vanessa Davies, 2002)

The simulations undertaken in this paper will be based on the RWM model; the utility setdest will be used with the NS2 simulator in order to generate the RWM mobility scenarios. The node movement pattern for each mobility file is randomly selected by the software setdest. Each simulation will be run for 3 repetitions using different mobility files in order to provide a more accurate average of output. The reason for repetition of each simulation being necessary is to stop the case of an extreme situation whereby all nodes in the mobility file group to one side of the topology thus providing a false output, for data analysis purposes the average will be taken based on each set of 3 repetitions.

The field size used will be 500m * 500m, this network size is large enough to represent a network with a sufficient number of nodes in order to simulate various network topologies on. The use of this field size can be seen in other simulation studies on routing protocols such as (Gao Fang et al. 2007), (Agrawal, Tiwari & Vyas 2008), (Ku-Lan Kao, Chih-Heng Ke & Ce-Kuen Shieh 2006), (Saurabh Rastogi 2006). The larger the network topology the more processing power is required and time taken to generate simulations is increased thus the larger the topology the more powerful the computer used must be in order to generate the simulations in an adequate amount of time. This factor also contributes to the field size chosen for this study being in the middle range due to time constraints and computing power. Topology sizes vary rapidly throughout simulation studies with the most common larger topologies around 1000m * 1000m as in (Yamamura, Nakashima & Fukushima 2008a), (Klein 2008), (Wei, Zou 2008), (Mbarushimana, Shahrabi 2007) hence the choice for a field size 500m * 500m for the purpose of this study.

The speed of node movement is set to 20m/sec with the exception to group 3, this is a common speed used in similar research although the research referenced may include varied speeds (Saurabh Rastogi 2006), (Chenna Reddy, ChandraSekhar Reddy 2006), (Ren, Yeung & Jin 2006), (Boukhalkhal et al. 2007). Varied speeds are used within (Yamamura, Nakashima & Fukushima 2008b) where the maximum speed is 20m/sec ranging from 5m/sec and the comparison given advises these speeds represent a bicycle up to the speed of a moving car.

The node speed altered for control group 3 will range from (5m/s, 10m/s, 15m/s, 20m/s), control groups 1 and 2 will use the constant speed of 20m/s.

A pause time of 0 will be used as a constant with the exception for control group 2 which means the MNs will not pause for any length of time once they reach a waypoint before changing direction. The pause time variations for group 2 range from (0m/s, 50m/s, 100m/s, 300m/s, 500m/s), control groups 1 and 3 will use the constant pause time of 0.

Simulations will run for a time of 500 seconds as used in (Gao Fang et al. 2007), the study by Fang et al is similar to this project as a field size of 500m * 500m is used and varied node speeds are simulated from 0m/s to 25m/s.

The simulation setup is represented in Table 1 below:

Table 1 – Simulation Setup

Parameter	**Variable**
Number of Nodes (n)	Varied for group 1 = (50, 100, 150, 200) Constant for groups 2 & 3 = 100
Pause Time (pt)	Varied for group 2 = (0m/s, 50m/s, 100m/s, 300m/s, 500m/s) Constant for groups 1 & 3 = 0m/sec
Speed	Varied for group 3 = (5m/s, 10m/s, 15m/s, 20m/s) Constant for groups 1 and 2 = 20m/sec
Area X axis	500
Area Y axis	500
Type of Traffic	CBR
Amount of Traffic	5in/s
RadioTransmitter Range	250 meters
Radio Bit Rate	2Mb/ps
Antenna	Omni-directional antenna
MAC Layer	IEEE 802.11 DCF
Simulation Time	500 seconds
Mobility Model	Random Waypoint

3.1.4 Simulation Variables

The parameters chosen aim to simulate a topology with varying network characteristics in order to test the performance of routing protocols AODV, DSDV & DSR. A number of chosen parameters will be varied in order to test each protocols efficiency under different network conditions.

As identified in section 2.6 of the literature review the dynamic environment of a MANET imposes a number of problems in routing data and by simulating the MANET routing protocols under various conditions that would be present in a MANET the performance of each protocol can be determined and compared. The attributes that will be varied include number of nodes, type of traffic and amount of traffic. These parameters result in the creation of three simulation groups in order to base the simulations on.

Group 1

The number of nodes will be varied for this group with the other variables remaining constant. The number of nodes will vary from 50 – 200 incrementing in steps of 50 (50, 100, 150, 200). This results in four simulations with 3 repetitions for each resulting in 12 simulations per protocol. Each protocol will be simulated in turn for 12 simulations resulting in a total of 36 simulations.

The aim of this group is to simulate a sparse to dense network topology to test the protocols performance to route data under the varied conditions placed on a protocol in sparse or dense topologies. As stated previously in this paper in section 1.2.1, dense topologies represent problems with finding paths due to the large number of nodes, this however also provides many links in order to make a connection. Sparse topologies consist of a few nodes and as such the connection may be intermittent. (Divecha et al. 2007)

The parameters for group 1 are represented in table 2 below:

Table 2 – Group 1 Setup

Parameter	Variable
Number of Nodes (n)	50, 100, 150, 200
Pause Time (pt)	0
Speed	20m/sec
Area X axis	500
Area Y axis	500
Type of Traffic	CBR
Amount of Traffic	5in/s

Group 2

The pause times of the mobile nodes is varied in this group in order to simulate movement from a state of constant movement to a state of no movement. Variation of pause times provides a means of testing a protocols efficiency under different mobility settings and as identified in section 2.6 the aspect of mobility which is a constant characteristic in MANETs is a vital aspect of research for this project.

Due to this other research papers such as (Saurabh Rastogi 2006, V, Aithal & ChandraSekaran 2006) include variation of pause times as a topic within their research. As the simulation time is 500 seconds a pause time of 500ms represents no movement and a pause time of 0 represents continuous movement. Varying the pause times will test the ability of a routing protocol to route data based on varied node movements and stationarity. Pause times will be varied from 0ms to 500ms in the following order (0m/s, 50m/s, 100m/s, 300m/s, 500m/s) resulting in 5 different simulations.

Each simulation will have 3 repetitions with different mobility files and will be run for each of the three protocols AODV, DSDV & DSR resulting in 45 simulations in total.

The number of nodes used is kept at 100 in order to represent an average sized network for the field size used of 500m * 500m as represented in group 1 200 nodes is dense and 50 is sparse for the purpose of this study.

Parameters for group 2 are represented in table 3 below:

Table 3 – Group 2 Setup	
Parameter	**Variable**
Number of Nodes (n)	100
Pause Time (pt)	(0m/s, 50m/s, 100m/s, 300m/s, 500m/s)
Speed	20m/sec
Area X axis	500
Area Y axis	500
Type of Traffic	CBR
Amount of Traffic	5in/s

Group 3

Varying the speed of the nodes tests each protocols efficiency in dealing with different mobility scenarios. Starting with a value of 5m/sec up to a value of 20m/sec incrementing in steps of 5 (5m/s, 10m/s, 15m/s, 20m/s) resulting in four different simulations.

Sections 1.2.2 and 2.6 detail the reason for assessing each protocols ability to route data whilst the network experiences changes in mobility is due to mobility being a primary characteristic of MANETs due to the dynamic nature of the topology. Due to this the speed of mobility is tested in this group.

All other variables remain constant and each simulation will be repeated 3 times with a different mobility file for each protocol as is the procedure for each group. The total simulations run will be 36, 4*3(12) four simulations repeated three times + 12*3(36) overall amount of simulations carried out for each of the three protocols.

Parameters for group 3 are represented in table 4 below:

Table 4 – Group 3 Setup

Parameter	**Variable**
Number of Nodes (n)	100
Pause Time (pt)	0
Speed	5m/s, 10m/s, 15m/s, 20m/s
Area X axis	500
Area Y axis	500
Type of Traffic	CBR
Amount of Traffic	5in/s

3.1.5 Metrics

In order to analyse a protocols performance metrics must be used in order to provide a bench mark in which to measure and compare the protocols performance against.

The set of metrics which this project will use to test the performance of the protocols under a simulation environment are:

1.) Data Packet Delivery Ratio

This metric is calculated based on the number of packets received at the destination compared to the number of packets that were sent by the source. This tests the protocol performance ratio for successful packet delivery. This metric is important in order to analyse the efficiency of a protocol to deliver packets, if a protocol is not able to successfully deliver data packets that are sent communication would not be effective.

2.) Average End-to-End Delay

Measures how long it takes for a packet sent from the source to reach the destination node. This metric tests the performance of a protocol in relation to the time required for detecting paths, this is also useful to know for time sensitive applications that require a low end-to-end delay in order to function efficiently.

3.) Normalised Protocol Overhead

In order to measure a protocols routing overhead the number of routing packets sent are divided by the number of data packets delivered. As each protocol uses different methods in order to route data, variations in the amount of routing overhead sent can be examined by using this metric. In a MANET environment bandwidth is constrained, high routing overhead would mean a greater utilization of bandwidth and as such would render the protocol ineffective.

4.) Throughput

Throughput is measured based on the number of data packets delivered divided by simulation time giving a measurement of how many packets were delivered per second. (Al-Maashri, Ould-Khaoua 2006)A higher throughput is desirable as this reflects the rate of higher packet delivery. If a low throughput was present the data packets are somehow being dropped due to collisions or some other factor. Measuring the throughput of each routing protocol will thus prove vital in comparison of performance in varied network characteristics as imposed during the simulations of this project.

5.) Packets Dropped

As MANET routing protocols work in a dynamic environment they have to be able to route data effectively whilst the network experiences continual change. Measuring the amount of packets dropped gives an indication of the effectiveness for a routing protocol to route data. Problems may arise when the network is dense or has high mobility as studies in this report. A low rate of this metric is desirable, high rates indicate packet loss is a problem meaning data will have to be resent in order to reach its destination.

The above metrics are commonly utilised in analysing protocol performance, examples of use can be seen in the following publications: (Saurabh Rastogi 2006, V, Aithal & ChandraSekaran 2006)(Aschenbruck et al. 2004)(Abolhasan, Wysocki & Lipman 2005), (Al-Maashri, Ould-Khaoua 2006)

Protocol overhead and average end-to-end delay metrics are also used in (Ahmed Al-Maashri, Mohamed Ould-Khaoua 2006) and Dow et al state packet delivery ratio and overhead as commonly used metrics from their survey on IEEE MANET papers from 1998 until 2003 (Dow et al. 2005).

3.1.6 Analysis of Trace File Output

The data generated from each simulation is output to a trace file as identified in section 3.1.1, in order to process this trace output an AWK file is used. AWK is a programming language which is used to process data from lines of text. The initials AWK are based on the name of the authors, Alfred V. Aho, Brian Kernighan and Peter Weinberger. AWK was based on the original GREP language and processes raw text by treating every line of code as an individual record where each word or character that makes up an individual word is treated as separate fields. The AWK program is written to identify patterns within the text and on finding a match of the pattern AWK outputs a result. The AWK program is stable and widely used for analysing text files. (Hamilton 2008)

For the purpose of this report the AWK scripts generated aim to process the data generated within the trace files and produce output results for the metrics identified in this report being PDR, NRL, End to End Delay, Throughput and No. of Packets dropped.

The AWK script which processes the data for PDR, NRL, End to End Delay and No. of Packets Dropped is saved under the file name parameters.awk. For the throughput metric the AWK script is saved under a file named throughput.awk. The code for these AWK scripts is included for reference in Appendix 7.7, 7.8, 7.9 and 7.10.

An executable file invokes the AWK scripts to run after the simulations are complete, the name of this file used for this project is AODV-PB-studies.sh.

3.1.7 Procedure

In order to run the simulations for each of the scenarios the relevant files must first be generated. The main parameters detailing routing protocol and physical settings are held within a TCL file. The protocols simulated are therefore changed in this file from AODV, DSR and DSDV. The physical layer settings are set to 250 meters range as per Table 1. The communication range is set as per section 18.4 of the NS Manual (Fall, Varadhan 2008a),(Fall, Varadhan 2008b) by giving a value for the Rx Threshold as per the following code extract “Phy/WirelessPhy set RXThresh_ \<value\>”.

The NS Manual (Fall, Varadhan 2008a) states that the Rx threshold is the receiving threshold. The Pt value of the wireless physical (PHY) layer parameters is the transmit power; tx power is the transmit power in watts and rx power is the receive power in watts.

The settings used for the wireless/Phy layer in NS2 are:

```
set val(txPower)        0.66  ; #250 meters
Phy/WirelessPhy set CPThresh_ 10.0
Phy/WirelessPhy set RXThresh_ 3.652e-10 ;#250 meters
Phy/WirelessPhy set Pt_ 0.2818 ;#250 meters tx distance
Phy/WirelessPhy set CSThresh_ 1.559e-11 ;#250 meters
Phy/WirelessPhy set Rb_ 2*1e6
Phy/WirelessPhy set freq_ 914e+6
Phy/WirelessPhy set L_ 1.0
```

The TCL file code used for AODV, DSDV and DSR can be viewed in further detail in Appendix 7.4, 7.5 and 7.6.

Next the relevant scenario and traffic files are created detailing the parameters tested such as number of nodes, pause time and speed as set out in Table 1. The scenario file is used to create scenario files which are reflective of each of the required parameters in Table 1 for each group such as speed, pause time. The script for the scenario file invokes the utility setdest which generates mobility based on the random waypoint model as explained in section 3.1.3. The traffic file sets out the number of nodes required for each simulation within each group, the type of traffic and size of traffic; being CBR traffic of a size of 512 bytes for this project. For group 1 traffic files are required detailing 50, 100, 150 and 200 nodes. For groups 2 and 3 a traffic file detailing 100 nodes is used.

The scenario and traffic files are executable files ending in .sh. These files are run before running the main TCL script as the traffic and scenario files generate the files necessary that include the mobility parameters set out to be researched for this project in Table 1. These files are required to be generated and in place before the simulation can be run. These files hold the necessary mobility parameters required by the protocol being simulated within the TCL script. For each scenario 3 repetitions were created as to give an overall average and to avoid inaccurate data caused by one off events such as all nodes grouping to one side of the simulation as identified in section 3.1.3. The code for the scenario and traffic files can be viewed in appendix 7.11, 714, 7.15 and 7.17.

An executable file was also created which invokes the simulations based on the TCL, scenario and traffic files and runs the simulations for each of the three repetitions. On completion of the simulations this file also runs the AWK files which calculate the necessary data for the metrics identified in this report from the trace file output from the simulations. The code for this studies file named AODV-PB-studies.sh can be viewed in appendix 7.13, 7.16 and 7.18.

3.1.8 Steps in Procedure

1. Install NS2 version 2.34

2. Set the appropriate paths in the Bash file

3. Validate the install

4. Create the script and files necessary for simulation of each scenario (traffic, scenario, TCL and overall executable file to run the simulations)

5. Test the simulation environment is functioning as required and make amendments as necessary.

6. After successful testing proceed with the simulations.

7. Run the traffic and scenario files to create the necessary mobility files (traffic.sh and scen.sh

8. Run the AODV-PB-studies.sh file which runs the simulations and the AWK scripts

9. Analyse the output data and calculate the average of each metric.

3.1.8 Hypothesis Testing

The identified hypothesis in section 1.2.1 will be proven or disproven based on the metric calculations applied in relation to the hypothesis.

Hypothesis number 1 can be tested by examining the packet delivery ratio metric and comparing the results against high and low mobility simulation data for each protocol. By comparing the results from this metric it can be proven or disproven that DSDV will have a lower packet delivery ratio than AODV & DSR.

Hypothesis number 2 will be tested by studying the packet delivery ratio for AODV & DSR then comparing the results against high and low mobility simulation data. This will portray if the assumption is correct that due to the use of a cache by DSR in high mobility scenarios AODV will outperform DSR for packet delivery.

Hypothesis number 3 can be tested by comparing the normalised routing overhead metric data against all three protocols for high and low mobility scenarios.

The data produced from this metric will show if routing overhead increases with mobility and if the proactive protocol DSDV has a higher routing overhead than the reactive protocols AODV and DSR.

3.2 Method Analysis

This section aims to give an analysis of the primary research methods given in this report.

3.2.1 Primary Method

The project aims to evaluate the performance of mobile ad hoc routing protocols AODV, DSDV and DSR by conducting a series of simulations based on the outline given of the primary methods in section 3.1. The project is an experimental project as defined in (Oates 2006) where it is stated experimental studies are characterised by some of the below criteria:

1. Observation and Measurement

By changing the variables used the outcome is affected, by analysing these outcomes observations can be made pertaining to the metrics used to analyse. Section 3.1 describes the variables changed and that will affect the outcome of the simulations.

2. Proving or disproving a relationship between two or more factors.

As outlined in the literature review in section 2.5 each protocol operates in a unique way based on which assumptions can be made about the relationship the protocol will have with the given network scenario.

3. Explanation and Prediction.

A number of factors were set out in the hypothesis in section 1.2.1 and how they will be evaluated is set out in section 3.1.8. The hypothesis will either be proven or disproved depending on the performance of the protocols against the metrics and variable they are tested with.

4. Repetition

As outlined in section 3.1.3, simulations will be repeated 3 times for the purpose of this study. This ensures a certainty for the measurements gathered from the observations of the results.

Simulations will be carried out using the NS2 simulator as set out in section 3.1.1. As mobile ad hoc networks are still not yet commercially implemented due to the various factors that affect MANETs but would provide many benefits in the identified uses they are an active research area. Research into MANET routing protocol performance is important as to understand what protocol and algorithm would best perform given a certain situation. This information would enable network engineers to deploy the routing protocol suited best to the situation.

3.2.2 Structure

The outline of the entire simulation setup is identified in section 3.6. The structure of the simulation study is based on using NS2 to carry out a series of simulations based on a set of metrics. In order to study the affects of mobility and node density three control groups have been introduced. Each control group has a parameter that will be changed in order to test the protocols performance against a variable.

For the purpose of this study the variables include speed, pause time and number of nodes. The justification for this study in section 1.2.2 explains the reasons for the changes to these variables.

A number of factors remain constant throughout the simulations and are outlined in table 1 included in section 3.6. The parameters mentioned above are the only variables that will be changed throughout the simulations in order to identify the performance of the protocols with regards to the project question and to test the project hypothesis on.

3.2.3 Analysis

Data from the simulations is output to a trace file. The trace file contains output based on the parameters set for the simulation. Each simulation contains 3 repetitions as outlined in section 3.1.3 and further justified in section 3.2. Simulations will be analysed on the metrics data packet delivery ratio, end-to-end delay, normalised protocol overhead, throughput and packets dropped as outlined in section 3.1.5. The average measurement will be taken based on the individual measurements of the 3 repetitions. The data presented for conclusions will be based on the average calculations taken for all simulations for each protocol. The hypothesis will be analysed based on the methodology set out in section 3.1.6. Data will be presented in graph form and explanation given of the simulation outcome. Oates, B.J advises, analysis of artificial situations are not comparable with real world simulations, however the research strategy can prove causal relationships. (Oates 2006)

3.2.4 Conclusion

Simulation is the best method identified in this report in order to compare the performance of MANET routing protocols primarily due to the reason that MANETs are not yet commercially deployed as identified in section 1.1.9. Although some test beds have been implemented as identified in (Royer, Perkins 2000) this technology is not yet available on the market and much research is still being done in order to find out how to make this technology work and perform optimally in the real world.

NS2 provides the wireless capabilities through the wireless and MANET extensions in order to simulate MANET routing protocols.

NS2 was also identified in this report as being the most popular choice within the research community for simulating MANET protocols and as such is the simulation software of choice for the purpose of this study. Simulating MANET routing protocols AODV, DSDV and DSR based on the setup explained in the methods chapter and gathering data from the simulations based on the identified metrics from section 3.1 which are Packet Delivery Ratio, Normalised Protocol Overhead, End to End Delay, Throughput and No. of Packets Dropped gives relevant output showing the performance of each protocol. The data can be analysed and the routing protocols compared against one another for each of the scenarios where the network setup is changed. The statistics collected and the results of the performance analysis will show the variance in protocol performance for the different network scenarios, this data can be used to identify the weaknesses and strengths of the protocols depending on the environment.

The results of this research is useful in knowing what protocol gives optimal performance under certain network conditions and therefore depending on the network to be deployed the administrator can select the optimum protocol for deployment to suit their particular network needs.

3.3 Testing the Simulation Environment

This section aims to look at how the simulation environment was tested before the project simulations were run for real.

In order to test the simulation environment two areas require to be looked at; firstly the simulation software itself must be tested for validity; secondly the simulation parameters as outlined in section 3 of this report must be setup and tested to ensure the simulation runs for those parameters and output is received. The testing process is important as any issues can be identified and rectified and further to this by testing the software and parameters it can be ascertained that both are functioning correctly forming a base point where it is known that successful running operation and output occurred. This base point can be used as reference to identify any future issues where the simulation does not function as is expected. The simulation software must be able to pass the testing process in order to be functional to meet the required objectives of this project.

3.3.1 Testing the Simulation Environment

NS2 simulator is an open source download and the version downloaded for this project was 2.34. The all in one package was used which means that the components do not have to be built independently, all the required components are included with the download. To run the software the file must be unzipped using the command line in Linux and installed by running the install executable file. Once the simulator was installed the output message stated the install was successful.

Further to this the steps advised must be followed to ensure that the correct paths are entered into the path environment which tells NS2 where the components are located. Once these steps are complete the installed software must be validated. NS2 provides an executable file which runs a series of test simulations and returns output to advise if the install is functioning or if there are any issues. To run this validation using the command line in Linux, the correct folder where the validate file is located is navigated to, the validate file is then run. The install and validation tests run for this part of the project were both successful and showed that the simulation environment was functioning correctly.

3.3.2 Testing the Simulation Parameters

In order to setup the simulation parameters several files must be created. For the purpose of this experiment a traffic file that sets out the traffic parameters needs to be created; a scenario file which outlines the scenarios needs to be created; a TCL file holding the main simulation parameters such as wireless physical parameters, routing protocol used needs to be created and finally a file which reads the main TCL file script and runs this accordingly with the correct traffic and scenario files is used. This file also runs the AWK script files which analyse the simulation output based on the parameters identified in this report and provide the required data which can then be analysed and turned into a graph form. Two AWK files are used: parameters.awk which gives the output for PDR, NRL, End to End delay and packets dropped; throughput.awk which gives output on the throughput for each scenario.

The parameters identified in section 3 of this report were used to create the relevant files required to run the simulations. These files are executable files and end in .sh. Firstly the traffic.sh file was run giving the required traffic files which sets out the number of nodes to be used for that scenario. Next the scenario file scen.sh is run to create the required scenarios detailing pause time, speed and so forth. The setdest utility is used by this file which uses the random waypoint model to create node movement and pattern. For each scenario 3 repetitions are created as to allow for any inconsistencies and thus an average figure can be taken giving a true value rather than the data being based on a single output. Once the traffic and scenario files are created the executable file is run which studies the main TCL file and runs this along with the relevant traffic and scenario files for each repetition of a scenario. On completion of the simulations this file runs the AWK files which study the simulation output and collect the relevant statistics. These files were run for each of the three routing protocols identified in this report and the findings from these tests are explored in section 3.3.4.

3.3.4 Test Output

The simulations run for each scenario correctly and output data was collected, the metric NRL however returned a value of zero.

Test Problem 1

NRL is required to find out the normalised routing load and therefore is a necessity for this project. The AWK file script was checked and verified to be correct in that the calculations were included in the script for NRL and the command to print the output was correct. On checking the TCL script it was found that the router trace was set to off, this was set to on and the AWK scripts re-run. This rectified the issue and an output for routing packets was present and as such NRL could be calculated.

Test Problem 2

DSDV had a problem where the simulation would hang. Research was undertaken on this and it was found from post an ns-users mailing list post by Sahraei, S. (Sahraei 2006) that DSDV did not like particular wireless physical parameters settings. Failing to find a solution the researcher posted similar questions on various mailing lists an example of which can be seen in Appendix 7.3 along with the post by Sahraei, S. in Appendix 7.2.

The post by Sahraei, S. (Sahraei 2006)identified DSDV to have an issue with the physical layer Rx Threshold setting for 250 meter range (Phy/WirelessPhy set RXThresh_ 3.652e-10), the setting which was identified to work was (Phy/WirelessPhy set RXThresh to 1.47635e-07). This setting was however contributed to high packet loss.

The physical layer parameters that were identified to work with DSDV in (Sahraei 2006) were tried and the simulation did run successfully, however there was significant packet loss thus the settings could not be used to compare the routing protocols against and also the settings did not reflect a wireless scenario of 250 meters. The validation tests were successful that were run on the software to test all aspects of NS2 therefore it was known that this protocol ran as expected for this process. No solutions that worked were found to this problem from Internet posts or by further research and attempts to change settings and re-install NS2. The NRL output would still however show as zero, the AWK scripts and TCL files were all checked to be correct. Different versions of AWK script were used with the problem still persisting. Due to such huge packet loss and negligible data the reason for the AWK script results could have been due to the physical settings used.

Linux was installed on a partition on a Sony Vaio laptop, the files created by NS2 could be significantly large and as such memory could have been a significant factor. NS2 was installed on a 250GB partition on an external hard drive (HDD), after this the validation tests were run and the output advised these were successful. DSDV was re-run on the new install on the external HDD and this time the simulations ran successfully for 250 meters wireless physical settings and the output data collected was as required for each metric. This problem was thus attributed to low memory and was rectified by relocation of NS2 to an external HDD providing the sufficient memory required.

3.3.5 Testing Conclusion

The testing process identified a few issues which had to be rectified for the project to progress as required. Investigation into the issues identified problems which once rectified meant the simulation environment and parameters ran as required. Validating the software meant it could be known that any further issues were not being caused by a software bug present from install and that the components worked as required. Testing the simulation parameters ensured these were working at the appropriate state before the project simulations were run. After the problems identified were fixed, simulations run for each protocol were successful and the output was as required.

3.4 Data Analysis

Section 3.4 provides details of how the data gathered for each metric was analysed.

3.4.1 Methods of Data Analysis

The output retrieved from the trace files by the AWK scripts provided the required statistics for the metrics identified in this report which are PDR, NRL, End to End Delay, Throughput and No. of Packets Dropped.

As outlined previously 3 repetitions were carried out from which an average was taken e.g. PDR + PDR + PDR /3. Therefore for each of the metrics detailed the data was analysed from each of the three repetitions and a single average figure was derived from these results for each of the routing protocols. The raw data can be seen in Appendix 7.19 – 7.36 for groups 1, 2 and 3 for each routing protocols. The data is output as 3 repetitions for each variable being simulated e.g. three outputs for 50 nodes followed by three outputs for 100 nodes and so on.

This average was used for the purpose of the graph data used for this report for each of the metrics. In order to calculate the overall performance graph the data for each metric had to be normalised and averaged, in order for all data to have similar a value.

For the metrics throughput, end to end delay, NRL and no. of packets dropped the maximum of the average values was found and the values for all three routing protocols was divided by this maximum value (v) for each metric e.g. max/v1, v2, v3. The metric PDR is a percentage thus each value was divided by 100 (v1, v2, v3 /100). Positive results are desirable for throughput and PDR. The metrics end to end delay, no. of packets dropped and NRL all favour negative numbers therefore these had to be reversed, this was achieved by dividing the normalised value by 1 e.g. 1/NRL. This ensured the routing protocol with the least data value was now shown to be favourable in the form of the highest figure. The result once again had to be normalised by finding the max value and dividing the outputs by this figure so that no value was greater than 1. Once all the required data was produced by the calculations the overall performance was calculated by adding the result of each metric together and taking the average of this e.g. PDR + NRL + End to End Delay + Throughput + No. of Packets Dropped = / 5

It can be desirable to designate a weighting value for the metrics used for the purpose of networking. This value sets the importance of a value to be more or less in comparison to the other metrics such as a weighting of 80 for PDR would set PDR to have 30% more importance over the metric NRL with a weighting of 50.

