An Investigation of the Impact of Routing Protocols on MANETs using Simulation Modelling

by

Wilford Gibson LOL

A dissertation submitted to

Auckland University of Technology

in partial fulfilment of the requirements for the degree of

Master of Computer and Information Sciences

2008

School of Computing and Mathematical Sciences

Primary Supervisor: Nurul I. Sarkar

Contents

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signature: ______________________________

Wilford Gibson LOL

Acknowledgements

I would like to take the opportunity to thank the people who have supported me during this process.

First, I would like to thank my supervisor Nurul I. Sarkar for the kind commitment, encouragement, guidance, comments and making OPNET available for simulations to be carried out during this research process. Without his contributions this research would not have been possible.

I am also grateful to my fellow class mates Xiaomin Kuang and Rafiq Mohammed. Their suggestions, discussions and comments led to a viable contribution to the simulation experiment and dissertation write-up. Thank you for your support.

Finally, I would like to thank my parents and family who contributed their moral support regardless of the distance apart, encouraging me in difficult times during this process. Your support is greatly acknowledged.

Abstract

A mobile ad hoc network (MANET) is a collection of wireless stations that are dynamically and arbitrarily located in such a manner that the interconnections between stations may change on a continual basis. To facilitate communication among the active stations on the network, a routing protocol is used to discover routes between stations. A routing protocol plays an important role for the overall performance of MANETs. A variety of routing protocols for MANETs have been developed by network researchers and designers primarily to improve the performance of MANETs with respect to correct and efficient route establishment between a pair of stations for message delivery. Examples of commonly used MANET routing protocols include optimized link state routing protocol (OLSR), ad-hoc on-demand distance vector (AODV), dynamic source routing (DSR), and temporary ordered routing algorithm (TORA). A good understanding of the effect of each of these routing protocols on a typical IEEE 802.11 network will assist an efficient design and deployment of appropriate MANETs.

This research aims to study the impact of routing protocols on MANETs by simulation experiment. In the investigation four routing protocols OLSR, AODV, DSR and TORA were used and the impact of network performance under varying network sizes, node mobility and traffic loads was considered. Experimental results show that TORA performs better under high traffic loads for medium and large sized networks. DSR is best suited for small and low mobility networks. The aggressive behaviour in flooding the network for valid routes may not be suitable for large network with high mobility. Despite its aggressive behaviour towards mobility DSR also performs well in large networks with high node mobility. AODV perform better for medium sized networks under high traffic loads. OLSR perform best in most environment, however, it suffers and degrades when mobility and traffic load increases. This dissertation discusses the performance evaluation and comparison of four MANET routing protocols in different simulation scenarios drawing valuable conclusions and future improvements.

List of Abreviations and Acronyms

AODV	Ad hoc on-demand distance vector
CBR	Continuous bit rate
CDM-AODV	Centre base distance multi-path AODV
DAG	Directed acyclic graph
DISTANCE	Distance besed route maintenance
DOA	DSR over AODV
DSDV	Destination sequence distance vector
DSR	Dynamic source routing
e-TORA	Energy TORA
FSR	Fisheye state routing
GPS	Global position system
MAC	Medium access control
MANET	Mobile ad hoc network
MDSR	Modified DSR
MPR	Multi-point relay
N	Number of nodes
NS	Node speed
OLSR	Optimised link state routing
P-AODV	Priority AODV
PDA	Personal digital assistants
PL	Packet length
QoS	Quality of service
RERR	Route error
RREP	Route reply
RREQ	Route request
SARA	Simple ant routing algorithm
SARP	Scalable ad hoc routing protocol
SBC	Stability based clustering
SP	Node speed
TBRPF	Topology broadcast based on reserve path forwarding
TC	Topological control
TORA	Temporary ordered routing algorithm
ZRP	Zone routing protocol

List of Figures

List of Tables

Chapter 1

Introduction

An ad hoc network is comprised of a set of mobile nodes that are connected using wireless links. These nodes can communicate and share information without a central facilitated infrastructure. Nodes in an ad hoc environment are not always stationary, most are mobile hence the network topology (the physical connectivity of communication in a network) keeps changing. To make possible communication between active nodes a routing protocol is used to find path(s) to be followed by data packets, from source to destination nodes. A routing protocol is a principle or standard that controls how nodes come to agree in the way to route packets (using multi-hops) between computing devices in MANETs. Communications and formalising agreement among nodes is crucial to the overall performance of a MANET.

In recent years a variety of MANET routing protocols have been developed. Examples of routing protocols are, Optimized Link State Routing Protocol (OLSR) [1-8], Dynamic Source Routing Protocol (DSR) [8-17], Ad hoc On Demand Distance Vector Routing (AODV) [4, 7, 8, 12-14, 16-20], Wireless Routing Protocol (WRP) [20-22] and Temporally Ordered Routing Algorithm (TORA) [17, 19, 20, 23].

The purpose of routing protocols is to establish the shortest, correct and most efficient route between a pair of nodes. However, not all routing protocols developed perform well in a given situation; hence factors affecting routing protocols require thorough investigation. Factors such as mobility, network size, network load, bandwidths and signal strength do affect the performance of MANET routing protocols.

Mobile ad hoc networks (MANETs) are being extensively deployed currently since they provide features that conventional networks find impossible or difficult to emulate. The ideal applications include settings that deal with mobile nodes; these include home networks, disaster operations, search and rescue operations and military operations. Furthermore, new application are rapidly developing for MANETs [18] and are also finding new entry in commercial usage like the vehicle ad hoc network used in taxi service operation [24].

The nature of MANETs also brings about drawbacks in regards to communication link formation. The uncontrollable nodes causing uncertainty of when nodes disappear and reappear from the network communication range, causing highly variable message delays. These factors have an impact on routing protocol performance. Moreover as the potentials usage of MANET applications grow, it has raised critical concerns over identifying the routing protocol that best works in a given situation. Factors like mobility of nodes, the network size and packet size need to be considered in determining which routing protocol to be deployed in a situation.

1.1 Research objective

The aim of this research is to investigate the impact of routing protocols on MANETs. Simulation methodology is used in the investigation. In this dissertation the following research question is considered: what impact do different routing protocols have on a MANET performance and how can the impact be quantified? In particular, what effect OLSR, DSR, AODV and TORA routing protocols have on MANETs for different network sizes, node mobility and traffic loads. A detailed description of the practical investigation is outlined in Chapter 4.

1.2 Dissertation structure

Figure 1.1 shows the structure of this dissertation. Chapter 2 and Chapter 3 present background material. In Chapter 2, a literature on MANET routing protocols is presented. Chapter 3 describes the research methodology adopted, with a comparison among simulation, real experiment and analytical methodologies. The main contributions are reported in Chapters 4 and 5. The experimental designs and investigation carried out are described in Chapter 4. The experimental results and proposed improvement for a new MANET routing protocol are presented in Chapter 5. Chapter 6 summarised the dissertation.

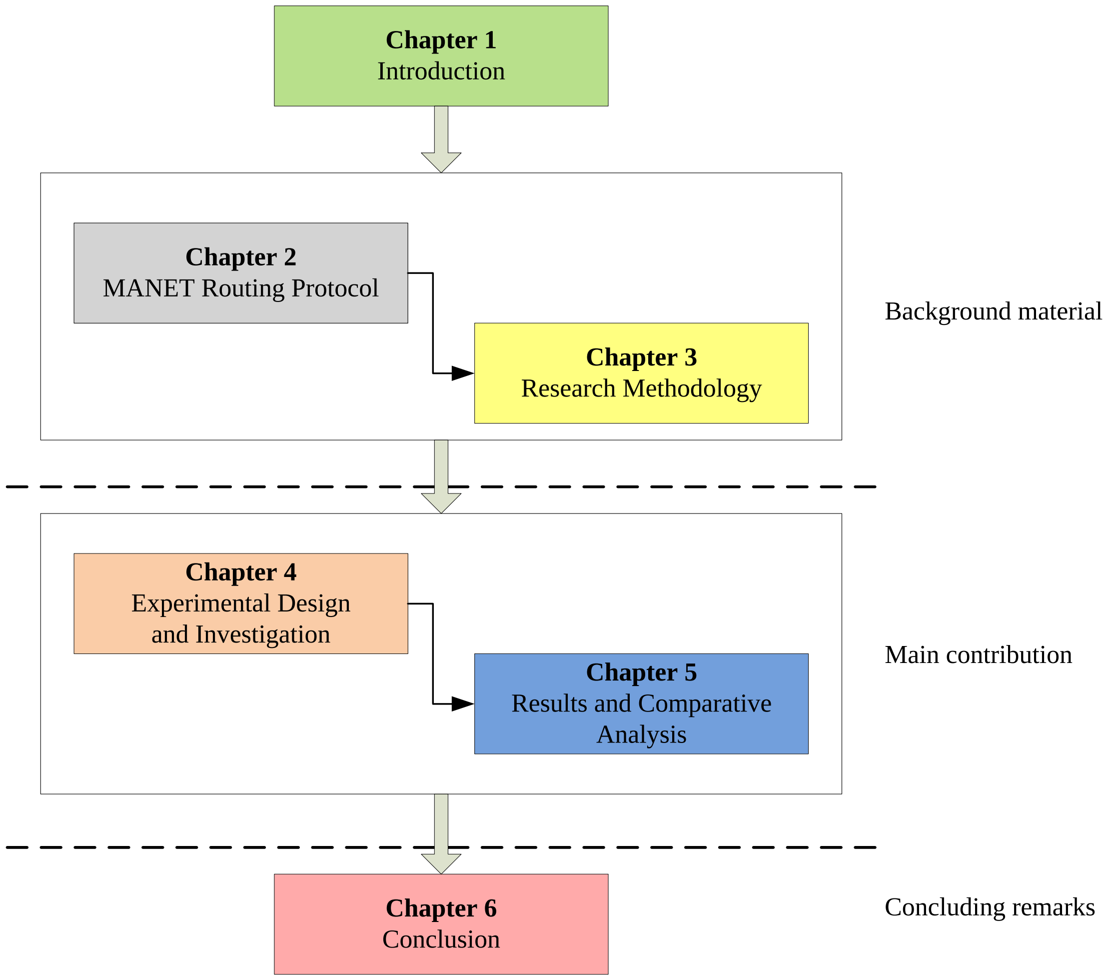

Figure 1.1: Dissertation Structure.

Chapter 2
Mobile Ad Hoc Network Routing Protocols

In Chapter 1, the motivation for the impact of routing protocols on MANETs was outlined. This chapter provides a review of literature on MANET routing protocols. In definition MANET routing protocols are mechanisms to transfer information in data packets from a source to a destination in a network. Generally, two activities take place in routing protocols which enables communication to occur between two nodes. First is to determine optimal routing paths and the transferring of packets through the network but still using low computing power. Second, to achieve these activities, each routing protocol uses different metrics to evaluate the best path that data packets should use when sending packets in a network. To accomplish effective performance the nature of routing algorithms, design and performance issues require careful consideration.

This chapter is divided into seven sections. Section 2.1 outlines the routing protocol design issues. The properties of routing protocols are presented in Section 2.2 and routing approaches to MANETs in Sections 2.3. The comparison of routing protocols is discussed in Section 2.4 and the related work on performance of routing protocols in Section 2.5. The intended approach used is outlined in Section 2.6 and Section 2.7 summarised this chapter.

2.1 Routing protocol design issues

There are number of routing protocol issues to consider when designing MANET routing protocols. Designing a routing protocol is very challenging due to the distributed state of unreliable environments they are found in such as, a dynamic topology resulting from mobility of nodes, limited network capacity in terms of bandwidth and various types of wireless communication constraints. Some of these constrains are: variable link quality, energy constrained nodes, interference and hidden collisions[25]. Limited resources in terms of power, and hidden and exposed terminal problems are vital to be considered when designing a routing protocol [26].

Distributed state in unreliable environment

The status and condition of the environmental challenges is an important role to routing protocols performance. The distribution of resources in any unreliable environment becomes a challenge to enable communication, therefore routing protocols should consider best utilisation of resources like bandwidth, processing power and battery life.

Dynamic topology (Mobility)

The network topology in a MANET is dynamically changing due to the mobility of nodes, therefore causing sessions of transferring packets to suffer from interference, leading to frequent path breaks. The interference occurs when an intermediate or destination node in a route disappears from the network range. When a path breaks it is important that a routing protocol efficiently seeks to learn new available paths and builds a new topology so that reliable connections are established. The network load causing overhead if lowered, the overall performance will increase. Mobility management is extremely important therefore it justifies the need for efficiency in any MANET routing protocol [26].

Limited network capacity (Bandwidth)

Unlike wired networks with abundant bandwidth, MANETs are limited in radio bandwidths therefore data transfer rates are less than those of wired networks. This raised the need for a routing protocol to optimally use the bandwidth. Furthermore, limited bandwidth results in less stored topology information. A complete topology information is required for an efficient routing protocol, however this cannot to be the case in MANET routing protocol as this will cause an increase in node control messages and overheads which wastes more bandwidth. Control message are messages send over the network enabling nodes to establish connections before packet messages are transfer. An efficient routing protocol is required for a balanced usage of the limited bandwidth.

Resource constraints

The two resource constraints which are essential to nodes in MANETs are processing power and battery life. Increasing processing power consumes more battery life. Nodes in a MANET are portable hence processing power and battery life is limited. When overheads occurred more processing and battery life is used to resolve the situation. Hence it is important to design a routing protocol that efficiently allow transfer within the limited life span of battery life using less processing power.

Interference and collisions (Hidden and expose terminal problems)

During simultaneous transmission of two nodes, collision occurs when each node does not know about each other's transmission. The exposed terminal problem contributes to the inability of a node that has been blocked due to transmission of a nearby node to another node, thus the radio reusability spectrum is affected. Transmission cannot occur when spectrum is affected, so it is important to correct the transmission and promote handshakes.

2.2 Properties of routing protocols

The efficient performance of a routing protocol in terms of high throughput, less overheads and a sufficient delay, is determine by the properties of a routing protocol. The essential routing protocol properties are: distributed in operation, free loop, routing computation and maintenance, demand based operation, multiple routes and power conservation.

Routing protocols should be *distributed in operation* and not to be dependent on a centralised node as centralised operations are not scalable. Since nodes can enter or leave a network due to mobility of nodes, a distributed routing operation is more fault tolerant than a centralised routing operation.

Routing protocols should guarantee that routes supplied are *free loop* and are free from stale routes that consume bandwidth and processing power. The efficient *routing computation and maintenance* is another property required to involve a minimum number of nodes. These nodes are required to have access to the route as quickly as possible within a minimum desired setup connection time.

Proactive routing protocols store complete topological information to minimize the control overhead however they consume network resources like battery life, bandwidth and processing power, hence protocols use should be reactive or a *demand based operation.*

To avoid and reduce reactions to topological changes and congestion, *multiple routes* property is inherited. Every node tries to keep a valid record and at least 2 stable route, so that in an event where one is not available the other route is executed saving bandwidth and processing power to be consumed by broadcast control information messages.

Power conservation is a desirable property as nodes like Laptops and Personal Digital Assistants (PDA) have very limited resources therefore an optimal use of scarce resources like bandwidth, processing power, memory and battery life is vital.

Collisions of packets may occur when packets are transferred from source to destination hence a *minimum packet collision* is a property required. This strategy minimises the collision as much as possible during broadcast messages. This amounts to a reliable reduction of data loss and prevention of stale route occurrences.

The radio environment may cause formation of unidirectional links. Utilizing *unidirectional links* will improve routing protocol performance.

MANET encounters different types of data packets, some of which may require some *Quality of Service (QoS)* control. Providence to a certain level of QoS is an essential requirement by some sensitive and real-time applications.

2.3 Routing approaches for MANETs

Routing protocols for MANETs have distinguishing features in regard to the way they exchange information and establish communication. The protocols developed in recent years are classified into three broad categories. These are: flat, hierarchical and geographical routing. This research focuses on flat routing scheme. The flat routing is further classified into two main categories. These are table driven and source initiated on-demand routing protocols [2].

On demand [reactive] routing protocols determine routes only when a node has a data packet to send. A node with a packet to send is referred to as source node. If the route to the destination is not known, the source node initiates a search (route discovery) to find possible routes to the destination [11]. The optimised route is then used and maintained, establishing connection and communication until such a route is no longer required or becomes invalid [10]. The DSR, AODV and TORA are examples of on demand routing protocols.

Table driven [proactive] routing protocols attempt to maintain consistent and up to date information of all possible routes, to all destinations, at all times, regardless of whether the routes are needed. To support this consistency, the protocol sends messages by propagates (broadcast) to gather update information and all possible connectivity through the network [10]. Proactive protocols require each node to maintain more than one table to store routing information regardless of the need for such route information [17, 27]. They also share common features like, background information exchange regardless of the communication request strategy employed [2]. Examples of table driven routing protocols are: Fisheye State Routing (FSR), OLSR, Destination Sequenced Distance Vector (DSDV) and Topology Broadcast Based on Reverse Path Forwarding (TBRPF). Figure 2.1, outlines the classification of proactive and reactive routing protocols. Routing protocols namely OLSR, DSR, AODV and TORA are further described and discussed in the sections below.

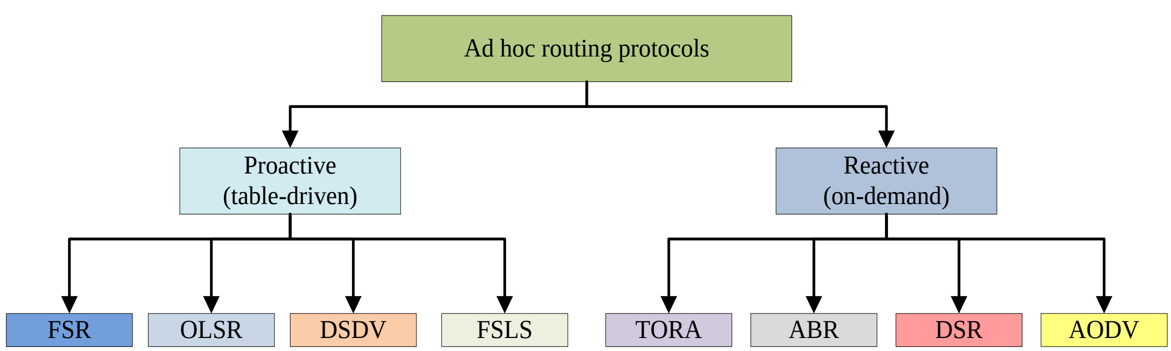

Figure 2.1: Routing protocol classification.

2.3.1 Optimised Link State Routing (OLSR)

The OLSR protocol is an optimised pure state link algorithm. It is designed to reduce retransmission duplicates and with a proactive nature the routes are always available when needed. It uses hop by hop mechanics when forwarding packets [1, 3]. To accommodate this, the nodes exchange topological information periodically using Multi Point Rely (MPR) nodes. MPR is a distinctive feature over other protocols. Other features of OLSR include Neighbouring Sensing, Hello and Topological Control (TC) message. Figure 2.2 shows MPR and how messages are forward. In OLSR, MPRs selected nodes are the only nodes that forwards control traffic hence reducing the size of the control message from flooding the network therefore minimising the overheads [7]. MPRs (for example GIBS in figure 2.2) periodically advertise their link state information to each other nodes. MPR also forms a route from a given source to destination. A hello message is periodically broadcast by each node for link sensing, neighbour detection and MPR selection process. A neighbouring detection is a process where two nodes link, sense, and considers each other as a neighbour only if a link is established symmetrically. A link can be considered a bio or unidirectional. A hello message sent by a node contains its address and all the address for its neighbours. Each node can obtain topological information up to 2 hops from a hello message.

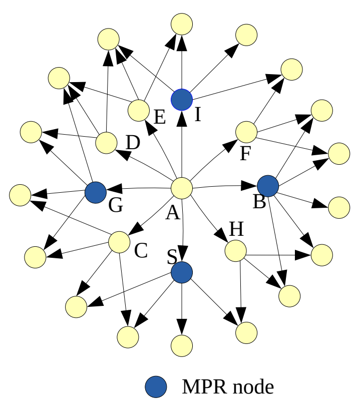

Figure 2.2: OLSR multipoint relays [1, 3].

The MPR selection process that uses 1 and 1 hop symmetrical information to recalculate the MPR set. MPR recalculation occurs when a change in 1 or 2 hop neighbourhood's topology has been detected. When receiving the update information, each node recalculates and updates the route to each known destination [28]. TC message is used to broadcast topological information throughout the network however, only MPR nodes are used to forward the TC messages to nodes in its routing table.

Figure 2.3 illustrates OLSR routing algorithm where a node has a packet to be sent to a destination. It begins by checking if any route to the destination is available in the routing table.

If the route to the destination is not available the source node initiates a broadcast for all possible routes. Should there be a route available, the link is established using a hello message and the sender is ready to send the packet. Once the destination is reached transmission begins. If failure occurs the TC message is sent to update topological changes in MPR nodes.

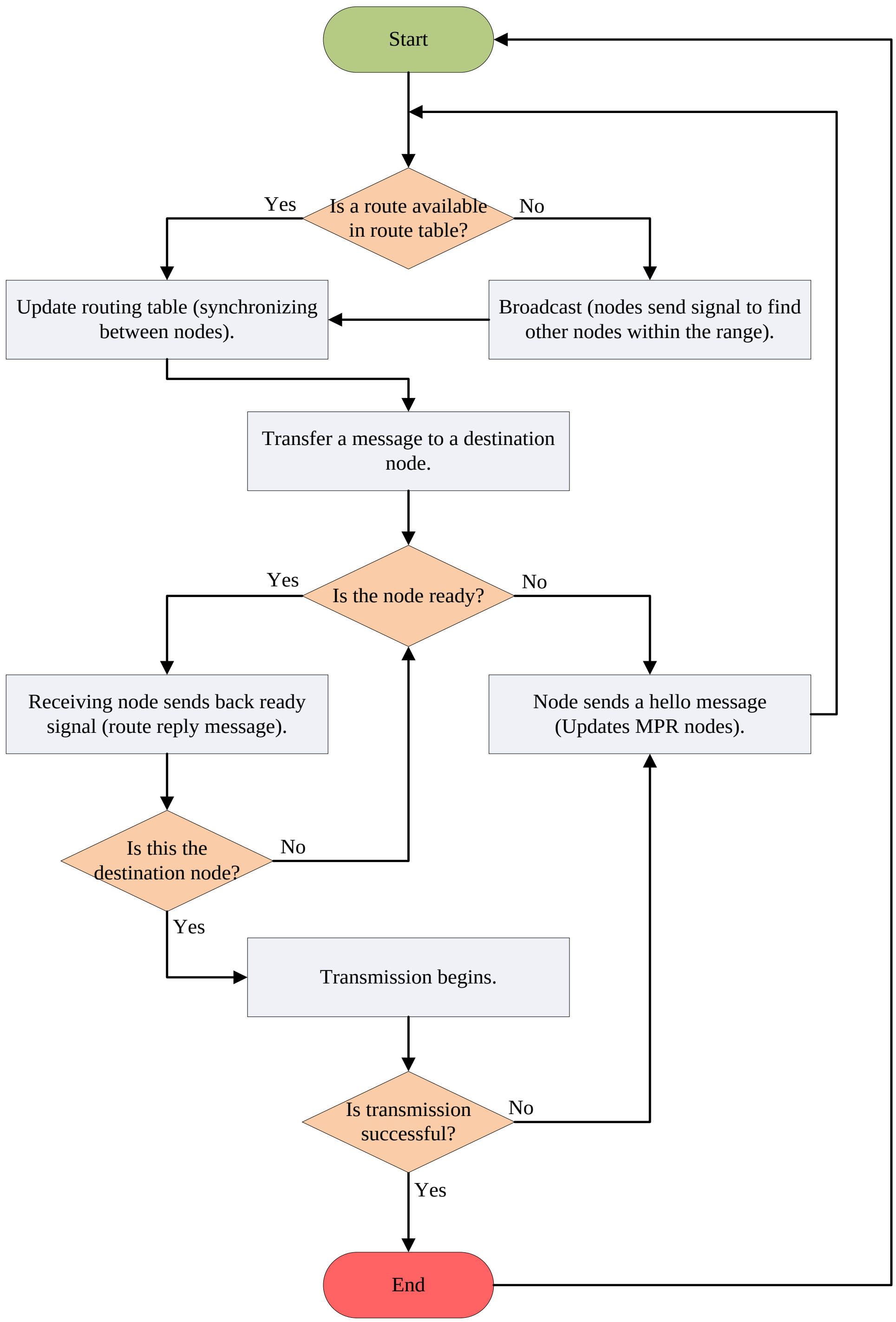

Figure 2.3: OLSR routing algorithm.