In order to achieve this, the percentage of the weighting must be included within the calculations. Liarokapis et al (Liarokapis, Shahrabi & Raeburn 2008) explore the inclusion of such a metric and provide the formula for accomplishing the calculation to include a weighting value for metrics. The formula is defined as Quality where a percentage is given for the combination of composite metrics reachability and speed. The Quality metric is used to compare different metric values for a particular scenario with the weighting of the values A values decided by the researcher. Although no weightings have been applied to the metrics within this project the calculation for this is detailed below as per illustrated by Liarokapis et al (Liarokapis, Shahrabi & Raeburn 2008):

Quality Metric – $Q(\%) = (A_1xM_1+A_2xM_2+ \ldots + A_nxM_n)x100$

The above metric can be further explained as per the below quotation.

"$A_1+A_2 + \ldots + A_n = 1$ and $M_{1,}$ $M_2 + \ldots, M_n$ are normalised values of regular metrics like Reachability, Delay, Speed, Retransmission Attempts e.t.c." (Liarokapis, Shahrabi & Raeburn 2008)

4.0 Results

This section looks at the data produced from the simulations and provides an analysis of these results in relation to the chosen metrics. They hypothesis are also tested and shown to be proven or disproven as per the test strategy set out in section 3.1.8.

4.1 Introdctory Overview

The aim of this project is to investigate the performance of MANET routing protocols AODV, DSDV and DSR with the presence of varied network characteristics as concluded in section 2.6 of the literature review this research is of interest to the development of wireless technologies. For the purpose of this study three control groups were set up which aim to research the performance of each protocol in relation to node density and mobility. Each protocols performance will be analysed in comparison to each other based on the data collected from the 3 control groups detailed in Table 1 of section 3.1.3.

This project is an experimental based project which as identified in section 3.2.1 aims to observe the outcomes based on variability by use of specific metrics. Relationships between two or more factors can be proved or disproved. (Oates 2006)

Simulation was concluded to be the best method for evaluating the performance of MANET routing protocols as concluded in section 2.6 due to the cost of real world implementation and problems with lack of repeatability. The NS2 simulators was identified to be the best choice of simulation software as per section 3.1.1 and as such all simulations were carried out using NS2 version 2.34.

This project therefore aims to evaluate the performance of AODV, DSDV and DSR using the NS2 simulator and by incorporating the varied network characteristics of node density and mobility. The control groups thus vary the number of nodes, pause times and speeds in order to test variations in node density and mobility and compare the performance of AODV, DSDV and DSR. A number of metrics are used in order to base analysis on which are Packet Delivery Ratio, Normalised Routing Load, End to End Delay, Throughput and No. of Packets Dropped.

4.2 Analysis of Results for Group 1, 2 and 3

The statistics for the metrics PDF, NRL, End to End Delay and No. of Packets Dropped are presented in graph form for the three test groups and analysis is given accordingly.

4.2.1 Group 1 Results

This section explains the results obtained for group 1 simulation data where the number of mobile nodes was varied as set out in section 3.1.1.

The variables used for group 1 as identified in section 3.1.1 were 50, 100, 150 and 200 nodes. Testing the routing protocols using varied node numbers aims to find out how each protocol performs in sparse and dense networks. For the purpose of this study 50 nodes is sparse and 200 nodes is dense. The pause time is set to zero meaning there is constant movement and the speed is kept at a constant of 20m/s.

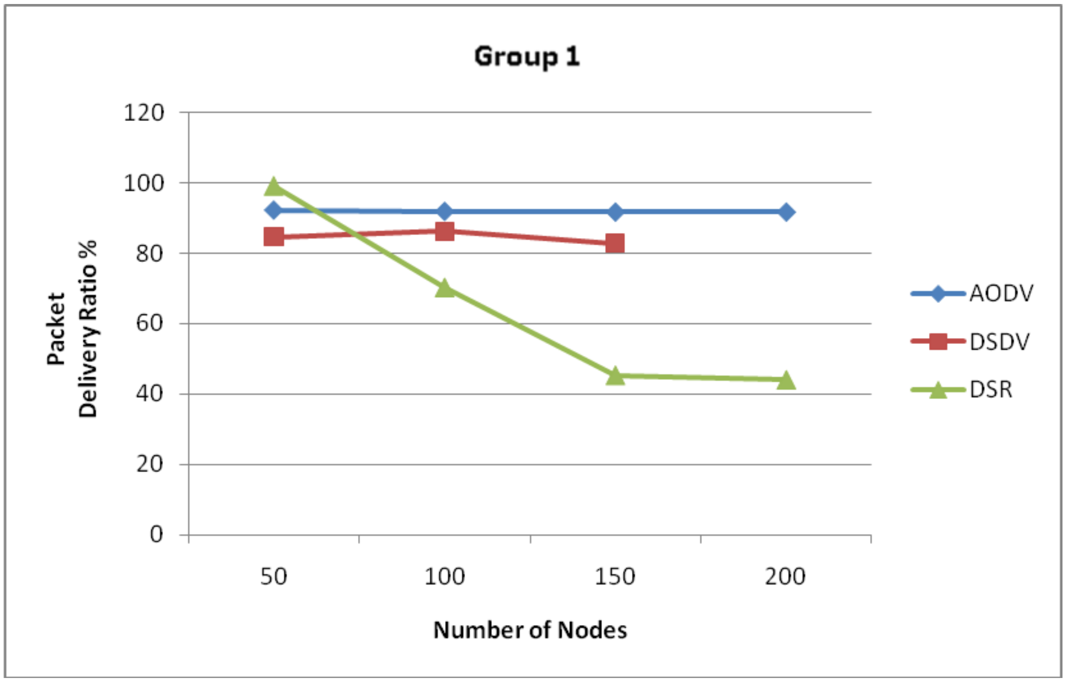
Packet Delivery Ratio

Graph 1 shows that for a sparse network of 50 nodes DSR gives the highest PDR, closely followed by AODV and DSDV. DSR can outperform DSDV and AODV in small to medium sized network, identified in section 2.5.2, as the protocol stores alternative routes to destinations and can recover well from changes (Abolhasan, Wysocki & Dutkiewicz 2004). DSR has a max capacity of 200 nodes and due to the large routing overhead it does not scale well as it stores the complete address from source to destination (Johnson, Hu & Maltz 2007). This can be seen by a sharp fall in PDR after 50 nodes.

Although AODV is a reactive protocol meaning that it sources routes on demand and DSDV is a proactive routing protocol; both have similarities as identified in section 2.5.1 in that both make use of periodic beaconing of hello messages and the use of sequence numbers to base routing decisions. DSR does not use sequence numbers or periodic beaconing, it relies on source based routing and first checks its cache for an available route. AODV sources routes reactively where as DSDV is pro active on obtaining routes to all other nodes and maintaining this data. DSDV also does not scale well due to the vast overhead produced by maintaining routes in a routing table to all other nodes, as such it is predicted that DSDV reached its capacity and was saturated after 150 nodes as after this point the simulation for 200 nodes would not complete, hence there is not data for DSDV for 200 nodes.

AODV has a consistent rate of performance for each of the node scenarios showing that it works well in sparse networks and can also scale well without there being any huge difference in performance.

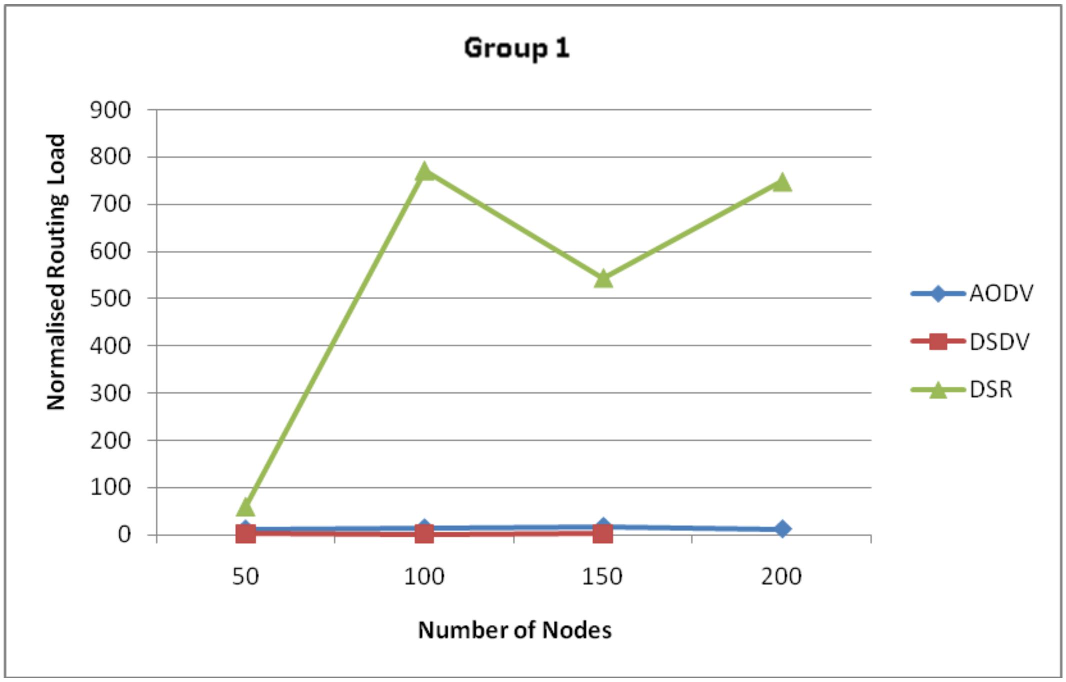
The amount of packets delivered to the destination is a top consideration for networks and AODV has managed to do this at a consistent rate during varied node densities. AODV has the benefit of keeping overhead down by using sequencing numbers as compared to DSR which stores full routes, it also can scale better than DSDV as the overhead of storing large routing tables and maintaining these is not an issue, routes are sourced on demand.



Graph 1 – Average PDR

<u>Normalised Routing Overhead</u>

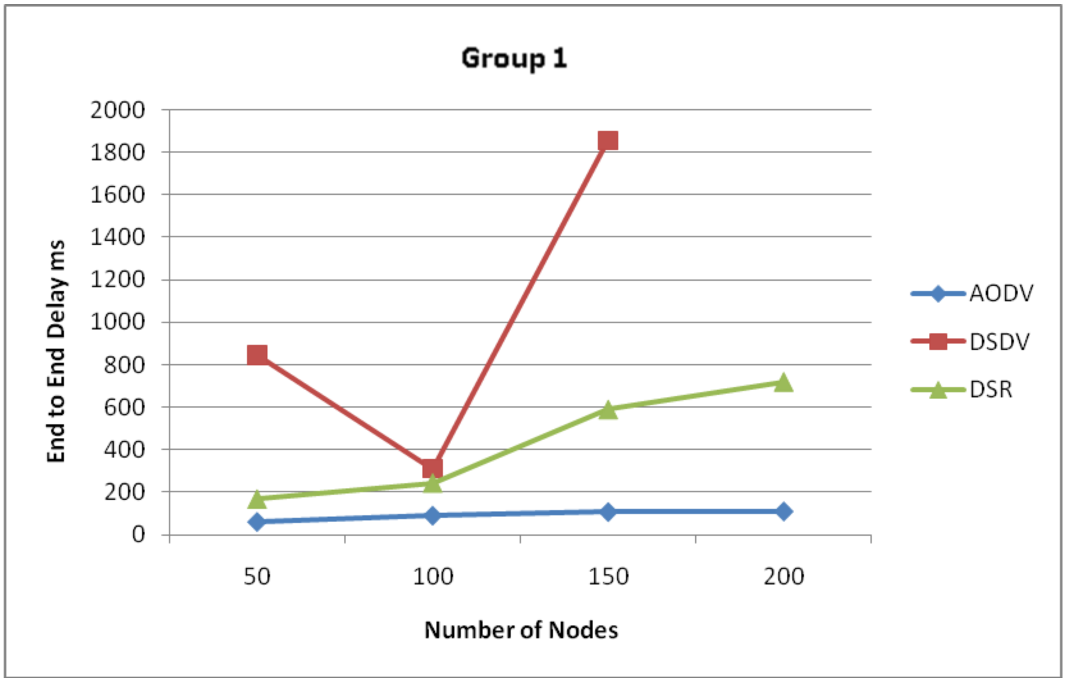
The large routing overhead produced by DSR as the network grows is evident in graph 2 showing DSR to have the highest NRL by a marked increase above AODV and DSDV. This is due to DSR storing the complete address information from source to destination. Another factor is that once the network scales the NRL produced to locate routes and source alternate routes grows rapidly. AODV is shown to have a slightly larger NRL than DSDV, there are two possibilities as to this occurrence; 1. AODV sources routes on demand and therefore requires to send routing packets in the form of RREQ messages each time a packet requires to be sent. DSDV uses a routing table and the routing overhead produced would be to maintain these tables or find a route if an entry is no longer valid therefore routes would not require to be sourced every time a request was made for a packet to be transmitted; 2. AODV has a higher PDR than DSDV meaning that more routing information would be required to deliver a higher amount of packets.



Graph 2 – Average NRL

<u>End to End Delay</u>

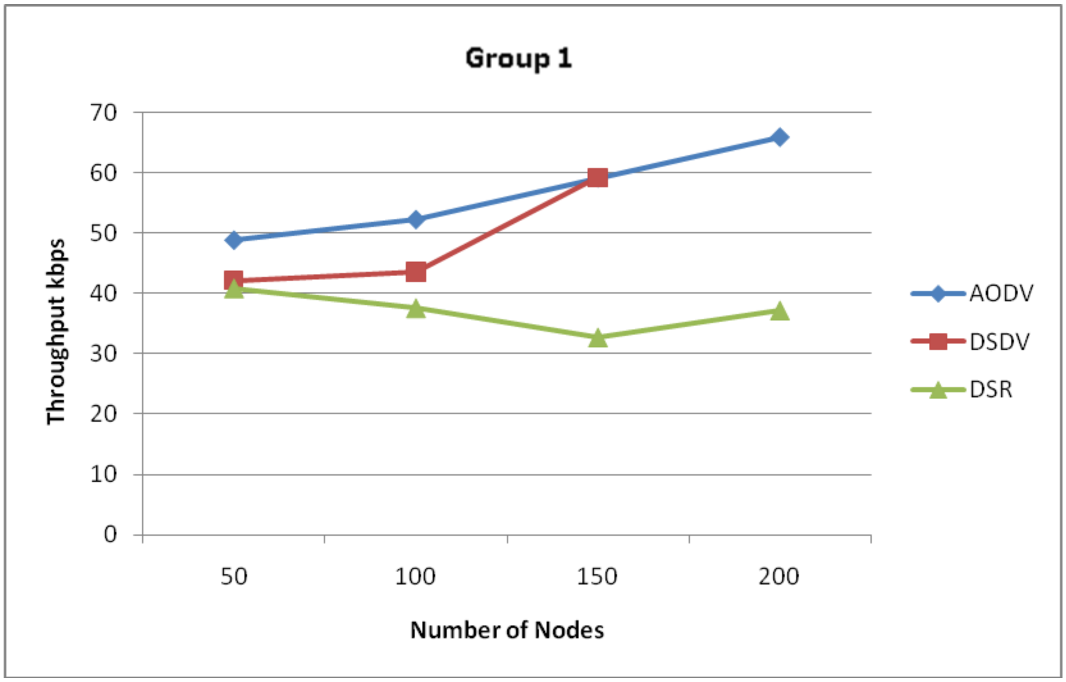
Graph 3 represents the end to end delay experienced by packets based on the time taken for packets to be sent and delivered. DSDV has the highest end to end delay, at 50 nodes the problem of intermittent links would be present as detailed in section 1.2.2, as more nodes are added and more links are available a sharp decrease in end to end delay can be seen for 100 nodes although this is still higher than DSDV or AODV. A sharp increase in delay is present for the limit of 150 nodes, this would occur as DSDV would struggle to maintain routes for a larger network, it would take longer to build and refresh routing tables and keep them up to date, due to the routing overhead encountered DSDV does not scale well. DSR can also be seen to experience an increase in delay as the network grows again accounted for by the large routing overhead. Both DSDV and DSR would suffer from stale routes if the routing tables were not up to date meaning a route discovery process would require to be initiated, this would then reflect in a delay for routing the packet. DSR stores alternative routes and will try to recover by using these. AODV experiences the least end to end delay and as can be seen in Graph 3 the increase in delay as the network scales is slight. The reactive nature of AODV therefore helps to ensure there is least delay as a network scales as the routes used are always fresh.



Graph 3 – Average End to End Delay

<u>Throughput</u>

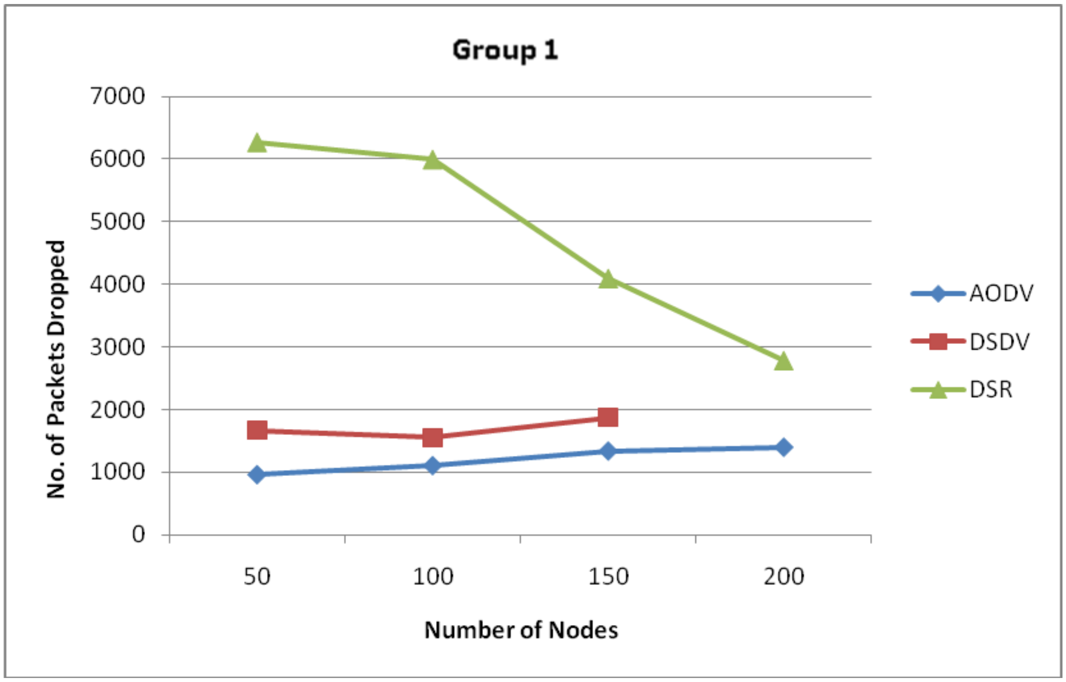
AODV has the highest throughput as per graph 4 as AODV has the highest PDR and throughput is based on the number of packets delivered per second over the simulation time, also AODV remains fairly consistent for the previous metrics. DSDV is shown to have an increase in throughput from 100 nodes to the limit of 150 nodes and throughput for DSR decreases from 50 nodes as the network scales due to an increase in overhead and delay and a decrease in PDR.



Graph 4 – Average Throughput

Number of Packets Dropped

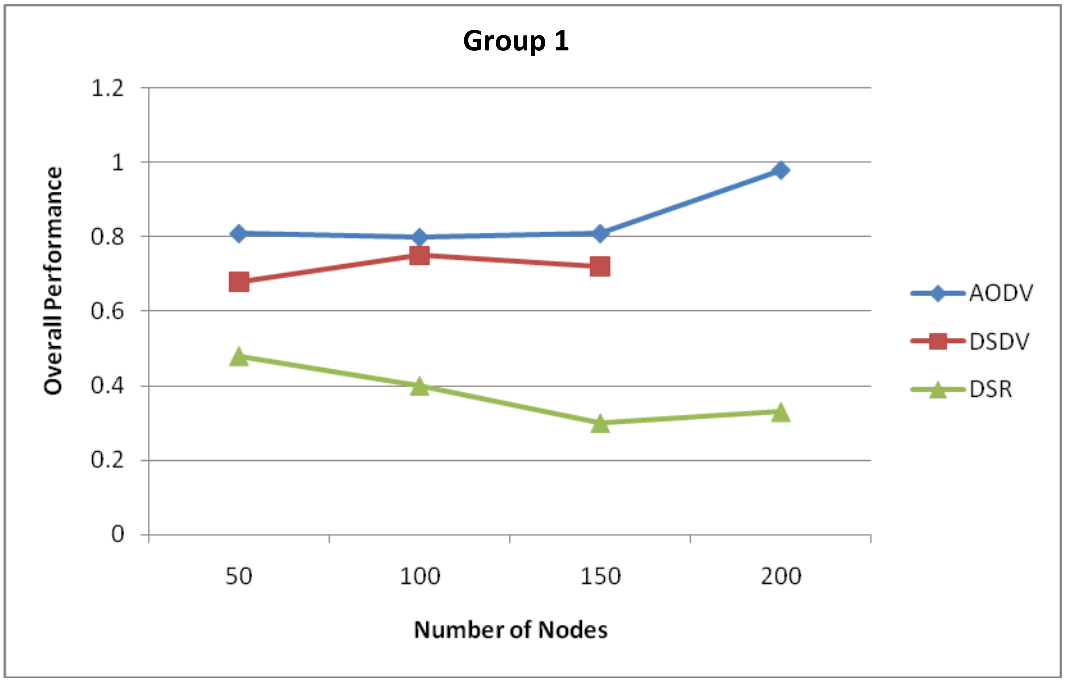
The number of packets dropped by each of the routing protocols can be seen in Graph 5. AODV has the lowest figure out of the three and experiences only a slight increase as the numbers of nodes grow. AODV uses sequence numbers and updates routing information to ensure the routes are fresh based on the most up to date information received from the network, as per section 2.5.1, meaning there is a higher possibility of packets reaching the intended destination. DSDV maintains a fairly consistent average with again a slight increase in dropped packets as the network scales up to 150 nodes. DSDV has a slightly higher rate of dropped packets most likely down to stale routes but is still not significantly higher than AODV however any increase in packet loss has a significant impact on the network. DSR experiences the highest rates of packet loss although manages to gradually decrease this gap to the point of 200 nodes. From Graph 4 it can be seen that the throughput of DSR has a slight increase for 200 nodes as compared with 150 nodes, this increase in packets delivered would be evident in a decrease in dropped packets. The number of dropped packets is however significantly higher from 50 nodes which could be down to collisions or packets dropped due to stale routes.



Graph 5 – Average No. of Packets Dropped

<u>Overall Performance</u>

Graph 6 represents an overall average of performance for AODV, DSDV and DSR based on the data from the metrics analysed in Graph 1 to Graph 5. The data was normalised and averaged to show an overall performance value. AODV can be seen to provide the best performance overall for scenarios of dense and sparse networks. This was evident in the graph data showing AODV to have the highest PDR and throughput and least packets dropped. DSDV is a close second up to networks of 150 nodes as it did not scale to 200 nodes. DSR experienced high packet loss and overhead compared to AODV and DSDV, the values for PDR and throughput were also lower overall in comparison with AODV and DSDV making it the least suitable protocol for this group up to 150 nodes. DSR is more favourable than DSDV beyond this point as DSDV did not scale to 200 nodes. AODV provides the most stability and best performance overall for group 1.



Graph 6 – Average Overall Normalised Values

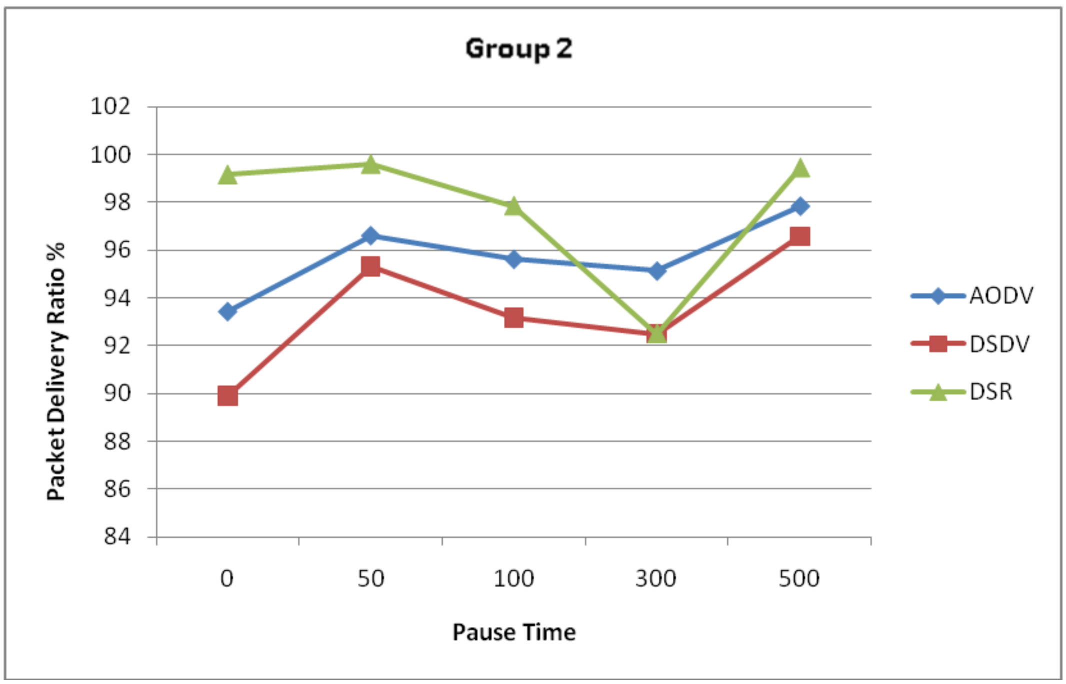
4.2.2 Group 2 Results

Section 4.2.2 provides analysis of the results from the various simulation scenarios set out in section 3.1.1 which for group 2 encompassed a varied pause time of between 0, 50, 100, 150, 300 and 500 ms. The pause time of 500 ms represents the uncharacteristic scenario of a stationary network, however it is still included within this study to analyse the performance of the routing protocols as although this scenario is uncharacteristic the chance of occurrence is still a possibility.

Group 2 aimed to test the routing protocols based on varied mobility parameters. A pause time of 0 indicates continuous movement up to a pause time of 500 which indicates zero movement as the simulation time is 500 seconds. A stated earlier a pause time of 500 is not characteristic of a MANET environment in that there is no mobility. This is included for this project to consider how the protocols would behave if all nodes were stationary. The number or nodes is kept at a constant of 100 and speed at a constant of 20 m/s.

Packet Delivery Ratio

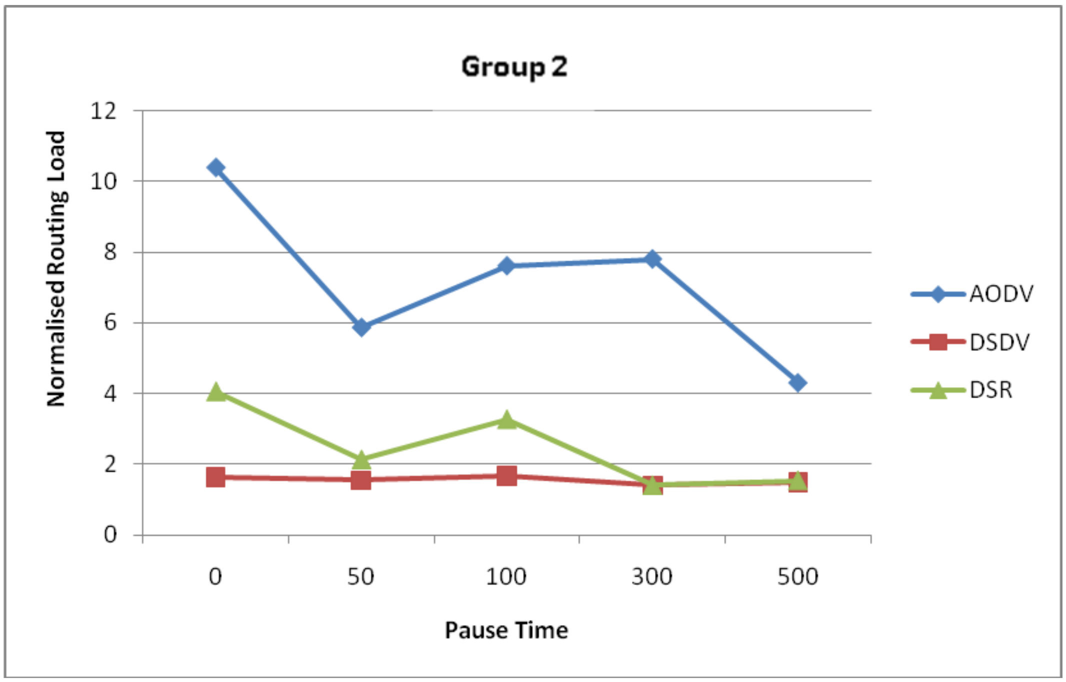
Graph 7 represents the PDR for each protocol for various pause times. DSR achieves the highest PDR experiencing a decrease in PDR at a pause time of 300 and returning to outperform AODV and DSDV at a pause time of 500 where no movement is present. As identified in section 2.5.2 DSR could outperform AODV and DSDV for high mobility rates due to the protocol being able to recover rapidly using the support of multiple routes in the cache and low overhead (Johnson, Hu & Maltz 2007). Low overhead would only be seen in small to medium sized networks as DSR has a problem in scaling due to the amount of overhead produced in large networks. DSDV has the lowest PDR most likely due to stale routes with high mobility; the PDR gradually increases as the mobility decreases. AODV performs better than DSDV in that it reactively sources routes however the ability of DSR to recover quickly in high mobility situations is evident reflecting in the highest PDR for high mobility rates.



Graph 7 – Average PDR

Normalised Routing Load

Graph 8 shows the amount of NRL for AODV, DSDV and DSR. DSDV has the lowest NRL, however DSDV also has the lowest PDR and as less packets are delivered a lower NRL would be expected. AODV has the highest NRL especially for a pause time of 0 indicating high mobility, this is due to the reactive nature of AODV, as AODV is required to initiate a RREQ for every packet that requires to be sent. DSDV and DSR make use of routing table data which is shown in Graph 8 to significantly lower the NRL. DSR experiences a higher NRL than DSDV however DSR has a significantly higher PDR than DSDV showing that more packets were delivered successfully and as such a higher NRL would be expected.

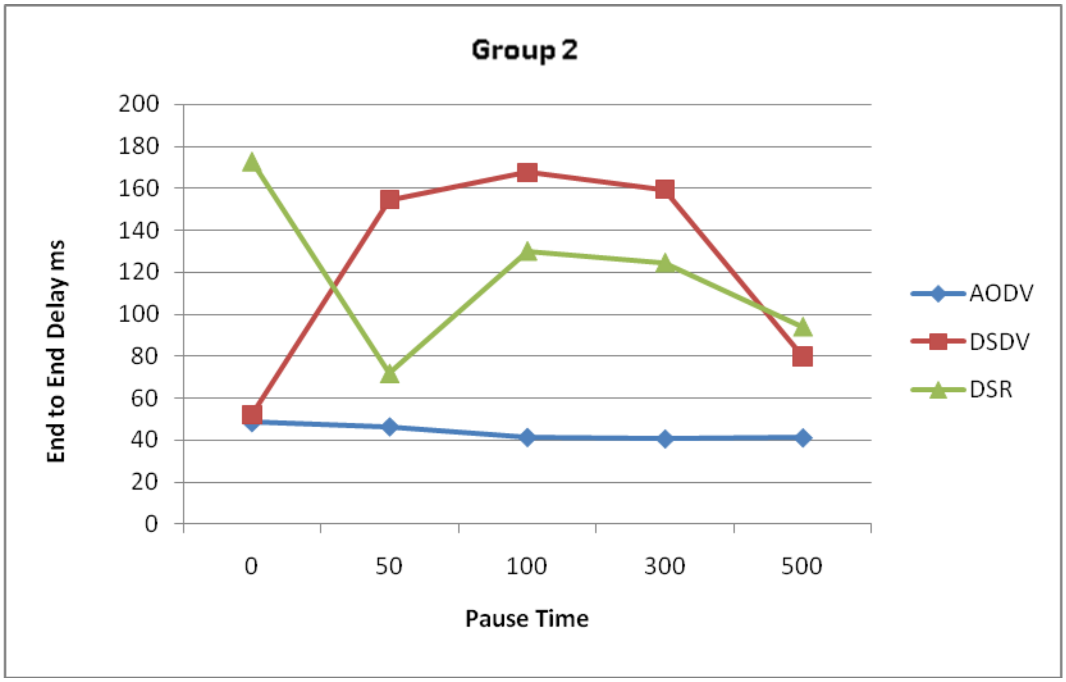


Graph 8 – Average NRL

End to End Delay

DSR can be seen to have the highest end to end delay for graph 9 for a pause time of 0, however DSR had a significantly higher PDR which would influence this result in comparison to AODV and DSDV as the packets delivered by ADOV and DSDV were much lower than DSR.

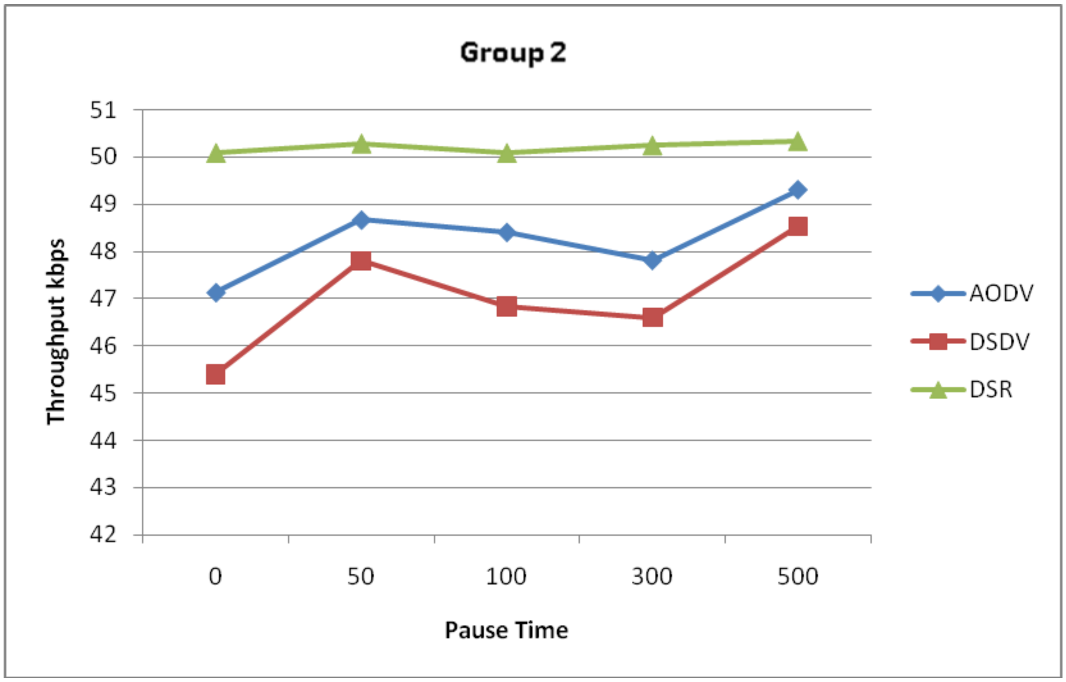
The use of stale routes would also results in delays for DSR. DSDV overall has the highest end to end delay as DSDV had the lowest PDR DSDV struggled to deliver packets to the destination and without the use of multiple routes would take longer to recover from stale routes than DSR resulting in higher delays. The end to end delay for AODV is the lowest as routes are actively sourced the delay is generally less. In high mobility scenarios though as can be seen in graph 7 the ability for DSR to use alternative routes results in DSR outperforming DSDV and AODV.



Graph 9 – Average End to End Delay

Throughput

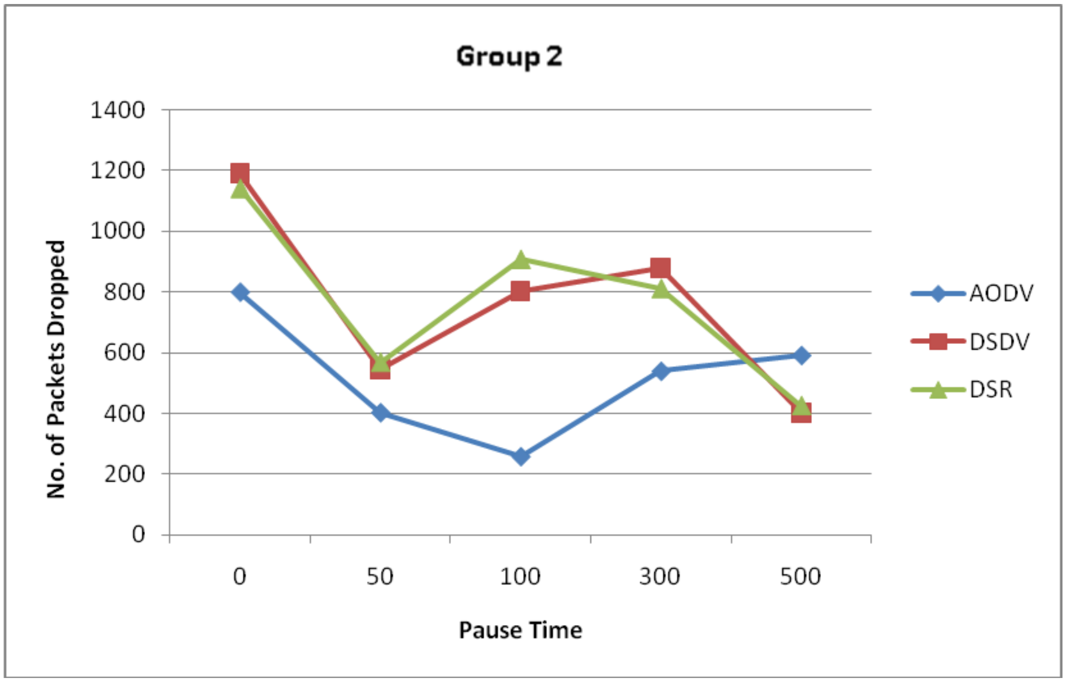
The throughput of each protocol is characteristic of performance of each protocol for Graph 7. DSR outperforms AODV and DSDV in Graph 10 achieving the highest throughput. AODV achieves a higher throughput than DSDV as the reactive nature of AODV meant that routes could be sourced with more accuracy. DSDV struggled with high mobility scenarios as the protocol would encounter stale routes and would struggle to maintain the routing tables to reflect the location of destination nodes. DSR could rely on alternative routes to locate a destination node before having to initiate a route discovery meaning that DSR could recover faster and deliver more packets.



Graph 10 – Average Throughput

<u>Number of Packets Dropped</u>

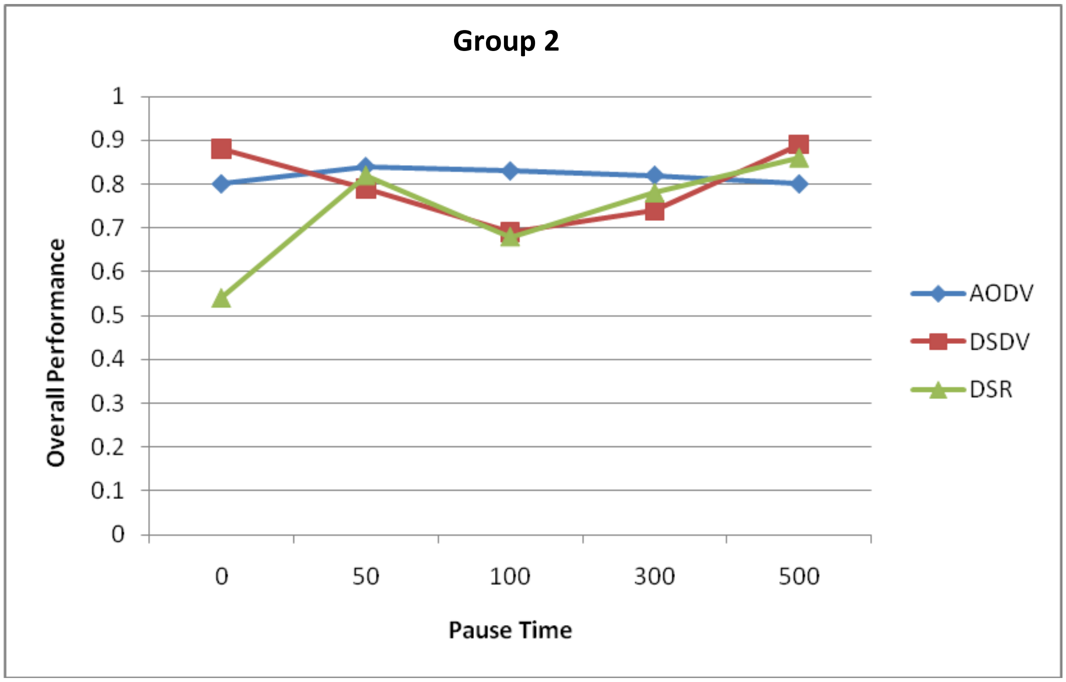
Graph 11 shows the average number of packets dropped by AODV, DSR and DSDV. DSDV and DSR have a comparable figure throughout reflecting the similarity in the use of routing table data between the two in which stale routes would result in packets being dropped. AODV has the least amount of packets dropped as AODV does not make use of tables there is less chance of a route being stale. When all nodes are stationary at a pause time of 500, DSDV and DSR drop fewer packets than AODV as the routing table data held by both DSDV and DSR would mostly be correct as there is no node movement.



Graph 11 – Average No. of Packets Dropped

<u>Overall Performance</u>

The overall performance of each protocol for group 2 is represented in Graph 12. The graph shows DSR to be the worst for a pause time of 0 as compared to AODV and DSDV and shows DSDV to be the best choice. If the performance was based on PDR and throughput DSR can be seen to be the preferred routing protocol. DSDV clearly does not perform better than AODV and DSR for group 2, the data however takes into account the NRL which for DSDV was the lowest of all, coupled with a low end to end delay value comparable with AODV and significantly lower than DSR thus the overall value for DSDV appears to give a higher performance. As also stated earlier in this report a lower PDR for DSDV would result in lower NRL and end to end delay statistics as the amount of packets processed by the protocol are lower. Therefore in this case the performance graph does not truly represent the favourable routing protocol which for high mobility scenarios would be DSR. AODV is the second contender throughout and experiences the least delays and number of packets dropped. DSDV and DSR however outperform AODV for the metric no. of packets dropped in situations where there is no mobility although AODV outperforms DSDV for PDR and throughput leaving DSR to be the strongest protocol for no mobility scenarios, this however as stated earlier is not characteristic of MANETs.



Graph 12 – Average Overall Performance Values

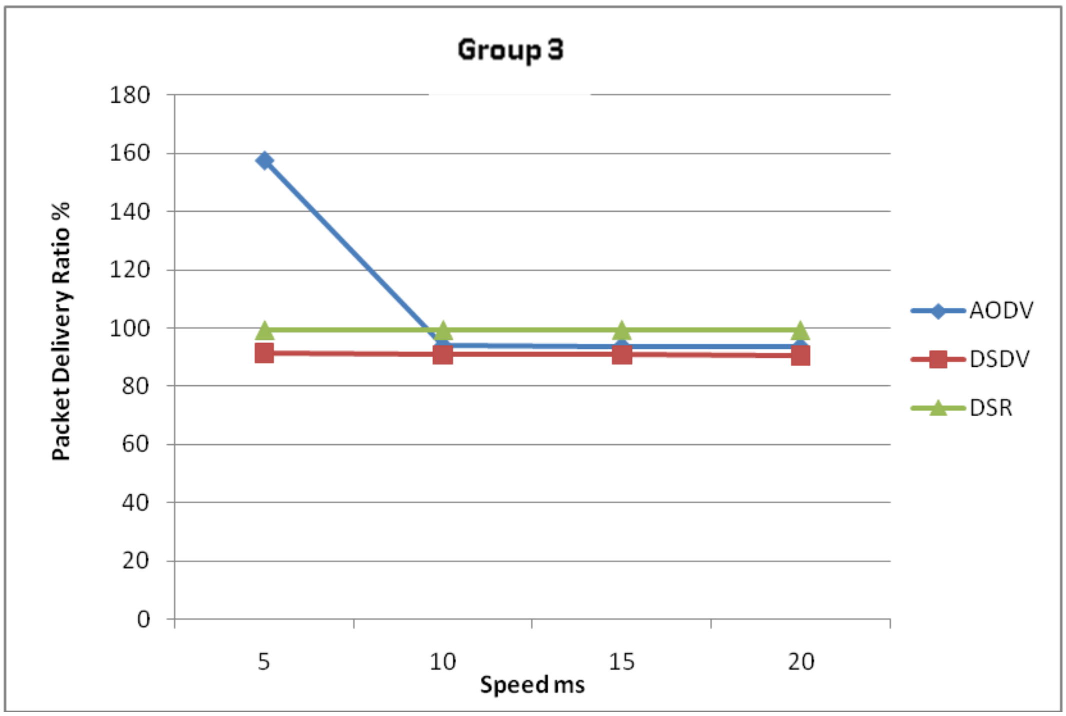
4.2.3 Group 3 Results

Section 4.2.3 analyses the output for group 3 which as per section 3.1.1 aims to test the routing protocols performance over varied mobility speeds ranging from 5, 10, 15 and 20 m/s.

Group 3 focuses on testing the performance of AODV, DSDV and DSR for varied speeds. The speeds chosen and identified in section 3.1.1 are 5 m/s, 10 m/s, 15 m/s and 20 m/s. The number of nodes used in group 3 is kept at a constant of 100 and the pause time is kept at a constant of 0. The mobility of the nodes is therefore high as there is no pause time; the speed of the node movement is used in group 3 to test the protocols performance over varied speeds. As a MANET is a mobile and dynamic environment it is important to test the efficiency of a routing protocol over different mobility scenarios, this group tests the ability of a protocol to route data when the speed of mobility is varied and node movement is constant.

Packet Delivery Ratio

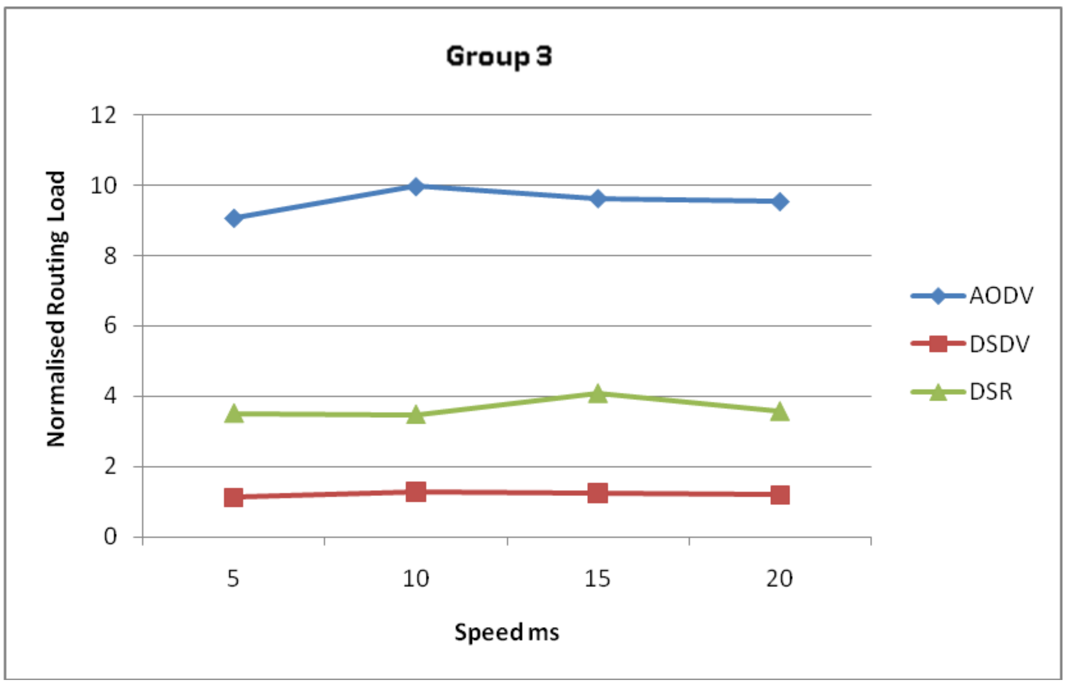
Graph 13 illustrates for a low speed of 5 m/s AODV outperforms DSR and DSDV in terms of PDF by achieving a PDF of 160 %. The ability of AODV to route data quickly with little overhead provides the mechanisms for the marked increase in performance for AODV when the speed of mobile nodes is slow. AODV experiences a drop in PDF as speed increases from 10 m/s; this would be due to the increased speed of mobility for mobile nodes meaning valid paths would be shorter lived, however PDF is consistent from a speed of 10 m/s to 20 m/s. DSR and DSDV have a similar almost stable PDF, DSR outperforms DSDV by use of alternative routes in the cache. From a speed of 10 m/s DSR offers the highest PDF. Al-Maashri et al (Al-Maashri, Ould-Khaoua 2006) state that the performance of DSR is down to the ability of intermediate nodes to learn routes by using an over hearing strategy allowing routes to be cached for future use. Al-Maashri et al (Al-Maashri, Ould-Khaoua 2006)further go on to state that by using acknowledgements at the data link layer, DSR has the ability to discover broken links and recover from these quickly by responding quicker to the network changes.



Graph 13 – Average PDR

Normalised Routing Load

Graph 14 illustrates the normalised routing load for DSDV, DSR and AODV over varied speeds. AODV experiences the highest NRL in comparison to DSR and DSV. This is due to the reactive nature of AODV where the route discovery process using RREQ messages takes place for every request; AODV also makes use of periodic hello messages which increase the overall routing load. DSR and DSDV have a much lower routing load in comparison to AODV. This lower overhead is due to the ability to store routes in a routing table and locate routes from this table in the first instance before initiating the route discovery process. DSR experiences a higher NRL than DSDV, the cause of this would be the use of further stale routes, which were stored as alternative routes. An increase in the mobility of mobile nodes means the probability of a route becoming stale increases. DSR also holds more routing information as the protocol stores the full address of every node along the path.

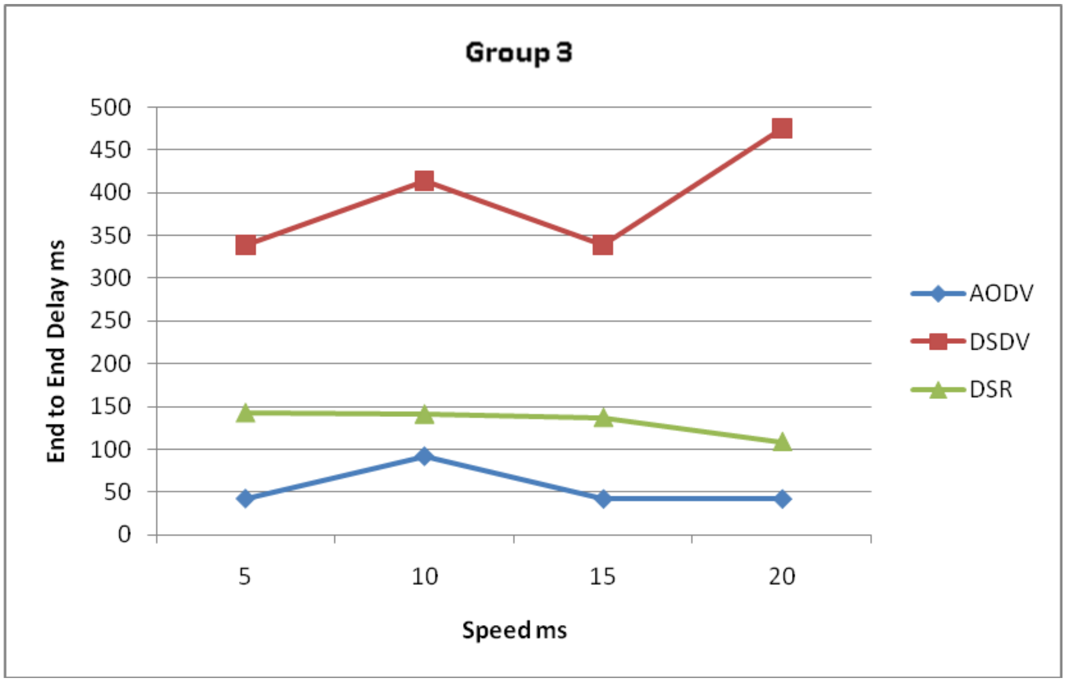


Graph 14 – Average NRL

End to End Delay

Graph 15 shows the average end to end delay in milliseconds for AODV, DSDV and DSR. DSDV can be observed to have the highest end to end delay with delay increasing with higher speeds. DSDV struggles as speed increases due to the number of stale routes increasing within the routing table. The increase in speed and mobility of mobile nodes means that routes become shorter lived. DSDV uses periodic hello messages and attempts to keep an up to date table of the entire network, the delays in updating the routing tables and the increased node mobility leading to path changes means that there is a higher occurrence of stale routes which escalates with increased mobility. DSR has significantly lower end to end delay than DSDV as seen in Graph 15. As identified earlier by Al-Maashri et al (Al-Maashri, Ould-Khaoua 2006) the ability of DSR to learn routes by using an overhearing mechanism aids to the performance of DSR. DSR thus learns routes by a variety of means and can recover quickly using these mechanisms and alternative routes to destinations. As identified in section 2.5.2 of the literature review DSR uses acknowledgement packets for the process of detecting active routes, if an ACK is not received the route is determined to be broken, once a broken link is determined by means of an RERR message that path is removed from the routing table. DSR thus uses alternative methods as compared to DSDV to source and maintain routes which enable DSR to recover quicker which is reflected in lower delays than DSDV.

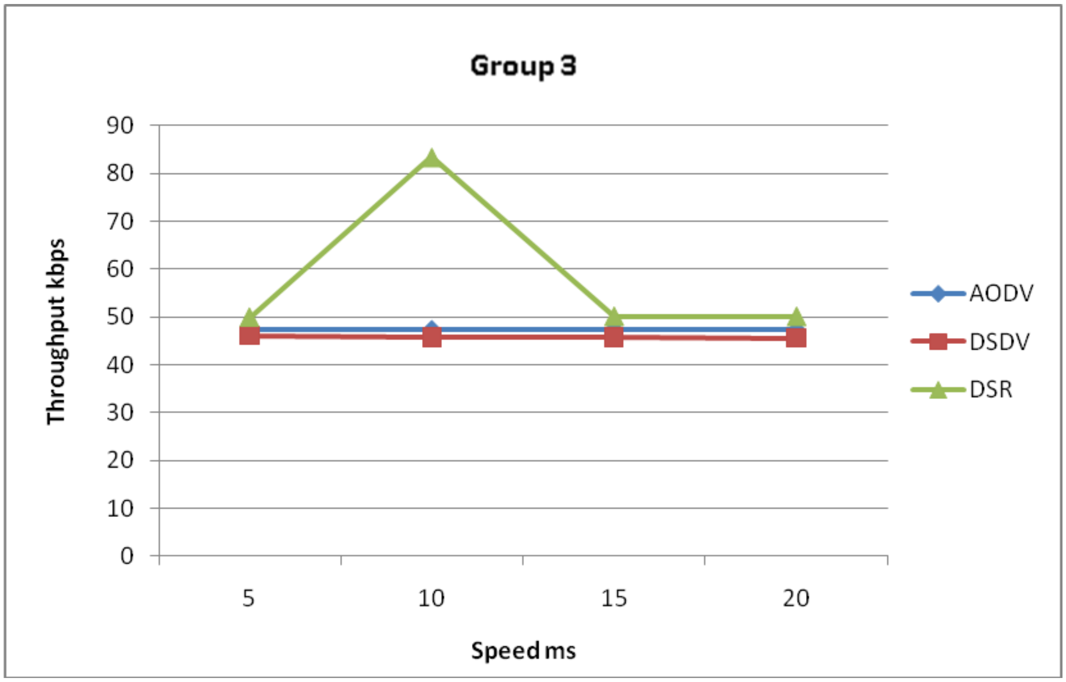
AODV experiences the lowest end to end delay overall; this can be explained in comparison to DSDV and DSR. DSDV attempts to store routes to all nodes within the network and keep this information up to date, DSDV also uses periodic hello messages in order to detect broken links, both of these functions mean delays will incur due to the increase in stale routes. AODV uses periodic hello messages to identify network changes but does not have the overhead of DSDV of holding routes to every destination on the network for every node. AODV can therefore respond faster to network change resulting in a decreased delay. AODV has a lower end to end delay than DSR as DSR will experience stale routes with mobility as compared to AODV which uses the latest information received from other mobile nodes in order to base routing decisions. Al-Maashri et al (Al-Maashri, Ould-Khaoua 2006) also state AODV can replace the routing information at a later time if an updated path is received, meaning the data is routed on the most up to date information and as such the overall end to end delay is lower as there is less chance of routes to be stale.