2.3.2 Dynamic Source Routing Protocol (DSR)

DSR is a reactive routing protocol that uses the arithmetic of source node routing where the source node determines the route that a data packet should follow to the destination. DSR works by using the following two procedures to be completely self configured and self organising. These procedures are route discovery and route maintenance. Unlike proactive protocols, DSR does not require periodic table update however, when a node wants to send a message to a destination, it uses route cache to verify the availability of a route and initiate a route request, if such route to the destination is not available in its route cache [26].

A r*oute discovery* consists of two processes, these are route request and route reply. A route request (RREQ) message is broadcast over the network to find all possible routes to destination. A route request header contains source, destination, and the hops count it takes to reach the destination as illustrated in Figure 2.4. Each node receiving the packets checks if it knows the route to the destination. If it does have a record from a route request sent recently it discards the request and forwards the request along its links. However, if it does not have a have a record it stores to its own address and forwards the request along the outing links. In receiving the route request packet the destination node responds by sending a *route reply* (RREP) packet to the source node that carries the route incorporated in the route request packet. A route being established is stored in route cache where the source node explicitly lists these routes in data packets header. This scheme allows a multi-hop route to the destination.

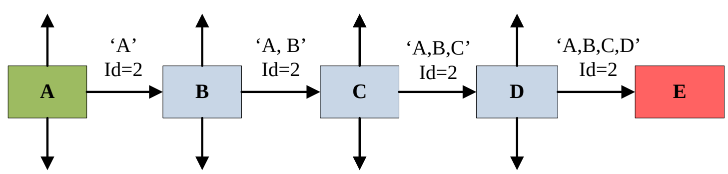

Figure 2.4: DSR route discovery [17].

A RREP message is generated when the RREQ message reaches the destination, or a node that has an expired route. If the node generating the route reply message is the destination node, it places the record of nodes in the route request into a route reply which has the source, destination, source route information [17].

Route maintenance is executed when it receives a route error message (RERR) generated from a node that has transmission problems. Receiving an error packet the node that generated the error packet is removed from the route cache and in all the route cache containing hops to this node. In addition to route maintenance, acknowledge packets are also used for verification of correctness in route links.

DSR advantages include source node alternative route awareness. With this DSR is quick and easy to recovery from link failures. There are also no chances of routing loops as they are easily detected and avoided. DSR works efficiently in lower mobility networks but there are disadvantages as well, like a large route acquisition delay due to initiating route discovery. This may not be acceptable in situations where the mobility rate is high and, during busy connections established over a short period of time which increases message overheads due to low maintenance capability [10]. Aggressive flooding is problematic in DSR and is an important factor to consider since it decreases the ability to maintain overheads in mobility situations. Furthermore a larger header is required to store information in large network therefore using extra bandwidth and processing power for its computation.

The algorithm in Figure 2.5 shows how DSR enables communication between two nodes. If a node has a packet to send, the algorithm checks for a valid route to the destination in its route cache. If the route is not available a route request is initiated and broadcast over the network. However, if the route to the destination is available in route cache, it is then established and the node sends a packet to the receiving node. If the receiving node is ready, transmission begins and terminates if transmission is successful. If a failure occurred, a route RERR is sent that triggers route maintenance which enables the source node to look for possible alternative routes.

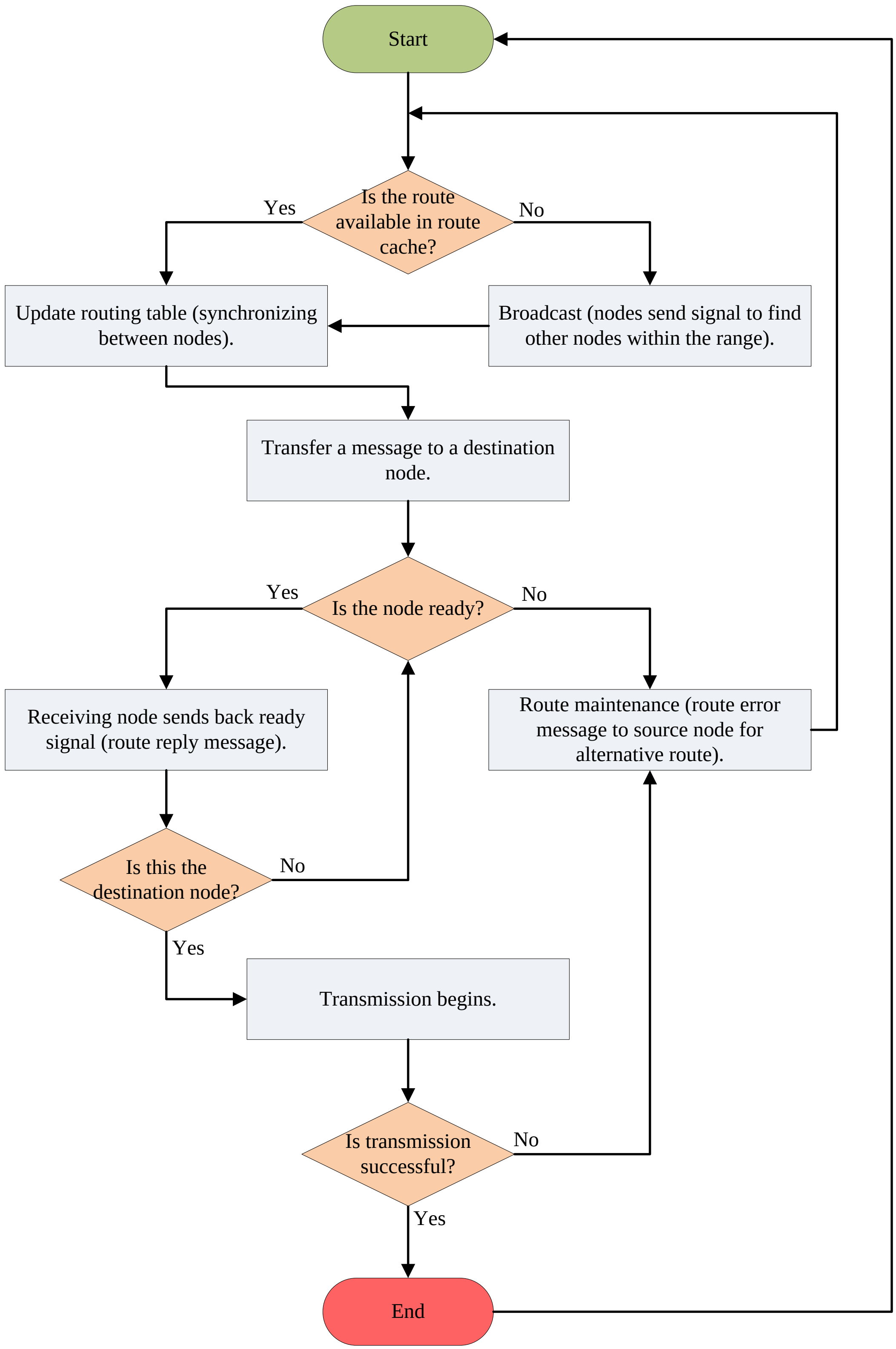

Figure 2.5: DSR routing algorithm.

2.3.3 Ad hoc On Demand Distance Vector Routing (AODV)

AODV provides a good compromise between proactive and reactive routing protocols. AODV uses a distributed approach which means that a source node is not required to maintain a complete sequence of intermediate nodes to reach the destination [10]. It is also an improvement from DSR by addressing the issue of high messaging overhead and large header packets in maintaining routing tables at nodes, so that packets do not have to store much routing information in the headers. AODV uses a routing table in each node and keeps one to two fresh routes. The incorporated features of AODV include features of DSDV, like the use of hop by hop routing, periodic beacon messaging and sequence numbering. A periodic beacon message is used to identify neighbouring nodes. The sequence numbering guarantees a loop free routing and fresh route to destination. AODV has the advantage of minimizing routing table size and broadcast process as routes are created on demand [29]. The two mechanisms; route discovery and route maintenance of AODV are like those of DSR.

In *Route discovery*, if a node wants to send a packet to a destination like DSR, it initiates RREQ throughout the network. A RREQ message contains the source node address, source sequence number, destination sequence number, destination address, hop count and broadcast ID. The combination of source broadcast ID and source address is to uniquely identify a route request message. Any node with a valid route to the destination also needs to have the destination responding by sending a route reply message. A link failure or invalid or expired route will trigger route maintenance. During route discovery there are two pointers set at intermediate nodes between source and destination. Forward pointers, as illustrated in Figure 2.6, are pointers set for route request and packets to propagate from source to destination while back pointers relay reply messages from destination to source. During route request, if the route is found in the table list, the route request message will not be saved but forward to other nodes [9, 10, 30].

Route maintenance is performed using three different messages: hello message, RERR message and route timeout message. A periodic hello message is to prevent forward and backward pointers form expiring. Route timeout messages are sent if there is no activity on a certain route for some time so that route pointers in immediate nodes will timeout (expired) therefore are deleted. An up-stream route error message is initiated when one of the links in the route fails hence the error packet is broadcast globally. Nodes affected, illustrated in Figure 2.6, are nodes 3 and 4; they immediately broadcast an update message to remove the affected route in their route cache and to other nodes that stored the failed route [31]. Route maintenance is accomplished through the use of error packets and acknowledgement [17], when link is broken (transmission error) an error message is sent to other nodes. The nodes with the error routes are erased from route tables.

When a link failure occurs, the route repair is executed using local and global route repair. A local route repair is where the intermediate nodes tries to repair the route at first however, if there is no available routes in intermediate nodes, the message is then sent to the source where the source initiates a global route repair [32].

Without source routing, AODV relies on routing table entries to propagate a route reply (RREP) back to the source node and subsequently to a route data packets to the destination [33]. The advantages of AODV are Loop free routing, optional multicast, reduced control overhead and a quick response to link breakage. The disadvantages are delay caused by route discovery process and the bidirectional connection needed in order to detect a unidirectional link.

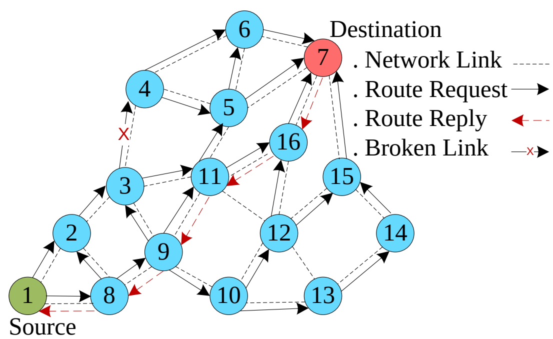

Figure 2.6: AODV routing mechanism [20, 31].

One of the challenges AODV face is the large delay during route construction. Link failures can also initiate another route discovery, therefore creating extra delays and consuming more bandwidth, when the size of network increases [1]. Immediate nodes can lead to inconsistent routes if the sequence number is very old and has a higher but not the latest destination sequence number thereby having stales entries [20].

Figure 2.7 illustrates the AODV routing algorithm. The flow chart shows how packets transfer from a source to a destination and the actions they take when an error occurs. The algorithm checks if a route to destination exists in the route table. It establishes connection and proceeds to transmission. If an error occurs, a local route is initiated among the intermediate nodes. If a route to destination does not exist in the intermediate nodes, a global route repair is trigged enabling the sender to initiate a broadcast for possible routes to the destination.

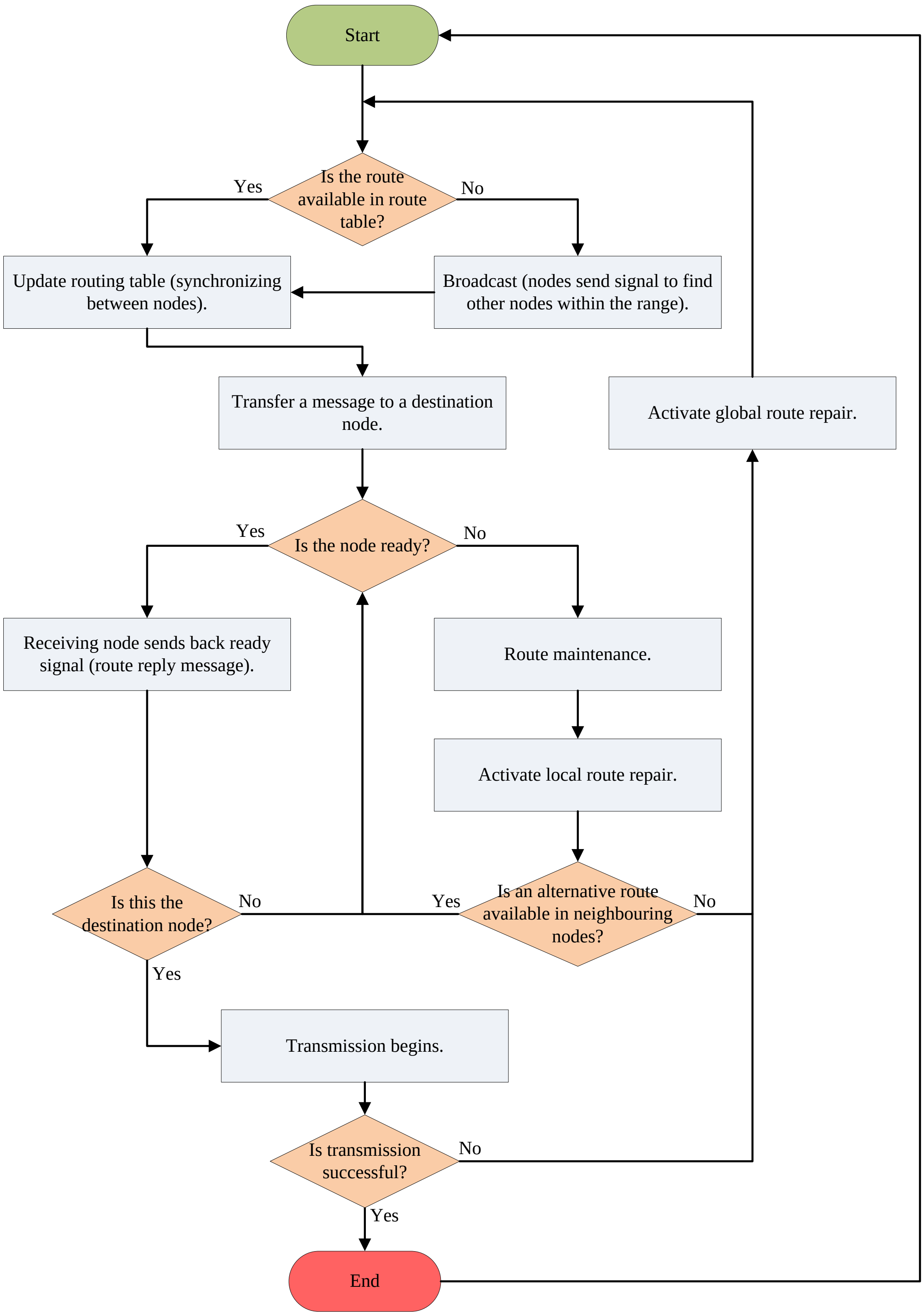

Figure 2.7: AODV routing algorithm.

2.3.4 Temporally Ordered Routing Algorithm (TORA)

TORA is a distributed routing protocol which uses a reversal algorithm. It is designed for routes initiated by source nodes or rather, on demand. TORA is unique by maintaining multiple routes to a destination establishing a route quickly and minimising overhead by not reacting during topological changes until all possible routes are lost. The protocol then initiates a route discovery when all routes to the destination are lost [27, 34]. Like distance vector routing approach, TORA still maintains state on a per-destination basis. However the shortest route paths are considered less important therefore preference is given to longer routes to avoid overheads in trying to rediscover new routes [19, 33]. Additionally, metric used in establishing a routing structure does not represent a distance. In TORA the destination oriented nature of the routing structure supports a mixture of reactive and proactive routing per destination base. During reactive operations, the source node initiates the establishment of a route to the destination on demand. This form of operation is of advantage in high dynamic networks, with relatively thin traffic patterns, as it may not be necessary or desirable to maintain routes between every source/destination pair at all times. Likewise, selecting a proactive operation, resembles a traditional table driven approach hence allowing the route to proactively be maintained to destinations for which routing is frequently and consistently required [19]. TORA however does not work well in low mobility networks.

TORA consist of three basic functions, these are: route creation, route maintenance and route erasure. During route creation and maintenance, nodes use a height metric to establish a Directed Acyclic Graph (DAG) rooted at the destination. The links are then assigned an upstream or downstream direction, based on the relative height metric of neighbouring nodes. During mobility DAG route is usually broken therefore route maintenance is initiated to re-establish a DAG. Reestablishment of route occurs in an infinite number of times, which means its directed portions return to a destination within an infinite time. Once a network partition is detected all links in that portion of the network, those that become partitioned from the destination are marked as undirected to enable erasure of invalid routes [20, 33, 35]. Timing is an important factor as the metric height depends on logical time of link failure. TORA assumes that all nodes have a synchronised clock system. Each node runs a separate copy of the algorithm for each destination thus, when a node requires a route it broadcasts to all the nodes in the network. All query packets contain the destination address for the required route. Each node maintains a one hop local topology information and has detection partition capabilities. Another unique property differentiating it from other routing protocols is that it has limiting control packets to a smaller region during the reconfiguration process initiated by a link failure [26].

Figure 2.8 illustrates the movements of TORA routing protocol. Node 1 sends a route request and creates a route. A possible DAG is created using nodes 2 and 3. In the event of a failure node moves to the next level of reference, to find possible routes to destination before deleting the route and changing the topology. When broadcast in the event of a failure, it activates the cycle and starts again by generating a reference level and forming a possible DAG.

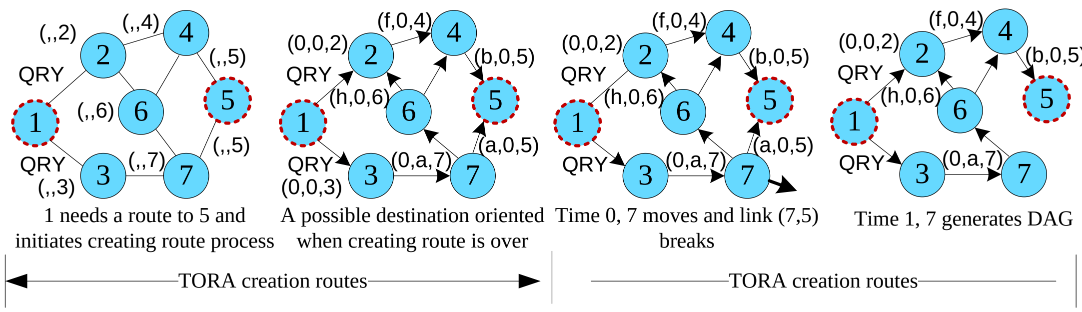

Figure 2.8: TORA routing mechanism [20, 35]

The unique feature of TORA is seen as an advantage over other on-demand routing protocol in high mobility networks. However limitations and challenges occur in the concurrent detection of partitions and subsequent detection of routes, resulting in temporary oscillation and transient loops. Hence local reconfiguration of paths resulted in a lesser and non-optimal route. This causes TORA to be very sensitive to link failures.

Figure 2.8, shows the algorithm for TORA enabling communication and features the three basic functions: route creation (broadcast), route maintenance and route erasure. The algorithm first checks if a route is available to the destination. A broadcast message is initiated if there is no route is available. A topology is generated and the height of nodes to destination is calculated. If there is a failure, route maintenance is trigged and undergoes various checks to resolve the connection. If a possibility is not found, the route is erased and a broadcast message is initiated to regenerate topology. Should the route exist and be without failure, the connection is established and transmission is executed.

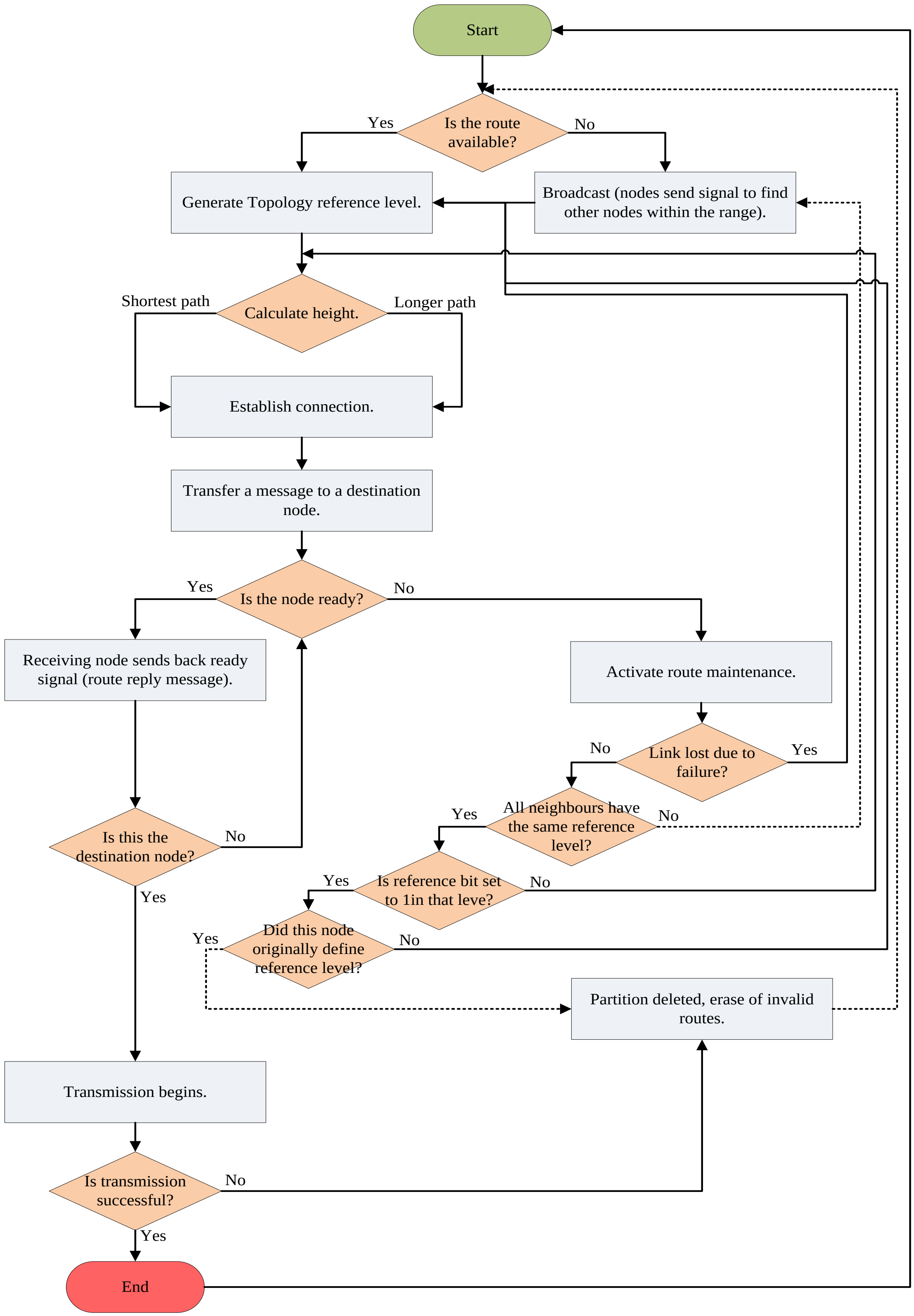

Figure 2.8: TORA routing algorithm.