Graph 15 – Average End to End Delay

<u>Throughput</u>

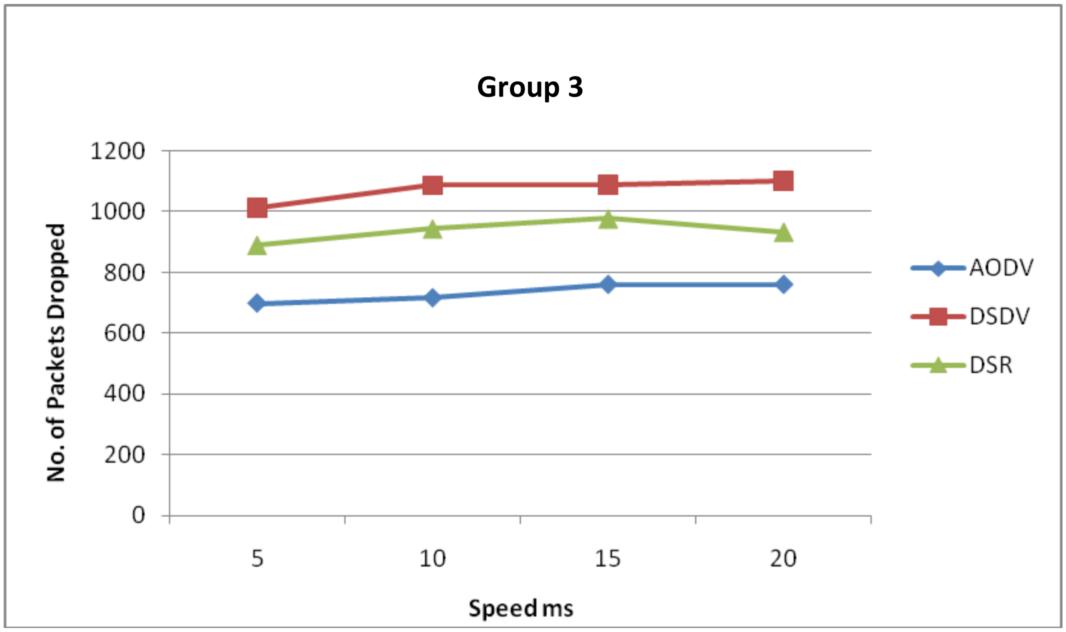
Graph 16 shows the highest throughput is achieved from DSR. DSR had the most stable PDF and manages the highest throughput meaning that it delivers more messages per second than any of the other protocols. DSR manages this by storing alternative routes in the cache and updating routes based on additional routes learned as identified in section 2.5.2 of the literature review aiding to quick recovery and as such the ability to route more packets. The performance in throughput of DSDV and AODV is comparable and is subsequently less than that of DSR due to the ability of DSR to recover quickly.



Graph 16 – Average Throughput

Packets Dropped

Graph 17 illustrates the number of packets dropped for AOD, DSDV and DSR for each of the speed scenarios used for group 3. AODV can be observed to have the lowest amount of dropped packets. Section 2.5.1 of the literature review details the reactive nature of AODV and as this protocol acts instantly on the latest information from other mobile nodes the result is a lower rate of dropped packets. As stated previously AODV can also update the path information at a later stage in the process of sending a packet and as such routing information is kept up to date along the lifetime of a packet traversing the network. DSDV and DSR will encounter problems with stale routes and this will result in packet loss. This will be more prominent as the speed increases. DSR has a lower rate of dropped packets compared to DSDV as DSR can learn additional routes and stores these as alternative routes meaning there is more chance of an up to date route being present in the routing table of DSR than of DSDV, this coupled with the ability of DSR to recover faster means DSR experiences less packet loss than DSDV. DSDV experiences the highest packet loss due to stale routes which increases with the increase in speed.



Graph 17 – Average No. of Packets Dropped

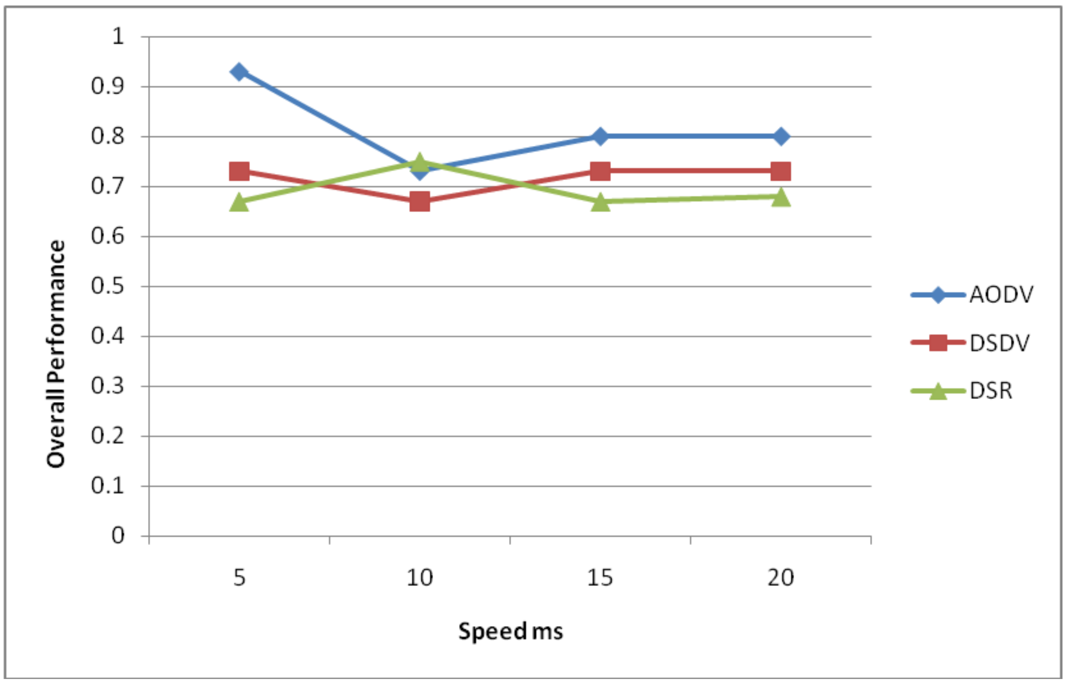
<u>Overall Performance</u>

Graph 18 gives an overview of the performance metrics detailed in the previous graphs for group 3. All data was normalised and negative values reversed such as 1/NRL to give the relevant data to calculate an overall performance. DSR which gives the highest PDR and Throughput on average is reflected in Graph 18 as the protocol with the worst performance overall apart from a speed of 10 m/s. The reason for this output is that the protocol experiences a higher number of packets dropped and end to end delay as compared to AODV as well as a lower PDR for 5 m/s. In comparison to DSDV, DSR had a higher NRL rate from which the use of stale alternate routes could be a cause along with the fact that DSR sent more packets successfully as compared to DSDV and as such would have a higher NRL in order to achieve this. The aspects of these metrics thus reflect in the overall calculation therefore although DSR was the best protocol overall for throughput and PDR the performance statistics of the other metrics mentioned bring down the overall score in comparison to DSDV and AODV.

The low NRL statistic for DSDV over AODV and DSR is the main metric that has given DSDV a positive result as DSDV had the least favourable performance for the other metrics studied, having the highest delays, number of packets dropped and the lowest PDR and throughput.

AODV had the lowest number of packets dropped and the lowest end to end delays giving a positive outcome for these metrics. AODV can be seen to perform second best overall for PDR and throughput although can be observed to have the highest NRL due to the reactive nature of the protocol and as such this metric was not favourable for AODV in the overall calculations.

Therefore although the overall performance graph is indicative of the outcome for all metrics it is clear that other factors must be considered as a favourable outcome for one metric which may give the protocol a high score may not be reflective of the actual performance of the routing protocol. This is the case for DSDV, due to a low NRL the protocol appears favourable over DSR, however the performance of DSDV for the other metrics must be considered and for group 3 this was not favourable, also as DSDV achieved the lowest PDR and throughput it is evident that DSDV delivered the least packets. DSR and AODV would therefore have a higher NRL in order to achieve deliver of a higher packet rate, by nature these protocols may have a higher NRL but combined with the issue of DSDV delivering a lower packet rate a direct comparison cannot be concluded, all metrics must be analysed in order to determine the performance of a routing protocol.



Graph 18 – Average Overall Performance Values

4.3 Hypothesis Testing and Analysis

The hypotheses identified in this report in section 1.2.2 are tested based on the strategy set out in section 3.1.6 and analysis given for these results as to whether the hypothesis was proven or disproven.

4.3.1 Hypothesis Test Results

Hypothesis No. 1

Hypothesis number one as per section 1.2.2 was as follows:

'1.) DSDV will have a lower packet delivery ratio than AODV and DSR in high mobility scenarios due to the table-driven nature of the protocol, where an attempt is made by the protocol to store all routes for the network topology at a given time and whereby data is forwarded to a destination based on the routing information held in the tables. In scenarios where mobility is high the possibility of stale routes increases meaning packets will be dropped.'

In order to test this hypothesis the following testing procedure was set out in section 3.1.6:

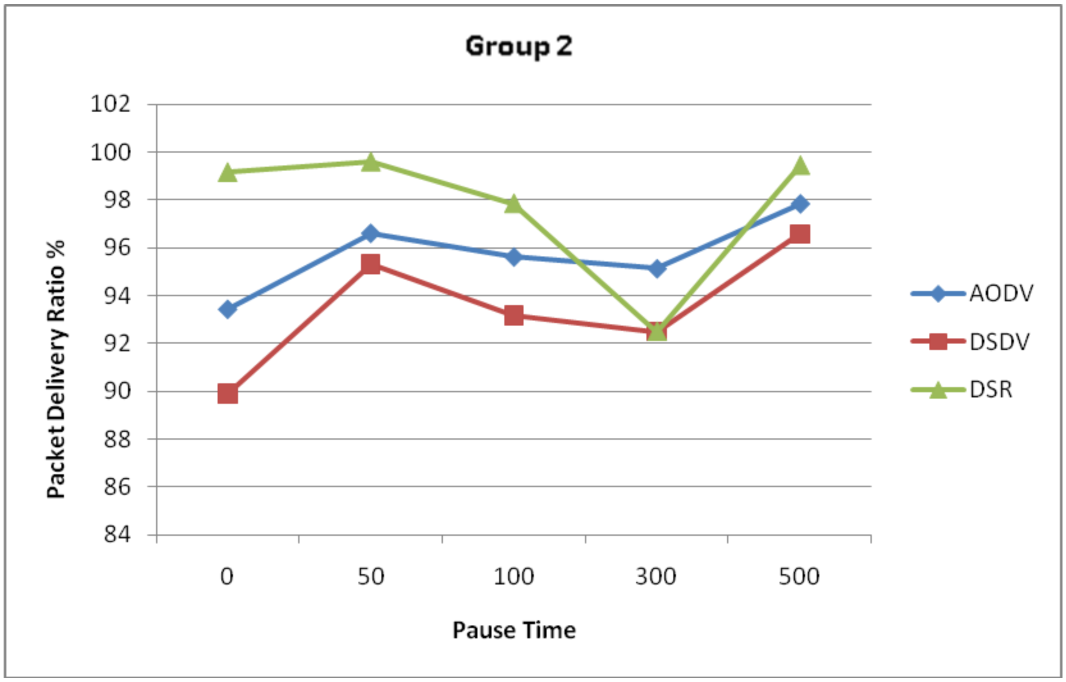
'Hypothesis number 1 can be tested by examining the packet delivery ratio metric and comparing the results against high and low mobility simulation data for each protocol. By comparing the results from this metric it can be proven or disproven that DSDV will have a lower packet delivery ratio than AODV & DSR.'

This procedure will be followed in order to test the hypothesis and data from group 2 and group 3 simulations PDR output will be used for the purpose of testing hypotheses 1 as both of these groups focussed on mobility using varied speeds and pause times. The statistics on the number of packets dropped will also be analysed in relation to hypotheses 1.

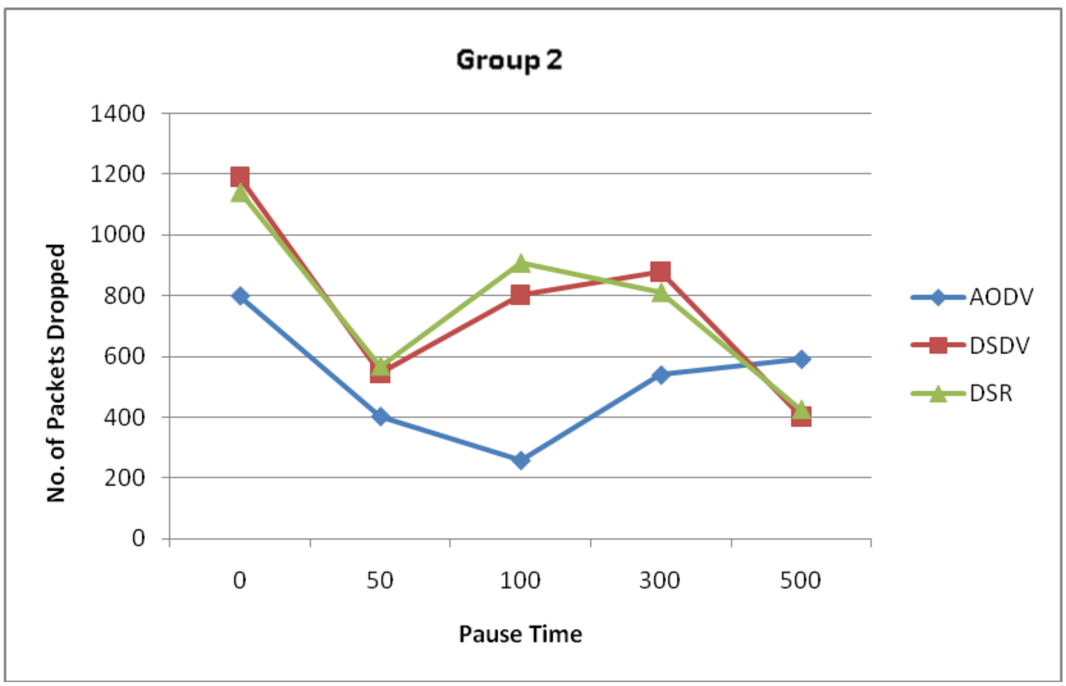
Group 2 and Group 3 PDR Output

The PDR graphs 7 and 13 from group 2 and group 3 show the percentage of packet delivery ratio for each protocol. DSDV can be clearly observed to have the lowest PDR for both group 2 and group 3. Further to this graphs 11 and 17 can be observed from group 2 and group 3 showing the number of packets dropped for each protocol. DSDV although comparable with DSR for graph 11 still has the overall highest packet loss. In graph 17 it can be clearly seen that DSDV incurs the highest amount of packet loss.

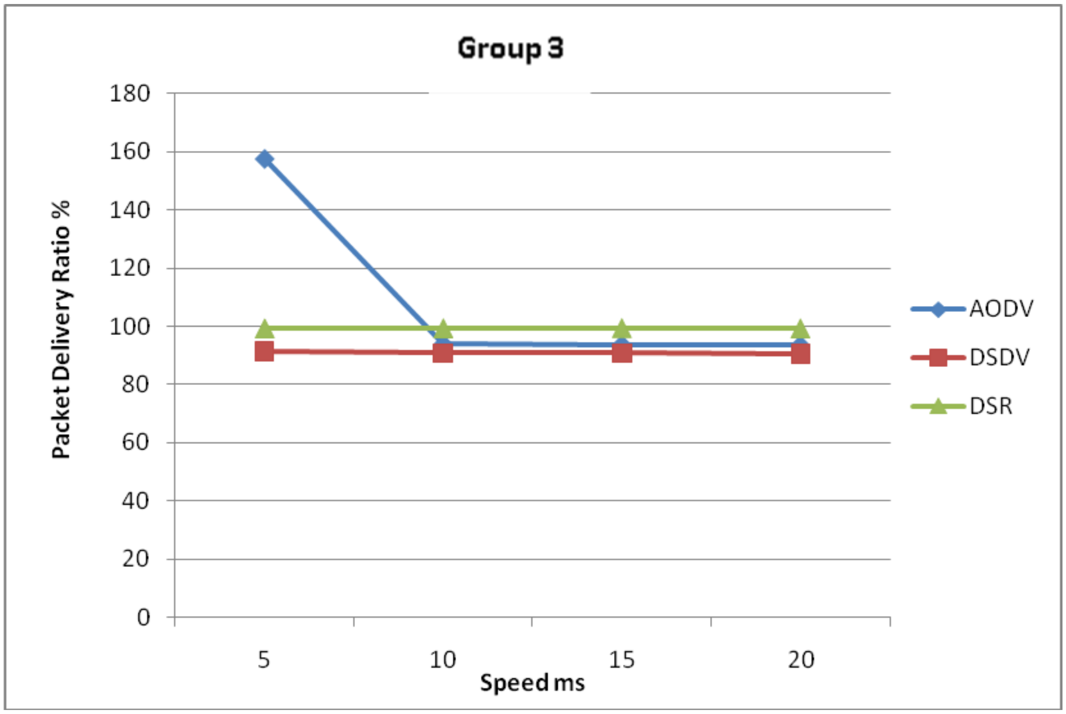
As DSDV has been found to have the lowest PDR values for both mobility groups and the highest rate of packet loss it can therefore be found that hypothesis number 1 is proven to be correct.



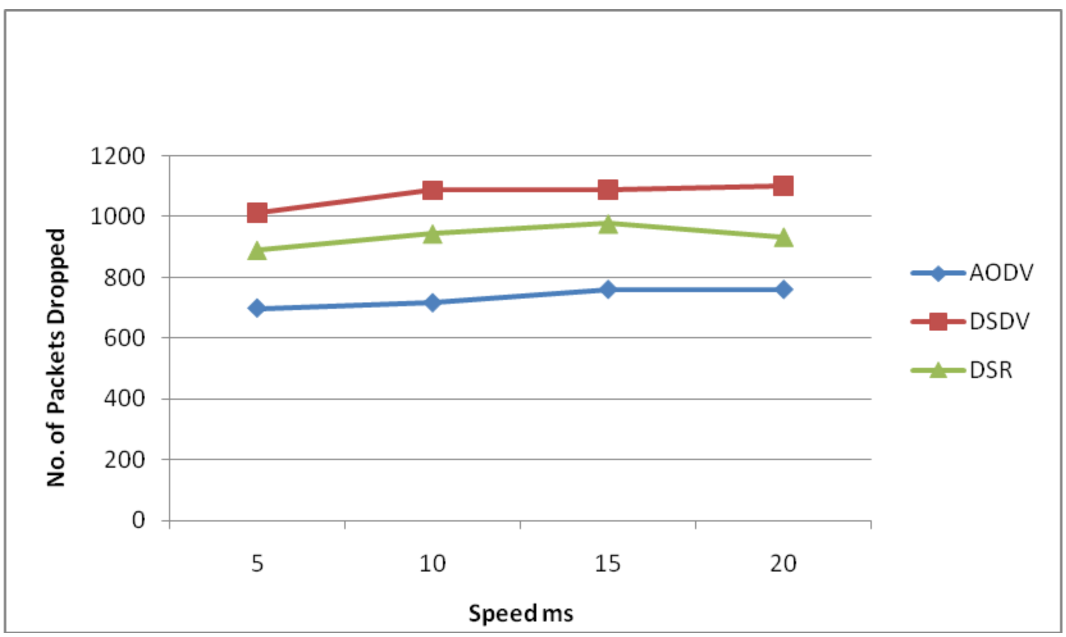
Graph 7 – Average PDR



Graph 11 – Average No. of Packets Dropped



Graph 13 – Average PDR



Graph 17 – Average No. of Packets Dropped

Hypothesis No. 2

Hypothesis number two as per section 1.2.2 was as follows:

'2.) AODV will achieve a greater packet delivery ratio than DSR in high mobility scenarios. The reason for this is that DSR utilises aggressive caching, in high mobility scenarios there are increased link breakages meaning that the probability of the cached routes utilised by DSR being stale are high. Stale routes lead to a decrease in delivery of packets, once detected the protocol is required to initiate a route request.'

In order to test this hypothesis the following testing procedure was set out in section 3.1.6:

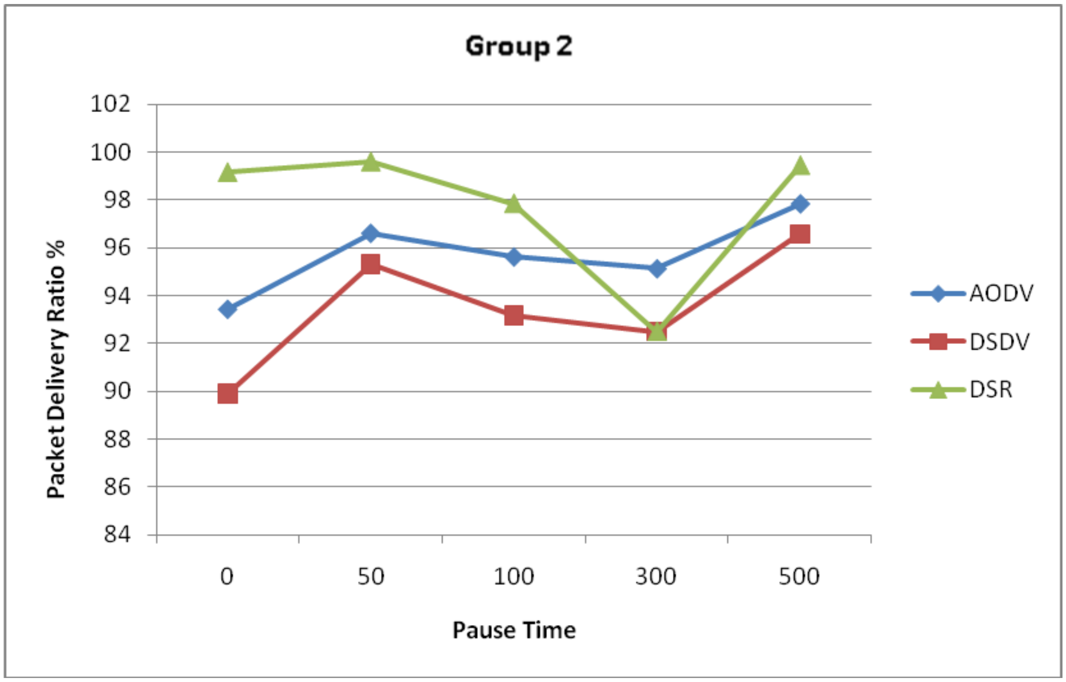
'Hypothesis number 2 will be tested by studying the packet delivery ratio for AODV & DSR then comparing the results against high and low mobility simulation data. This will portray if the assumption is correct that due to the use of a cache by DSR in high mobility scenarios AODV will outperform DSR for packet delivery.'

In order to test hypothesis 2 as per the above testing procedure, data from group 2 and group 3 PDR graphs will be analysed as these groups encompass varied mobility scenarios testing the protocols during varied pause times ad for varies speeds.

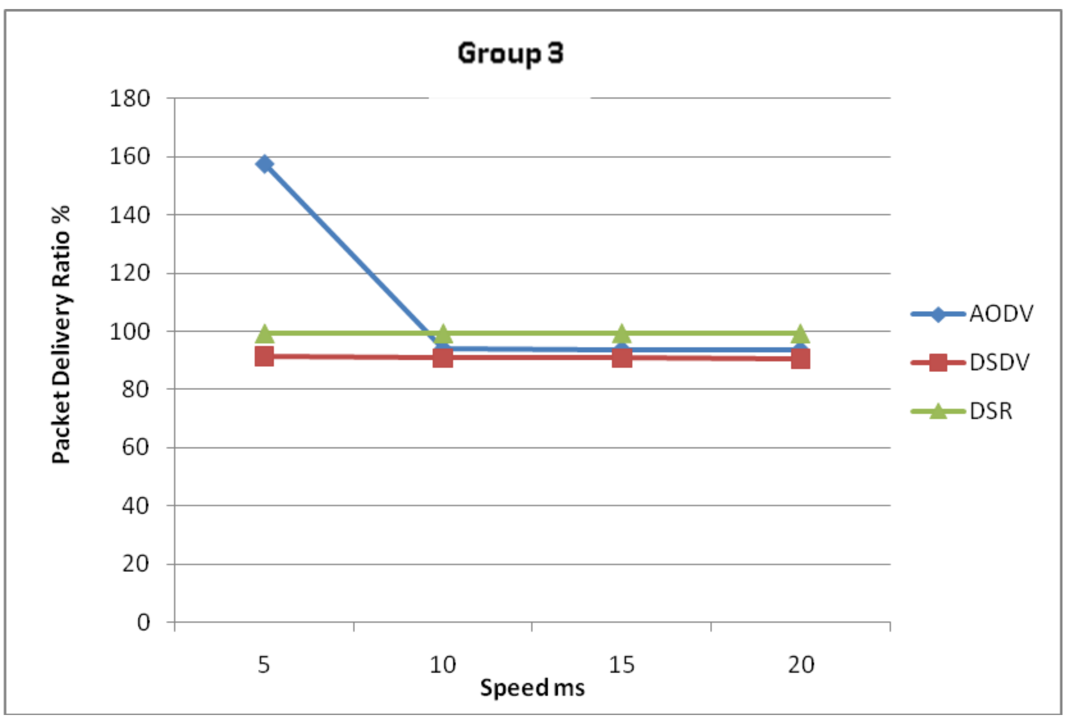
Group 2 and Group 3 PDR Output

Graphs 7 and 13 from group 2 and group 3 give the PDR value for the varied mobility scenarios. Graph 7 shows AODV to have a higher PDR than DSR for a pause time of 300; however DSR has the highest overall PDR. Graph 13 shows AODV to have the highest PDR for a speed of 5 m/s, as the speed increases DSR outperforms AODV and has again the overall highest PDR.

Hypothesis 2 is therefore incorrect as DSR outperforms AODV for high mobility scenarios. DSR manages to do this by keeping overhead to a minimum and mainly by having the ability to rapidly recover in high mobility scenarios by using alternate routes and by learning other routes to the destinations as outlined in section 2.5.1.



Graph 7 – Average PDR



Graph 13 – Average PDR

Hypothesis No. 3

Hypothesis number three as per section 1.2.2 was as follows:

'3.) Routing overhead for DSR , AODV and DSDV will increase as mobility increases, however DSDV will always have a higher routing overhead as compared to the reactive protocols as the protocol will require to send more updates in order to update the routing tables.'

In order to test this hypothesis the following testing procedure was set out in section 3.1.6:

'Hypothesis number 3 can be tested by comparing the normalised routing overhead metric data against all three protocols for high and low mobility scenarios. The data produced from this metric will show if routing overhead increases with mobility and if the proactive protocol DSDV has a higher routing overhead than the reactive protocols AODV and DSR'

Hypothesis number 3 will be tested as per stated above by looking at the NRL graph data from groups 2 and 3 which had varies mobility parameters applied for pause time and speed.

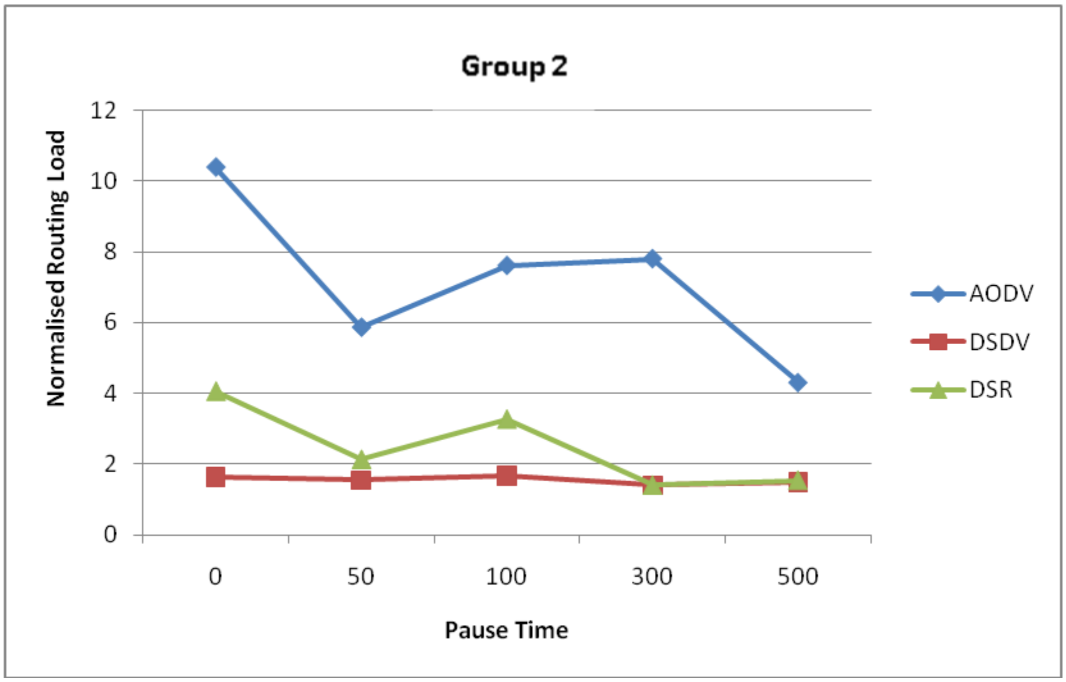
Group 2 and Group 3 NRL Output

Graph 8 shows a higher NRL for a pause time of 0 which is high mobility, thereafter NRL drops down until a pause time of 500 which is reflective of no node movement for the period of simulation. Graph 8 therefore indicates an increase in NRL for higher mobility scenarios. Graph 14 shows a slight increase in NRL as speed increases indicating that routing overhead increases with the speed of the network. This is due to rapid changes in node location meaning routes used could be stale and new routes to the destination would need to be discovered.

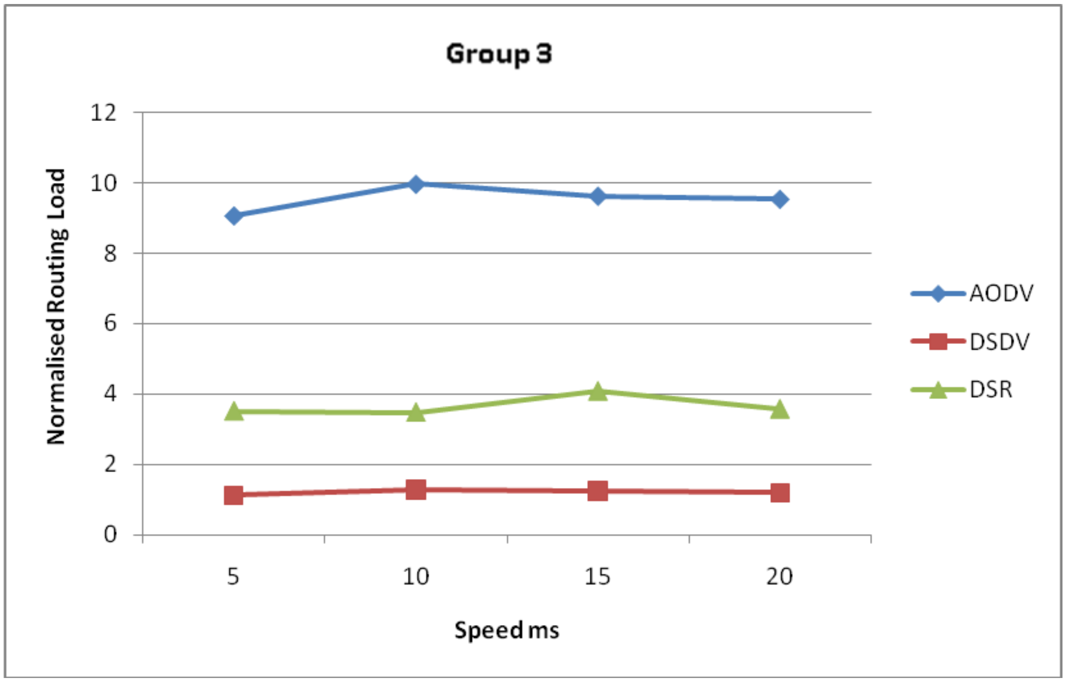
It can be observed from graphs 8 and 14 that DSDV has the lowest overhead in comparison to AODV and DSR. Although DSDV produces a lot of overhead as the network scales AODV and DSR produce more overhead. This is especially the case for AODV as outlined in section 2.5.1 the reactive nature of the protocol means that routes require to be discovered on demand. AODV has the benefit of using the most up to date information immediately but as routing overhead is produced for every request initiated the overall NRL for AODV is much greater than that of DSDV and DSR. DSR incurs higher overhead than DSDV due to the use of alternate routes which may turn out to be stale in high mobility scenarios, however DSR also delivers more packets than DSDV and recovers quicker therefore more routing overhead would be shown for DSR as more packets were delivered than that of DSDV.

An increase in NRL can be observed with an increase in mobility therefore this part of hypothesis number 3 is proven to be correct.

DSDV is shown to have lower overhead than DSR and AODV as such this part of hypothesis number 3 has proven to be incorrect although the results are influenced by a reduced packet delivery rate for DSDV which would affect the NRL value in relation to DSR. Due to this an accurate prediction cannot be made between DSR and DSDV and thus this hypothesis cannot be proven to be incorrect if the number of packets delivered were equal between DSDV and DSR. DSR could have a lower NRL rate if this was the case due to the ability of the protocol to recover quicker and respond to network change.



Graph 8 – Average NRL



Graph 14 – Average NRL

5.0 Conclusion

5.1 Overview

The research undertaken for this project was experimental research as outlined in section 3.2.1 where the aim is to observe the output of varied parameters by analysing specific metrics. These results can be used to prove or disprove relationships that exist between the entities studied; in this case routing protocols AODV, DSDV and DSR are compared to each other in relation to performance factors. (Oates 2006)

This project aimed to investigate the performance of MANET routing protocols AODV, DSDV and DSR by researching the performance output based on the varied network characteristics of node density and mobility. Section 1.1.2 explained that dense topologies provide adequate links in order to route data however finding the path to a destination node is problematic due to the high number of nodes to consider. Therefore dense topologies will invariably affect the amount of overhead produced by each routing protocol due to the number of nodes that require to be considered. Sparse topologies introduce the problem of intermittent connections as the spatial position of nodes may mean that connections drop due to few nodes being widely spaced apart. Varied mobility patterns test the effectiveness of a routing protocol to route data where the node position is not kept constant, this problem will affect the routing overhead produced by a routing protocol as attempts are made to locate the destination node and keep path information up to date. (V, Aithal & ChandraSekaran 2006, Garousi 2005a, Divecha et al. 2007, Yamamura, Nakashima & Fukushima 2008b)

As concluded in section 2.6 of the literature review the way in which each routing protocol handles the various network conditions imposed is based on the mechanisms each employs to undertake routing decisions. These detailed mechanisms were outlined in section 2.5 where it can be understood that DSDV and DSR keep tables which are referred to in the first instance and thus the rate of mobility and node numbers will affect the refresh rate and number of stale routes. AODV bases routing decisions on the freshest information received and can alter the path of a routed packet based on the most up to date information collected.

Section 2.3.7 illustrated the investigation of MANET topics within the research community to identify solutions to the routing problems faced within MANETs. MANET research involved finding solutions to the problems faced by routing protocols in the dynamic environment of MANETs such as locating routes, dealing with stale routes, the amount of overhead produced and the requirement to consider the restrictions of wireless media such as limited bandwidth and power consumption of devices. The routing protocols investigated for the purpose of this study although different than those designed for infrastructure based networks are still developed around the principles of distance vector and link state algorithms. (Boukerche 2004b, Narayan, Syrotiuk 2003)(Layuan, Chunlin & Peiyan 2007)

Research into wireless networks has also increased within the research community due to the popularity of wireless technologies as identified in section 2.1.3 this sector has expanded with rapid growth. With the move towards 4G technologies and pervasive computing as outlined in section 1.1.2 , 2.1.4 and 2.3.9 the need for research into the area of wireless communications is vital as the use of this technology is predicted to be a prominent factor in future networks such as vehicle to vehicle, military, wearable computing equipment and even as last mile solutions. (Ramanathan, Redi 2002)

As outlined in section 2.1.2 of the literature review the first wireless packet network was based on the research conducted from the ALOHAnet which saw the creation of the first packet radio network in the 1970's. ALOHAnet was a single hop, packet broadcasting system and laid the foundations of a shift away from wired networks (Kiess, Mauve 2007b), (Abramson 1985). New techniques in random access communication were developed from the ALOHAnet project and transmission of data was accomplished through packet switching techniques similar to those used for ARPANET (Kuo 1974). Based on this research a new project PRNET was set up which saw the creation of the first MANET multi-hop packet radio network and as such the foundations were accomplished for MANETs, the mechanics of which are still used today. PRNET was replaced by SURAN (Kiess, Mauve 2007a). The SURAN project aimed to research networking technologies which could offer a robust communication method for dynamic topologies by finding solutions to the problems that arise from dynamic topologies. Advancements were made in link-layer routing algorithms and were set out in a SURAN protocol suite called SURAP. Simulations were carried out on the research produced from the project and later the framework provided the information necessary to develop a real test bed (Beyer 1990). The foundations of MANETs and mechanisms employed by the routing protocols are thus based on the findings of these research projects.

With the advancements identified earlier in this report and the need for wireless technologies to offer more advanced functionality it can be seen that research into this are is if importance and will provide the necessary insight and solutions to enable wireless networking to progress onto the next steps to meet future networking needs.

5.1.1 Reflexion of Research Results

AODV, DSDV and DSR were investigated for performance by varying node and mobility parameters. These parameters were set out in three control groups and analysed against the metrics PDR, NRL, End to End Delay, Throughput and No. of Packets Dropped as explained within section 3 of this report.

<u>Group 1</u>

The routing protocols were tested for performance in sparse and dense networks as identified in section 1.1.2 there is unique problems experienced within dense networks such as the ability to route data over a high number of mobile nodes and for sparse networks the problem of intermittent connections results from few nodes spaced widely apart. As concluded in section 2.6 of the literature review these factors are part of the dynamic nature of MANETs and the routing protocols must be able to function accordingly.

For control group 1 the setup as per Table 1 was varied node numbers ranging from 50, 100, 150 and 200 nodes. Speed was kept at a constant of 20 m/s and constant mobility was introduced from a pause time of 0 throughout.

DSR offered the best performance for a network of 50 nodes in terms of PDR as can be observed in Graph 1. This was due to the ability of DSR to outperform DSDV and AODV in small to medium sized networks by use of storing alternate routes in the route cache meaning DSR can respond well to change as identified in section 2.5.2 (Abolhasan, Wysocki & Dutkiewicz 2004).

However due to the number of stale routes and overhead produced DSR suffered a fall in performance after 50 nodes. DSR was designed to work in a network up to a maximum of 200 nodes as outlined in section 2.5.2 and the results of the simulation showed that DSR did manage to function for a network up to 200 nodes as compared to DSDV which did not manage to scale to a network of 200 nodes (Johnson, Hu & Maltz 2007). The NRL in Graph 2 shows the dramatic increase in overhead produced by DSR after 50 nodes, the end to end delay in Graph 3 shows the rise in delay experienced when routing packets and as such Graph 4 shows a decrease in throughput as the number of packets delivered per second become less.

DSDV shows an increased performance over DSR as the network scales. It can be observed from Graph 1 where DSR experiences a dramatic decrease in PDR, DSDV experiences only a slight decrease beyond 100 nodes. DSDV however did not scale to 200 nodes due to the assumption DSDV reached saturation past this point due to the vast amount of routing overhead required to store details of all routes within a dense network, this issue was identified in section 2.5.3 (Khan et al. 2008). DSDV performed best at 100 nodes, as can be observed from Graph 1 a slight increase is present in PDR. It can also be observed that the end to end delay is higher for DSDV in Graph 3 for 50 nodes where DSDV struggles to find paths through intermittent connections, as more connections are present from the increase to 100 nodes a marked drop in end to end delay is present. This dramatically climbs as the network reaches saturation at 200 nodes. DSDV however does have an increase in throughput in Graph 4 beyond 50 nodes showing that the protocol performs better with the more connections that are present and a decrease in dropped packets in Graph 5 can be observed beyond 100 nodes.

Graph 2 shows DSDV to have the lowest NRL overall, this is due to AODV requiring to produce more overhead from the reactive nature of the protocol and a higher NRL experienced by DSR as the protocol struggles to route packets as the network scales.

The reactive nature of AODV meant that this protocol had the best performance overall for Group 1 as can be seen in Graph 6. AODV managed to outperform DSDV and DSR in relation to PDR, end to end delay, throughput and no. of packets dropped as the protocol requests the routing information from the network before it routes a packet and therefore acts instantly to this information. The information kept in the routing tables of DSDV and DSR may involve stale routes as the information has been stored for a time before the packet requires to be sent and the location of the destination node may have changed. Routing changes take time to be propagated throughout the network leading to delays and stale routes. AODV has a higher overhead than DSDV due to the reason that overhead is generated every time a packet requires to be transmitted. In conclusion to group 1 the reactive routing protocol AODV handles the problems of dense and sparse networks better overall than DSR and DSDV.

DSR is useful in small to medium sized networks, illustrating the effectiveness of this protocol to deal with intermittent links, after this DSDV provides better performance up to a point of 150 nodes in comparison to DSR and AODV outperforms both DSDV and DSR. These results show DSR to perform well in situations of fewer nodes and intermittent links for PDR; however the no. of packets dropped is greatest for DSR for 50 nodes. DSDV and AODV perform better with more connections present than DSR, however DSDV does not manage to scale and AODV achieves greater performance over DSDV and does scale well in comparison to a network of 200 nodes meaning AODV gives the best performance overall for group 1.

Group 2

In order to test the protocols ability to route data within a MANET environment different mobility scenarios require to be introduced. As outlined in section 2.3.2 the dynamic nature of MANETs leads to a range of dynamic, random movements (Corson, Macker 1999). Control groups 2 and 3 aims to address the evaluation of performance characteristics through the introduction of varied mobility parameters.

Group 2 introduces a variance in pause time as outlined in Table 1. The pause times used were 0, 50, 100, 300 and 500 ms. A pause time of 0 ms is indicative of continuous movement and a pause time of 500 ms relates to no movement for the duration of the simulation. As explained this is not characteristic of a MANET environment but as it may occur for interest this pause time was explored. Mobile nodes are stationary for the duration of the pause time required before moving on randomly to a different way point.

For a pause time of 0 ms for PDR in Graph 7, DSR far outperforms AODV and DSDV due to the ability of DSR to use multiple routes stored in the cache meaning DSR can recover rapidly in high mobility scenarios as outlined in section 2.5.1 (Johnson, Hu & Maltz 2007). The PDR of DSR falls after this point to below the PDR of AODV at 300 ms; however for a PDR of 500 ms the performance of DSR returns to giving the best PDR out of the routing protocols compared. DSDV can be observed to have the worst PDR due to the presence of stale routes that occur with mobility. DSR overcomes this with the use of alternative routes and AODV actively sources the routing paths meaning the presence of stale routes would be less than with DSDV.

Due to the necessity for AODV to initiate a route request RREQ message for every transmission request as detailed in section 2.5.1, the overhead produced by the reactive protocol is considerably higher than DSDV and DSR. This higher NRL for AODV can be observed in Graph 8. DSR has slightly higher rates of NRL than DSDV however DSR delivers more packets than DSDV which could account for this occurrence as more overhead is produced in order to deliver more packets. This would also contribute to the higher rates seen in Graph 9 for end to end delay for DSR for high mobility scenarios as the PDR for DSR was significantly higher than for AODV and DSDV. After a pause time of 0 ms DSDV experiences a dramatic increase in end to end delay due to stale routes and the longer time period experienced for DSDV to recover from these. DSR has the highest NRL for a pause time of 500 ms where no node movement is present but as stated earlier the rate of PDR would affect this outcome and for a pause time of 500 ms DSR has the highest rate of PDR. AODV experiences the least delay overall as the reactive nature of sourcing routes ensure the delay for packet delivery is less in comparison to DSDV and DSR.

Due to the ability of DSR to recover when dealing with the dynamic nature of the MANET mobility variances for Graph 10 the throughput of DSR can be seen to be the highest overall especially for a pause time of 0 ms where mobility is highest. AODV has the second highest throughput due to the ability to use the most up to date routing information sourced reactively to requests. DSDV can be observed to have the lowest throughput in Graph 10 due to the presence of stale routes and the longer length of time taken to recover.

In Graph 11 the benefits of using the most up to date information as is the case for AODV is apparent in that AODV has the least amount of packets dropped. AS DSDV and DSR both make use of stored routes within a table the amount of packets dropped is comparable although DSDV has the higher overall rate of dropped packets. As DSR has the highest PDR and throughput in comparison to DSDV it can be predicted that the overall number of packets dropped would be still further lower than that of DSDV if the figures of PDR and throughput were equal.

In Graph 12 the overall performance of AODV can be seen to be the steadiest out of the three. Although AODV performs second in comparison to DSR for PDR and throughput and experiences the highest NRL out of the three protocols, AODV has the least end to end delay and no. of packets dropped by far in comparison to DSDV and DSR. Graph 12 shows DSDV to perform the best for 0 ms pause time. The metrics that influenced this outcome were NRL and end to end delay where DSDV has the lowest figure out of the three protocols. These metrics along with the number of packets dropped have also influenced the result for DSDV for a pause time of 500 ms. As the PDR and throughput values were lowest for DSDV for a pause time of both 0 ms and 500 ms the NRL and end to end delay rate would be affected as the number of packets delivered is less the overall delay and overhead would also be less. The number of packets dropped for a pause time of 500 ms is more or less equal to that of DSR as both make use of routing tables. As the network is stationary at 500 ms the number of stale routes would be less than experienced in high mobility scenarios. AODV drops more packets than DSDV and DSR at a pause time of 500 ms as more overhead is produced in sourcing routing paths.

For group 3 the performance of DSR is greater than that of DSDV with the output seen in Graph 12 explained in relation to the low PDR and throughput of DSDV. From the results of PDR and throughput it is evident the conclusion from section 2.5.2 is correct in that DSR can outperform DSDV and AODV in high mobility scenarios due to the ability to rapidly recover from change. AODV manages to keep end to end delay and no. of packets dropped to a minimum during mobility due to the reactive nature of the protocol. Due to the results of PDR and throughput it is derived that DSR offers the best performance for high mobility scenarios. AODV is a good alternative to DSR due to the low delays and no. of packets dropped and the fact the protocol outperforms DSDV. For the uncharacteristic scenario of no mobility DSR and DSDV drop the least amount of packets however AODV is stronger than DSDV for PDR and throughput and DSR again outperforms AODV and DSR. DSR and AODV are found to be the best protocols to use from the research undertaken for varied pause times, with DSR better for high mobility and no mobility scenarios.

Group 3

The speed of mobility was varied for group 3 as per Table 1 the speeds were set at 5, 10, 15 and 20 m/s with a constant pause time of 0 ms and the number of nodes set to 100 throughout. The protocols ability to deal with high mobility over varied speeds will be tested for group 3.

For the lowest speed of 5 m/s in Graph 13 the reactive nature of AODV proves to offer the best performance in terms of PDR as there will be fewer changes to the routes sourced on demand. As speed increases the PDR of AODV drops and as was concluded earlier DSR has the best ability to deal with high mobility scenarios therefore from 10 to 20 m/s DSR has the highest PDR rate. DSDV has the lowest PDR due to the stale routes within the routing table and the inability to react as quickly as DSR and AODV in resolving this issue. In Graph 16 the ability of DSR to perform in mobility scenarios is evident as the protocol has the highest throughput, followed by AODV and DSDV has the lowest.

It was concluded from Al-Maashri et al (Al-Maashri, Ould-Khaoua 2006)that the ability for DSR to learn routes via intermediate nodes and the use of acknowledgements meant that DSR could learn of broken links and adapt routes as per the finding of fresher routes and thus can recover by responding quickly to network changes.

Again AODV has the lowest end to end delay seen in Graph 15 and the least number of packets dropped as per Graph 17, the reason for this is as described earlier in that AODV sources routes on demand and therefore the occurrence of stale routes is less than that of DSDV and DSR which use routing table data before initiating a route discovery request. The method used by AODV of sourcing routes on demand for every request again also accounts for the highest NRL in Graph 14. DSDV experiences the highest end to end delays and number of packets dropped however the NRL is less than that of DSR. DSR could be accounted to have a higher NRL than DSDV due to the increased PDR and throughput levels as compared to DSDV, also if any stale routes were present for the alternative routes used this would contribute to further higher overhead.

Graph 18 which provided a comparison based on the data from all metrics shows AODV to perform the best overall; this is down to the low end to end delays and no. of packets dropped and the highest PDR rate at a speed of 5 m/s. DSR has the highest throughput and PDR rate from 10 m/s as explained this protocol is best for higher mobility scenarios than AODV and DSDV in terms of PDR and throughput although for these calculations the other factors of end to end delay and no. of packets dropped affects the score for DSR in relation to AODV. The higher NRL rate affects this result in relation to DSDV as for all other metrics DSR outperforms DSDV. Again as DSR delivers more packets than DSDV the overhead produced would be greater in order to achieve this thus a direct comparison for NRL is not possible but it is envisaged that the NRL would be less for DSR if the amount of packets delivered were equal with DSDV.

It can therefore be concluded that for high mobility scenarios DSR offers the highest PDR and throughput and for low speeds AODV offers the greatest performance. AODV offers the least end to end delays and no. of packets dropped throughout.

5.1.2 Overall Conclusion

In terms of the research question which aimed to investigate the performance of MANET routing protocols AODV, DSDV and DSR in relation to varied network parameters of node density and mobility the following conclusions can be derived. From the analysis of results it can be concluded that reactive protocols work more efficiently for MANETs as the performance of AODV was favourable for group 1 and for groups 2 and 3 the performance of AODV and DSR was greater than DSDV.

AODV outperformed DSDV and DSR for the majority of group 1 where factors of dense and sparse networks were introduced. The ability of AODV to source routes on demand proved most effective in dealing with routing data as the network scaled.

As predicted in section 2.5.2 DSR performed best in small to medium sized networks and for a network of 50 nodes this was proved to be correct. DSR was therefore proved to be useful in small networks and AODV was shown to be the most effective for networks beyond 50 nodes. DSDV performed better than DSR for a network of between 100 and 150 nodes due to the overhead produced by DSR, although as the overhead for DSDV grow significantly the protocol could not scale past 150 nodes.

The prediction identified in section 2.5.2 was proven to be correct in that DSR outperformed DSDV and AODV for high mobility scenarios therefore for control groups 2 and 3 for high mobility scenarios DSR offered the best performance in terms of packets delivered. DSR was also found to offer the best performance where no mobility was present. DSR is a reactive protocol but also makes use of a cache table which stores routes to destinations and also stores alternate routes and thus has similarities of AODV and DSDV. As the cached routes are checked first DSR suffers from stale routes within the cache as does DSDV. DSR can learn routes over heard by intermittent nodes and detect broken links as identified in (Al-Maashri, Ould-Khaoua 2006) meaning that the protocol can recover faster than DSDV and the use of alternate routes proves beneficial in high mobility scenarios. AODV experiences the lowest end to end delays and drops the least packets in relation to DSR and DSDV for both control groups 2 and 3 due to the problem of stale routes affecting this protocol the least as this protocol will source routes on demand and will not make use of routing table entries. Therefore DSR and AODV proved more beneficial for the mobility scenarios introduced in groups 2 and 3 with DSR being more effective in high mobility high speed environment in terms of throughput and packets delivered. The proactive nature of DSDV to source routes to all nodes within the topology proved ineffective in comparison for the mobility scenarios tested due to the presence of stale routes.

5.1.2 Hypothesis Conclusion

The table driven nature of DSDV was proven to be the cause of a lower PDR in high mobility scenarios as per the analysis of the PDR graphs 7 and 13 from control groups 2 and 3 which focussed on the varied mobility parameters of speed and pause time. Hypothesis number one was thus proven to be correct as the number of stale routes present within the routing table in high mobility scenarios for DSDV meant that the overall PDR was less in comparison to reactive protocols AODV and DSR. Due to this reason DSDV had the highest number of packets dropped for groups 2 and 3 as can be seen from graphs 11 and 17. Thus it can be derived that reactive protocols are better placed in high mobility scenarios as compared to pro-active protocols.

Hypothesis number 2 was proved wrong in that it was determined AODV would have the highest PDR for high mobility scenarios. The conclusion from studying PDR graphs 7 and 13 showed DSR to have the highest PDR for high mobility scenarios.

For a low speed of 5 m/s and a pause time of 300 ms AODV had the highest PDR but overall DSR outperformed AODV for the remainder and especially for the highest mobility settings with a PDR for a pause time of 0 and a speed of 20 m/s. DSR was hypothesised to have the lowest PDR due to the use of the cache and the presence of stale routes as mobility grows. Certainly if the end to end delay is analysed for groups 2 and 3 in graphs 9 and 15 it can be observed AODV has the lowest delay due to the use of fresher routes. However as concluded previously DSR can outperform AODV in high mobility scenarios due to the ability to use alternate routes and source routes new routes by over hearing new routing information via intermittent nodes. The use of acknowledgments also alerts DSR to broken links (Al-Maashri, Ould-Khaoua 2006). This ability for DSR to recover quickly meant that although the end to end delays were higher and also the number of packets dropped due to stale routes was higher as seen in graphs 11 and 17 the ability to recover quickly meant that the PDR and throughput was more for DSR in high mobility scenarios compared to AODV. AODV did have the better performance in terms of end to end delay and throughput but as routes were sourced on demand the overall PDR and throughput was lower than DSR. Due to a higher packet delivery DSR therefore performs best for high mobility scenarios and achieves a higher PDR through the use of the cache and ability to recover quickly from change.