2.4 Comparison of routing protocols

The task of routing protocols is to establish and enable transfer of data packets from a source to a destination node in a MANET. Each routing protocol reacts differently to enable connections and maintain route. This section provides comparisons for the routing properties outlined in Section 2.2. The three on-demand protocols (DSR, AODV and TORA), share some common properties, while each has their own strengths and weaknesses. Using on-demand routing, one is certain to use valid routes. Each route is stored in route cache, or a route table, for a period of time. In most reactive routing, the route maintenance is carried out by real time monitoring, rather than periodic updates and only entries for the active destination are monitored. OLSR is the proactive routing protocol and has routes that are always available to a destination. Updates are executed periodically or triggered by changes in the network. There exists a common feature in both proactive and reactive routing protocols however, despite the common features, there are several important differences that give a significant difference in performance [30].

Table 2.1 compares the four routing protocols. The parameters compared include route computation, routing updates, loop freedom, advantages and disadvantages. The routing protocols share similarities in loop freedom and routing metric properties. AODV not only uses shortest path but also the freshest route in its routing metric. AODV and TORA, although reactive in their route computation, inherit a proactive routing approach like OLSR to store information in routing tables. DSR on the other hand used cache routing. TORA and DSR share similarities using multiple routes. DSR, AODV and TORA share the same properties of routing updates. Being reactive, routing updates occur as needed therefore the entire topological information is not required. OLSR, being proactive, needs the entire topology information therefore route tables require periodical update. Updating information and route maintenance are dealt with quite differently. OLSR uses a neighbour’s link state to update and maintain its routes. TORA uses the node height following a waterfall model to determine the optimising route to a destination. DSR and AODV use the route error message to trigger maintenance and updating of routes. In DSR the route error message is sent back to the source before route maintenance is triggered however, in AODV, a local route repair is sent to find alternatives to destination and, if this fails, a global route error message is sent to the source node which initiate the route maintenance by broadcasting through the network. These differences demonstrate the advantages and disadvantages in their behaviours towards routing performance.

Parameter	OLSR	DSR	AODV	TORA
Route computation	Table-driven	On-demand	On-demand	On demand/Proactive
Routing structure	Flat	Flat	Flat	Flat
Routes maintained	Route table	Route cache	Route table	Route table
Multiple route possibilities	No	Yes	No	Yes (DAG)
Source routing	No	Yes	No	No
Method	Flooding	Broadcast	Broadcast/ Flooding	Broadcast
Stored information	Entire topology	Routes to desired destination	Next hop for desired destination	Neighbours heights
Routing updates	Periodically	As needed (event driven)	As needed (event driven)	As needed (event driven)
Hello messages	Hello message used to find information about link status and host neighbours; from MPR nodes to all the nodes	No hello message	Small size, used as a supplement for neighbour detection	LMR messages to query about neighbours and heights
Update information & Route maintenance	Neighbours link state	Route error	Route error	Nodes height
Multicast capability	No	No	Yes	No
Routing metric	Shortest path	Shortest path	Freshest and shortest path	Shortest path
Loop free	Yes	Yes, Source route	Yes, Sequence number	Yes
Mechanism of routing	One hop	Source routing	Next hop	Heights
Loop freedom maintenance	Sequence Number	Source route	Sequence number	DAG query update
Advantages	Reduced number of broadcasts	Promiscuous overhearing and multiple routes	Adaptable to highly dynamic topologies	Multiple routes
Disadvantage	Overlapping MPR sets	Scalability problems due to flooding, source routing and large delays	Large delays, Scalability problem, hello messages	Temporary routing loops, causing large delays

Table 2.1: Comparison of four MANET routing protocols.

2.5 Related work on performance of routing protocols

There exist a number of factors contributing to performance of MANET routing protocols. Some of the many factors affecting performance are discussed in Section 2.5.1. Furthermore, various researches are carried out to improve routing protocols performance. Some of these researches are outlined in Section 2.5.2.

2.5.1 Performance issues

Performance is considered by the way a routing protocol deals with providing an optimal Quality of Service (QoS). A QoS should be considered for all data traffics requesting communication in MANETs. Other factors that would hinder performance of routing protocols are; mobility of nodes, increase of node sizes and traffic loads.

Quality of service (QoS)

QoS conditions and management in an ad hoc protocol remains a challenging task to support real time applications, due to mobility of nodes. Providing optimum performance requires a QoS routing protocol and a resource reservation scheme. Real time application traffic requires reservation of bandwidth, a low delay and a high reliability routing protocol [36]. Best effort routing protocols are considered to be both proactive and reactive. In terms of low mobility proactive routing protocols like OLSR can provide a good quality of service. In higher mobility environment, reactive protocols like DSR, AODV and TORA provide a better QoS performance rate. The investigation of AODV, DSR and DSDV [12], shows that in real time traffic the use of AODV is preferred over DSDV and DSR. QoS consists of managing the characteristics and lowering the constraints that existed between a source and a destination, enabling a guaranteed connection for communication [32]. Providing a QoS to most data and real time application traffic is quantified in terms of timeouts and delay avoidance and utilisation of the limited resources.

Mobility of nodes

The speed of a node in MANET plays an important role towards the performance of routing protocols. Mobility of nodes has a direct impact on pause time; it is a time for which a data packet stays in a node waiting for a destination, before moving to another destination. Pause time is also use to measure the performance of mobile nodes in MANET [7]. The research in [3] shows that more packet drops are due to unreliable routes when node speed increases in both DSR and AODV. In a low speed network environment DSR performance is constantly good provided that routes maintained in route cache are valid and useful and without breakage. In a high speed network AODV performed better than DSR. Since DSR relies on cache routes, during high mobility routes become stale. This can lead to an increased number of packet drops. The optimised proactive protocol OLSR is also found to be superior over both DSR and AODV due to its mechanism of early detection of link failures [3, 16]. Furthermore DSR has a lower delay than AODV with a longer pause time [37].

The performance results in [38] confirm that AODV is reliable in a high speed environment and gets a better throughput, however the reliability of TORA is worst. DSR performs poorly in high mobility environments since it exploits caching aggressively to maintain multiple routes to destination and suggested that the use of DSR should focus in networks with less mobility [20]. Yet in earlier studies [34, 39] AODV is found to perform poorly in high mobility due to the picking up of stale routes and hence having a higher packet drop than DSR and TORA. The multiple routes, DAG property and multicast environment in TORA provides sustainable performance in higher mobility environments [29].

The effects of varying mobility on the four routing protocols are significantly different. Mobility imposes stress on routing protocols especially in the event of route failure, and subsequent route re-discovery, which decreases data packet transmission. Traffic patterns, if not implemented or dealt with by routing protocols, will degrade the performance in mobility networks [18, 40]. The increase of speed not only increases the delay but also increases the medium of access delay. If nodes move at a lower speed, routes can be sustain for a longer period. High mobility also suggests that rather than looking for the shortest routing path, a more optimise path should be considered and used to reduce overhead [41].

Network size

The network size or the number of nodes in a network plays an important role towards the overall performance of a routing protocol. AODV is considered to have performed poorly in a small size network, due to the flooding of routing packets. In smaller networks DSR outperformed TORA and AODV. TORA, on the other hand performed poorly in small networks than other routing protocols. In OLSR, the overhead also increases as the number of nodes increases, therefore, resulting in the increase in routing table size and the number of broadcast messages. As network size increases the average delay also increases [7]. Most proactive protocols do well in small networks however, OLSR, also performed well in large networks [16]. The underlying reason is to do with the way routes are requested and maintained in OLSR. However, Zaballos et al. [29] recommended that OLSR should nether be used in networks with a large number of nodes nor in a mobility environment. This is due to a high probability of not maintaining a route quickly, therefore increasing convergence time and the constant searching for possible destination does increases control traffic.

In another study [3], of the effect of network size on routing protocols, stress that for a large network size, nodes may communicate with each other if path lengths are kept constant. The routing loads always increases when a network becomes denser. DSR performs better than AODV in regards to delay in network when nodes is between 10 to 20, while AODV has a better delay than DSR in a 30 source nodes network [39]. Layuan et al. [38] further confirms that AODV has a smaller throughput in a network with a size less than 30 as compared to DSR. TORA has a greater drop in throughput for network size smaller than 50 than network of size greater than 50 nodes. To keep the speed constant while nodes increase, DSR shows a larger throughput than AODV [20].

Traffic pattern has an impact on varying network size therefore, considering traffic pattern in an increasing network is of great importance since the cost to pay for a bad route caching decision is high in larger networks for route rediscovery [18]. In a mobile environment, and in a large sized network, the probability of finding a node for re-route discovery also increases [40]. The performance comparison in [11] supports the literature by identifying OLSR and DSR as recommended routing protocols for small networks; OLSR and AODV as protocols for medium networks and TORA and OLSR for large networks. TORA and AODV have efficient performance while OLSR has degraded performance in large networks and when mobility increases.

The performance for all four routing protocols becomes less constant when network size increases. With a large density more and more nodes will try to access the common medium therefore this increases collision rates resulting in packet loss and a decreasing throughput [41]. Routing protocols with efficient performance must have a mechanism to cater for mobility and be able to rediscover a route in a way that reduces or keeps the overhead at constant.

Data traffic load

The performance of routing protocols is also determined by how protocols manage traffic loads. Data traffic loads are types of data running simultaneously over the network, whether it is a light, medium or heavy load. Traffic load is also determined by the packet length of a type of data. The protocols, in accordance to their respective algorithm nature, reacted differently to traffic loads. In their study Perkins et al. [42] conclude that data traffic load does have a different impact on routing performance as the network size varies. DSR outperformed other reactive protocols when traffic load is low and OLSR shows the best performance at every traffic load. When considering routing overhead, routing load increases tremendously when traffic load increases. The increase in traffic load results in establishing more routes to be sorted hence this will increase the overhead, yet Mbarushimana et al. [3] in their results shows that OLSR has lowest lower delay than DSR and AODV.

The increase in data traffic also increases bandwidth usage. The consumed bandwidth for delivered packets is the same as those use to traverse through the network. Additionally, bandwidth is also required for data packets that are dropped. Routing protocols with unicast slows down packet transmission therefore, DSR with unicast suffers more than AODV [14]. The increase in the traffic volume affects the performance of all routing protocols; the worst affected is DSR, being primarily composed of unicast packets, while AODV has a high fraction of overheads due to its multicast mechanism [18].

2.5.2 Researchers and their contributions

Various improvements have been proposed to improve MANET routing protocol performance. This section presents a summary of contributions towards improving routing protocols in Table 2.2. The contributions are summarised as: preventing link failures, reducing delay to improve throughput, lengthening the lifetime of a route, controlling broadcast initiated by neighbouring nodes, division of parts to allow higher transmission data to follow one while non real time traffic follows the other, utilising longest path rather than shortest path, identifying easily repairable routes from the density of neighbouring nodes, decreasing the number of route requests, choosing two paths from the centre of the network, coping with dynamic situations using hybrid routing of both reactive and proactive protocols, defining and using intra-segments for local repair and intersegments for global repair and ware energy of nodes to determine the best possible routes. These suggested improvements aim to contribute towards better performance and a lowering of the fail or the expire links reducing delay.

Sjaugi et al. [43] proposed a new route maintenance strategy for DSR by utilising location and adding a node to source list preventing link failures in order to improve packet sending ratios and to minimise delays. Since the route discovery mechanism is associated with great delay in DSR, Alilou et al. [44] proposed the change of the DSR route selection mechanism to behave proactively in order to improve throughput and reduce delay. Clustering is also a technique used in reducing route acquisition overhead. In another study Taing et al. [15] proposed a new improvement to the DSR protocol called Modified DSR (MDSR). It functions by understanding the data transmission traffic and separating it into two groups. The first group consists of priority transmission of real time application traffic where delays are sensitive. MDSR uses a larger transmission power for the first group. The second group, non-real time traffic, uses less transmission power where delays can be allowed. Having separate transmission ranges for the type of traffic shows a performance increase in MDSR as compared to DSR.

Researcher	Contribution	Main ideas/description
Sjaugi et al. 2008	DISTANCE [43]	New route maintenance strategy called DIstance beSed rouTe maintenANCE (DISTANCE) to improve packet sending ratios and delays by preventing links from failure
Alilou et al. 2005	PDSR [44]	DSR route selection mechanism implemented to behave proactively reducing delay and improving good put.
Yang et al. 2006	SBC [45]	Introducing stability based clustering (SBC) to improve performance over those of zone routing protocol
Correia et al. 2008	SARA [46]	Simple ant routing algorithm (SARA) uses controlled neighbour broadcast route discovery aiming to reduce routing overheads.
Taing et al. 2006	MDSR [15]	Modified DSR (MDSR) proposed routing scheme with two groups of transmission range, higher transmission rate using shortest path to destination for real-time traffic application while non real time application traffic uses the other routes where delay can be allowed while transmitting.
Tseng et al. 2003	DSR lifetime [47]	A model to predict the lifetime of routing paths and usages of the longest expected lifetime is developed. Choosing the shortest path has a high probability of becoming broken.
Quintero et al. 2004	AODV repairable route [32]	Improving route discovery aim by selecting the most easily repairable route among other routes during route discovery. Taking into account density and availability of neighbouring nodes.
Khamforoosh et al. 2008	CDM AODV [48]	Acquires a new multi path in AODV routing called Centre base Distance Multi-path AODV (CDM-AODV). Choosing two paths from the centre of the network makes use of the reverse relationship therefore it replays packets which have information about the network centre and distance between nodes.
Espes et al. 2007	AODV [49]	Improvements to AODV routing in dense network and decreases the number of route requests by limiting the search area by using a quadrilateral with two angles giving GPS coordinates passing from source to destination.
Costa-Requena et al. 2006	SARP [50]	Scalable ad hoc routing protocol (SARP). MRP nodes are implemented in the network distributing evenly over the network while other nodes, if not MRP, use AODV routing scheme. Provide effective performance in both reactive and proactive situation. SARP is a cross breed develop from AODV & OLSR
Bai et al. 2006	DOA [22]	DOA (DSR over AODV) implements two levels of route repair defined as intra-segment and inter-segment route repair. Operates as a local and global route repair in AODV, however, takes into consideration 1 segment using intra-segment and inter-segment over multiple segments.
Yu et al. 2007	e-TORA [23]	Energy aware routing protocol (e-TORA) utilises nodes with higher energy to ensure high probability in route path. Combination of hop count with residual energy of nodes to ensure that there is a trade off in residential energy usages hence prolong network lifetime.

Table 2.2: Researchers and their contributions on MANET routing protocols.

Yang et al. [45] proposed stability based clustering (SBC) to improve performance rather than zone routing protocol. Simple ant routing algorithm (SARA) proposed by Correia et al. [46], uses controlled neighbour broadcast route discovery aiming to reduce routing overheads.

Tseng et al. [47] present a model to predict the lifetime of routing paths. The scheme proposed chooses the longest expected lifetime. DSR and most routing protocols adopt shortest path routing which is not always reliable and is not always the best option as there is a high probability of a route failure under high network density.

DSR over AODV (DOA), proposed by Bai et al. [22], targeted route maintenance. DOA implements two levels of route repair defined as intra-segment and inter-segment route repair. If a route fails intra-segment tries to fix it by finding alternative routes within one segment. If it succeeds then way point nodes on routes to source nodes are not changed, hence the source node needed not to be notified. However if it fails, inter-segment will try fixing it by finding alternative routes over multiple segments include downstream and broken segments. If intra-segment succeeds the repaired route will be send to source node and packets to be send using this route. However if inter-segment fails an inter-segment error message is sent to the source node which subsequently starts a new global route discovery.

With regards to AODV Quintero et al. [32] proposed a new protocol for route discovery aiming to select the most easily reparable route, among other routes, during route discovery, by taking into account the density and availability of neighbouring nodes. The availability of neighbouring nodes is associated with its repair fitness. In another research Khamforoosh et al. [48] presented the idea of a new multi path in AODV routing called Centre base Distance Multi-path AODV (CDM-AODV). The two paths in this algorithm are chosen from the centre of the network. The reason being is that there is a reverse relationship between the distances of the node to the centre of network. When request packets are sent, replay packets have the information about the centre of network and distance between nodes. In a more recent study Espes et al. [49] improves AODV routing in dense network and decreases the number of route request by limiting the search area by using a quadrilateral with two angles giving global position system (GPS) coordinates passing from a source to a destination. A combination of AODV and OLSR for scalable routing is proposed by Costa-Requena et al. [50] called scalable ad hoc routing protocol (SARP). SARP considers the whole network as a zone and reacts opposite to those of zone routing protocol (ZRP). MRP nodes are implemented distributing evenly over the network, while other nodes, if not MRP use AODV routing scheme. In so doing hello message establishes routes and forward messages are handled well in small networks. In high network the combination of MRP and AODV is used.

A new TORA- based energy aware routing protocol (e-TORA) is proposed by Yu et al. [23] to ensure that nodes with more energy have higher probability of being chosen as a route path. TORA chooses routes with the shortest hops when network topology is not changing. Most packets will then be sent using the same route, repeatedly from a source to a destination. Under heavy loads, nodes will exhaust its energy and network lifetime will decrease. If some nodes stop in the operation, it will result in network partitioning and communication interruption. In order to prolong the life time of nodes, e-TORA ensures that traffic sent can avoid nodes with a low energy. The combination of hop count with residual energy of nodes is utilised so that there is a trade off in residential energy usages, hence prolong network lifetime.

The need to defeat routing overhead is a compelling factor, every routing protocol develop are trying to achieved. Excess routing overhead leads to a delay in transmitting packets to destination, since there is a big queue of messages requesting up to date information in the event of a link failure or lack of confirmation. Proactive protocols aim to reduce overhead by keeping a route table at each node. However in network situations where nodes leave and appear will increase messages broadcast over the network since stale routes requires a topology update. Reactive, on the other hand, aims to reduce overhead by either source routing or trying to fix the broken link as soon as it breaks, by looking at the routing cache or tables of neighbouring nodes. Routing protocols perform best in different network scenarios.

The energy consumption in processing power and battery life plays an important role towards the overall performance; however, it may contribute less to routing performance than addressing ways to defeat overheads in the routing algorithm. A poor management strategy in dealing with message packets over the network will consume a lot of network resource like processing power, bandwidth and battery life.

2.6 Intended research

This research aims to find out which routing protocol performs best when mobility is present in MANETs. One of the unique features of this experiment is that it considers mobility in all scenarios. A low speed will be used for the movement of people while the other two consider moving objects (i.e. cars, war machines and etc) and at a high speed as possible.

The network size scenarios considered are small, medium and large. A small network would be defined with nodes less than 15, a medium networks with nodes in the range of 15 to 90 and a large network with a node size of 100 and above.

Data traffic considers a normal traffic, a medium traffic and a worst possible traffic load. Another unique feature is that it will consider worst possible mobility together with the highest rate of data traffic in scenarios of varying mobility and traffic load. This helps measure the impact it has on routing protocols. The scalability of routing protocol starts with a careful design that only one parameter is changed at one time to ensure the assessments and isolation of the effects of mobility, traffic load and network size. A detailed discussion of the design and investigation conducted is outlined in Chapter 4.

2.7 Summary

This chapter provides background information reviewing the literature on MANET routing protocols. Specifically, a closer look at the nature and properties of routing protocols, the properties that provided a significant difference between each routing protocol and the research carried out for routing improvement. Reiterating, the objective of this research is to take a closer look at the influence of node mobility, network size and traffic loads impact on routing protocols. A simulation methodology approach will be used to examine the impact on routing protocols on MANETs performance is presented in Chapter 3.

Chapter 3
Research Methodology

In Chapter 2, a review of literature on routing protocols was presented. This chapter outlines the research methodology used in the investigation to study impact of routing protocols on MANETs. This chapter is divided into three sections. Section 3.1 presents the research paradigms and methodology used. Section 3.2 outlines the tools used in carrying out the experimental research. Section 3.3 summaries the chapter.

3.1 Research paradigm

Based on networking and its related areas, methodologies used for modelling and performance evaluation of routing protocols are analytical modelling, direct or real experiment and computer simulation. Analytical modelling is based on mathematical computation and analysis. Although analytical analysis may found to be a good ground for formulating new routing protocols, the weaknesses lies in operating and controlling protocols [51]. Furthermore analytical modelling cannot represent the dynamic nature of MANETs, its configuration and reconfiguration for large networks would be too troublesome.

Real experiment however has an advantage in obtaining fairly accurate results as the research is carried out in reality where the influences and routing behaviours can be observed depending on the surrounding they exist in. Lui et al, [51] stress that simple levels of abstraction in simulation cannot provide a solid base validation of routing protocol behaviour as compared to real experiment. The complexity of MANETs, however, could not be all tested in real experiments due to the high cost and the complex nature of mobile ad hoc networks, taking numerous efforts and resources to carry out the experiments and performance evaluations.

A simulation experiment is defined [52] as a process of constructing model(s) of a system which consists of a problem and then conducting simulation experiments with the model using a computer program (also referred to as simulation tool or simulator) to help solve or find a solution to the problem. The goal of a using any simulator is to accurately model and predict the behaviour of a real world problem in a system.

Computer simulation is used to generalise measurement results, verify analytical models, compare the performance of existing protocols and also evaluate the performance of new protocols. However a potential problem exists in simulations where simulators are not generating accurate or representative results. An extensive knowledge about a good simulator is required to overcome this problem. A good simulator will be easy to use, is flexible in model development and the process of modification and validation and incorporates appropriate analysis of results [53].