Hypothesis number 3 had determined that DSDV would have a higher NRL for high mobility scenarios due to the attempts made to store routes to every other node on the network and with mobility the number of stale routes increase leading to higher overhead. Graphs 8 and 14 were observed for mobility groups 2 and 3 and DSDV was found to have the lowest NRL. DSDV did have the lowest throughput and PDR overall for groups 2 and 3 as can be observed from graphs 16, 14, 10 and 7 which would affect the amount of NRL produced as explained earlier in this report. It was also determined from the results in section 4.2.2 and 4.2.3 that reactive protocols produce more overhead overall as overhead is produced every time a request is made in order to first source the route where as DSDV first makes use of existing routing table entries. DSR has lower rates of NRL as can be observed from graphs 8 and 14 as although DSR is classed as a reactive routing protocol it first makes use of routes stored within the cache and thus NRL is comparative with DSDV. A direct comparison cannot be made as also identified previously in sections 4.2.2, 4.2.3 and 5.1.2 as the rate of PDR and throughput is less for DSDV than that of DSR meaning DSR will produce more overhead in order to route more packets. Thus in terms of NRL performance for high mobility scenarios a comparison between DSDV and DSR cannot be accurately made. As DSDV has a lower PDR and throughput for high mobility scenarios in comparison to DSR it could be presumed that in the case of reactive protocol DSR, DSDV would have a higher NRL rate and thus this hypothesis could be proven correct. Graph 8 shows DSR and DSDV to have the same level of NRL for pause times of 300 and 500 seconds where no mobility is present. Graph 8 shows the PDR of DSDV and DSR to be the same for 300 seconds and higher for DSR for 500 seconds.

As the NRL rates are comparable and favourable for DSR where no mobility is present for group 2 in graph 8 as compared to AODV it can be observed that due to the use of routing tables both perform similar in terms of routing in this aspect. As mobility increases DSR which has been proven to have the highest PDR and throughput rates delivers more packets than DSDV by far and thus requires more overhead in order to do so. It can then be further concluded the probability of the reactive protocol DSR producing less NRL than DSDV if the amount of packets delivered were equal is most likely the case and would prove this hypothesis correct in terms of comparison with DSR.

5.1.3 Benefits of this Research

This research has helped understand the performance characteristics of AODV, DSDV and DSR in relation to varied network parameters of node density and mobility. The conclusions of this research has found reactive protocols to offer the best performance in terms of routing operation for MANETs based on the parameters PDR, NRL, End to End Delay, Throughput and No. of Packets Dropped. These conclusions also showed the difference in performance for reactive routing protocols AODV and DSR with AODV being able to cope better with node density beyond 50 nodes and DSR to perform better with high mobility rates. These results can therefore aid the deployment of the most effective routing protocol dependant on the type of network and offer and insight into developments of MANET routing protocols for the scenarios studied within this report.

5.2 Future Research

The future directions of MANETs identified in section 2.3.9 of the literature review refers to future directions of research focussing on large scale dense deployments which make use of multi-media applications. Other uses identified including vehicle communication systems, military, last mile solutions and wearable computing equipment mean that these systems will not only have to function for the purpose of being able to route data but will also have to handle different types of data effectively. (Ramanathan, Redi 2002)

Multi-media applications are becoming more prevalent and part responsible for the growth in wireless networking as accessibility to different platforms grows devices have become multi-functional allowing for the user to carry out a variety of tasks on a single device. Multi-media applications require a level of quality of service (QOS) and delays affect the output and usability of this type of media. Section 2.1.4 and 2.3.9 identifies 4G technologies as the next step in wireless devices offering faster data rates, reliability and applications (Chou, Chang & Wu 2008), (Anderson, Daim & Kim 2008b). It is envisioned that 4G technologies would allow for the ubiquitous vision of MANETs to become a reality (Penttinen).

With more demands being placed on the type of data used on a network and a requirement for a level of (QOS) MANETs must not only be able to deal with the issues faced by dynamic topologies but must also be able to route data to a level of QOS in order to support the multi-media driven networks of today and the future.

The 802.11e standard aims to address the issues of QOS for delay sensitive applications and 802.11n is predicted to offer the data rates required for future wireless technologies as explained in section 2.1.4 (Cisco Networking Academy Program Fundamentals of Wireless LANs Companion Guide 2004), (Paul, Ogunfunmi 2008). The dynamic nature of a MANET where the environment is unpredictable poses a problem in relation to achieving QOS. As outlined in section 2.3.8 Royer et al (Royer, Chai-Keong Toh 1999) identified a number of issued that are prevalent in MANETs including QOS. The dynamic nature was not the only problem identified to pose a problem in relation to achieving QOS, the very nature of wireless media introduces issues such as the hidden and exposed node problem, channel fading and signal interference.

Due to the findings of the future requirements of MANETs it would be beneficial for further research to be undertaken as to find out how MANET routing protocols perform with QOS parameters introduced and time sensitive traffic. As this report has found reactive protocols to be beneficial the findings also showed that although DSR was beneficial for high mobility scenarios the end to end delay and number of packets dropped were fewer overall for AODV. Thus it would be an interesting research point to identify the performance characteristics of MANET protocols in relation to achieving QOS. QOS has been identified as a factor which will be required in order to achieve the wireless networks envisaged for the future, therefore MANET routing protocols must be able to provide a level of QOS to meet the demands of the networks they will be part of in the future.

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Trung, H.D., Benjapolakul, W. & Duc, P.M. 2007b, "Performance evaluation and comparison of different ad hoc routing protocols", *Computer Communications,* vol. 30, no. 11-12, pp. 2478-2496.

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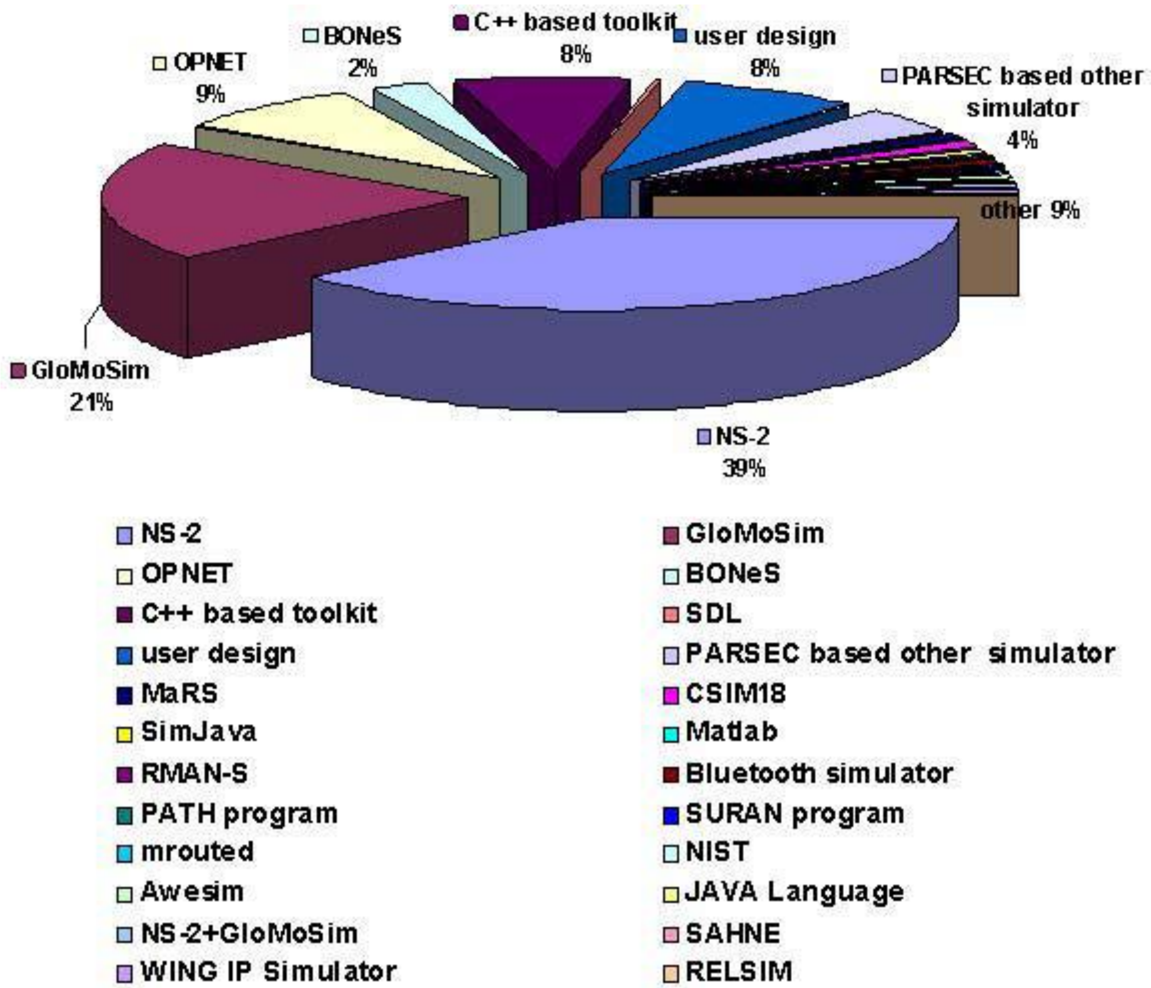
7.0 Appendix

7.1 NS2 Usage (Dow et al. 2005)



7.2 NS Mailing List Thread (Sahraei 2006)

[ns] NS hangs with certain physical layer settings

Sasan Sahraei
Sat, 01 Apr 2006 21:31:06 -0800

> Hi All,
>
> When I set the physical layer parameters as below, ns hangs when ONLY using DSDV
>
> Phy/WirelessPhy set CPThresh_ 10.0
> Phy/WirelessPhy set CSThresh_ 1.559e-11
> Phy/WirelessPhy set RXThresh_ 3.652e-10 <--- note this one
> Phy/WirelessPhy set bandwidth_ 2e6
> Phy/WirelessPhy set Pt_ 0.2818
> Phy/WirelessPhy set freq_ 914e+6
> Phy/WirelessPhy set L_ 1.0
>
> but when I set RXThresh to 1.47635e-07, it works perfectly but then it result in dropping so many packets (due to propagation model settings combinations)
>
> but I don't understand why ns should hang. (again only for DSDV, as it works correct for AODV).
>
> Any opinions will be appreciated.
>
> Thanks,
> Sasan

http://www.mail-archive.com/ns-users@isi.edu/msg01739.html

7.3 DSDV Mailing List Post

FW: DSDV physical layer problem, cannot get DSDV to work with any other setting apart from RXThresh_ 1.47635e-07 otherwise the simulation hangs, need to simulate DSDV for Phy/WirelessPhy set RXThresh_ 3.652e-10

by catj Feb 28, 2010; 10:01pm :: Rate this Message: - Use ratings to moderate (?)

Reply | Print | View Threaded | Show Only this Message
Hi,

I have a problem with the physical layer parameters for DSDV routing protocol. I am simulating AODV, DSR and DSDV and for AODV and DSR the physical layer parameters for 250 or 100 meters work fine. DSDV however hangs and will not simulate for the same physical layer settings, the only setting that works with DSDV is RXThresh_ 1.47635e-07 this is the only setting I can get DSDV to work with and due to this I cannot accurately compare the routing protocols for my project. I have a problem where I cannot obtain any results for Normalised Routing Load for DSDV when running the awk scripts, I am assuming the the problems with the output I need from the awk scripts may be due to large packet loss from not being able to simulate DSDV under physical layer settings other than the one stated above. I would like to simulate DSDV for 250 meters and 100 meters. The following parameters are what I use for AODV and DSR for 250 meter range. When simulating DSDV I have to omit all of the 250 meter range attributes and use only RXThresh_ 1.47635e-07 otherwise my simulation hangs.

```
set val(txPower)        0.66  ; #250 meters
Phy/WirelessPhy set CPThresh_ 10.0
Phy/WirelessPhy set RXThresh_ 3.652e-10 ;#250 meters
Phy/WirelessPhy set Pt_ 0.2818 ;#250 meters tx distance
Phy/WirelessPhy set CSThresh_ 1.559e-11 ;#250 meters
Phy/WirelessPhy set Rb_ 2*1e6
Phy/WirelessPhy set freq_ 914e+6
Phy/WirelessPhy set L_ 1.0
```

I cannot measure NRL (Normalised Routing Load) through my awk scripts as routing packets appear as 0.00. If I could overcome the problem with the physical layer settings it would enable me to compare these three routing protocols accurately. If anyone has encountered this problem or knows how to resolve it please help me overcome this problem.

Thanks,
Jafar

http://old.nabble.com/FW:-DSDV-physical-layer-problem,-cannot-get-DSDV-to-work-with-any-other-setting-apart-from-RXThresh_-1.47635e-07-otherwise-the-simulation-hangs,-need-to-simulate-DSDV-for-Phy-WirelessPhy-set-RXThresh_-3.652e-10-td27738397.html

7.4 AODV TCL File Code

```
# Copyright (c) 1999 Regents of the University of Southern California.
# All rights reserved.
#
# Redistribution and use in source and binary forms, with or without
# modification, are permitted provided that the following conditions
# are met:
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# 3. All advertising materials mentioning features or use of this software
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#      This product includes software developed by the Computer Systems
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THE
# IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A
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# ARE DISCLAIMED.  IN NO EVENT SHALL THE REGENTS OR CONTRIBUTORS BE
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# FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR
CONSEQUENTIAL
# DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE
GOODS
# OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION)
# HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN
CONTRACT, STRICT
```

```
# LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN
ANY WAY
# OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF
# SUCH DAMAGE.
# wireless1.tcl
# A simple example for wireless simulation

#
======================================================================
=
# Define options
#
======================================================================
=
set val(chan)           Channel/WirelessChannel
set val(prop)           Propagation/TwoRayGround
set val(netif)          Phy/WirelessPhy
set val(mac)            Mac/802_11
#set val(ifq)           CMUPriQueue
set val(ifq)            Queue/DropTail/PriQueue
set val(ll)             LL
set val(ant)            Antenna/OmniAntenna
set val(x)          500   ;# X dimension of the topography
set val(y)          500   ;# Y dimension of the topography
set val(ifqlen)       50    ;# max packet in ifq
set val(seed)        0.0
set val(adhocRouting)   AODV

#set val(nn)          50 ;# how many nodes are simulated
#set val(cp)          "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/dimi/traffic/cbr-n50-s1.0-
mc50-r0.2"
#set val(cp)          "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/tcl/mobility/scene/cbr-3-test"
#set val(sc)          "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/dimi/scen/n50-s20-1.scen"
#set val(sc)          "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/tcl/mobility/scene/scen-3-test"
#set val(stop)         500.0          ;# simulation time

set val(txPower)        0.66  ; #250 meters
#set val(txPower)       0.0075  ; #100 meters
#Phy/WirelessPhy        set Pt_ 7.214e-3 ;#100 meters tx distance


# ==================================================
# Other Default Settings
# ==================================================
```

```
ns-random 538474442L

LL set mindelay_            50us
LL set delay_               25us
LL set bandwidth_           0 ;# not used

Agent/Null set sport_       0
Agent/Null set dport_       0

Agent/CBR set sport_        0
Agent/CBR set dport_        0

Agent/TCPSink set sport_    0
Agent/TCPSink set dport_    0

Agent/TCP set sport_        0
Agent/TCP set dport_        0
Agent/TCP set packetSize_   512

Queue/DropTail/PriQueue set Prefer_Routing_Protocols   1

# unity gain omni-directional antennas
Antenna/OmniAntenna set X_ 0
Antenna/OmniAntenna set Y_ 0
Antenna/OmniAntenna set Z_ 1.5
Antenna/OmniAntenna set Gt_ 1.0
Antenna/OmniAntenna set Gr_ 1.0

#Shared Media interface for 914MHz WaveLan DSSS
Phy/WirelessPhy set CPThresh_ 10.0
Phy/WirelessPhy set CSThresh_ 1.559e-11 ;#250 meters
#Phy/WirelessPhy set CSThresh_ 1.42681e-08 ;#100 meters
Phy/WirelessPhy set RXThresh_ 3.652e-10 ;#250 meters
#Phy/WirelessPhy set RXThresh_ 1.42681e-08 ;#100 meters
#Phy/WirelessPhy set RXThresh_ 1.47635e-07 ;#DSDV only setting the works
Phy/WirelessPhy set Rb_ 2*1e6
Phy/WirelessPhy set Pt_ 0.2818 ;#250 meters tx distance
#Phy/WirelessPhy set Pt_ 7.214e-3 ;#100 meters tx distance
#Phy/WirelessPhy set Pt_ 8.5872e-4 ;#40 meters tx distance
Phy/WirelessPhy set freq_ 914e+6
Phy/WirelessPhy set L_ 1.0
```

```
#
==========================================================================
# Read from comand line
#
==========================================================================

set val(op)       [lindex $argv 0]
set val(sc)       [lindex $argv 1]
set val(cp)         [lindex $argv 2]
set val(nn)       [lindex $argv 3]
set val(stop)      [lindex $argv 4]


#
==========================================================================
# Main Program
#
==========================================================================
=

#
# Initialize Global Variables
#

# create simulator instance

set ns_             [new Simulator]

# setup topography object

set topo            [new Topography]

# create trace object for ns and nam

set nt [open $val(op) w]

$ns_ use-newtrace
$ns_ trace-all $nt


# define topology
$topo load_flatgrid $val(x) $val(y)

#
# Create God
```

```
#
set god_ [create-god $val(nn)]

#
# define how node should be created
#

#global node setting

$ns_ node-config -adhocRouting $val(adhocRouting) \
		-llType $val(ll) \
		-macType $val(mac) \
		-ifqType $val(ifq) \
		-ifqLen $val(ifqlen) \
		-antType $val(ant) \
		-propType $val(prop) \
			-phyType $val(netif) \
		-channelType $val(chan) \
			-topoInstance $topo \
			-agentTrace ON \
		-routerTrace ON \
		-macTrace ON

#
#  Create the specified number of nodes [$val(nn)] and "attach" them
#  to the channel.

for {set i 0} {$i < $val(nn) } {incr i} {
	set node_($i) [$ns_ node]
	$node_($i) random-motion 0		;# disable random motion
}


#
# Define node movement model
#
puts "Loading connection pattern..."
source $val(cp)

#
# Define traffic model
#
puts "Loading scenario file..."
source $val(sc)
```

```
# Define node initial position in nam

for {set i 0} {$i < $val(nn)} {incr i} {

    # 20 defines the node size in nam, must adjust it according to your scenario
    # The function must be called after mobility model is defined

    $ns_ initial_node_pos $node_($i) 100
}


#
# Tell nodes when the simulation ends
#
for {set i 0} {$i < $val(nn) } {incr i} {
    $ns_ at $val(stop).0 "$node_($i) reset";
}

$ns_ at  $val(stop).0002 "puts \"NS EXITING...\" ; $ns_ halt"

puts $nt "M 0.0 nn $val(nn) x $val(x) y $val(y) rp $val(adhocRouting)"
puts $nt "M 0.0 sc $val(sc) cp $val(cp) seed $val(seed)"
puts $nt "M 0.0 prop $val(prop) ant $val(ant)"

puts "Starting Simulation..."
$ns_ run
```

7.5 DSDV TCL File Code

```
# Copyright (c) 1999 Regents of the University of Southern California.
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#
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# modification, are permitted provided that the following conditions
# are met:
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#    must display the following acknowledgement:
#      This product includes software developed by the Computer Systems
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#    specific prior written permission.
#
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THE
# IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A
PARTICULAR PURPOSE
# ARE DISCLAIMED.  IN NO EVENT SHALL THE REGENTS OR CONTRIBUTORS BE
LIABLE
# FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR
CONSEQUENTIAL
# DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE
GOODS
# OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION)
# HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN
CONTRACT, STRICT
# LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN
ANY WAY
```

```
# OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF
# SUCH DAMAGE.
# wireless1.tcl
# A simple example for wireless simulation

#
======================================================================
=
# Define options
#
======================================================================
=
set val(chan)           Channel/WirelessChannel
set val(prop)           Propagation/TwoRayGround
set val(netif)          Phy/WirelessPhy
set val(mac)            Mac/802_11
#set val(ifq)           CMUPriQueue
set val(ifq)            Queue/DropTail/PriQueue
set val(ll)             LL
set val(ant)            Antenna/OmniAntenna
set val(x)          500   ;# X dimension of the topography
set val(y)          500   ;# Y dimension of the topography
set val(ifqlen)       50    ;# max packet in ifq
set val(seed)        0.0
set val(adhocRouting)   DSDV

#set val(nn)           50 ;# how many nodes are simulated
#set val(cp)           "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/dimi/traffic/cbr-n50-s1.0-
mc50-r0.2"
#set val(cp)           "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/tcl/mobility/scene/cbr-3-test"
#set val(sc)           "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/dimi/scen/n50-s20-1.scen"
#set val(sc)           "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/tcl/mobility/scene/scen-3-test"
#set val(stop)          500.0          ;# simulation time

set val(txPower)         0.66  ; #250 meters
#set val(txPower)        0.0075  ; #100 meters
#Phy/WirelessPhy       set Pt_ 7.214e-3 ;#100 meters tx distance


# ==========================================================
# Other Default Settings
# ==========================================================


ns-random 538474442L
```

```
LL set mindelay_           50us
LL set delay_              25us
LL set bandwidth_          0 ;# not used

Agent/Null set sport_      0
Agent/Null set dport_      0

Agent/CBR set sport_       0
Agent/CBR set dport_       0

Agent/TCPSink set sport_   0
Agent/TCPSink set dport_   0

Agent/TCP set sport_       0
Agent/TCP set dport_       0
Agent/TCP set packetSize_  512

Queue/DropTail/PriQueue set Prefer_Routing_Protocols   1

# unity gain omni-directional antennas
Antenna/OmniAntenna set X_ 0
Antenna/OmniAntenna set Y_ 0
Antenna/OmniAntenna set Z_ 1.5
Antenna/OmniAntenna set Gt_ 1.0
Antenna/OmniAntenna set Gr_ 1.0

#Shared Media interface for 914MHz WaveLan DSSS
Phy/WirelessPhy set CPThresh_ 10.0
Phy/WirelessPhy set CSThresh_ 1.559e-11 ;#250 meters
#Phy/WirelessPhy set CSThresh_ 1.42681e-08 ;#100 meters
Phy/WirelessPhy set RXThresh_ 3.652e-10 ;#250 meters
#Phy/WirelessPhy set RXThresh_ 1.42681e-08 ;#100 meters
#Phy/WirelessPhy set RXThresh_ 1.47635e-07 ;#DSDV only setting the works
Phy/WirelessPhy set Rb_ 2*1e6
Phy/WirelessPhy set Pt_ 0.2818 ;#250 meters tx distance
#Phy/WirelessPhy set Pt_ 7.214e-3 ;#100 meters tx distance
#Phy/WirelessPhy set Pt_ 8.5872e-4 ;#40 meters tx distance
Phy/WirelessPhy set freq_ 914e+6
Phy/WirelessPhy set L_ 1.0


#
=====================================================================
```

```
# Read from comand line
#
=======================================================================

set val(op)      [lindex $argv 0]
set val(sc)      [lindex $argv 1]
set val(cp)        [lindex $argv 2]
set val(nn)      [lindex $argv 3]
set val(stop)      [lindex $argv 4]


#
=======================================================================
# Main Program
#
=======================================================================
=

#
# Initialize Global Variables
#

# create simulator instance

set ns_            [new Simulator]

# setup topography object

set topo           [new Topography]

# create trace object for ns and nam

set nt [open $val(op) w]

$ns_ use-newtrace
$ns_ trace-all $nt


# define topology
$topo load_flatgrid $val(x) $val(y)

#
# Create God
#
set god_ [create-god $val(nn)]
```

```
#
# define how node should be created
#

#global node setting

$ns_ node-config -adhocRouting $val(adhocRouting) \
                -llType $val(ll) \
                -macType $val(mac) \
                -ifqType $val(ifq) \
                -ifqLen $val(ifqlen) \
                -antType $val(ant) \
                -propType $val(prop) \
                        -phyType $val(netif) \
                -channelType $val(chan) \
                        -topoInstance $topo \
                        -agentTrace ON \
                -routerTrace ON \
                -macTrace ON

#
#  Create the specified number of nodes [$val(nn)] and "attach" them
#  to the channel.

for {set i 0} {$i < $val(nn) } {incr i} {
        set node_($i) [$ns_ node]
        $node_($i) random-motion 0              ;# disable random motion
}


#
# Define node movement model
#
puts "Loading connection pattern..."
source $val(cp)

#
# Define traffic model
#
puts "Loading scenario file..."
source $val(sc)

# Define node initial position in nam
```

```
for {set i 0} {$i < $val(nn)} {incr i} {

   # 20 defines the node size in nam, must adjust it according to your scenario
   # The function must be called after mobility model is defined

   $ns_ initial_node_pos $node_($i) 100
}


#
# Tell nodes when the simulation ends
#
for {set i 0} {$i < $val(nn) } {incr i} {
   $ns_ at $val(stop).0 "$node_($i) reset";
}

$ns_ at  $val(stop).0002 "puts \"NS EXITING...\" ; $ns_ halt"

puts $nt "M 0.0 nn $val(nn) x $val(x) y $val(y) rp $val(adhocRouting)"
puts $nt "M 0.0 sc $val(sc) cp $val(cp) seed $val(seed)"
puts $nt "M 0.0 prop $val(prop) ant $val(ant)"

puts "Starting Simulation..."
$ns_ run
```