The creditability of simulation not only lies in using a good simulator, but also has an advantage as simulation does have a process to validate and verify the results. The process includes parameter validation, operational graphics, comparison, event validation and historical data validation to compare with simulations findings in order to prove its viability [54, 55]. In addition, the guidelines outline in [56] if followed appropriately will reduce simulation pitfalls and errors.

Computer simulation methodology is used to carry out the proposed research. Usually, the performance of routing protocols is evaluated using computer simulation techniques which, unlike analytical methods, use fewer assumptions and behave more like real systems. The complexity of routing algorithms is another driving force for adopting simulation methodology. In addition, simulation offers more flexibility in model development, validation, and performance evaluation. To investigate the research question (*What impact do different routing protocols have on a MANET performance and how can this be quantified?*), a simulation methodological approach has been adopted to examine the impact of routing protocols on MANET performance. In the investigation, various network scenarios (based on OPNET Modeler) will be considered to study the impact of DSDV, AODV, DSR, and TORA on MANET performance.

3.2 Optimized Network Engineering Tool (OPNET) Simulator

There exist are number of network simulators which can be use to compare the impact of MANET routing protocols on mobility networks. NS2, GloMoSim, QualNet and OPNET are some of the popular network simulators [57-59].

NS2 is a discrete event network simulator and is regard as one of the most popular alternative of real network simulator. NS2 is originally design to simulate wired networks and now supports wireless networking. The core code of NS2 is written C++ and is popular of its open source licence. NS2 unfortunately suffers from limited documentation, coding in inconsistency across releases and the luck tools to describe simulation scenarios and most tools are written in scripting languages thus the learning curve is steep and debugging is difficult [57, 59]. GloMoSim is open source developed in Parsec therefore benefits from the ability to shared memory symmetric processor computers. Unfortunately the new protocols and modules must be build on Parsec and similarly like NS2 suffers from in depth and good documentation [59].

QualNet is a commercial MANET simulator that is based on GloMoSim. It now brings support to documentation and a complete user friendly environment and tools to build scenarios and make analysis of simulation outputs. However being based on GloMoSim, it inherits some of the limitation GloMoSim has and particularly QualNet is also written in Parsec [59].

OPNET is an object oriented, discrete event and general purpose network simulator [60]. OPNET is chosen for this research because it carries the distinct features of a good simulator. OPNET provides a comprehensive modelling environment for unique specification, simulation and analysis of the performance of computer networks. OPNET has several modules and tools embedded; this includes OPNET modeler, model library, analysis tools and planner. It is widely used in modelling networks, and also for evaluating and analysing network performances. The results obtained using OPNET simulator is barely comparable to those taken from GloMoSim, QualNet and NS2 [58, 59] Furthermore it has the capability to modelling MANET routing protocols, especially the protocols investigated in this research [60, 61].

OPNET is a commercial package, which employs a hierarchical modelling architecture consisting of three levels. The top level consists of the network model where topology is design, the second level consists of data flow models and the third level consists of the process editor which handles control data flow [53]. These levels are significant in modelling, evaluating and amendments of routing protocols.

The OPNET simulator has strengths and drawbacks. The drawback is that being a commercial package, it is very expensive and heavily controlled therefore parameter categorisation are not that transparent. Another drawback is that OPNET processes consume large amounts of CPU usage; therefore a high computing power is required. However, the main advantages of OPNET are the use of a graphical user interface, a user friendly environment, graphical and customisable output results. Furthermore it consists of a comprehensive library, source coding for all models developed and tools embedded for network models and protocols [62].

3.3 Summary

This chapter outlined three methodologies used in the area of network modelling and performance evaluation. Analytical and real experiments have shortcomings when dealing with the nature and complexity of MANET routing protocols. Simulation is considered the best, simulating real scenarios of real world environment with robust validation and verification rules, which if followed, will countermand the drawbacks of simulation. The OPNET simulator was selected as a good simulator due the characteristics it possesses. There are weaknesses, however, the strengths qualified OPNET as a good simulator for networks and MANET routing protocol modelling.

Chapter 4

Experimental Design and Investigation

The research methodology adopted in the dissertation is discussed in Chapter 3. This chapter provides the experimental design, including the parameters used for network modelling. This chapter is divided into three sections. Section 4.1 outlines the performance metrics. Section 4.2 presents the experimental scenario and Section 4.3 summaries the chapter.

4.1 Performance metrics

A metric is a standard measurement used in a routing algorithm to determine the best possible, effective and efficient route to a destination. The performance metrics used to measure the performance of routing protocols are; average throughput, average routing load, average retransmission and end to end delay.

Throughput – is the average rate of successful data packets received over a communication channel and is measured in bits per second (bits/sec). Throughput measures the effectiveness and efficiency of routing protocols usage (performance) over the network in delivering data packets from a source to a destination node. It also evaluates the quality of routes and the capacity of routing algorithm to a data flow and those associated with an active session or in a specific timeframe.

End to end delay –of data packets are all possible delays caused by queuing at an interference queue, buffering during discovery latency, propagation, transfer time and retransmission delays at medium access control (MAC). The end to end delay is the time taken to traverse from a source to a destination node. End to end delay evaluates the ability of routing protocols to make efficient use of network resources.

Routing load – is the number of routing packets transmitted per data packet delivered at destination. Every hop-wise transmission is counted as one transmission. *Packet overhead* constitutes the number of packets “transmitted” per data packet that is “delivered” at destination. In another interpretation, routing overhead is determined by the ratio of the amount of information needed to carry control traffic over information needed to carry data traffic.

Retransmission attempts – is the resending attempts of packets which have been lost or damaged due to link failure. It also shows the number packets failed and therefore requires retransmission.

Throughput and end to end delay are the most important metrics to consider for best effort traffic whereas routing load evaluates the efficiency of routing protocols. Since the experiment is considering factors impacting on routing protocols the retransmission attempts a routing protocol takes to send a message across the network is crucial. These metrics are not totally independent of each other. A large overhead may result in great delays and lower throughputs, on the other hand a short delay cannot be generalised or imply higher throughput since delay is only measured in data packets that are successfully delivered .

4.2 Assumptions

The assumptions made on experimental investigation are: 1) all the nodes in a network are not supposed to generate traffic at any given time; 2) multiple hops are used as required before arriving at the destination; 3) all nodes, including the destination are mobile and are moving at consistent allocated speed and 4) not all the nodes in a network are moving at a given time.

4.3 Network modelling and scenarios

The experimental scenarios are presented in Figure 4.1. The four routing protocols, OLSR, DSR, AODV and TORA are used in investigating varying network sizes, node mobility and data traffic loads. 802.11b is the network standard used and all nodes used are mobile nodes. These experiments aim to identify the impact of routing protocols performances on MANETs and make recommendation of possible protocol use.

The experimental investigations are classified into three categories. These are: 1) network sizes; 2) node mobility and 3) traffic loads. In the network size investigation, all four routing protocols are deployed in small, medium and large networks as illustrated in Figure 4.1. The node mobility and traffic load are also investigated in all three network sizes. Detailed descriptions of the experimental scenarios in each category are outline in Tables 4.4, 4.5 and 4.6.

The parameters used in assessing the scalability of protocols are carefully designed as outline in Tables 4.1 to 4.3. In all scenarios only one control parameter is varied at a time to stress the impact of a routing protocol in all possible directions. The parameters changed to reflect the impact of the protocols performance are node sizes (N), node speed (NS) and packet length (PL). Table 4.1 presents the general parameters configured in all experiments.

The experiments are conducted using an area space of 2,000 square meters. The three node sizes used are 10, 50 and 100. Node speeds are configured using the Random Waypoint mobility model; traffic patterns are not directly investigated therefore the Random Waypoint (Record Trajectory) is not required. The node speeds used are 5, 20 and 30 meters per second (m/s). The node speed of 5 m/s reflects the movement of people and the nodes speed of 20 and 30 m/s reflects mobility of objects like trains, cars, war machines and other moving objects. The File Transfer Protocol (FTP) is the data type used in generating traffic. The data rate used by the MAC for transmission of data frames via physical layer is 11 Mbps and the transmission rate used is 1000 m/s. The packet lengths used to investigate traffic loads are 1,000, 5,000 and 50,000 bytes. 1,000 bytes reflects a normal traffic load, 5,000 reflects a medium traffic loads and 50,000 bytes represents traffic that demands continuous transmission. All simulations are carried out in 900 seconds of simulation time.

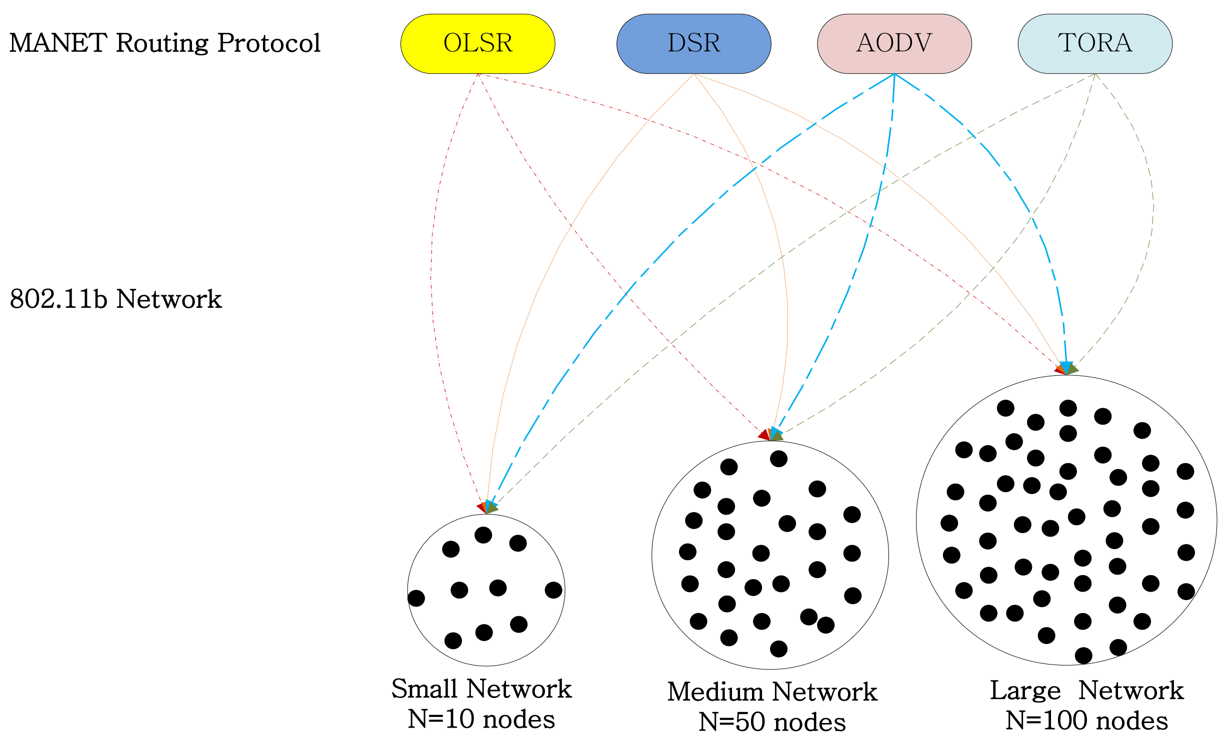

Figure 4.1: Simulation scenarios.

The simulation parameters are shown in Tables 4.2 and 4.3. Most parameters use are default settings; some of useful parameters for OLSR and DSR are listed in Table 4.2 likewise for AODV and TORA in Table 4.3.

Parameters	Value
Area	2000 x 2000 Square meters
Network Size (number of nodes)	10, 50, 100
Mobility model	Random way point
Data rate	11 Mbps
Transmission rate	1000 ms
Transmission power	0.005 Watt
Packet Size (traffic load)	1000, 5000, 50000 bytes/packet
Data Type	FTP,
Mobility speed	5, 20, 30 meters/second (m/s)
Simulation time	900 seconds

Table 4.1: General parameters used in simulation.

OLSR		DSR	
Parameters	**Values**	**Parameters**	**Values**
Willingness	default	Route expiry time (route cache)	300
Hello interval (sec)	2.0	Request table size (nodes) (route discovery)	64
TC Interval (sec)	5.0	Max Request retransmission (route discovery)	16
Neighbour hold time (sec)	6.0	Max request period (sec) route discovery	10
Topology hold time (sec)	15.0	Max buffer size for route maintenance (packets)	50
		Maintenance hold time (sec)	0.25
		Max maintenance retransmission	2
		Maintenance acknowledgement timer (sec)	0.5
		Route replies using cached routes	enabled
		Packet salving	enabled

Table 4.2: OLSR and DSR parameters.

AODV		TORA	
Parameters	**Values**	**Parameters**	**Values**
Route request retries (route discovery)	5	Mode of operation	On demand
Route request rate (pkts/sec)	10	OPT transmission interval (sec)	300
Hello interval (sec) (uniform)	(1, 11)	IP Packet discard timeout (sec)	10
Route error rate (pkts/sec)	10	Beacon period (sec)	20
Node traversal time (sec)	0.04	Max Beacon timer (sec)	60
Timeout buffer	2	Max tries (number of attempts)	3
Local Repair	enabled	Max packet length (bytes)	1,500

Table 4.3: AODV and TORA parameters.

Figure 4.2 illustrates the OPNET simulation environment with a network size of 100 nodes. The network area used is 2,000 square meters. The objects in the environment are nodes, mobility, application, profile and rx group. The node objects are labelled according to the number of nodes present in the network. For example N58 represents node number 58 in the network. N10 is a server (destination) configured to support and service FTP traffics. N58, like other nodes apart from N10, is configured to generate FTP traffic randomly, with the ability to route received packets to the destination. All nodes, including the destination node, are configured to use the same routing protocol. The mobility configuration object is used to configure the node speed.

The application configuration object is used in configuring the types of application used, and the packet length. The profile application object is used to group applications configured in the application object into a profile. For example; an FTP profile is the profile created in the profile object and configured to support FTP application created in the application object. The FTP profile is then configured in all nodes except the destination node. This will enable nodes to generate traffics. The rx group configuration object enables nodes to move within the 2000 square meter area allocated. Traffics generated from any node that is outside the range will be discarded. The experiment is duplicated and routing protocols are changed. This is repeated for the remaining three protocols. All four experiments, each configured with a different routing protocol, are placed together in a scenario.

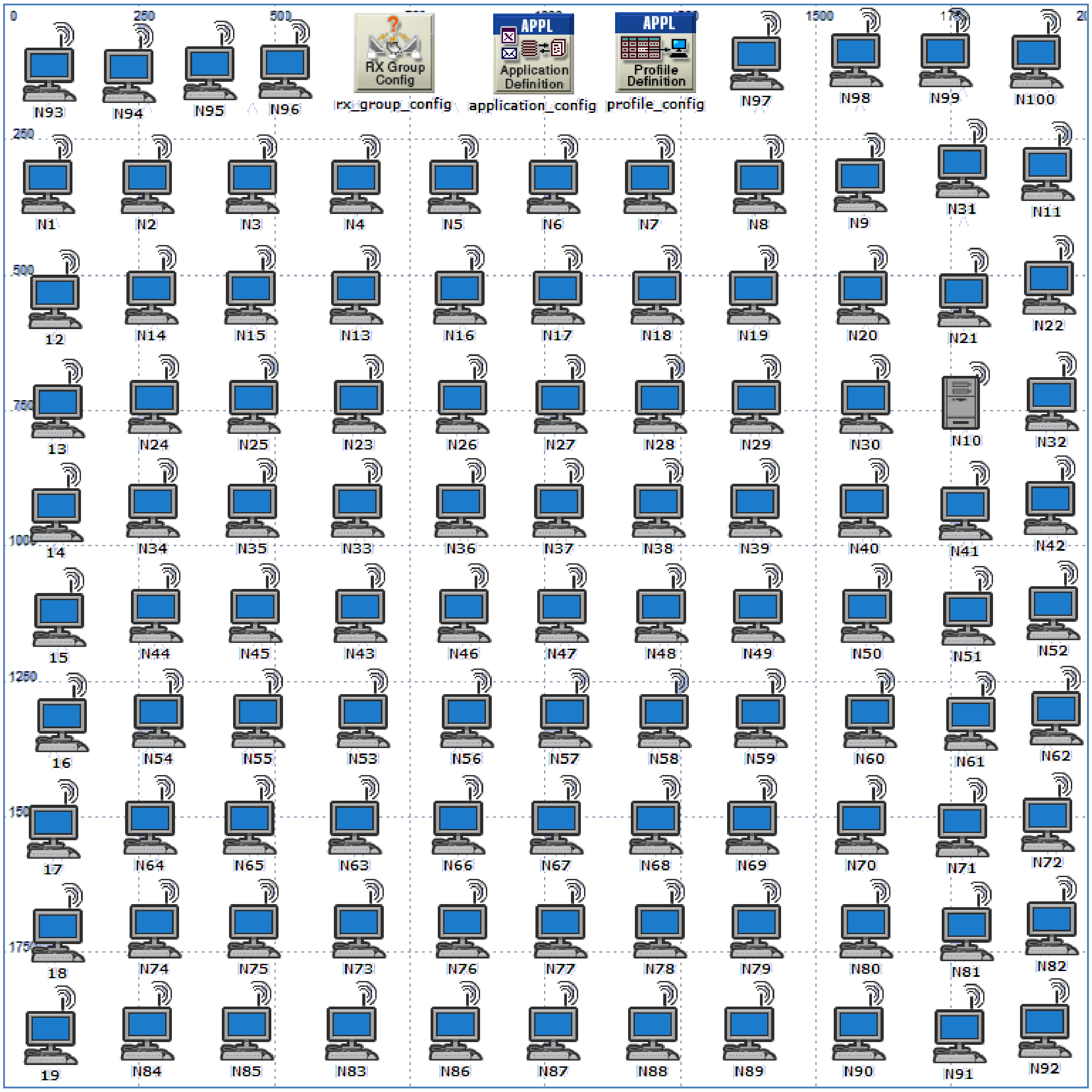

Figure 4.2: OPNET representation of 802.11b model (N =100).

A detailed description of each scenario is presented in Tables 4.4, 4.5 and 4.6. The tables describe the experiments in each scenario. Table 4.4 describe Scenarios 1, 2 and 3. Table 4.5 describe Scenarios 4, 5 and 6 and Table 4.6 describes Scenarios 7, 8 and 9. The additional figures showing the configuration of parameters are outline in the appendices section.

Network size (N = 10, 50, 100)

Table 4.4 describes the three scenarios for the node size investigation. Scenarios 1, 2 and 3 investigate routing protocols impact on three network sizes. These are small, medium and large networks.

Node size investigations	
Scenario	**Description**
1	Scenario 1 consists of four experiments, each experiments implement OLSR, DSR, AODV and TORA respectively. All experiments used the network environment and configuration illustrated in Figure 4.2 with a network size of 10 nodes, a node speed of 5 m/s and a packet length of 1,000 bytes. This scenario is intended to study the impact of routing protocols in a small network and aims to identify routing protocols that performs better in such an environment where mobility too is low.
2	Scenario 2 consists of four experiments same as those in Scenario 1. The node speed and packet length are kept constant and use the same values 5 m/s and 1,000 bytes respectively as in Scenario 1. The node size now changes to 50 nodes, representing a medium network. Scenario 2 is aimed at observing the reactions of the routing protocol and to identify the well performing routing protocols in medium network, based on the analysis of the performance metrics.
3	Scenario 3 has the same experimental setup with four experiments as Scenario 1. The only difference is the network size is now changed to 100 nodes to represent a large network. The aim of this scenario is to observe the reaction and patterns of routing protocols in a large network. The best performing routing protocols is identified based on performance metrics analysis.

Table 4.4: Node sizes experimental scenarios.

Node mobility (Speed = 20, 30 m/s)

Table 4.5 describes the three scenarios for the node mobility investigation. Scenarios 4, 5 and 6 investigate the reaction of routing protocols when node mobility increases, in small, medium and large networks.

Node speed investigations	
Scenario	**Description**
4	Scenario 4 consists of eight experiments, two experiments implemented OLSR, DSR, AODV and TORA respectively. The first four experiments each with a different routing protocol are configured to use the node speed of 20 m/s. The remaining four experiments are configured with the node speed of 30 m/s. Packet length is kept constant at 1000 bytes. Increasing traffic load in a mobility environment may impose a variety of reactions on the overall performance of a protocol. This experiment aims to find the node mobility impact on routing performance when the node speed increases in a small network (N=10). The performance of routing protocols will be analysed and compared against the speed used in Scenario 1.
5	Scenario 5 also consists of eight experiments, like Scenario 4. It uses a packet length of 1,000 bytes and node speed of 20 m/s and 30 m/s. The first four experiments each with a different routing protocol are configured to use the node speed of 20 m/s. The remaining four experiments are configured to use the node speed of 30 m/s. This scenario aims to investigate the behaviour of routing protocols when mobility increases in a medium size network (N=50). Performances of varying node speeds are compared and analysed against those obtained in Scenario 2.
6	Scenario 6 also consists of eight experiments like Scenario 4, with packet length of 1,000 bytes and node speeds of 20 m/s and 30 m/s. The first four experiments each with a different routing protocol are configured to use the node speed of 20 m/s. The remaining four experiments are configured with the node speed of 30 m/s. This scenario aims to investigate the reaction of routing protocol when the node speed changes from 20 to 30 m/s in a large network (N=100). The results are also compared with the node speed of 5 m/s performance in Scenario 3.

Table 4.5: Node speeds experimental scenarios.

Traffic load (Packet length = 5,000, 50,000)

Table 4.6 describes the three scenarios for the traffic load investigation. Scenarios 4, 5 and 6 investigate the reaction of routing protocols when the ftp packet length increases in small, medium and large networks.

Traffic load investigation	
Scenario	**Description**
7	This scenario also consists of eight experiments, like Scenario 4. The node speed is kept constant however, at a high speed of 30 m/s to represent worst case mobility scenarios. Packet length however varies. The first four experiments each with a different routing protocol are configured to use the packet length of 5,000 bytes. The remaining four experiments are configured to use the packet length of 50,000 bytes. The aim of these experiments is to observe the impact of routing protocols in a small size network (N = 10) and to identify the best performing protocols according to the performance metric analysis. The performances are also compared with the performances of the packet length of 1,000 bytes in Scenario 1.
8	Scenario 8 is similar to Scenario 7 with eight experiments, with a node speed of 30 m/s and packet lengths of 5,000 and 50,000 bytes. The first four experiments each with a different routing protocol are configured to use the packet length of 5,000 bytes. The remaining four experiments are configured with the packet length of 50,000 bytes. This experiment aims to observe the impact of routing protocols when traffic load varies in a medium size network (N=50). The results are also compared with the packet length of 1,000 bytes in Scenario 2.
9	Scenario 9 also consists of eight experiments, like Scenario 7, with a node speed of 30 m/s and packet lengths of 5,000 and 50,000 bytes. The first four experiments each with a different routing protocol are configured to use the packet length of 5,000 bytes. The remaining four experiments are configured to use the 50,000 bytes packet length. This scenario aims to investigate the impact and identify well performing routing protocols when the traffic load increases in a large network (N=100). The performances of the routing protocols with the two packet lengths are compared. The performances are also compared to those of 1,000 bytes packets length in Scenario 3.