7.6 DSR TCL File Code

```
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#
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CONSEQUENTIAL
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GOODS
# OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION)
# HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN
CONTRACT, STRICT
# LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN
ANY WAY
```

```
# OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF
# SUCH DAMAGE.
# wireless1.tcl
# A simple example for wireless simulation

#
=====================================================================
=
# Define options
#
=====================================================================
=
set val(chan)           Channel/WirelessChannel
set val(prop)           Propagation/TwoRayGround
set val(netif)          Phy/WirelessPhy
set val(mac)            Mac/802_11
set val(ifq)            CMUPriQueue
#set val(ifq)           Queue/DropTail/PriQueue
set val(ll)             LL
set val(ant)            Antenna/OmniAntenna
set val(x)          500   ;# X dimension of the topography
set val(y)          500   ;# Y dimension of the topography
set val(ifqlen)       50    ;# max packet in ifq
set val(seed)        0.0
set val(adhocRouting)   DSR

#set val(nn)          50 ;# how many nodes are simulated
#set val(cp)          "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/dimi/traffic/cbr-n50-s1.0-
mc50-r0.2"
#set val(cp)          "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/tcl/mobility/scene/cbr-3-test"
#set val(sc)          "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/dimi/scen/n50-s20-1.scen"
#set val(sc)          "/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/tcl/mobility/scene/scen-3-test"
#set val(stop)         500.0          ;# simulation time

set val(txPower)        0.66  ; #250 meters
#set val(txPower)       0.0075  ; #100 meters
#Phy/WirelessPhy        set Pt_ 7.214e-3 ;#100 meters tx distance


# ===================================================
# Other Default Settings
# ===================================================


ns-random 538474442L
```

```
LL set mindelay_            50us
LL set delay_               25us
LL set bandwidth_           0 ;# not used

Agent/Null set sport_       0
Agent/Null set dport_       0

Agent/CBR set sport_        0
Agent/CBR set dport_        0

Agent/TCPSink set sport_    0
Agent/TCPSink set dport_    0

Agent/TCP set sport_        0
Agent/TCP set dport_        0
Agent/TCP set packetSize_   512

Queue/DropTail/PriQueue set Prefer_Routing_Protocols   1

# unity gain omni-directional antennas
Antenna/OmniAntenna set X_ 0
Antenna/OmniAntenna set Y_ 0
Antenna/OmniAntenna set Z_ 1.5
Antenna/OmniAntenna set Gt_ 1.0
Antenna/OmniAntenna set Gr_ 1.0

#Shared Media interface for 914MHz WaveLan DSSS
Phy/WirelessPhy set CPThresh_ 10.0
Phy/WirelessPhy set CSThresh_ 1.559e-11 ;#250 meters
#Phy/WirelessPhy set CSThresh_ 1.42681e-08 ;#100 meters
Phy/WirelessPhy set RXThresh_ 3.652e-10 ;#250 meters
#Phy/WirelessPhy set RXThresh_ 1.42681e-08 ;#100 meters
#Phy/WirelessPhy set RXThresh_ 1.47635e-07 ;#DSDV only setting the works
Phy/WirelessPhy set Rb_ 2*1e6
Phy/WirelessPhy set Pt_ 0.2818 ;#250 meters tx distance
#Phy/WirelessPhy set Pt_ 7.214e-3 ;#100 meters tx distance
#Phy/WirelessPhy set Pt_ 8.5872e-4 ;#40 meters tx distance
Phy/WirelessPhy set freq_ 914e+6
Phy/WirelessPhy set L_ 1.0


#
======================================================================
```

```
# Read from comand line
#
==========================================================================

set val(op)      [lindex $argv 0]
set val(sc)      [lindex $argv 1]
set val(cp)        [lindex $argv 2]
set val(nn)      [lindex $argv 3]
set val(stop)      [lindex $argv 4]


#
==========================================================================
# Main Program
#
==========================================================================
=

#
# Initialize Global Variables
#

# create simulator instance

set ns_          [new Simulator]

# setup topography object

set topo         [new Topography]

# create trace object for ns and nam

set nt [open $val(op) w]

$ns_ use-newtrace
$ns_ trace-all $nt


# define topology
$topo load_flatgrid $val(x) $val(y)

#
# Create God
#
set god_ [create-god $val(nn)]
```

```
#
# define how node should be created
#

#global node setting

$ns_ node-config -adhocRouting $val(adhocRouting) \
                 -llType $val(ll) \
                 -macType $val(mac) \
                 -ifqType $val(ifq) \
                 -ifqLen $val(ifqlen) \
                 -antType $val(ant) \
                 -propType $val(prop) \
                         -phyType $val(netif) \
                 -channelType $val(chan) \
                         -topoInstance $topo \
                         -agentTrace ON \
                 -routerTrace ON \
                 -macTrace ON

#
#  Create the specified number of nodes [$val(nn)] and "attach" them
#  to the channel.

for {set i 0} {$i < $val(nn) } {incr i} {
        set node_($i) [$ns_ node]
        $node_($i) random-motion 0              ;# disable random motion
}


#
# Define node movement model
#
puts "Loading connection pattern..."
source $val(cp)

#
# Define traffic model
#
puts "Loading scenario file..."
source $val(sc)

# Define node initial position in nam
```

```
for {set i 0} {$i < $val(nn)} {incr i} {

   # 20 defines the node size in nam, must adjust it according to your scenario
   # The function must be called after mobility model is defined

   $ns_ initial_node_pos $node_($i) 100
}


#
# Tell nodes when the simulation ends
#
for {set i 0} {$i < $val(nn) } {incr i} {
   $ns_ at $val(stop).0 "$node_($i) reset";
}

$ns_ at  $val(stop).0002 "puts \"NS EXITING...\" ; $ns_ halt"

puts $nt "M 0.0 nn $val(nn) x $val(x) y $val(y) rp $val(adhocRouting)"
puts $nt "M 0.0 sc $val(sc) cp $val(cp) seed $val(seed)"
puts $nt "M 0.0 prop $val(prop) ant $val(ant)"

puts "Starting Simulation..."
$ns_ run
```

7.7 AODV Parameters AWK File Code

```
BEGIN {
      sends=0;
      recvs=0;
      routing_packets=0.0;
      droppedBytes=0;
      droppedPackets=0;
      highest_packet_id=0;
      sum=0;
      recvnum=0;
    }

  {
  time = $3;
  packet_id = $41;

  # CALCULATE PACKET DELIVERY FRACTION
  if (( $1 == "s") &&  ( $35 == "cbr" ) && ( $19=="AGT" )) {  sends++; }

  if (( $1 == "r") &&  ( $35 == "cbr" ) && ( $19=="AGT" ))   {  recvs++; }

  # CALCULATE DELAY
  if ( start_time[packet_id] == 0 )  start_time[packet_id] = time;
  if (( $1 == "r") &&  ( $35 == "cbr" ) && ( $19=="AGT" )) {  end_time[packet_id] = time;  }
      else {  end_time[packet_id] = -1;  }

  # CALCULATE TOTAL AODV OVERHEAD
  if (($1 == "s" || $1 == "f") && $19 == "RTR" && $35 =="AODV") routing_packets++;

  # DROPPED AODV PACKETS
  if (( $1 == "d" ) && ( $35 == "cbr" )  && ( $3 > 0 ))
      {
           droppedBytes=droppedBytes+$37;
           droppedPackets=droppedPackets+1;
      }

      #find the number of packets in the simulation
```

```
        if (packet_id > highest_packet_id)
          highest_packet_id = packet_id;
}

END {

for ( i in end_time )
{
start = start_time[i];
end = end_time[i];
packet_duration = end - start;
if ( packet_duration > 0 )
{    sum += packet_duration;
     recvnum++;
}
}

   delay=sum/recvnum;
   NRL = routing_packets/recvs;  #normalized routing load
   PDF = (recvs/sends)*100;  #packet delivery ratio[fraction]
   printf("send = %.2f\n",sends);
   printf("recv = %.2f\n",recvs);
   printf("routingpkts = %.2f\n",routing_packets++);
   printf("PDF = %.2f\n",PDF);
   printf("%.2f\t",PDF);
   printf("NRL = %.2f\n",NRL);
   printf("Average e-e delay(ms)= %.2f\n",delay*1000);
   printf("%.2f\n",delay*1000);
   printf("No. of dropped data (packets) = %d\n",droppedPackets);
   printf("No. of dropped data (bytes)   = %d\n",droppedBytes);
   printf("Packet Loss [%]= %.2f  \n", (droppedPackets/(highest_packet_id+1))*100);
}
```

7.8 DSDV Parameters AWK File Code

```
BEGIN {
      sends=0;
      recvs=0;
      routing_packets=0.0;
      droppedBytes=0;
      droppedPackets=0;
      highest_packet_id=0;
      sum=0;
      recvnum=0;
    }

 {
 time = $3;
 packet_id = $41;

 # CALCULATE PACKET DELIVERY FRACTION
 if (( $1 == "s") &&  ( $35 == "cbr" ) && ( $19=="AGT" )) {  sends++; }

 if (( $1 == "r") &&  ( $35 == "cbr" ) && ( $19=="AGT" ))   {  recvs++; }

 # CALCULATE DELAY
 if ( start_time[packet_id] == 0 )  start_time[packet_id] = time;
 if (( $1 == "r") &&  ( $35 == "cbr" ) && ( $19=="AGT" )) {  end_time[packet_id] = time;  }
      else {  end_time[packet_id] = -1;  }

 # CALCULATE TOTAL DSDV OVERHEAD
 if (($1 == "s" || $1 == "f") && $19 == "RTR" && $35 =="message") routing_packets++;

 # DROPPED DSDV PACKETS
 if (( $1 == "d" ) && ( $35 == "cbr" )  && ( $3 > 0 ))
      {
           droppedBytes=droppedBytes+$37;
           droppedPackets=droppedPackets+1;
      }
```

```
    #find the number of packets in the simulation
      if (packet_id > highest_packet_id)
        highest_packet_id = packet_id;
}

END {

for ( i in end_time )
{
start = start_time[i];
end = end_time[i];
packet_duration = end - start;
if ( packet_duration > 0 )
{    sum += packet_duration;
    recvnum++;
}
}

  delay=sum/recvnum;
  NRL = routing_packets/recvs;  #normalized routing load
  PDF = (recvs/sends)*100;  #packet delivery ratio[fraction]
  printf("send = %.2f\n",sends);
  printf("recv = %.2f\n",recvs);
  printf("routingpkts = %.2f\n",routing_packets++);
  printf("PDF = %.2f\n",PDF);
  printf("%.2f\t",PDF);
  printf("NRL = %.2f\n",NRL);
  printf("Average e-e delay(ms)= %.2f\n",delay*1000);
  printf("%.2f\n",delay*1000);
  printf("No. of dropped data (packets) = %d\n",droppedPackets);
  printf("No. of dropped data (bytes)   = %d\n",droppedBytes);
  printf("Packet Loss [%]= %.2f  \n", (droppedPackets/(highest_packet_id+1))*100);
}
```

7.9 DSR Parameters AWK File Code

```
BEGIN {
      sends=0;
      recvs=0;
      routing_packets=0.0;
      droppedBytes=0;
      droppedPackets=0;
      highest_packet_id =0;
      sum=0;
      recvnum=0;
    }

 {
 time = $3;
 packet_id = $41;

 # CALCULATE PACKET DELIVERY FRACTION
 if (( $1 == "s") &&  ( $35 == "cbr" ) && ( $19=="AGT" )) {  sends++; }

 if (( $1 == "r") &&  ( $35 == "cbr" ) && ( $19=="AGT" ))   {  recvs++; }

 # CALCULATE DELAY
 if ( start_time[packet_id] == 0 )  start_time[packet_id] = time;
 if (( $1 == "r") &&  ( $35 == "cbr" ) && ( $19=="AGT" )) {  end_time[packet_id] = time;  }
     else {  end_time[packet_id] = -1;  }

 # CALCULATE TOTAL DSR OVERHEAD
 if (($1 == "s" || $1 == "f") && $19 == "RTR" && $35 =="DSR") routing_packets++;

 # DROPPED DSR PACKETS
 if (( $1 == "d" ) && ( $35 == "cbr" )  && ( $3 > 0 ))
     {
          droppedBytes=droppedBytes+$37;
          droppedPackets=droppedPackets+1;
     }
```

```
    #find the number of packets in the simulation
       if (packet_id > highest_packet_id)
          highest_packet_id = packet_id;
}

END {

for ( i in end_time )
{
start = start_time[i];
end = end_time[i];
packet_duration = end - start;
if ( packet_duration > 0 )
{    sum += packet_duration;
     recvnum++;
}
}

   delay=sum/recvnum;
   NRL = routing_packets/recvs;  #normalized routing load
   PDF = (recvs/sends)*100;  #packet delivery ratio[fraction]
   printf("send = %.2f\n",sends);
   printf("recv = %.2f\n",recvs);
   printf("routingpkts = %.2f\n",routing_packets++);
   printf("PDF = %.2f\n",PDF);
   printf("NRL = %.2f\n",NRL);
   printf("Average e-e delay(ms)= %.2f\n",delay*1000);
   printf("No. of dropped data (packets) = %d\n",droppedPackets);
   printf("No. of dropped data (bytes)   = %d\n",droppedBytes);
}
```

7.10 Throughput AWK File Code

```
BEGIN {
    recvdSize = 0
    startTime = 1e6
    stopTime = 0
}

{
    # Trace line format: normal
    if ($2 != "-t") {
        event = $1
        time = $2
        if (event == "+" || event == "-") node_id = $3
        if (event == "r" || event == "d") node_id = $4
        flow_id = $8
        pkt_id = $12
        pkt_size = $6
        flow_t = $5
        level = "AGT"
    }
    # Trace line format: new
    if ($2 == "-t") {
        event = $1
        time = $3
        node_id = $5
        flow_id = $39
        pkt_id = $41
        pkt_size = $37
        flow_t = $45
        level = $19
    }

# Store start time
if (level == "AGT" && (event == "+" || event == "s") && pkt_size >= 512) {
  if (time < startTime) {
        startTime = time
```

```
        }
    }

 # Update total received packets' size and store packets arrival time
 if (level == "AGT" && event == "r" && pkt_size >= 512) {
     if (time > stopTime) {
         stopTime = time
         }
     # Rip off the header
     hdr_size = pkt_size % 512
     pkt_size -= hdr_size
     # Store received packet's size
     recvdSize += pkt_size
     }
 }

 END {
     #printf("Average Throughput[kbps] = %.2f\t\t
StartTime=%.2f\tStopTime=%.2f\n",(recvdSize/(stopTime-
startTime))*(8/1000),startTime,stopTime)
        printf("%.2f\n",(recvdSize/(stopTime-startTime))*(8/1000))
 }
```

7.11 Group 1 Scenario File Code

```
#!/bin/sh
#
# Generate Scenario Files
#
clear
echo "Generating Experiment Scenario Files..."
pauseTime=0
simTime=500
areaX=500
areaY=500



for n in 50 100 150 200          # number of nodes
do
	for s in 20                    # speed
	do
		for k in 1 2 3             # repetition number
		do
			echo "nodes $n, speed $s, repetition $k..."
			/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-
gen/setdest/setdest -v 1 -n $n -p $pauseTime -M $s -t $simTime -x $areaX -y $areaY >
/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/dimi/scen/n$n-s$s-$k.scen
		done
	done
done

echo "Complete!"
```

7.12 Group 1 Traffic File Code

```
#!/bin/sh

clear
echo "=========================================="
echo "Creating traffic file..."

seed=1.0
#connections=100
rate=0.2

echo "Creating traffic for 50 nodes, 100 connections, $rate rate.."
ns /home/Cat/Desktop/ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen/cbrgen.tcl -type cbr -
nn 49 -seed $seed -mc 49 -rate $rate > /home/Cat/Desktop/ns-allinone-2.34/ns-
2.34/dimi/traffic/cbr-n50-s$seed-mc50-r$rate
echo "Creating traffic for 100 nodes, 100 connections, $rate rate..."
ns /home/Cat/Desktop/ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen/cbrgen.tcl -type cbr -
nn 99 -seed $seed -mc 99 -rate $rate > /home/Cat/Desktop/ns-allinone-2.34/ns-
2.34/dimi/traffic/cbr-n100-s$seed-mc100-r$rate
echo "Creating traffic for 150 nodes, 100 connections, $rate rate..."
ns /home/Cat/Desktop/ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen/cbrgen.tcl -type cbr -
nn 149 -seed $seed -mc 149 -rate $rate > /home/Cat/Desktop/ns-allinone-2.34/ns-
2.34/dimi/traffic/cbr-n150-s$seed-mc150-r$rate
echo "Creating traffic for 200 nodes, 100 connections, $rate rate..."
ns /home/Cat/Desktop/ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen/cbrgen.tcl -type cbr -
nn 199 -seed $seed -mc 199 -rate $rate > /home/Cat/Desktop/ns-allinone-2.34/ns-
2.34/dimi/traffic/cbr-n200-s$seed-mc200-r$rate


echo "DONE"
echo "=========================================="
```

7.13 Group 1 AODV-PB-Studies File Code

```
#~/bin/bash
# mcb-default-full.sh

#
# Simulate Protocol
#

clear

protocol=dimi
tclfile=AODV-PB.tcl
pausetime=0
simtime=500
seed=1.0
connections=100
rate=0.2


echo "========================================="
echo "Simulating routing protocol $protocol..."

for n in 50 100 150 200
do
   for k in 1 2 3
   do
      ns /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/AODV-PB.tcl /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/simout/$protocol-n$n-s$seed-mc$n-r$rate-$simtime-$k.out /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/scen/n$n-s20-$k.scen /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/traffic/cbr-n$n-s$seed-mc$n-r$rate $n $simtime
      echo "......................................................"
   done
done
```

```
for k in 1 2 3
do

    for n in 50 100 150 200
    do
        gawk -f /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/parameters.awk /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/simout/$protocol-n$n-s$seed-mc$n-r$rate-$simtime-$k.out >> /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/simout/parameters-$protocol-$simtime.txt
        gawk -f /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/throughput.awk /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/simout/$protocol-n$n-s$seed-mc$n-r$rate-$simtime-$k.out >> /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/simout/throughput-$protocol-$simtime.txt
        gawk -f /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/delay.awk /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/simout/$protocol-n$n-s$seed-mc$n-r$rate-$simtime-$k.out >> /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/simout/delay-$protocol-$simtime.txt
    done
    echo "----------" >> /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/simout/parameters-$protocol-$simtime.txt
    echo "----------" >> /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/simout/throughput-$protocol-$simtime.txt
    echo "----------" >> /media/disk-1/ns-allinone-2.34/ns-2.34/dimi/simout/delay-$protocol-$simtime.txt
done

echo "DONE"
echo "========================================"
```

7.14 Group 2 Scenario File Code

```
#!/bin/sh

clear
echo "========================================"
echo "Creating traffic file..."

seed=1.0
#connections=100
rate=0.2

echo "Creating traffic for 50 nodes, 100 connections, $rate rate.."
ns /home/Cat/Desktop/ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen/cbrgen.tcl -type cbr -
nn 49 -seed $seed -mc 49 -rate $rate > /home/Cat/Desktop/ns-allinone-2.34/ns-
2.34/dimi/traffic/cbr-n50-s$seed-mc50-r$rate
echo "Creating traffic for 100 nodes, 100 connections, $rate rate..."
ns /home/Cat/Desktop/ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen/cbrgen.tcl -type cbr -
nn 99 -seed $seed -mc 99 -rate $rate > /home/Cat/Desktop/ns-allinone-2.34/ns-
2.34/dimi/traffic/cbr-n100-s$seed-mc100-r$rate
echo "Creating traffic for 150 nodes, 100 connections, $rate rate..."
ns /home/Cat/Desktop/ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen/cbrgen.tcl -type cbr -
nn 149 -seed $seed -mc 149 -rate $rate > /home/Cat/Desktop/ns-allinone-2.34/ns-
2.34/dimi/traffic/cbr-n150-s$seed-mc150-r$rate
echo "Creating traffic for 200 nodes, 100 connections, $rate rate..."
ns /home/Cat/Desktop/ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen/cbrgen.tcl -type cbr -
nn 199 -seed $seed -mc 199 -rate $rate > /home/Cat/Desktop/ns-allinone-2.34/ns-
2.34/dimi/traffic/cbr-n200-s$seed-mc200-r$rate


echo "DONE"
echo "========================================"
```

7.15 Group 2 and 3 Traffic File Code

```
#!/bin/sh

clear
echo "=========================================="
echo "Creating traffic file..."

seed=1.0
#connections=100
rate=0.2

echo "Creating traffic for 100 nodes, 100 connections, $rate rate..."
ns /home/Cat/Desktop/ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen/cbrgen.tcl -type cbr -nn 99 -seed $seed -mc 99 -rate $rate > /home/Cat/Desktop/ns-allinone-2.34/ns-2.34/dimi/traffic/cbr-n100-s$seed-mc100-r$rate



echo "DONE"
echo "=========================================="
```

7.16 Group 2 Studies File Code

```
#~/bin/bash
# mcb-default-full.sh

#
# Simulate Protocol
#

clear

protocol=dimi
tclfile=AODV-PB.tcl
simtime=500
pausetime=$p
seed=1.0
connections=100
rate=0.2


echo "======================================="
echo "Simulating routing protocol $protocol..."

for n in 100
do

 for p in 0 50 100 300 500
 do
   for k in 1 2 3
   do
      ns /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/AODV-PB.tcl /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/$protocol-n$n-p$p-s$seed-mc$n-r$rate-$simtime-$k.out /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/scen/n$n-s20-p$p-$k.scen /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/traffic/cbr-n$n-s$seed-mc$n-r$rate $n $simtime
      echo "......................................................"
   done
done
```

```
done

for k in 1 2 3
do

   for n in 100
   do

     for p in 0 50 100 300 500
     do

       gawk -f /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/parameters.awk /media/disk-2/ns-
allinone-2.34/ns-2.34/dimi/simout/$protocol-n$n-p$p-s$seed-mc$n-r$rate-$simtime-$k.out >>
/media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/parameters-$protocol-$simtime.txt
       gawk -f /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/throughput.awk /media/disk-2/ns-
allinone-2.34/ns-2.34/dimi/simout/$protocol-n$n-p$p-s$seed-mc$n-r$rate-$simtime-$k.out >>
/media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/throughput-$protocol-$simtime.txt
       gawk -f /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/delay.awk /media/disk-2/ns-allinone-
2.34/ns-2.34/dimi/simout/$protocol-n$n-p$p-s$seed-mc$n-r$rate-$simtime-$k.out >>
/media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/delay-$protocol-$simtime.txt
   done
   echo "----------" >> /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/parameters-$protocol-
$simtime.txt
   echo "----------" >> /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/throughput-$protocol-
$simtime.txt
   echo "----------" >> /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/delay-$protocol-
$simtime.txt
done
done

echo "DONE"
echo "==========================================="
```

7.17 Group 3 Scenario File Code

```
#!/bin/sh
#
# Generate Scenario Files
#
clear
echo "Generating Experiment Scenario Files..."
pauseTime=0
simTime=500
areaX=500
areaY=500



for n in 100     # number of nodes
do
	for s in 5 10 15 20				# speed
	do
		for k in 1 2 3			# repetition number
		do
			echo "nodes $n, speed $s, repetition $k..."
			/home/Cat/Desktop/ns-allinone-2.34/ns-2.34/indep-utils/cmu-scen-gen/setdest/setdest -v 1 -n $n -p $pauseTime -M $s -t $simTime -x $areaX -y $areaY > /home/Cat/Desktop/ns-allinone-2.34/ns-2.34/dimi/scen/n$n-s$s-$k.scen
		done
	done
done

echo "Complete!"
```

7.18 Group 3 Studies File Code

```
#~/bin/bash
# mcb-default-full.sh

#
# Simulate Protocol
#

clear

protocol=dimi
tclfile=AODV-PB.tcl
simtime=500
pausetime=0
speed=$s
seed=1.0
connections=100
rate=0.2


echo "========================================="
echo "Simulating routing protocol $protocol..."

for n in 100
do

 for s in 5 10 15 20
 do
   for k in 1 2 3
   do
       ns /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/AODV-PB.tcl /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/$protocol-n$n-s$s-s$seed-mc$n-r$rate-$simtime-$k.out /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/scen/n$n-s$s-$k.scen /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/traffic/cbr-n$n-s$seed-mc$n-r$rate $n $simtime
       echo "......................................................"
```

```
    done
done
done

for k in 1 2 3
do

    for n in 100
    do

      for s in 5 10 15 20
 do

        gawk -f /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/parameters.awk /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/$protocol-n$n-s$s-s$seed-mc$n-r$rate-$simtime-$k.out >> /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/parameters-$protocol-$simtime.txt
        gawk -f /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/throughput.awk /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/$protocol-n$n-s$s-s$seed-mc$n-r$rate-$simtime-$k.out >> /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/throughput-$protocol-$simtime.txt
        gawk -f /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/delay.awk /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/$protocol-n$n-s$s-s$seed-mc$n-r$rate-$simtime-$k.out >> /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/delay-$protocol-$simtime.txt
    done
    echo "----------" >> /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/parameters-$protocol-$simtime.txt
    echo "----------" >> /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/throughput-$protocol-$simtime.txt
    echo "----------" >> /media/disk-2/ns-allinone-2.34/ns-2.34/dimi/simout/delay-$protocol-$simtime.txt
done
done

echo "DONE"
echo "========================================"
```

7.19 Group 1 Parameters Output AODV

send = 3508.00
recv = 3224.00
routingpkts = 17514.00
PDF = 91.90
91.90   NRL = 5.43
Average e-e delay(ms)= 23.37
23.37
No. of dropped data (packets) = 579
No. of dropped data (bytes)   = 308028
Packet Loss [%]= 16.51
send = 6086.00
recv = 5652.00
routingpkts = 65552.00
PDF = 92.87
92.87   NRL = 11.60
Average e-e delay(ms)= 63.35
63.35
No. of dropped data (packets) = 860
No. of dropped data (bytes)   = 457520
Packet Loss [%]= 14.13
send = 8931.00
recv = 8172.00
routingpkts = 161982.00
PDF = 91.50
91.50   NRL = 19.82
Average e-e delay(ms)= 96.60
96.60
No. of dropped data (packets) = 1441
No. of dropped data (bytes)   = 766612
Packet Loss [%]= 16.13
send = 11084.00
recv = 10185.00
routingpkts = 263236.00
PDF = 91.89
91.89   NRL = 25.85

Average e-e delay(ms)= 170.32
170.32
No. of dropped data (packets) = 1687
No. of dropped data (bytes)   = 897484
Packet Loss [%]= 15.22
----
send = 3536.00
recv = 3297.00
routingpkts = 14477.00
PDF = 93.24
93.24   NRL = 4.39
Average e-e delay(ms)= 17.78
17.78
No. of dropped data (packets) = 472
No. of dropped data (bytes)   = 251104
Packet Loss [%]= 13.35
send = 6129.00
recv = 5542.00
routingpkts = 77268.00
PDF = 90.42
90.42   NRL = 13.94
Average e-e delay(ms)= 82.41
82.41
No. of dropped data (packets) = 1157
No. of dropped data (bytes)   = 615524
Packet Loss [%]= 18.88
send = 8947.00
recv = 8200.00
routingpkts = 159868.00
PDF = 91.65
91.65   NRL = 19.50
Average e-e delay(ms)= 125.31
125.31
No. of dropped data (packets) = 1464
No. of dropped data (bytes)   = 778848
Packet Loss [%]= 16.36
send = 11163.00
recv = 10094.00
routingpkts = 298849.00
PDF = 90.42
90.42   NRL = 29.61
Average e-e delay(ms)= 174.65
174.65
No. of dropped data (packets) = 2030
No. of dropped data (bytes)   = 1080018

Packet Loss [%]= 18.19
----
send = 3499.00
recv = 3250.00
routingpkts = 16199.00
PDF = 92.88
92.88   NRL = 4.98
Average e-e delay(ms)= 20.35
20.35
No. of dropped data (packets) = 520
No. of dropped data (bytes)   = 276872
Packet Loss [%]= 14.86
send = 6184.00
recv = 5667.00
routingpkts = 70426.00
PDF = 91.64
91.64   NRL = 12.43
Average e-e delay(ms)= 55.33
55.33
No. of dropped data (packets) = 1034
No. of dropped data (bytes)   = 550088
Packet Loss [%]= 16.72
send = 8919.00
recv = 8156.00
routingpkts = 159242.00
PDF = 91.45
91.45   NRL = 19.52
Average e-e delay(ms)= 108.23
108.23
No. of dropped data (packets) = 1429
No. of dropped data (bytes)   = 760228
Packet Loss [%]= 16.02
send = 11087.00
recv = 10181.00
routingpkts = 268197.00
PDF = 91.83
91.83   NRL = 26.34
Average e-e delay(ms)= 164.89
164.89
No. of dropped data (packets) = 1732
No. of dropped data (bytes)   = 921656
Packet Loss [%]= 15.62

7.20 Group 1 Throughput Output AODV

26.56
46.56
67.29
83.87

27.15
45.63
67.52
83.12

26.77
46.68
67.16
83.83

7.21 Group 1 Parameters Output DSDV

send = 3496.00
recv = 3066.00
routingpkts = 3166.00
PDF = 87.70
87.70   NRL = 1.03
Average e-e delay(ms)= 304.28
304.28
No. of dropped data (packets) = 822
No. of dropped data (bytes)   = 437404
Packet Loss [%]= 12.29
send = 6100.00
recv = 5455.00
routingpkts = 6852.00
PDF = 89.43
89.43   NRL = 1.26
Average e-e delay(ms)= 119.17
119.17
No. of dropped data (packets) = 1235
No. of dropped data (bytes)   = 657100
Packet Loss [%]= 9.50
send = 8906.00
recv = 6844.00
routingpkts = 22159.00
PDF = 76.85
76.85   NRL = 3.24
Average e-e delay(ms)= 2107.84
2107.84
No. of dropped data (packets) = 2950
No. of dropped data (bytes)   = 1569420
Packet Loss [%]= 9.49
----
send = 3520.00
recv = 3130.00
routingpkts = 2735.00
PDF = 88.92
88.92   NRL = 0.87