Table 4.6: Traffic loads experimental scenarios.

4.4 Summary

The detailed experimental designs and parameters used are presented in this chapter. A proper investigation design provides good results by validation and verification of the results gained from these experiments. The experimental results in performance metrics such as throughput, end to end delay, routing load and retransmission are provided in Chapter 5 together with evaluation and analysis of the findings.

Chapter 5

Results and Comparative Analysis

In Chapter 4, the experimental design and detail investigation was presented. The chapter reports on experimental results. This chapter is divided into 6 sections. Section 5.1 outlines the results and the comparative analysis. Section 5.2 presents the overall observation and network performances. Section 5.3 discussed validation of results. Section 5.4 outlines a proposal for an improved routing protocol and Section 5.6 summarises the chapter.

5.1 Experimental results

The experiments results are classified into three categories, these are: varying node sizes, node speeds and traffic load. The varying node sizes (small, medium and large sized network) present the experimental results obtain from scenarios 1 2 and 3. The varying node speeds in small, medium and large sized network put forward the experimental results collected from scenarios 4, 5 and 6. The varying traffic load in small, medium and large sized network present the experimental results acquire from scenarios 7, 8 and 9.

Figure 5.1 outlines the summary of the investigation. The diagram is categorised into three sections: performance metrics, scenarios and result figures. The scenarios are also grouped into network size, mobility and traffic load. The results of a scenario can be easily mapped using the performance metrics. For instance, throughput results of the four routing protocols in a medium sized network located in scenario 5 (N = 50, NS =20 & 30 m/s, PL=1000 bytes) is presented in Figure 5:18. In addition, the distinguish features of each scenario are highlighted.

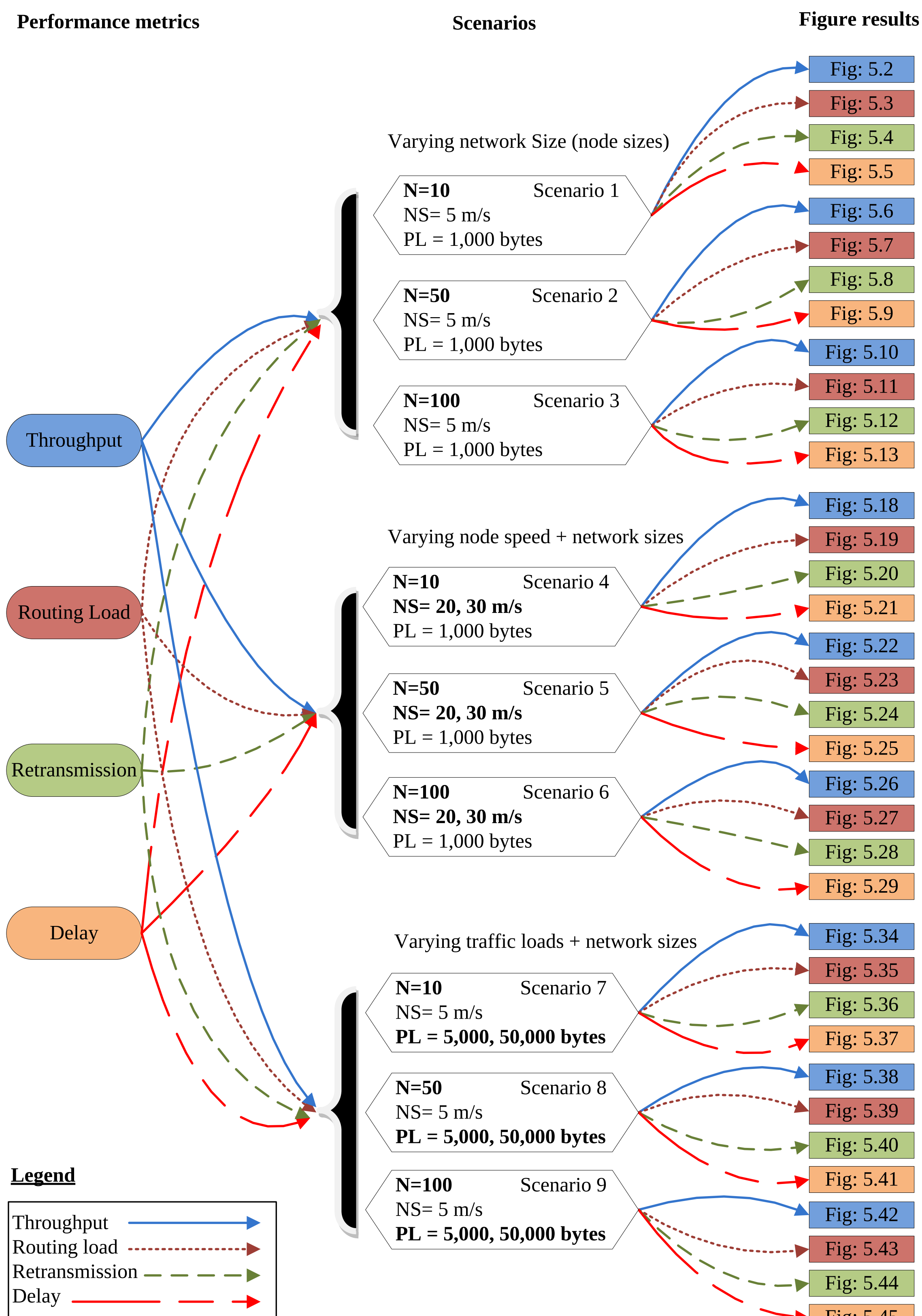

Figure 5.1: Summary of investigation.

5.1.1 Varying Network Size

This section present the results obtained from experimental scenarios 1 2 and 3. These scenarios outline the results of network size impact on routing protocols performance. Each scenario is presented with node sizes representing small, medium and large networks.

Scenario 1: Small sized network (N=10, NS = 5 m/s, PL = 1,000 bytes)

Figure 5.2 compares the average throughput of OLSR, DSR, AODV and TORA for N = 10 stations. As shown in Figure 5.2, throughput of OLSR performs best in delivering 3,500 bits/sec of data as compared with the other three protocols. Considering the reactive protocols, DSR performed well achieving throughput of 700 bits/sec than AODV and TORA. The presence of mobility in the network allows TORA to do better than AODV. Throughput performance of TORA is 600 bits/sec and AODV achieves 400 bits/sec. AODV increases performance after 700 seconds while TORA decreases after 700 seconds of simulation time.

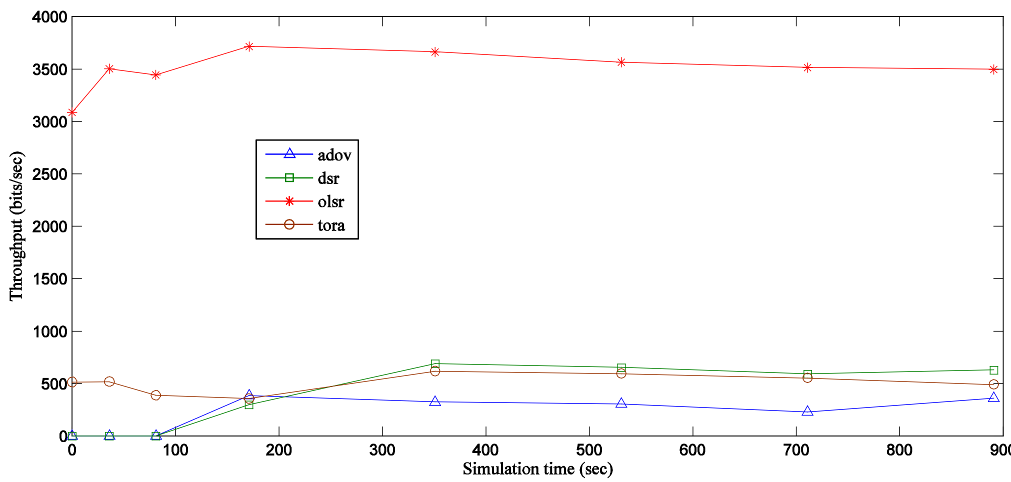

Figure 5.2: Average throughput versus simulation time (N=10, NS=5m/s, PL=1000 bytes).

Figure 5.3 shows the results of routing load. Most protocols maintained output behaviour similar to their throughput performance. TORA maintains a low routing load of 2,700 bits/sec as compared to its throughput performance. DSR, AODV and TORA maintain the same routing load as their throughputs which are 700, 400 and 600 bits/sec respectively.

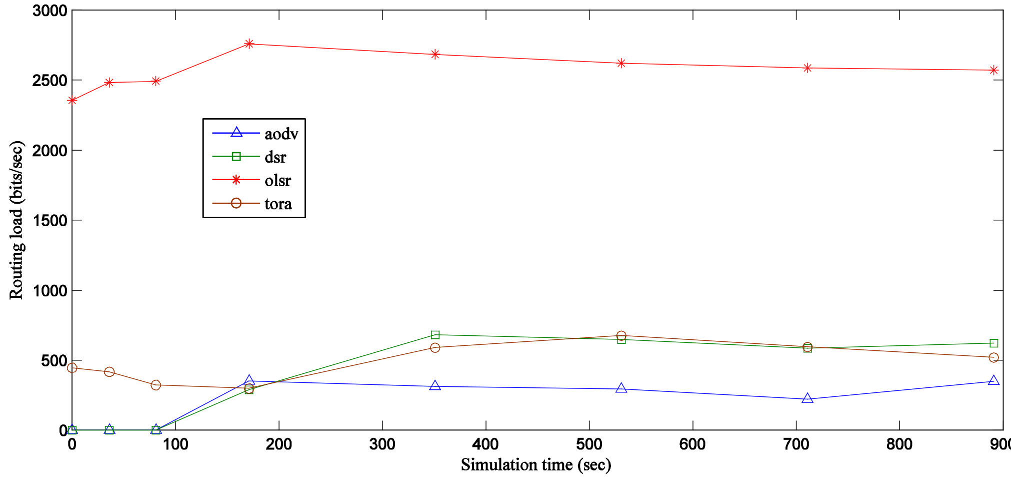

Figure 5.3: Average routing load versus simulation time (N=10, NS=5m/s, PL=1000 bytes).

Retransmission not only shows the rate of retransmission attempts, it also pointed out the number of packet drops per second which required retransmission. Figure 5.4 shows that TORA has the highest average retransmission rate of 0.6 packets/sec. OLSR has the second highest retransmission rate of 0.45 packets/sec. AODV maintains a consistent retransmission rate of 0.15 packets per second however towards the end of the simulation it increases its retransmission rate. DSR has a lower retransmission rate.

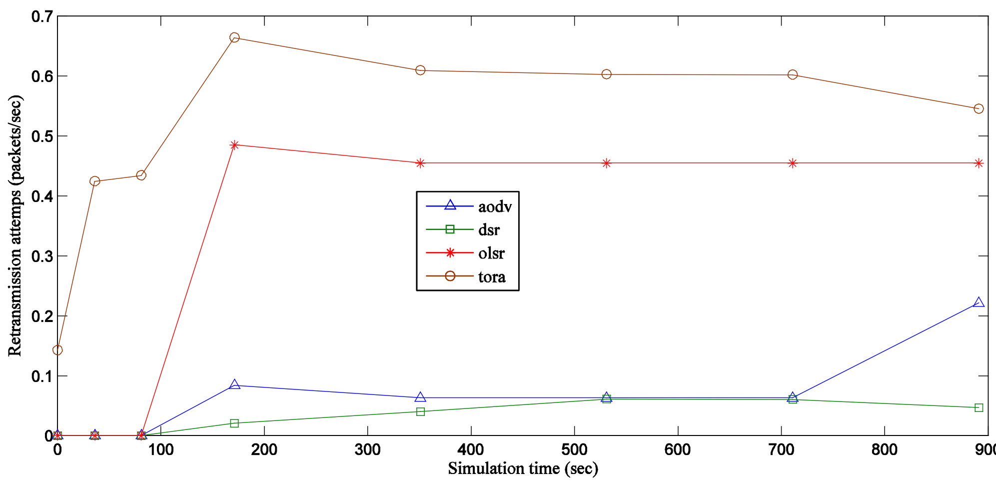

Figure 5.4: Average retransmission versus simulation time (N=10, NS=5m/s, PL=1000 bytes).

Figure 5.5 show that DSR has a high delay of 4.5 milliseconds (ms). It may be considered a small delay; however, other routing protocols have lowers delay values than DSR. TORA, AODV and OLSR accumulated 1.5 ms, 0.5 ms and 0.25 ms of delay, respectively.

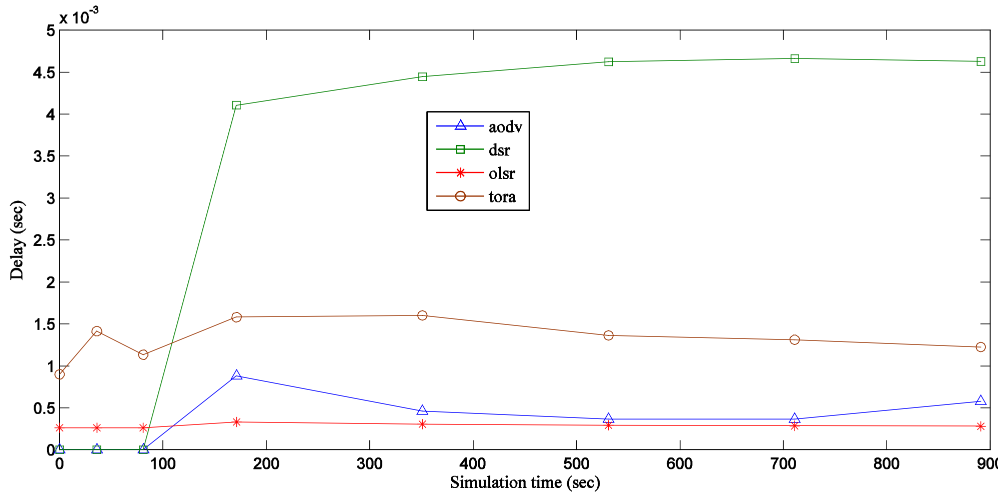

Figure 5.5: Average delay versus simulation time (N=10, NS=5m/s, PL=1000 bytes).

A reason for the great performance of OLSR is due the low speed network nodes have, resulting in fewer topological changes, which gives a rise of performance for proactive protocols. Furthermore, OLSR has an advantage in using only MPR nodes to send control message to other nodes therefore reducing and minimising overhead, resulting in a lower delay than other protocols. DSR is better suited for a small size network than AODV and TORA. In a small and low mobility network, the proactive protocol OLSR outperformed the reactive protocols. The recommended routing protocols for small networks are OLSR and DSR. The significant impact of mobility shows the ability of TORA to have some notable performance in small networks.

Scenario 2: Medium sized network (N=50, NS = 5 m/s, PL = 1,000 bytes)

Figure 5.6 illustrates throughput of DSR, OLSR, TORA and AODV for N=50 stations. Throughput increases when the number of nodes increases since more nodes are available to generate or route packets to the destination. Keeping the mobility and packet length constant, OLSR delivers a higher throughput of 44,000 bits/sec on average than reactive protocols. Reactive protocols now have a different pattern. In small network DSR is favoured over TORA and AODV, however in medium networks AODV steadily increases and outperforms TORA and DSR. AODV achieves a 12,500 bits/sec average throughput while TORA and DSR achieved 7,000 and 5,000 bits/sec respectively. The presence of mobility enables TORA to perform better than DSR in medium networks.

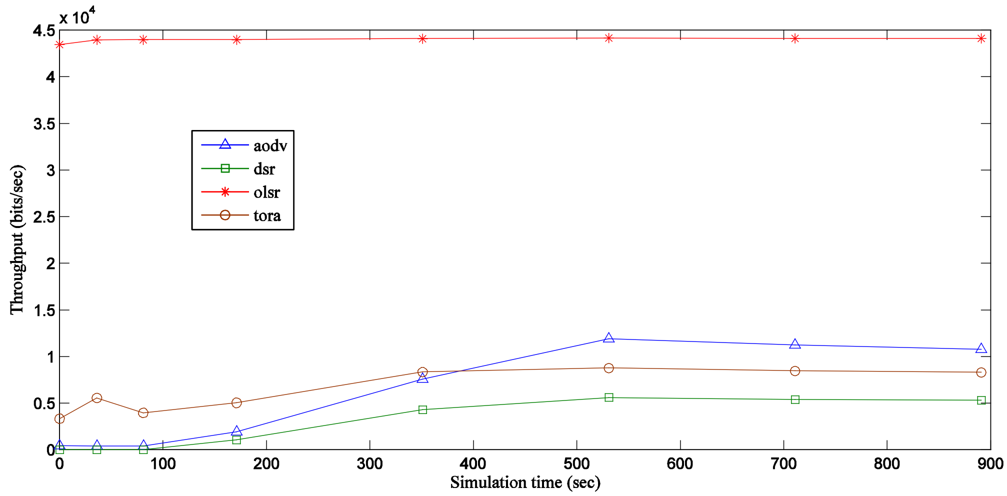

Figure 5.6: Average throughput versus simulation time (N=50, NS=5m/s, PL = 1000 bytes).

The routing load in Figure 5.7 shows a different representation as compared to throughput. TORA has a higher routing load than the packets it delivers to the destination. OLSR and AODV have routing loads of 14,000 and 6,000 bits/sec respectively. DSR has a routing load of 5,000 bits/sec and TORA has routing load of 7,500 bits/sec.

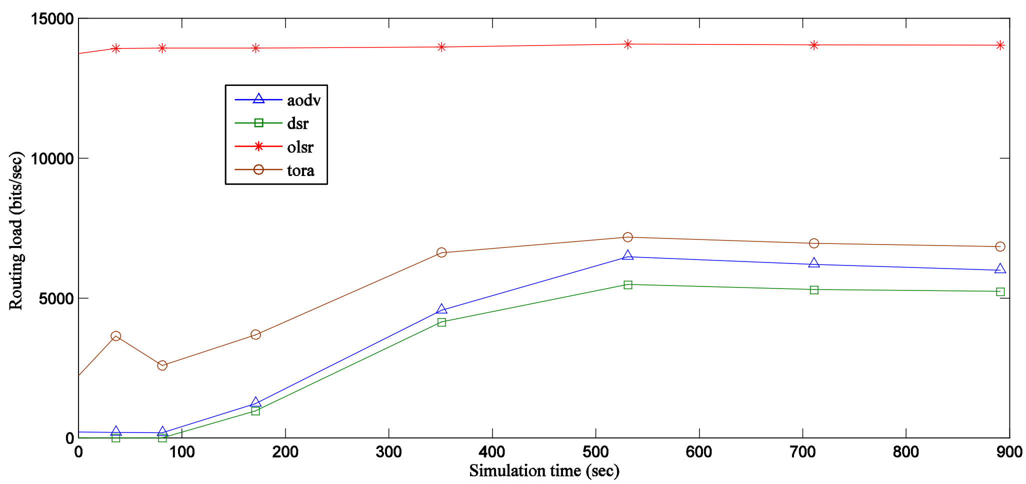

Figure 5.7: Average routing load versus simulation time (N=50, NS=5m/s, PL = 1000 bytes).

Figure 5.8 shows average retransmission rates. OLSR has 0 retransmissions. AODV is second best in terms of low transmission with a 0.19 packets/sec and maintains retransmission rate lower than DSR. TORA has a highest rate of 1.2 packets per second as compared to DSR with 0.2 packets/sec retransmission rate.

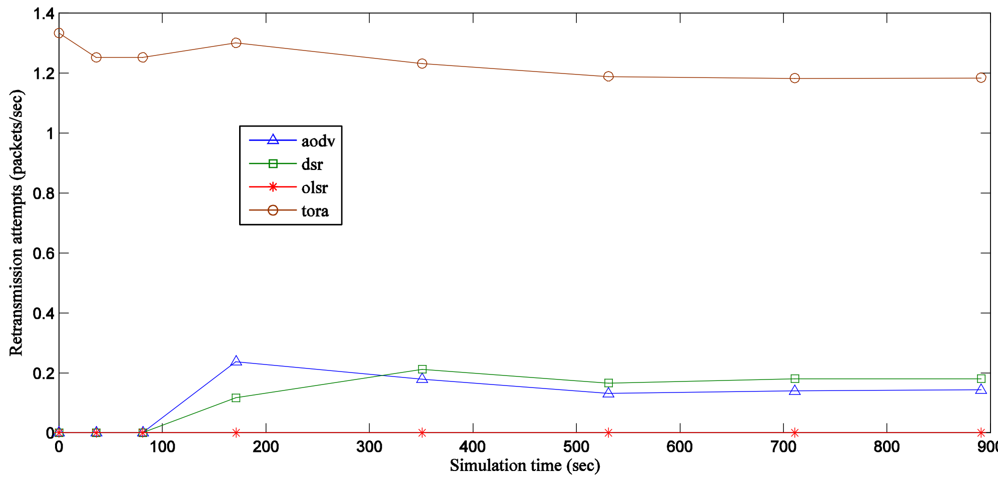

Figure 5.8: Average retransmission versus simulation time (N=50, NS=5m/s, PL = 1000 bytes).

Figure 5.9 shows delay performances. Node speed and the number of nodes for possible hop to the destination complicate DSR performance. Due to aggressive network flooding to establish a possible route connection increases the delay. TORA being sensitive to packet drops has a higher retransmission rate however; it maintained a lower delay than DSR. AODV has a lower delay of 0.0012 sec while OLSR has the lowest delay of 0.001 sec. As shown in Figure 5.6 AODV has higher throughput yet maintains a low delay. In comparison with a small network, DSR has a higher throughput and a high delay

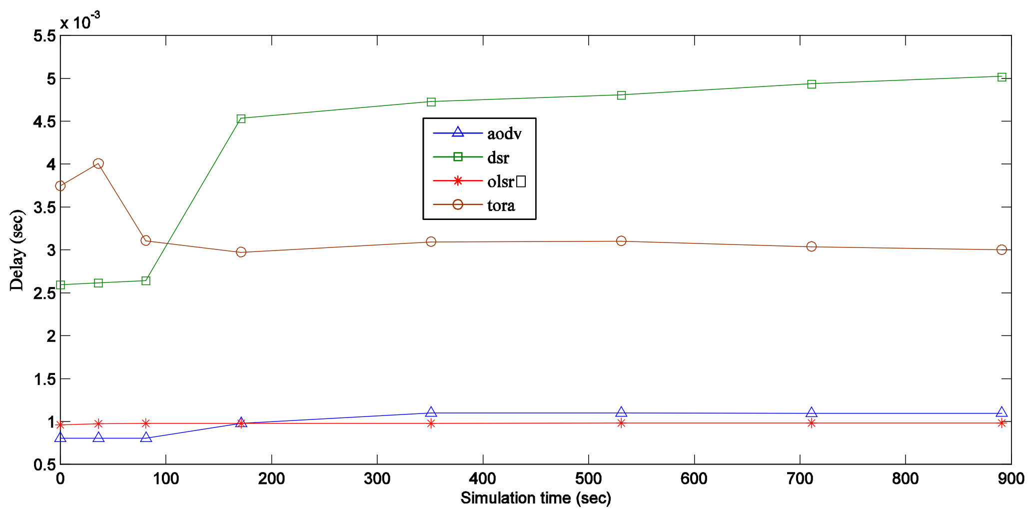

Figure 5.9: Average delay versus simulation time (N=50, NS=5m/s, PL = 1000 bytes).

A reason TORA has a high routing load and delay is due to the neighbouring mechanism TORA uses which require each node to transmit at least one hello message per beacon period. Higher routing load are also caused by mechanisms used to recreate and maintain routes when a failure occurs.

In summary, OLSR maintains a high throughput and a low delay. Comparing the three reactive protocols AODV performs better than TORA and DSR. AODV also maintains a lower delay. Of the four routing protocols OLSR and AODV perform best in medium sized networks.

Scenario 3: Large sized network (N=100, NS = 5 m/s, PL = 1,000 bytes)

Figure 5.10 shows throughput performance for a large size network (N= 100 nodes), node speed of 5 meters per second and packet length of 1,000 bytes. Throughput results show that OLSR performed particularly better than the reactive protocols. It however starts to decrease after 300 seconds of simulation time. TORA maintains a steady increase outperforming other reactive protocols. AODV maintains a consistent throughput, lower than TORA. DSR performance is also lower than TORA however it increases throughput towards the end of the simulation period. Throughput results of OLSR, TORA, AODV and DSR are 120,000, 30,000, 25,000 and 20,000 bits/sec, respectively. Reactive routing protocols in a large network show TORA to outperformed AODV and DSR.

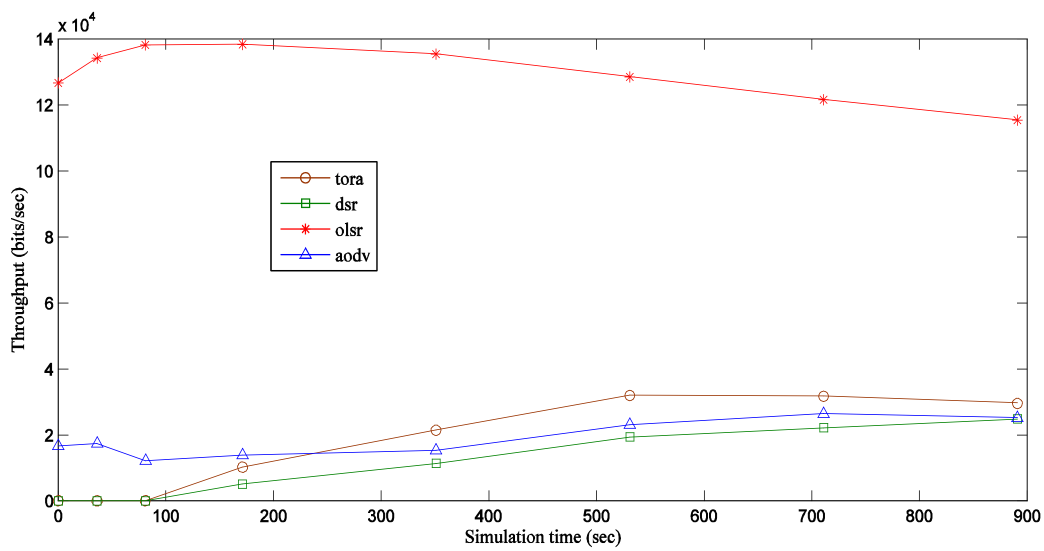

Figure 5.10: Average throughput versus simulation time (N=100, NS=5m/s, PL = 1000 bytes).

OLSR, AODV and TORA maintain a lower routing load than their throughput delivery performance as presented in Figure 5.11. DSR however has a higher routing load of 22,500 bits/sec compared to its throughput of 20,000 bits/sec. The routing loads of TORA and AODV became consistent after 500 seconds of simulation time while DSR continues to increase. The behavior is due of DSR properties to finding possible routes when a link failure has occurred.

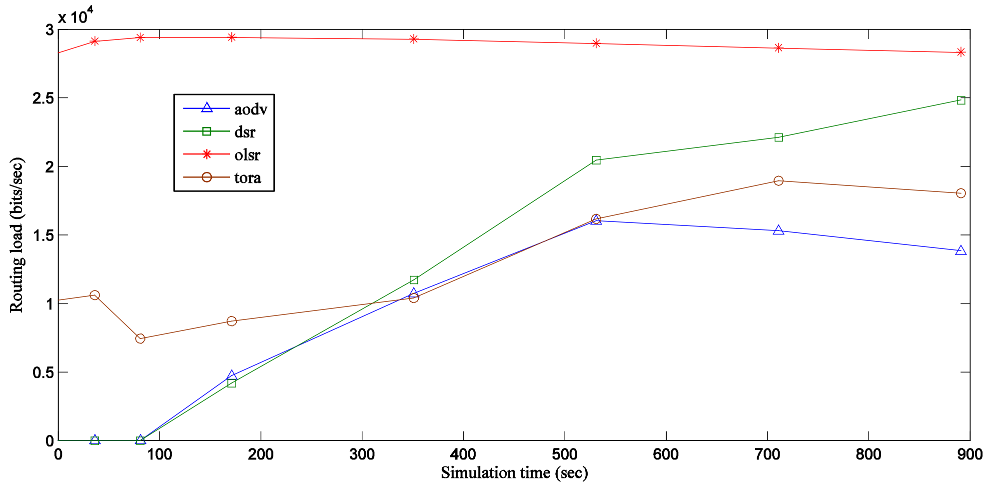

Figure 5.11: Average routing load versus simulation time (N=100, NS=5m/s, PL = 1000 bytes).

Figure 5.12 shows TORA achieving higher packet drops. TORA has a retransmission rate of 1.4 packets per second while DSR and AODV have 0.6 and 0.2 packet/sec respectively. The result shows that TORA and AODV maintain consistency while DSR keeps a steady increase to the end of simulation time.

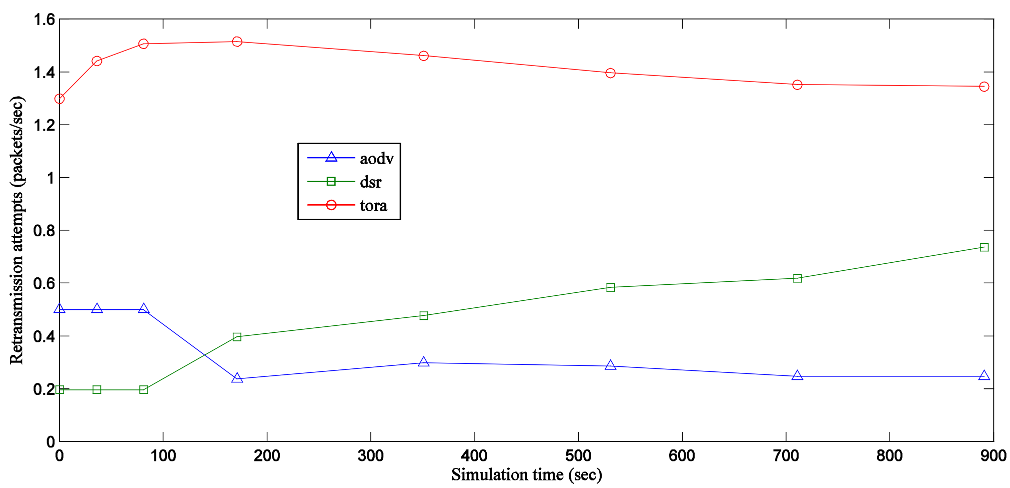

Figure 5.12: Average retransmission versus simulation time (N=100, NS=5m/s, PL = 1000 bytes).

Although TORA has the second highest throughput in large network, Figure 5.13 shows TORA to have a higher delay as compared with the other routing protocols. A reason for the behaviour of TORA is that it has a different transformation trend and is sensitive to pause times and network size. Protocols with lesser and better delay times in a large network are AODV and OLSR. DSR increases in delay and exceeds TORA between 400 and 600 seconds of simulation time. It however decreases and maintains a lower delay than TORA. DSR, using a reactive approach in a large network, there is a high probability that packets will wait in the buffer before a route is learned therefore contributes to a high delay.

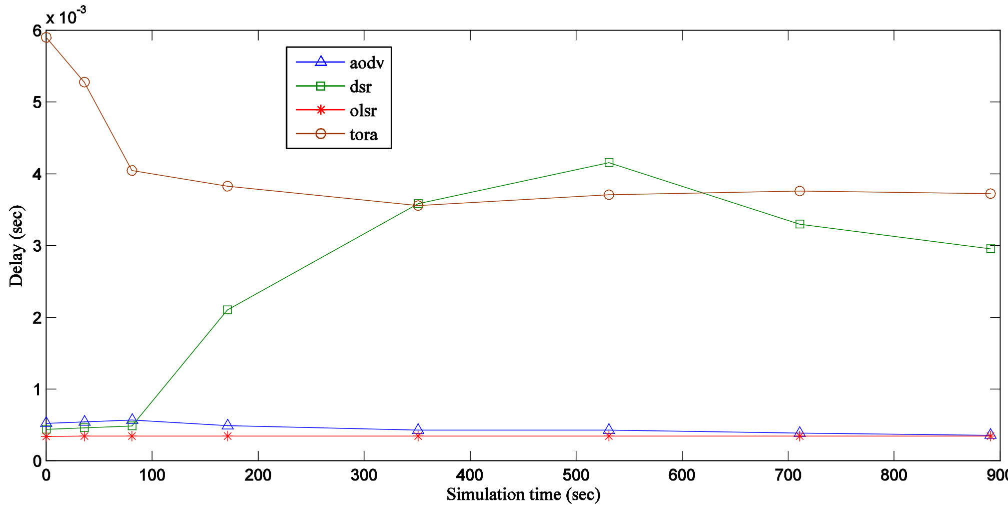

Figure 5.13: Average delay versus simulation time (N=100, NS=5m/s, PL = 1000 bytes).

OLSR performed well in a large network (N=100) however the results are obvious that OLSR does decrease its performance as time passes. TORA on the other hand performs well in a large network and maintains a consistent performance. Unfortunately it has a higher retransmission rate which therefore leads to higher delays. OLSR and AODV, according to the results, maintain a good delay in a large network. Despite the drawbacks, the results show that OLSR and TORA are capable of running in a large network with more advantages for TORA over OLSR.

5.1.2 Summary of Network Size

This section presents the summary results on the impact of routing protocols when network increases. The summary graph presented the three network size used (N=10, 50,100). An average of the results is presented from a simulation time of 900 seconds. The results showed a variation of performance amongst the routing protocol when network size increased from 10, 50 and 100 nodes. In a small network size and with the presents of mobility, all routing protocol performed to a certain degree however as network size increase to 50 nodes, Figure 5.14 shows a variation in throughput performance. OLSR and AODV performed well, this is due the OLSR sensing neighbouring nodes to establish a connection. AODV having an alternative route that is cached of neighbouring nodes enables a route to be establish quickly hence a higher number of packet received at destination. In network size of 100, OLSR and TORA performed well. AODV now suffers from mobility and a delay on reconstruction of routes. DSR also suffered a great delay as seen in Figure 5.17 due to aggressive flood network to establish a valid route. In network size of 10 nodes OLSR and DSR performed well however when network size increases to 50 nodes AODV outperformed DSR and in large network TORA outperformed AODV. A further explanation on the effects of network size on routing protocols is discussed in Section 5.2.

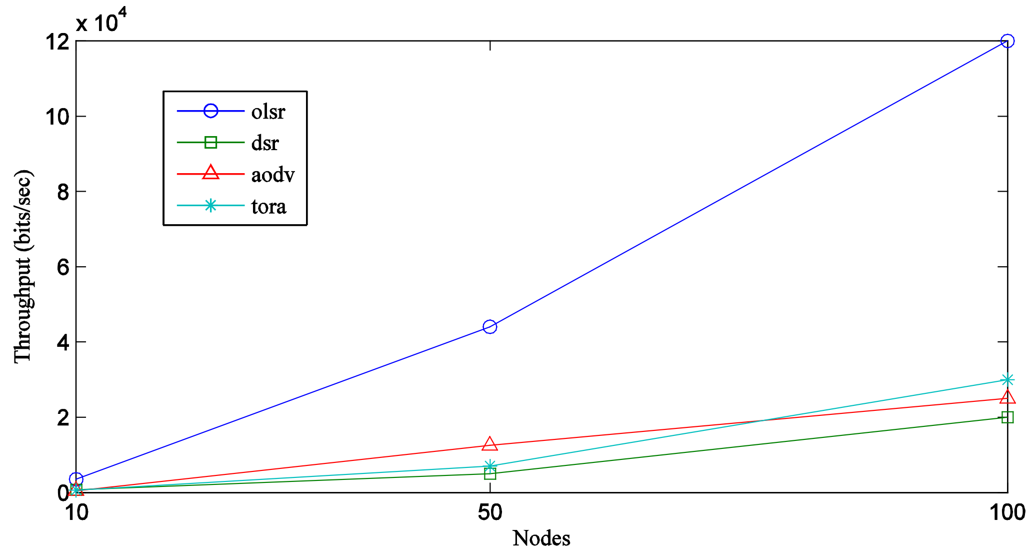

Figure 5.14: Average throughput versus network size (N=10, 50, 100)

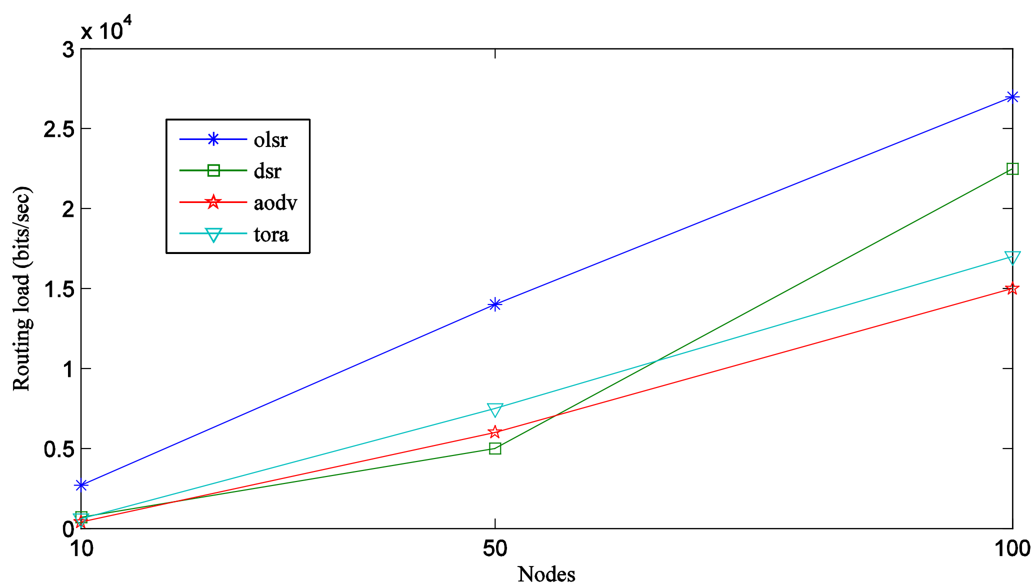

Figure 5.15: Average routing load versus network size (N=10, 50, 100)

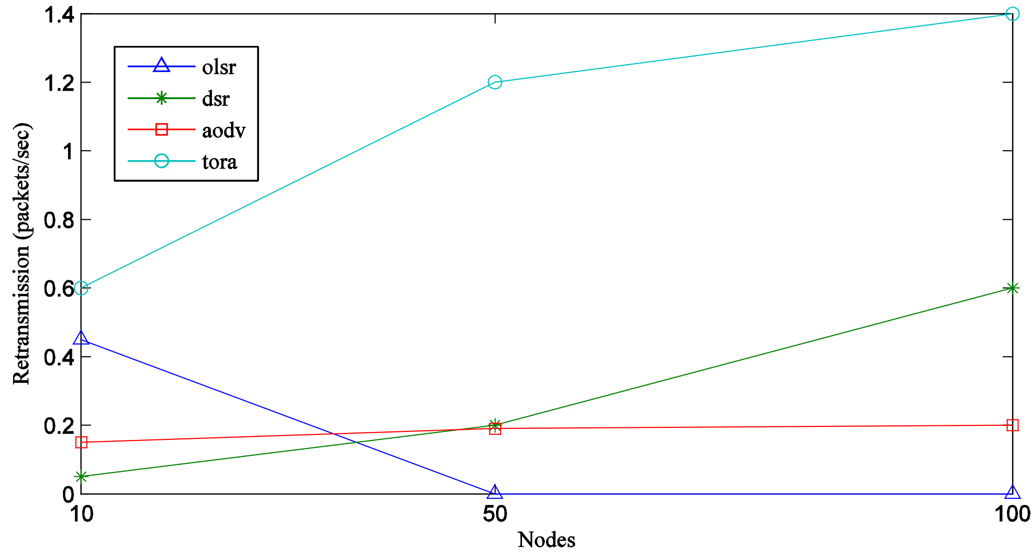

Figure 5.16: Average retransmission versus network size (N=10, 50, 100)

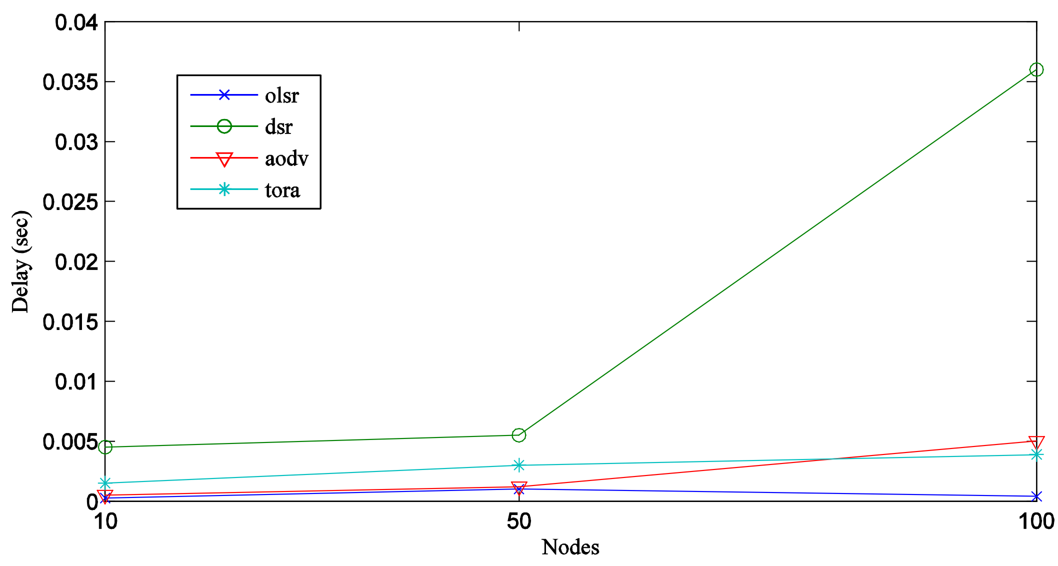

Figure 5.17: Average delay versus network size (N=10, 50, 100)

5.1.3 Varying node speed

This section presents results obtained from experimental Scenarios 4, 5 and 6 investigating node mobility (node speed 20 and 30 ms) impacts on routing protocols performance in three different network sizes, representing small medium and large networks.

Scenario 4: Varying node speed in a small sized network (N=10, NS = 20 & 30 m/s, PL = 1,000 bytes)

Figure 5.18 presents the packet delivery of varying node speeds and the impact node mobility has in small networks. OSLR performed well however, it has a lower throughput than those of Scenario 1 when node speed is 5 m/s. When node speed increases to 20 m/s, OLSR has a higher throughput as compared to the nodes speed of 30 m/s. This illustrates that as node mobility increases in small networks the throughput performance of OLSR decreases. In comparison, Figure 5.2 shows OLSR throughput of 3500 bits/sec when node mobility is 5 m/s, and it decreases to 2700 bits/sec when node speed increased to 20 m/s. OLSR drops even lower, to 2000 bits/sec, when node speed is 30 m/s. DSR protocol which used to be the best reactive routing protocol for small networks when node speed is low (5 m/s) now achieves a lower throughput in node speeds 20 & 30 m/s as compared to AODV. When node speed is 5 m/s DSR, in Figure 5.2, shows a throughput of 700 bits/sec, as mobility increases to 20 m/s, throughput decreases to 100 bits/sec and 25 bits/sec in 30 m/s as shown in Figure 5.18.

TORA protocol reacted favourably to node speed, as mobility increases throughput increases. TORA with 5 m/s in Figure 5.2 shows a throughput of 600 bits/ sec. Figure 5.18 shows an increase in throughput to 700 and 800 bits/sec for node speeds 20 and 30 m/s, respectively. AODV reacted in the same way as TORA however the effects of mobility lowered the throughputs. AODV, with node speed of 5, 20, and 30 m/s accumulated throughputs of 400, 100 and 300 bits/sec, respectively.

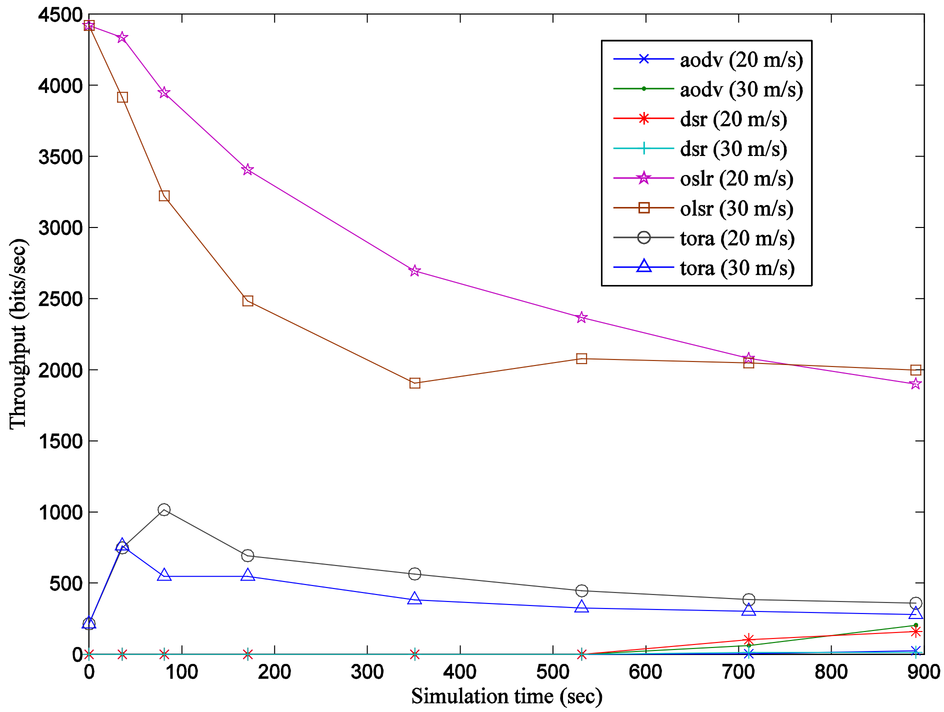

Figure 5.18: Average throughput versus simulation time (N=10, NS=20 & 30 m/s, PL = 1000 bytes).