Average e-e delay(ms)= 171.79
171.79
No. of dropped data (packets) = 747
No. of dropped data (bytes)   = 397404
Packet Loss [%]= 11.89
send = 6138.00
recv = 5270.00
routingpkts = 10213.00
PDF = 85.86
85.86   NRL = 1.94
Average e-e delay(ms)= 399.25
399.25
No. of dropped data (packets) = 1628
No. of dropped data (bytes)   = 866176
Packet Loss [%]= 9.93
send = 8924.00
recv = 7476.00
routingpkts = 15905.00
PDF = 83.77
83.77   NRL = 2.13
Average e-e delay(ms)= 630.05
630.05
No. of dropped data (packets) = 2276
No. of dropped data (bytes)   = 1211008
Packet Loss [%]= 9.16
----
send = 3504.00
recv = 3040.00
routingpkts = 2991.00
PDF = 86.76
86.76   NRL = 0.98
Average e-e delay(ms)= 196.46
196.46
No. of dropped data (packets) = 899
No. of dropped data (bytes)   = 478388
Packet Loss [%]= 13.79
send = 6094.00
recv = 5348.00
routingpkts = 7863.00
PDF = 87.76
87.76   NRL = 1.47
Average e-e delay(ms)= 494.26
494.26
No. of dropped data (packets) = 1441
No. of dropped data (bytes)   = 766690

Packet Loss [%]= 10.23
send = 8949.00
recv = 6627.00
routingpkts = 25875.00
PDF = 74.05
74.05   NRL = 3.90
Average e-e delay(ms)= 4187.24
4187.24
No. of dropped data (packets) = 3281
No. of dropped data (bytes)   = 1745802
Packet Loss [%]= 9.42

7.22 Group 1 Throughput Output DSDV

25.26
44.93
56.36

25.78
43.40
61.56

25.03
44.04
54.57

7.23 Group 1 Parameters Output DSR

send = 3516.00
recv = 3489.00
routingpkts = 9721.00
PDF = 99.23
NRL = 2.79
Average e-e delay(ms)= 101.15
No. of dropped data (packets) = 877
No. of dropped data (bytes)   = 485412
send = 6113.00
recv = 6087.00
routingpkts = 31540.00
PDF = 99.57
NRL = 5.18
Average e-e delay(ms)= 89.97
No. of dropped data (packets) = 1123
No. of dropped data (bytes)   = 624392
send = 8907.00
recv = 3123.00
routingpkts = 531120.00
PDF = 35.06
NRL = 170.07
Average e-e delay(ms)= 312.44
No. of dropped data (packets) = 6335
No. of dropped data (bytes)   = 3441406
send = 11140.00
recv = 1389.00
routingpkts = 1602977.00
PDF = 12.47
NRL = 1154.05
Average e-e delay(ms)= 540.27
No. of dropped data (packets) = 10047
No. of dropped data (bytes)   = 5463428
----
send = 3492.00
recv = 3458.00
routingpkts = 7074.00

PDF = 99.03
NRL = 2.05
Average e-e delay(ms)= 36.61
No. of dropped data (packets) = 641
No. of dropped data (bytes) = 353892
send = 6118.00
recv = 6084.00
routingpkts = 38716.00
PDF = 99.44
NRL = 6.36
Average e-e delay(ms)= 155.29
No. of dropped data (packets) = 1588
No. of dropped data (bytes) = 881128
send = 8906.00
recv = 2318.00
routingpkts = 594627.00
PDF = 26.03
NRL = 256.53
Average e-e delay(ms)= 1043.79
No. of dropped data (packets) = 7005
No. of dropped data (bytes) = 3805234
send = 11131.00
recv = 1213.00
routingpkts = 1701741.00
PDF = 10.90
NRL = 1402.92
Average e-e delay(ms)= 653.52
No. of dropped data (packets) = 10118
No. of dropped data (bytes) = 5499086
----
send = 3475.00
recv = 3448.00
routingpkts = 10447.00
PDF = 99.22
NRL = 3.03
Average e-e delay(ms)= 74.77
No. of dropped data (packets) = 871
No. of dropped data (bytes) = 482532
send = 6111.00
recv = 6067.00
routingpkts = 30817.00
PDF = 99.28
NRL = 5.08
Average e-e delay(ms)= 247.55
No. of dropped data (packets) = 1339

No. of dropped data (bytes)   = 743444
send = 8947.00
recv = 2183.00
routingpkts = 642588.00
PDF = 24.40
NRL = 294.36
Average e-e delay(ms)= 794.12
No. of dropped data (packets) = 7168
No. of dropped data (bytes)   = 3894734
send = 11119.00
recv = 938.00
routingpkts = 1824741.00
PDF = 8.44
NRL = 1945.35
Average e-e delay(ms)= 1121.87
No. of dropped data (packets) = 10316
No. of dropped data (bytes)   = 5606824

7.24 Group 1 Throughput Output DSR

28.76
50.13
43.69
34.22

28.48
50.10
39.03
30.85

28.41
49.96
36.86
24.77

7.25 Group 2 Parameters Output AODV

send = 6108.00
recv = 5602.00
routingpkts = 70290.00
PDF = 91.72
91.72   NRL = 12.55
Average e-e delay(ms)= 48.26
48.26
No. of dropped data (packets) = 999
No. of dropped data (bytes)   = 531468
Packet Loss [%]= 16.36
send = 6137.00
recv = 5750.00
routingpkts = 57866.00
PDF = 93.69
93.69   NRL = 10.06
Average e-e delay(ms)= 45.11
45.11
No. of dropped data (packets) = 774
No. of dropped data (bytes)   = 411826
Packet Loss [%]= 12.61
send = 6132.00
recv = 5821.00
routingpkts = 49675.00
PDF = 94.93
94.93   NRL = 8.53
Average e-e delay(ms)= 51.99
51.99
No. of dropped data (packets) = 624
No. of dropped data (bytes)   = 332084
Packet Loss [%]= 10.18
send = 6116.00
recv = 6001.00
routingpkts = 23826.00
PDF = 98.12
98.12   NRL = 3.97
Average e-e delay(ms)= 33.63

33.63
No. of dropped data (packets) = 219
No. of dropped data (bytes)   = 116508
Packet Loss [%]= 3.58
send = 6113.00
recv = 6105.00
routingpkts = 10476.00
PDF = 99.87
99.87   NRL = 1.72
Average e-e delay(ms)= 44.75
44.75
No. of dropped data (packets) = 7
No. of dropped data (bytes)   = 3724
Packet Loss [%]= 0.11
----
send = 6124.00
recv = 5626.00
routingpkts = 67053.00
PDF = 91.87
91.87   NRL = 11.92
Average e-e delay(ms)= 60.84
60.84
No. of dropped data (packets) = 984
No. of dropped data (bytes)   = 523546
Packet Loss [%]= 16.07
send = 6143.00
recv = 5735.00
routingpkts = 62352.00
PDF = 93.36
93.36   NRL = 10.87
Average e-e delay(ms)= 50.66
50.66
No. of dropped data (packets) = 811
No. of dropped data (bytes)   = 431626
Packet Loss [%]= 13.20
send = 6156.00
recv = 5857.00
routingpkts = 49142.00
PDF = 95.14
95.14   NRL = 8.39
Average e-e delay(ms)= 40.21
40.21
No. of dropped data (packets) = 610
No. of dropped data (bytes)   = 324752
Packet Loss [%]= 9.91

send = 6142.00
recv = 6043.00
routingpkts = 21547.00
PDF = 98.39
98.39   NRL = 3.57
Average e-e delay(ms)= 33.09
33.09
No. of dropped data (packets) = 197
No. of dropped data (bytes)   = 105384
Packet Loss [%]= 3.21
send = 6087.00
recv = 6085.00
routingpkts = 9701.00
PDF = 99.97
99.97   NRL = 1.59
Average e-e delay(ms)= 23.34
23.34
No. of dropped data (packets) = 2
No. of dropped data (bytes)   = 1064
Packet Loss [%]= 0.03
----
send = 6117.00
recv = 5631.00
routingpkts = 66035.00
PDF = 92.05
92.05   NRL = 11.73
Average e-e delay(ms)= 50.58
50.58
No. of dropped data (packets) = 971
No. of dropped data (bytes)   = 516630
Packet Loss [%]= 15.87
send = 6108.00
recv = 5704.00
routingpkts = 57544.00
PDF = 93.39
93.39   NRL = 10.09
Average e-e delay(ms)= 47.90
47.90
No. of dropped data (packets) = 800
No. of dropped data (bytes)   = 425716
Packet Loss [%]= 13.10
send = 6162.00
recv = 5848.00
routingpkts = 48131.00
PDF = 94.90

94.90   NRL = 8.23
Average e-e delay(ms)= 47.32
47.32
No. of dropped data (packets) = 614
No. of dropped data (bytes)   = 326648
Packet Loss [%]= 9.96
send = 6147.00
recv = 6066.00
routingpkts = 19311.00
PDF = 98.68
98.68   NRL = 3.18
Average e-e delay(ms)= 45.77
45.77
No. of dropped data (packets) = 154
No. of dropped data (bytes)   = 81928
Packet Loss [%]= 2.51
send = 6112.00
recv = 6110.00
routingpkts = 9353.00
PDF = 99.97
99.97   NRL = 1.53
Average e-e delay(ms)= 30.25
30.25
No. of dropped data (packets) = 8
No. of dropped data (bytes)   = 4604
Packet Loss [%]= 0.13

7.26 Group 2 Throughput AODV

46.13
47.35
47.95
49.42
50.27

46.33
47.22
48.23
49.77
50.11

46.37
46.97
48.17
49.96
50.31

7.27 Group 2 Parameters DSDV

----
send = 6146.00
recv = 5381.00
routingpkts = 8033.00
PDF = 87.55
87.55   NRL = 1.49
Average e-e delay(ms)= 362.89
362.89
No. of dropped data (packets) = 1476
No. of dropped data (bytes)   = 785252
Packet Loss [%]= 10.35
send = 6134.00
recv = 5510.00
routingpkts = 8792.00
PDF = 89.83
89.83   NRL = 1.60
Average e-e delay(ms)= 408.81
408.81
No. of dropped data (packets) = 1190
No. of dropped data (bytes)   = 633160
Packet Loss [%]= 7.92
send = 6120.00
recv = 5648.00
routingpkts = 10114.00
PDF = 92.29
92.29   NRL = 1.79
Average e-e delay(ms)= 52.11
52.11
No. of dropped data (packets) = 906
No. of dropped data (bytes)   = 482386
Packet Loss [%]= 5.54
send = 6071.00
recv = 5902.00
routingpkts = 7312.00
PDF = 97.22
97.22   NRL = 1.24

Average e-e delay(ms)= 13.90
13.90
No. of dropped data (packets) = 327
No. of dropped data (bytes) = 174218
Packet Loss [%]= 2.43
send = 6105.00
recv = 6099.00
routingpkts = 7642.00
PDF = 99.90
99.90 NRL = 1.25
Average e-e delay(ms)= 12.35
12.35
No. of dropped data (packets) = 6
No. of dropped data (bytes) = 3312
Packet Loss [%]= 0.04
----
send = 6095.00
recv = 5415.00
routingpkts = 11665.00
PDF = 88.84
88.84 NRL = 2.15
Average e-e delay(ms)= 437.55
437.55
No. of dropped data (packets) = 1302
No. of dropped data (bytes) = 692936
Packet Loss [%]= 7.31
send = 6080.00
recv = 5439.00
routingpkts = 9238.00
PDF = 89.46
89.46 NRL = 1.70
Average e-e delay(ms)= 351.89
351.89
No. of dropped data (packets) = 1233
No. of dropped data (bytes) = 656268
Packet Loss [%]= 8.00
send = 6132.00
recv = 5631.00
routingpkts = 10315.00
PDF = 91.83
91.83 NRL = 1.83
Average e-e delay(ms)= 137.03
137.03
No. of dropped data (packets) = 966
No. of dropped data (bytes) = 514400

Packet Loss [%]= 5.84
send = 6096.00
recv = 5988.00
routingpkts = 8917.00
PDF = 98.23
98.23   NRL = 1.49
Average e-e delay(ms)= 13.72
13.72
No. of dropped data (packets) = 209
No. of dropped data (bytes)   = 111578
Packet Loss [%]= 1.39
send = 6097.00
recv = 6090.00
routingpkts = 7819.00
PDF = 99.89
99.89   NRL = 1.28
Average e-e delay(ms)= 12.13
12.13
No. of dropped data (packets) = 7
No. of dropped data (bytes)   = 3844
Packet Loss [%]= 0.05
----
send = 6107.00
recv = 5354.00
routingpkts = 6470.00
PDF = 87.67
87.67   NRL = 1.21
Average e-e delay(ms)= 176.80
176.80
No. of dropped data (packets) = 1422
No. of dropped data (bytes)   = 756562
Packet Loss [%]= 11.20
send = 6152.00
recv = 5533.00
routingpkts = 9515.00
PDF = 89.94
89.94   NRL = 1.72
Average e-e delay(ms)= 289.72
289.72
No. of dropped data (packets) = 1207
No. of dropped data (bytes)   = 642358
Packet Loss [%]= 7.66
send = 6111.00
recv = 5595.00
routingpkts = 9759.00

PDF = 91.56
91.56   NRL = 1.74
Average e-e delay(ms)= 209.53
209.53
No. of dropped data (packets) = 990
No. of dropped data (bytes)   = 526778
Packet Loss [%]= 6.20
send = 6103.00
recv = 5995.00
routingpkts = 7080.00
PDF = 98.23
98.23   NRL = 1.18
Average e-e delay(ms)= 11.48
11.48
No. of dropped data (packets) = 206
No. of dropped data (bytes)   = 109652
Packet Loss [%]= 1.55
send = 6092.00
recv = 6089.00
routingpkts = 9342.00
PDF = 99.95
99.95   NRL = 1.53
Average e-e delay(ms)= 19.04
19.04
No. of dropped data (packets) = 8
No. of dropped data (bytes)   = 4606
Packet Loss [%]= 0.05

7.28 Group 2 Throughput Output DSDV

44.31
45.37
46.51
48.60
50.22

44.59
44.79
46.38
49.31
50.16

44.09
45.56
46.09
49.37
50.14

7.29 Group 2 Parameters Output DSR

send = 6139.00
recv = 6084.00
routingpkts = 32451.00
PDF = 99.10
NRL = 5.33
Average e-e delay(ms)= 137.58
No. of dropped data (packets) = 1266
No. of dropped data (bytes) = 700454
send = 6154.00
recv = 6104.00
routingpkts = 23829.00
PDF = 99.19
NRL = 3.90
Average e-e delay(ms)= 262.19
No. of dropped data (packets) = 1174
No. of dropped data (bytes) = 652292
send = 6107.00
recv = 6060.00
routingpkts = 17938.00
PDF = 99.23
NRL = 2.96
Average e-e delay(ms)= 118.44
No. of dropped data (packets) = 988
No. of dropped data (bytes) = 549168
send = 6101.00
recv = 6068.00
routingpkts = 5193.00
PDF = 99.46
NRL = 0.86
Average e-e delay(ms)= 27.96
No. of dropped data (packets) = 301
No. of dropped data (bytes) = 166378
send = 6112.00
recv = 6110.00
routingpkts = 1772.00
PDF = 99.97

NRL = 0.29
Average e-e delay(ms)= 12.65
No. of dropped data (packets) = 2
No. of dropped data (bytes)   = 1108
----
send = 6179.00
recv = 6141.00
routingpkts = 32194.00
PDF = 99.39
NRL = 5.24
Average e-e delay(ms)= 175.00
No. of dropped data (packets) = 1400
No. of dropped data (bytes)   = 775314
send = 6136.00
recv = 6077.00
routingpkts = 29426.00
PDF = 99.04
NRL = 4.84
Average e-e delay(ms)= 148.70
No. of dropped data (packets) = 1392
No. of dropped data (bytes)   = 774070
send = 6135.00
recv = 6072.00
routingpkts = 24610.00
PDF = 98.97
NRL = 4.05
Average e-e delay(ms)= 164.45
No. of dropped data (packets) = 1118
No. of dropped data (bytes)   = 621724
send = 6127.00
recv = 6100.00
routingpkts = 5553.00
PDF = 99.56
NRL = 0.91
Average e-e delay(ms)= 77.55
No. of dropped data (packets) = 213
No. of dropped data (bytes)   = 118162
send = 6110.00
recv = 6110.00
routingpkts = 2002.00
PDF = 100.00
NRL = 0.33
Average e-e delay(ms)= 13.10
No. of dropped data (packets) = 0
No. of dropped data (bytes)   = 0

----
send = 6134.00
recv = 6071.00
routingpkts = 29791.00
PDF = 98.97
NRL = 4.91
Average e-e delay(ms)= 152.27
No. of dropped data (packets) = 1208
No. of dropped data (bytes)   = 669546
send = 6185.00
recv = 6124.00
routingpkts = 25867.00
PDF = 99.01
NRL = 4.22
Average e-e delay(ms)= 208.54
No. of dropped data (packets) = 1226
No. of dropped data (bytes)   = 680994
send = 6146.00
recv = 6064.00
routingpkts = 20853.00
PDF = 98.67
NRL = 3.44
Average e-e delay(ms)= 104.61
No. of dropped data (packets) = 1035
No. of dropped data (bytes)   = 575732
send = 6187.00
recv = 6169.00
routingpkts = 5639.00
PDF = 99.71
NRL = 0.91
Average e-e delay(ms)= 29.37
No. of dropped data (packets) = 237
No. of dropped data (bytes)   = 131770
send = 6107.00
recv = 6107.00
routingpkts = 1583.00
PDF = 100.00
NRL = 0.26
Average e-e delay(ms)= 14.53
No. of dropped data (packets) = 0
No. of dropped data (bytes)   = 0

7.30 Group 2 Throughput Output DSR

50.10
50.27
49.90
49.97
50.31

50.59
50.04
50.00
50.23
50.31

50.00
50.44
49.94
50.80
50.29

7.31 Group 3 Parameters Output AODV

send = 6074.00
recv = 5818.00
routingpkts = 41478.00
PDF = 95.79
95.79   NRL = 7.13
Average e-e delay(ms)= 36.81
36.81
No. of dropped data (packets) = 502
No. of dropped data (bytes)   = 267122
Packet Loss [%]= 8.26
send = 6104.00
recv = 5734.00
routingpkts = 55076.00
PDF = 93.94
93.94   NRL = 9.61
Average e-e delay(ms)= 49.14
49.14
No. of dropped data (packets) = 720
No. of dropped data (bytes)   = 383098
Packet Loss [%]= 11.80
send = 6163.00
recv = 5716.00
routingpkts = 59615.00
PDF = 92.75
92.75   NRL = 10.43
Average e-e delay(ms)= 41.32
41.32
No. of dropped data (packets) = 872
No. of dropped data (bytes)   = 463904
Packet Loss [%]= 14.15
send = 6099.00
recv = 5573.00
routingpkts = 73199.00
PDF = 91.38
91.38   NRL = 13.13
Average e-e delay(ms)= 104.89

104.89
No. of dropped data (packets) = 1049
No. of dropped data (bytes) = 558068
Packet Loss [%]= 17.20
----
send = 6115.00
recv = 5886.00
routingpkts = 44966.00
PDF = 96.26
96.26 NRL = 7.64
Average e-e delay(ms)= 87.58
87.58
No. of dropped data (packets) = 438
No. of dropped data (bytes) = 233016
Packet Loss [%]= 7.16
send = 6114.00
recv = 5777.00
routingpkts = 52847.00
PDF = 94.49
94.49 NRL = 9.15
Average e-e delay(ms)= 82.93
82.93
No. of dropped data (packets) = 660
No. of dropped data (bytes) = 351120
Packet Loss [%]= 10.79
send = 6134.00
recv = 5705.00
routingpkts = 58792.00
PDF = 93.01
93.01 NRL = 10.31
Average e-e delay(ms)= 38.75
38.75
No. of dropped data (packets) = 846
No. of dropped data (bytes) = 450130
Packet Loss [%]= 13.79
send = 6155.00
recv = 5591.00
routingpkts = 73669.00
PDF = 90.84
90.84 NRL = 13.18
Average e-e delay(ms)= 120.87
120.87
No. of dropped data (packets) = 1116
No. of dropped data (bytes) = 593712
Packet Loss [%]= 18.13

----
send = 6135.00
recv = 5973.00
routingpkts = 32275.00
PDF = 97.36
97.36   NRL = 5.40
Average e-e delay(ms)= 32.73
32.73
No. of dropped data (packets) = 317
No. of dropped data (bytes)   = 168644
Packet Loss [%]= 5.17
send = 6149.00
recv = 5820.00
routingpkts = 46634.00
PDF = 94.65
94.65   NRL = 8.01
Average e-e delay(ms)= 37.58
37.58
No. of dropped data (packets) = 628
No. of dropped data (bytes)   = 334096
Packet Loss [%]= 10.21
send = 6116.00
recv = 5698.00
routingpkts = 58541.00
PDF = 93.17
93.17   NRL = 10.27
Average e-e delay(ms)= 38.51
38.51
No. of dropped data (packets) = 822
No. of dropped data (bytes)   = 437304
Packet Loss [%]= 13.44
send = 6142.00
recv = 5711.00
routingpkts = 59012.00
PDF = 92.98
92.98   NRL = 10.33
Average e-e delay(ms)= 49.76
49.76
No. of dropped data (packets) = 829
No. of dropped data (bytes)   = 441028
Packet Loss [%]= 13.50

7.32 Group 3 Throughput Output DSDV

47.91
47.22
47.07
45.89

48.48
47.57
46.98
46.05

49.20
47.93
46.92
47.03

7.33 Group 3 Parameters Output DSR

send = 6119.00
recv = 5752.00
routingpkts = 5945.00
PDF = 94.00
94.00   NRL = 1.03
Average e-e delay(ms)= 287.50
287.50
No. of dropped data (packets) = 711
No. of dropped data (bytes)   = 378332
Packet Loss [%]= 5.85
send = 6149.00
recv = 5597.00
routingpkts = 6237.00
PDF = 91.02
91.02   NRL = 1.11
Average e-e delay(ms)= 134.72
134.72
No. of dropped data (packets) = 1039
No. of dropped data (bytes)   = 552848
Packet Loss [%]= 8.36
send = 6147.00
recv = 5466.00
routingpkts = 6703.00
PDF = 88.92
88.92   NRL = 1.23
Average e-e delay(ms)= 209.20
209.20
No. of dropped data (packets) = 1286
No. of dropped data (bytes)   = 684192
Packet Loss [%]= 9.95
send = 6158.00
recv = 5398.00
routingpkts = 8747.00
PDF = 87.66
87.66   NRL = 1.62
Average e-e delay(ms)= 336.95

336.95
No. of dropped data (packets) = 1455
No. of dropped data (bytes) = 774158
Packet Loss [%]= 9.73
----
send = 6138.00
recv = 5739.00
routingpkts = 6216.00
PDF = 93.50
93.50 NRL = 1.08
Average e-e delay(ms)= 316.64
316.64
No. of dropped data (packets) = 766
No. of dropped data (bytes) = 407590
Packet Loss [%]= 6.16
send = 6083.00
recv = 5552.00
routingpkts = 6516.00
PDF = 91.27
91.27 NRL = 1.17
Average e-e delay(ms)= 249.21
249.21
No. of dropped data (packets) = 1038
No. of dropped data (bytes) = 552256
Packet Loss [%]= 8.20
send = 6120.00
recv = 5535.00
routingpkts = 7404.00
PDF = 90.44
90.44 NRL = 1.34
Average e-e delay(ms)= 572.56
572.56
No. of dropped data (packets) = 1128
No. of dropped data (bytes) = 600214
Packet Loss [%]= 8.30
send = 6123.00
recv = 5262.00
routingpkts = 7399.00
PDF = 85.94
85.94 NRL = 1.41
Average e-e delay(ms)= 405.63
405.63
No. of dropped data (packets) = 1664
No. of dropped data (bytes) = 885268
Packet Loss [%]= 12.26

----
send = 6125.00
recv = 5878.00
routingpkts = 5646.00
PDF = 95.97
95.97   NRL = 0.96
Average e-e delay(ms)= 37.12
37.12
No. of dropped data (packets) = 473
No. of dropped data (bytes)   = 251736
Packet Loss [%]= 3.99
send = 6120.00
recv = 5678.00
routingpkts = 6366.00
PDF = 92.78
92.78   NRL = 1.12
Average e-e delay(ms)= 161.26
161.26
No. of dropped data (packets) = 862
No. of dropped data (bytes)   = 458624
Packet Loss [%]= 6.85
send = 6116.00
recv = 5466.00
routingpkts = 6915.00
PDF = 89.37
89.37   NRL = 1.27
Average e-e delay(ms)= 840.43
840.43
No. of dropped data (packets) = 1225
No. of dropped data (bytes)   = 651740
Packet Loss [%]= 9.35
send = 6106.00
recv = 5466.00
routingpkts = 6492.00
PDF = 89.52
89.52   NRL = 1.19
Average e-e delay(ms)= 423.26
423.26
No. of dropped data (packets) = 1218
No. of dropped data (bytes)   = 648016
Packet Loss [%]= 9.62

7.34 Group 3 Throughput Output DSDV

47.36
46.09
45.01
44.45

47.26
45.74
45.58
43.34

48.40
46.76
45.02
45.01

7.35 Group 3 Parameters Output DSR

send = 6139.00
recv = 6081.00
routingpkts = 15266.00
PDF = 99.06
NRL = 2.51
Average e-e delay(ms)= 110.09
No. of dropped data (packets) = 625
No. of dropped data (bytes)   = 344946
send = 6083.00
recv = 6036.00
routingpkts = 21861.00
PDF = 99.23
NRL = 3.62
Average e-e delay(ms)= 194.50
No. of dropped data (packets) = 960
No. of dropped data (bytes)   = 532360
send = 6118.00
recv = 6069.00
routingpkts = 26702.00
PDF = 99.20
NRL = 4.40
Average e-e delay(ms)= 123.52
No. of dropped data (packets) = 1083
No. of dropped data (bytes)   = 598554
send = 6082.00
recv = 6026.00
routingpkts = 28378.00
PDF = 99.08
NRL = 4.71
Average e-e delay(ms)= 201.93
No. of dropped data (packets) = 1313
No. of dropped data (bytes)   = 727166
----
send = 6171.00
recv = 6123.00
routingpkts = 13621.00

PDF = 99.22
NRL = 2.22
Average e-e delay(ms)= 125.85
No. of dropped data (packets) = 624
No. of dropped data (bytes) = 345264
send = 6155.00
recv = 6116.00
routingpkts = 21437.00
PDF = 99.37
NRL = 3.51
Average e-e delay(ms)= 95.35
No. of dropped data (packets) = 894
No. of dropped data (bytes) = 494460
send = 6177.00
recv = 6113.00
routingpkts = 27474.00
PDF = 98.96
NRL = 4.49
Average e-e delay(ms)= 149.44
No. of dropped data (packets) = 1047
No. of dropped data (bytes) = 579304
send = 6098.00
recv = 6054.00
routingpkts = 37939.00
PDF = 99.28
NRL = 6.27
Average e-e delay(ms)= 198.51
No. of dropped data (packets) = 1511
No. of dropped data (bytes) = 837252
----
send = 6116.00
recv = 6090.00
routingpkts = 8962.00
PDF = 99.57
NRL = 1.47
Average e-e delay(ms)= 63.62
No. of dropped data (packets) = 373
No. of dropped data (bytes) = 206290
send = 6137.00
recv = 6077.00
routingpkts = 16505.00
PDF = 99.02
NRL = 2.72
Average e-e delay(ms)= 110.87
No. of dropped data (packets) = 696

No. of dropped data (bytes)   = 385300
send = 6127.00
recv = 6068.00
routingpkts = 24708.00
PDF = 99.04
NRL = 4.07
Average e-e delay(ms)= 127.89
No. of dropped data (packets) = 1066
No. of dropped data (bytes)   = 591206
send = 6129.00
recv = 6097.00
routingpkts = 23958.00
PDF = 99.48
NRL = 3.93
Average e-e delay(ms)= 86.97
No. of dropped data (packets) = 1038
No. of dropped data (bytes)   = 574900

7.36 Group 3 Throughput Parameters DSR

50.08
49.71
49.97
49.62

50.42
50.37
50.34
49.85

50.16
50.06
49.97
50.21