Figure 5.19 shows the mean routing load. All protocols maintain a lower and consistent routing load as shown in throughput results in Figure 5.18. OLSR in throughput differs greatly when mobility of nodes increases, routing load however decreases as mobility increases. OLSR is a proactive protocol using only MPR nodes to generate and relay control messages; hence a lower routing load.

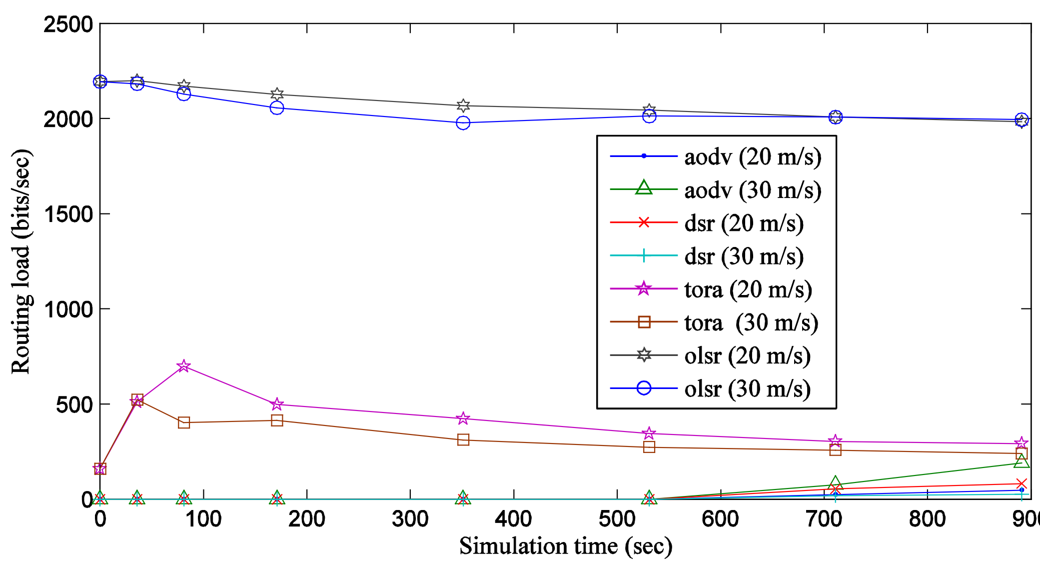

Figure 5.19: Average routing load versus simulation time (N=10, NS=20 & 30 m/s, PL = 1000 bytes).

As node mobility increases, the chances of a packet being dropped are higher. Figure 5.20 shows AODV and TORA to have higher retransmission attempts. TORA has a lower retransmission attempts when node speed is 30 m/s than node speed of 20 m/s. AODV on the other hand maintains lower retransmission attempts.

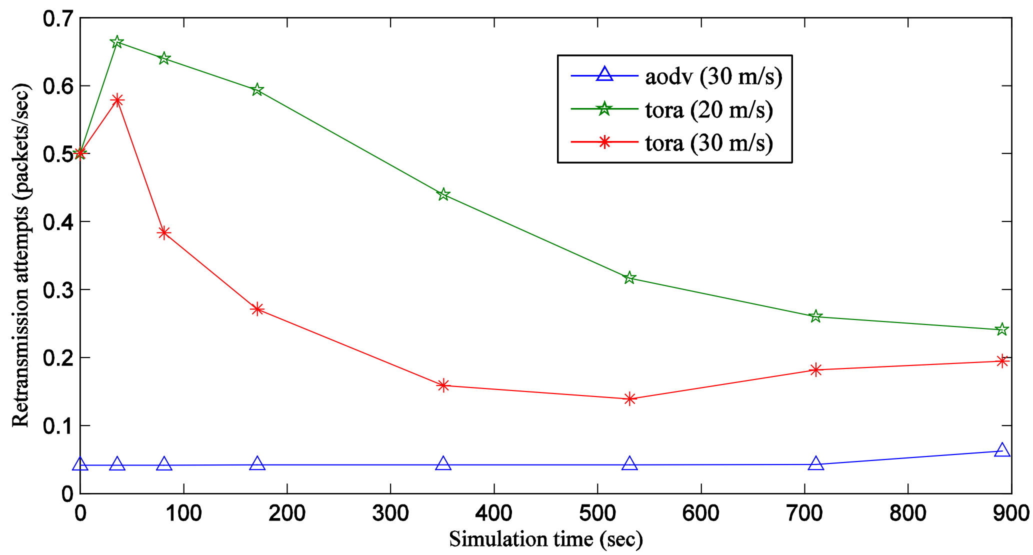

Figure 5.20: Average retransmission versus simulation time (N=10, NS=20 & 30 m/s, PL = 1000 bytes).

Figure 5.21 presents delay performances. TORA attained higher delay at both node speeds than other routing protocols. DSR with a node speed of 30 m/s also has some significant delay.

Both node speeds in AODV and OLSR maintained consistent and lower delay as did DSR with a node speed of 20 m/s. When mobility increases due to cache routes DSR has high probability of having stale routes and link breakage. The aggressive broadcast message sent to obtain a valid route in limited number of nodes is also a reason for the increase in delay. TORA has the same reasons, as discussed in previous scenarios. Interestingly it reacts favourably with node mobility which means as node speed increases throughput increases and delay decreases. TORA is said to perform well in high density networks and, due to mobility of nodes, it could well perform in small networks. TORA reacts more quickly to changing topology using multi-paths therefore throughput increases and recovers routes quickly, hence decreases delay. AODV follows the same behaviour since it supports mobility and stressful situations. OLSR decreases sharply in a mobility environment due to its proactive link state approach. This causes OLSR not to be able to cover the transmission range which therefore results in large disconnections and insufficient information when network topology is dynamically changing.

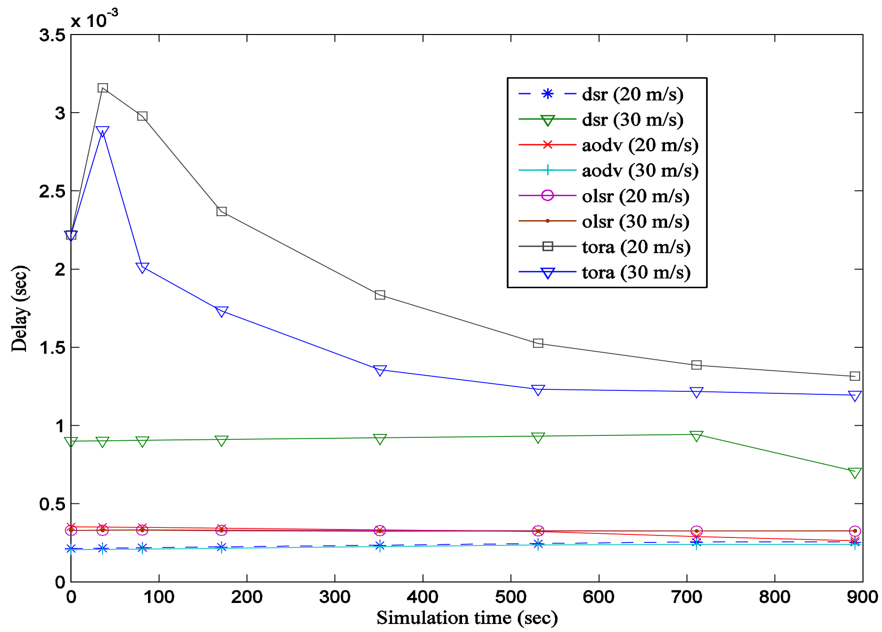

Figure 5.21: Average delay versus simulation time (N=10, NS=20 & 30 m/s, PL = 1000 bytes).

The impact of mobility on small size MANETs shows that OSLR rapidly decreases in performance. DSR could no longer maintain its lead among reactive protocols and was succeed by TORA and AODV, who shared a common reaction in favour of node speed. TORA and AODV increase performance when mobility increases while OLSR and DSR decrease performance. The recommended protocols according to the results are OLSR and TORA. It must be highlighted that OLSR reduces performance when mobility increases, in small size networks.

Scenario 5: Varying node speed in a medium sized network (N=50, NS = 20 & 30 m/s, PL = 1,000 bytes)

Figure 5.22 shows throughput for varying node speeds in a medium sized MANET. In this scenario packet length is kept constant. The throughput shows a reduced performance as compared to results of Scenario 2 with a node speed of 5 m/s. OLSR with a node speed of 5 m/s, attains 44,000 bits/sec of throughput. It reduces to 37,000 bits/sec when node speed increases to 20 m/s and further reduces to 30,000 bits/sec with node speed of 30 m/s. Similarly AODV and DSR face drawbacks when node speed increases. AODV throughput from 12,500 bits/sec with node speed of 5 m/s is reduces to 2500 bits/sec (20 m/s) and further reduces to 2000 bits/sec with node speed of 30 m/s. AODV is the recommended reactive routing protocol in medium networks as depicted in Scenario 2, however it struggles to keep its performance constant when node mobility increases. DSR likewise decreases performance as node mobility increases; it achieves 5,000 bits/sec of throughput with a node speed of

5 m/s as compared to 20 m/s obtaining 2,000 bits/sec and 1,000 bits/sec when a node speed increases to 30 m/s. TORA behaves by increasing throughput when mobility increases. The results of TORA are 7000 bits/sec (5 m/s), 10,000 bits/sec (20 m/s) and 12,000 bits/sec (30 m/s); therefore OLSR achieves a higher throughput followed by TORA, AODV and DSR.

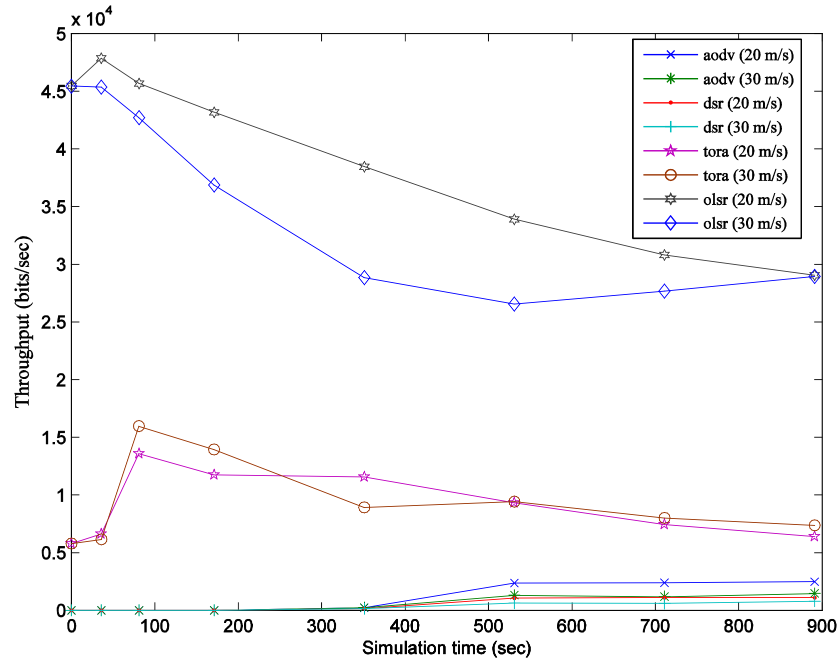

Figure 5.22: Average throughput versus simulation time (N=50, NS=20 & 30 m/s, PL = 1000 bytes).

Figure 5.23 shows the network load of a medium size network with varying mobility. The routing load shows a similar pattern to those of throughput performance in Figure 5.22.

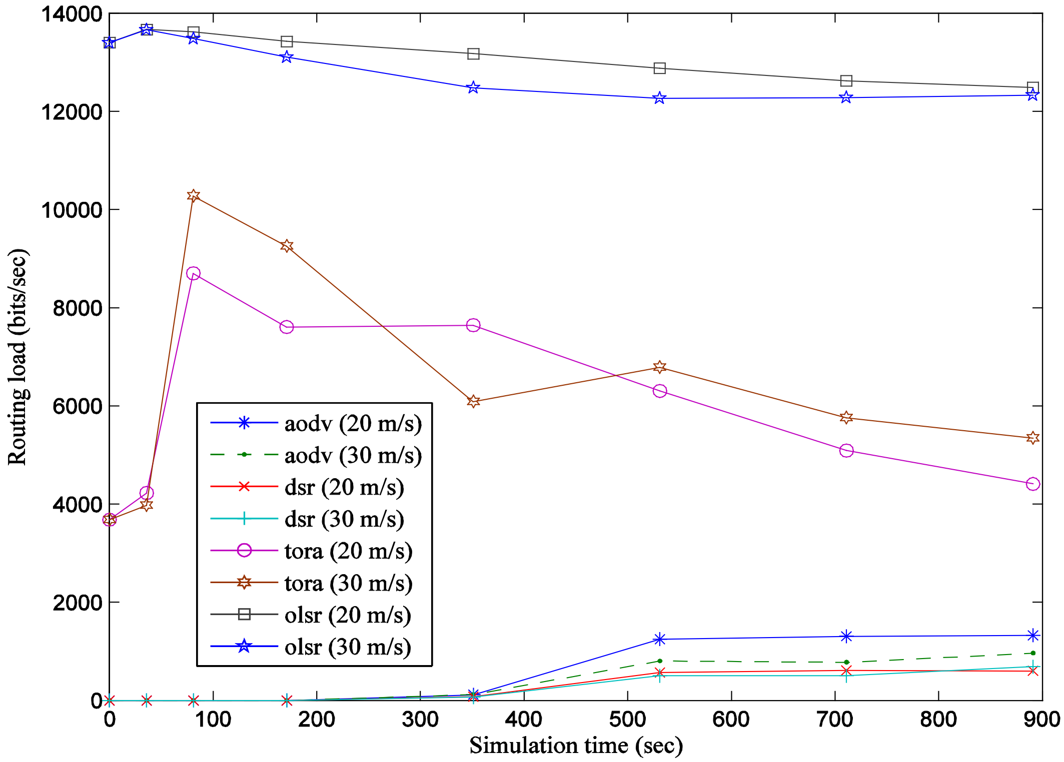

Figure 5.23: Average routing load versus simulation time (N=50, NS=20 & 30 m/s, PL = 1000 bytes).

When mobility increases more data packets are dropped. Figure 5.24 shows the retransmission attempts for TORA, DSR and AODV. TORA is however the exception here since it has retransmission attempts even when in low mobility. The pleasant behaviour of TORA is that when node mobility increases retransmission rate decreases more than in networks with lower node speeds. DSR has a higher retransmission rate than AODV. AODV, with a node speed of 30 m/s obtain the lowest retransmission rate of 0.18 packets/sec followed by DSR (30 m/s) with 0.3 packets/sec. TORA, with a node speed of 20 m/s, has a higher transmission of 0.8 packets/sec than TORA (30 m/s) with 0.7 packets/sec.

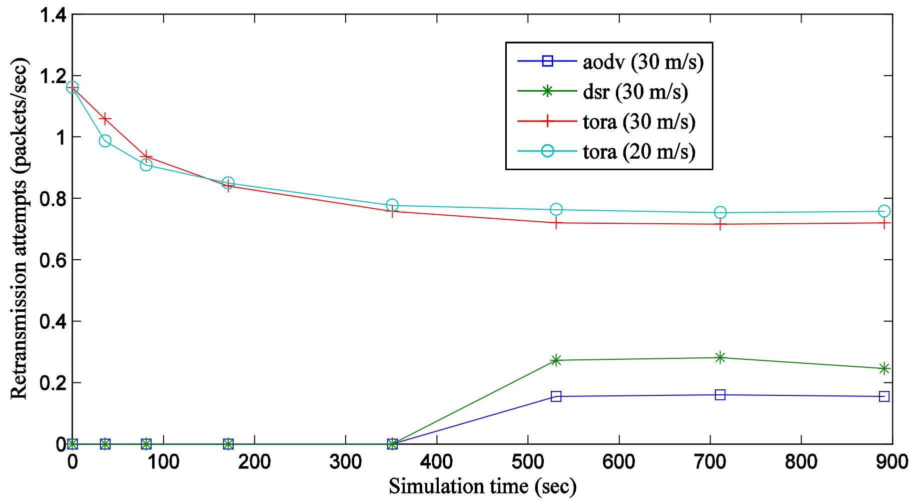

Figure 5.24: Average retransmission versus simulation time (N=50, NS=20 & 30 m/s, PL = 1000 bytes).

Figure 5.25 presents delay performance. As shown in Figure 5.25, OLSR maintains a lower delay regardless of changes in node mobility. DSR increases in delay as node mobility increases while AODV maintains a lower delay. TORA's delay in this scenario is different to its throughput and retransmission attempts. As node mobility increases throughput increases and retransmission attempts reduce, however the delay increases. TORAs delay, with a node speed of 30 m/s, is higher than at anode speed of 20 m/s. The average delays results are as follows; OLSR (20 and 30 m/s) obtain 0.0004 sec. DSR obtains 0.0002 sec of delay when node speed is 20 m/s, and 0.0005 sec when node speed is 30 m/s. AODV (30 m/s) has a delay of 0.002 sec. TORA, with a node speed of 30 m/s has delays of, 0.003 and 0.0025 sec when node speed is 20 m/s.

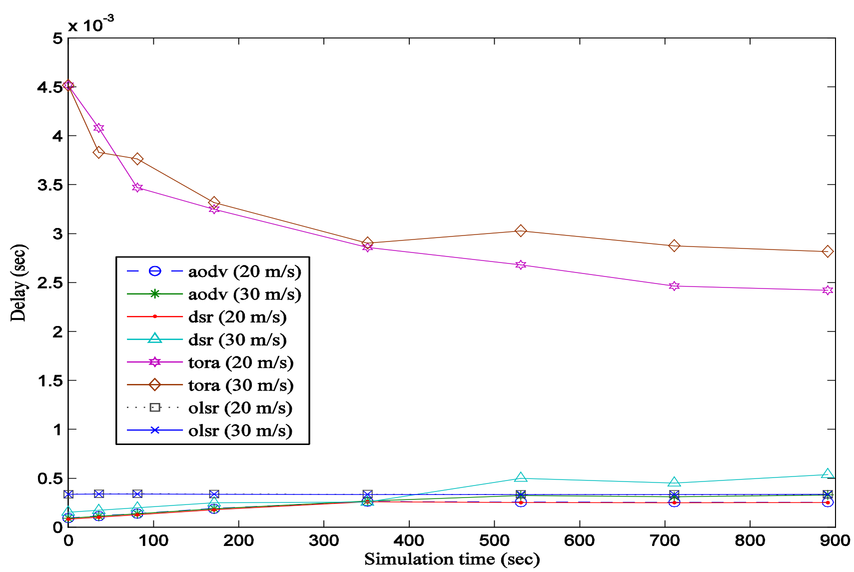

Figure 5.25: Average delay versus simulation time (N=50, NS=20 & 30 m/s, PL = 1000 bytes).

When mobility increases, AODV reduces performance as mobility increases. AODV is an effective media access protocol however mobility causes a pause time variations therefore resulting in a lower performance.

In summary, OLSR has a higher throughput performance however, OLSR has a decreasing trend which gives a rise to a recommendation that TORA be used in networks with 50 nodes and where higher node mobility is present. Considering delays, OLSR has lower delays than TORA. AODV, being the recommended reactive protocol in medium networks, is no longer competent when node mobility increases. TORA overtakes AODV since its routing properties best fit mobility environments.

Scenario 6: Varying node speed in a large sized network (N=100, NS = 20 & 30 m/s, PL = 1,000 bytes)

Figure 5.26 highlights the throughput of varying node speeds (20 & 30 m/s) in a large network (N=100 nodes) and a packet size of 1,000 bytes. As shown in Figure 5.26 TORA performed better than the other routing protocols when node mobility increases. When node speed is 20 m/s, TORA performed exceedingly well, past OLSR, with node speed of 30 m/s. OLSR is considered the next best routing algorithm, however, OSLR decreases performance when node speed increases. AODV reacted differently in a large network (N=100) as compared to a medium network (N=50 nodes). The increase of node speed resulted in an increase of throughput where as in medium networks, an increase in node speed resulted in a decrease of throughput. AODV can behave well in more stressful situations and given a large network the properties of AODV allow more possible routes to found and maintained as compared to medium network. DSR maintains similarity in all network sizes; as node mobility increases, throughput decreases.

The throughput results are as follows: TORA, with a node speed of 5 m/s, (Figure 5.10) achieves 30,000 bits/sec, and 90, 000 bits/sec when node speed is 20 m/s. It increases further to 130,000 bits/sec when node speed increases to 30 m/s. OLSR on the other hand has a decreasing throughput. With a node speed of 5 m/s OLSR achieves 120,000 bits/sec and decreases to 37,000 bits/sec when node speed increases to 20 m/s. It further decreases to 30,000 bits/sec when node speed increases to 30 m/s. AODV obtains 15,000 bits/sec and 20,000 bits/sec when node speed is 5 m/s and 20 m/s respectively. Throughput further increases to 30,000 bits/sec when node speed increases to 30 m/s. DSR obtained 20,000 bits/sec and 10,000 bits/sec in node speeds of 5 m/s and 20 m/s respectively. DSR further reduces throughput to 8,000 bits/sec when node speed increases to 30 m/s.

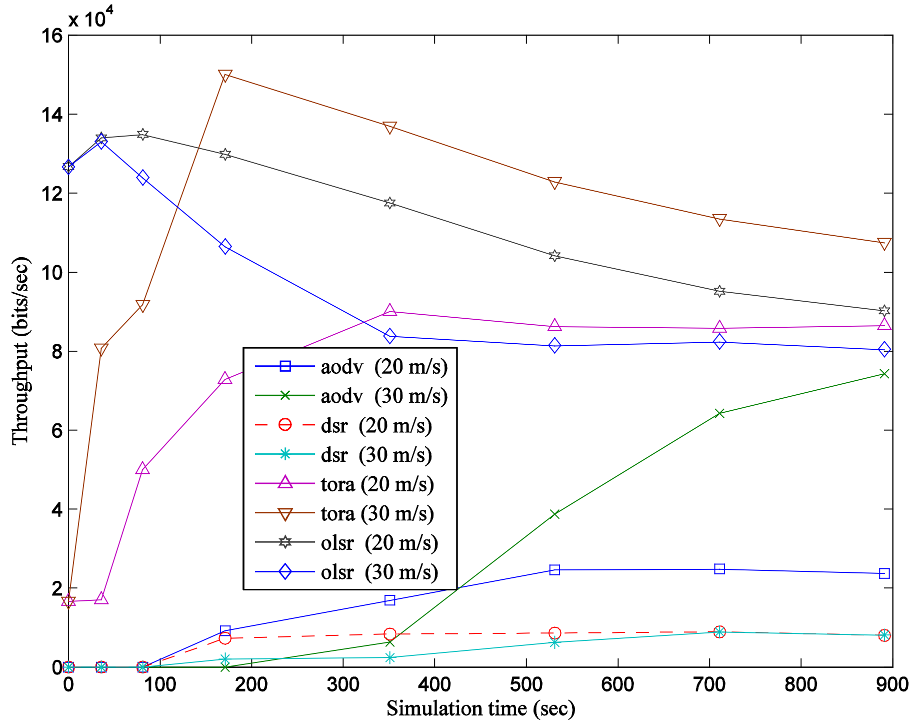

Figure 5.26: Average throughput versus simulation time (N=100, NS=20 & 30 m/s, PL = 1000 bytes).

Figure 5.27 shows the average routing load. OLSR keeps a consistent routing load throughout the simulation time, yet the impact of mobility could be seen in the graph as OLSR at the node speed of 30 m/s is a little lower in value than at the node speed of 20 m/s. TORA's routing load shows more reaction than the other protocols. The routing loads for node speed of 20 m/s increases steadily. At the node speed of 30 m/s from the start it increases rapidly but towards the end of the simulation period it drops lower than 20 m/s node speed. As shown in Figure 5.27, AODV has a higher routing load than DSR. AODV routing load also increases as node mobility increases while DSR routing load decreases as mobility increases.

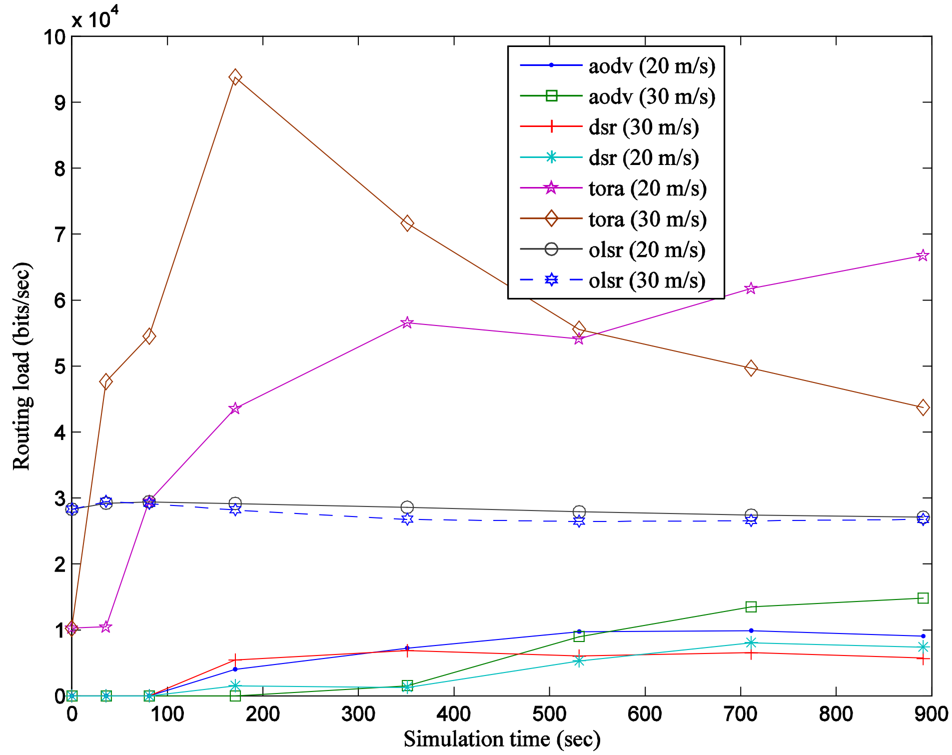

Figure 5.27: Average routing load versus simulation time (N=100, NS=20 & 30 m/s, PL = 1000 bytes).

Figure 5.28 shows the average rate of retransmission attempts. DSR maintains low retransmissions when the node speed is 20 m/s and increases retransmissions when node speed increases to 30 m/s. AODV on the other hand maintains a low retransmission while TORA has a higher retransmission rate when node speed is 20 m/s than 30 m/s.

The delay results in Figure 5.29 show OLSR and AODV maintaining a good and lower rate of delay than the other two protocols. DSR has a greater delay at higher node speed of 30 m/s, than at a node speed of 20 m/s. TORA has a higher delay compared to DSR, and follows a similar trend to DSR in increasing delay as mobility increases.

OLSR decreases throughput performance, however, it still maintains a lower delay than TORA. The sensitive towards a packet drop is the contributing factor towards overhead therefore resulting in a much greater delay. TORA is more sensitive to packet drops as compared to OLSR and AODV. OLSR, since using a routing table and using MRP nodes for message control flow flooded the network less than TORA therefore has less impact on delay. Likewise AODV, using a routing table with one route per destination and with properties to seek possible routes in neighboring nodes instead of flooding the network, resulted in a lower delay.

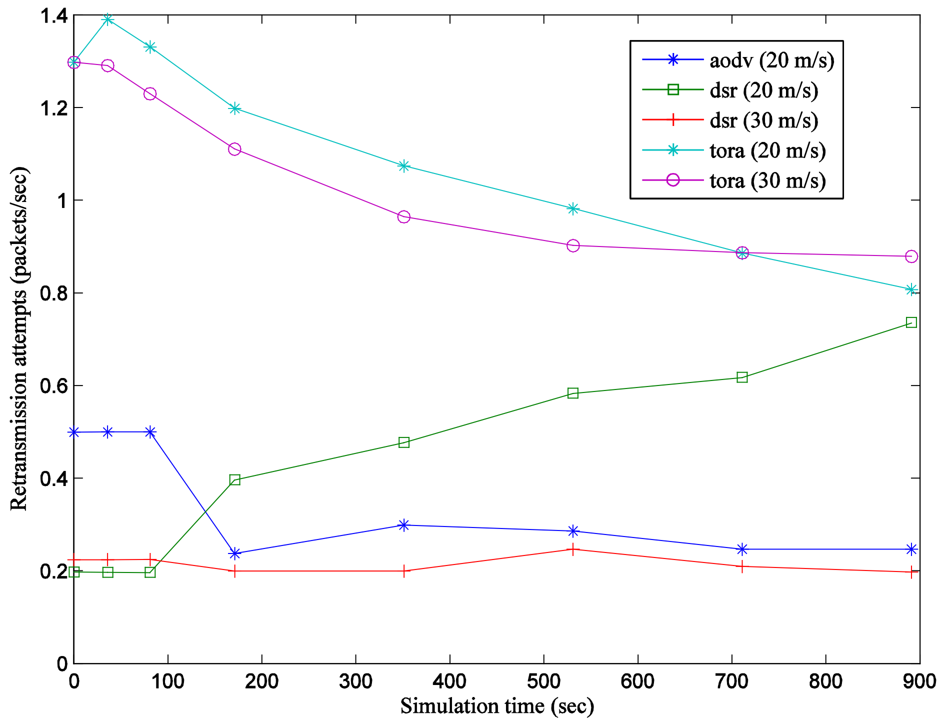

Figure 5.28: Average retransmission versus simulation time (N=100, NS=20 & 30 m/s, PL = 1000 bytes).

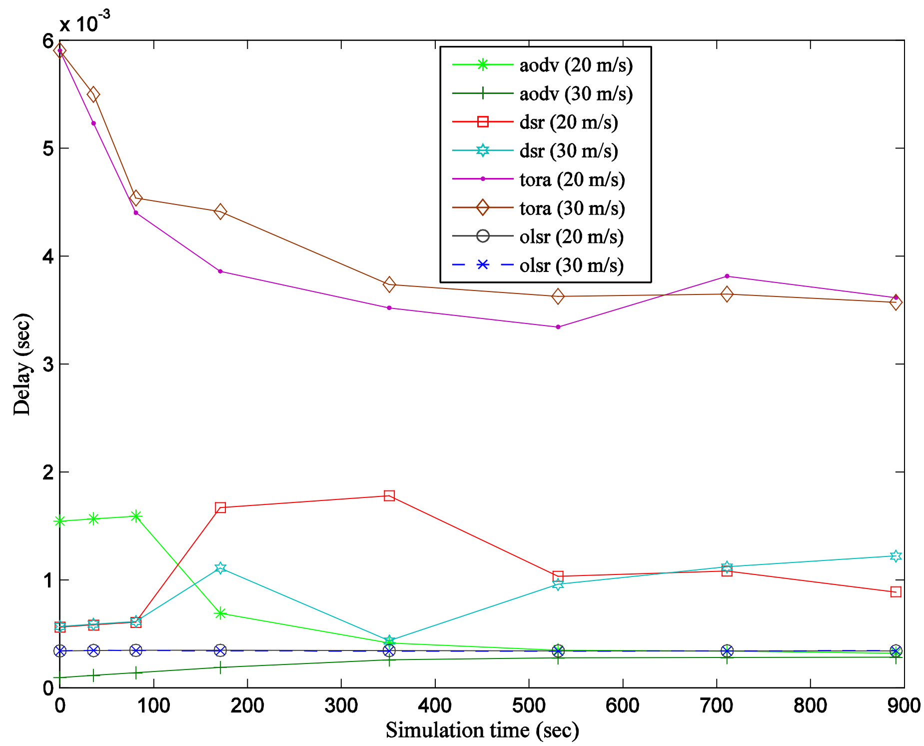

Figure 5.29: Average delay versus simulation time (N=100, NS=20 & 30 m/s, PL = 1000 bytes).

In summary, at varying node speeds in a large network (N=100), TORA performs exceedingly well over OLSR, DSR and AODV. OLSR decreases throughput however maintains a lower delay than TORA. AODV has a great potential to perform in such environment as it reacts the same way as TORA by increasing throughput when node speed increases. AODV behaves in this manner only in large and small networks. In medium network AODV has the opposite reaction. TORA's routing protocol is considered to be the best recommended routing protocol for increased node speed in a large network.

5.1.4 Summary of node speed

This section presents summary results on the impact of routing protocols with varying node speed in different network sizes. The summary graph presented three network size (N=10, 50,100) and two node speed (20, 30 m/s). Averages of the results are presented from a simulation time of 900 seconds. Figure 5.30 shows the effect of node mobility on network sizes. OLSR and TORA maintained good throughput performance in both network of size 10 and 50 nodes. However, when N = 100 nodes TORA again performed well past OLSR. TORA perform well in large network and in higher node mobility. While TORA performed well in mobility and large network, TORA suffers a great retransmission and delay as shown if Figure 5.32 and Figure 5.33. OLSR performed well in small and medium network however due to its proactive nature OLSR performed lower when N=100 nodes. AODV performed similarly to TORA's reaction to node mobility. DSR suffers a lower throughput performance as compared to the others. A further explanation on the effects of node mobility on routing protocols is discussed in Section 5.2.

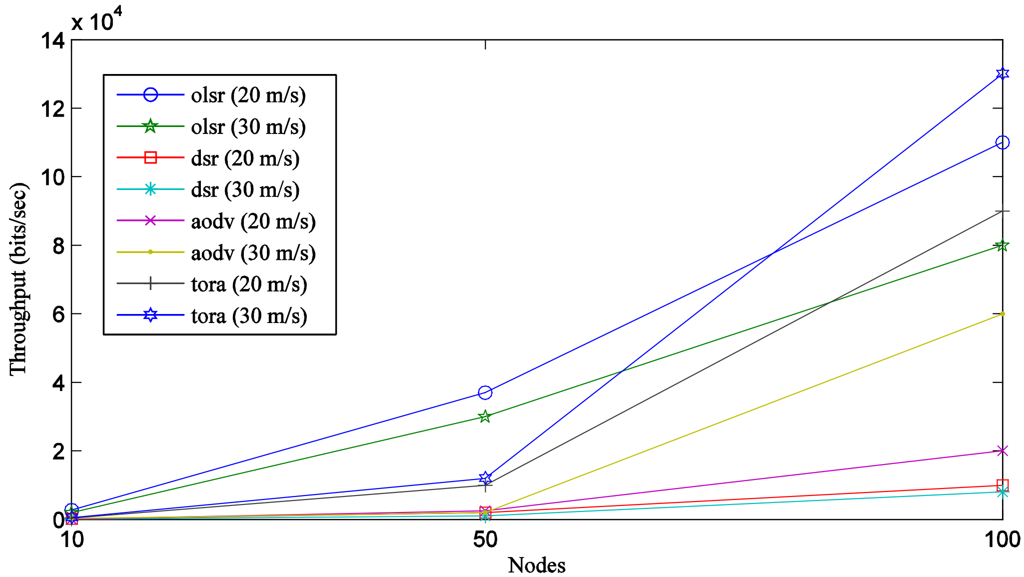

Figure 5.30: Average throughput versus network size with varying node speed (20, 30 M/S)

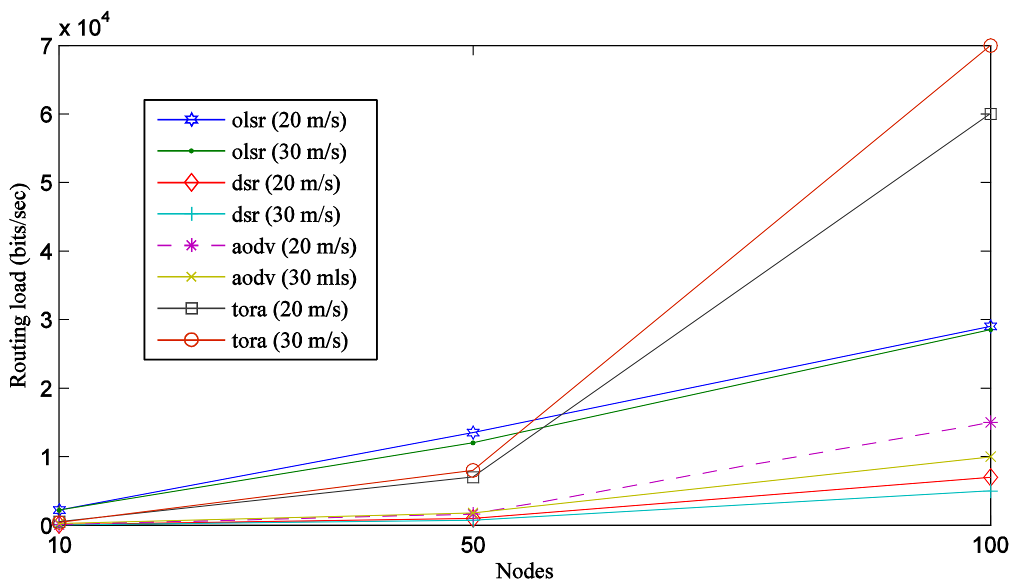

Figure 5.31: Average routing load versus network size with varying node speed (20, 30 M/S)

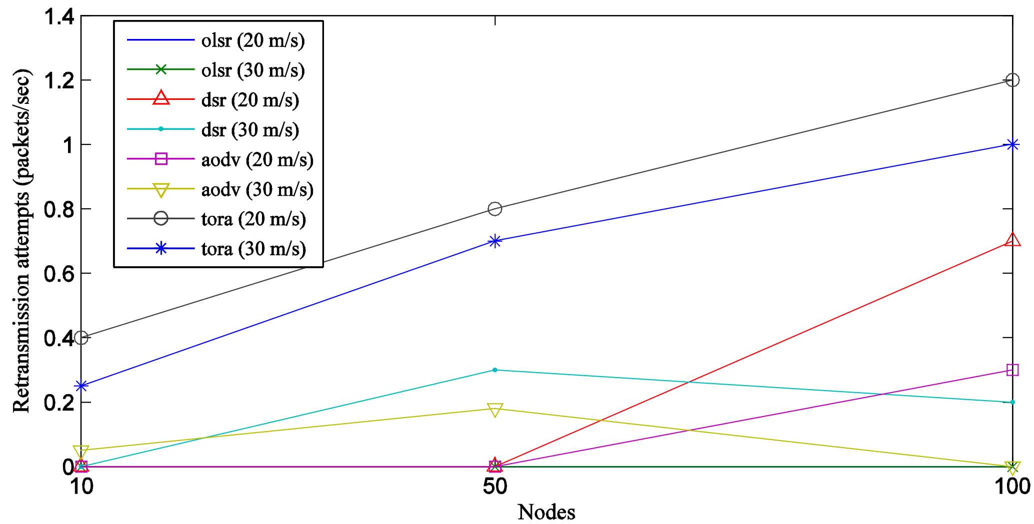

Figure 5.32: Average retransmission attempts versus network size with varying node speed (20, 30 M/S)

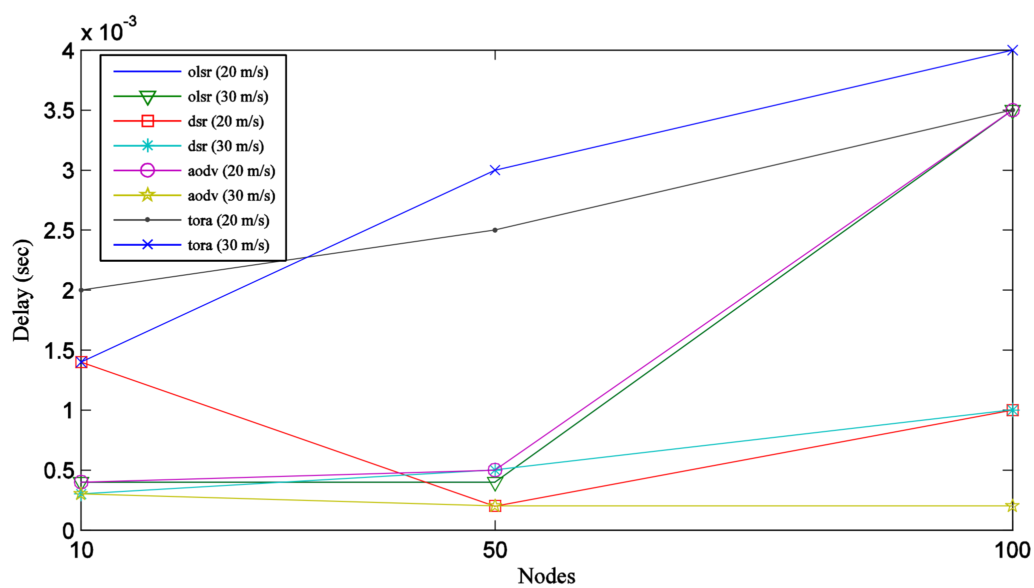

Figure 5.33: Average delay versus network size with varying node speed (20, 30 M/S)

5.1.5 Varying traffic load

This section present results obtained from experimental Scenarios 7, 8 and 9 investigating traffic loads in terms of varying packet lengths (5,000 and 50,000 bytes) and its impact on the routing protocols performance in three network sizes (N=10,50, 100), representing small medium and large networks respectively.

Scenario 7: Varying traffic load in a small sized network (N=10, NS = 30 m/s, PL = 5,000 & 50,000 bytes)

Figure 5.34 shows the throughput performance of TORA, AODV, OLSR and DSR in varying traffic loads in a small network, with two packet lengths of sizes 5,000 and 50,000 bytes and a constant node speed of 30 m/s. The results show that OLSR drops more than 50% when there is less mobility and less traffic load. OLSR did not react to varying packet lengths. The throughput remains the same in both packet lengths of 5,000 to 50,000 bytes. This also applies to throughputs of TORA and DSR. TORA kept a consistent throughput of 600 bits/sec for both packet lengths of 5,000 to 50,000 bytes.

When employing TORA in small network (N=10), node speed and traffic load does not have a great impact on throughput performance. In Figure 5.2, TORA throughput is the same when the node speed is 5 m/s and the packet length is 1,000 bytes. AODV reacted differently in this scenario, as the packet length increases its throughput starts to increase after 500 seconds of simulation time. It increases its performance better than TORA. AODV increases throughput passed OLSR with packet length of 50,000 bytes.

The respective throughput results of the protocols are as follows: OLSR data traffic loads with packet lengths 5,000 and 50,000 bytes attains 2000 bits/sec. TORA traffic load with packet length 5,000 and 50,000 bytes achieves 500 bits/sec. DSR data traffic with the packet length 5,000 and 50,000 bytes achieves 100 bits/sec and AODV data traffic with the packet length of 5,000 bytes attains 600 bits/sec and 2,500 bits/sec for packet length of 50,000 bytes.

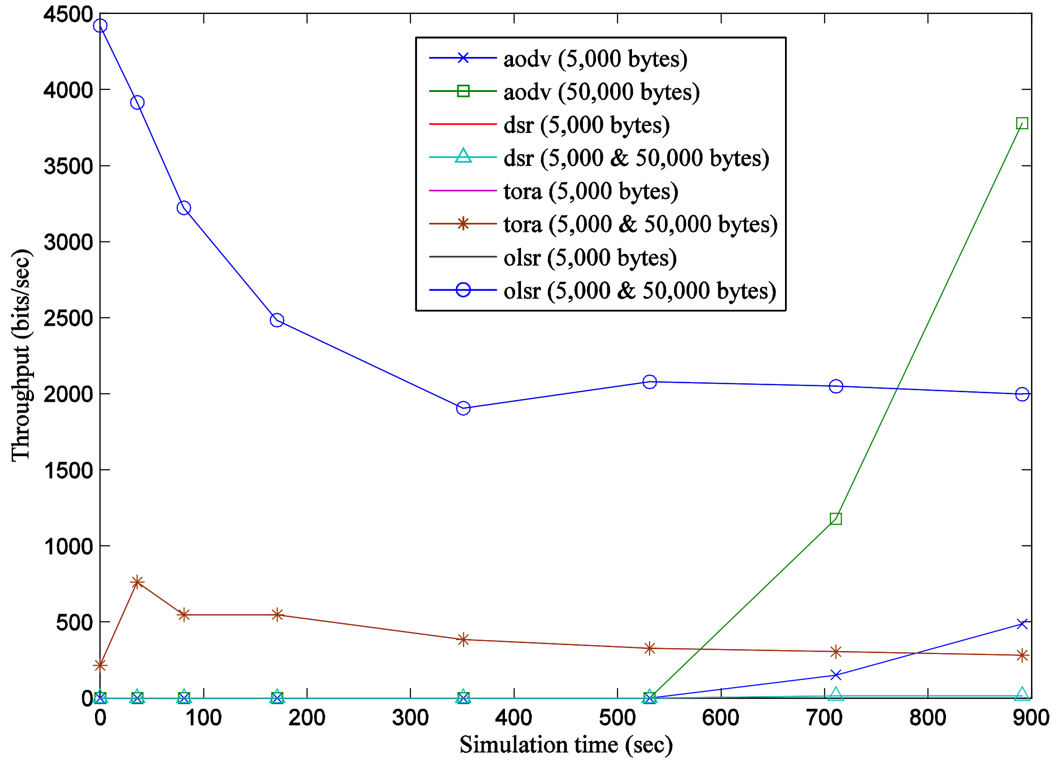

Figure 5.34: Average throughput versus simulation time (N=10, NS=30 m/s, PL = 5,000 & 50,000 bytes).

Figure 5.35 presents the network loads with varying traffic loads in a small network. Most routing protocols as shown in Figure 5.35 have the same behaviour as depicted in throughput. The only routing protocol that differs in routing load is OLSR, its routing load does not have a big drop, as compare to its throughput in Figure 5.34 it maintains a load of 2000 bits/sec. The routing load of AODV for packet lengths 5,000 & 50,000 bytes increases in a similar manner as delivery packets depict in throughput. TORA and DSR maintain a similar routing load as their throughput values.

Packet drop in this scenario is presented in Figure 5.36 by the number of retransmission attempts. OLSR has high retransmission attempts of 0.2 packets per second for both packet lengths. AODV with packet length of 50,000 bytes although achieving a high throughput the retransmission attempt is also higher with a rate value of 0.3 packets/sec. AODV with packet length of 5,000 bytes has the lowest retransmission rate of 0.1 packets/sec.

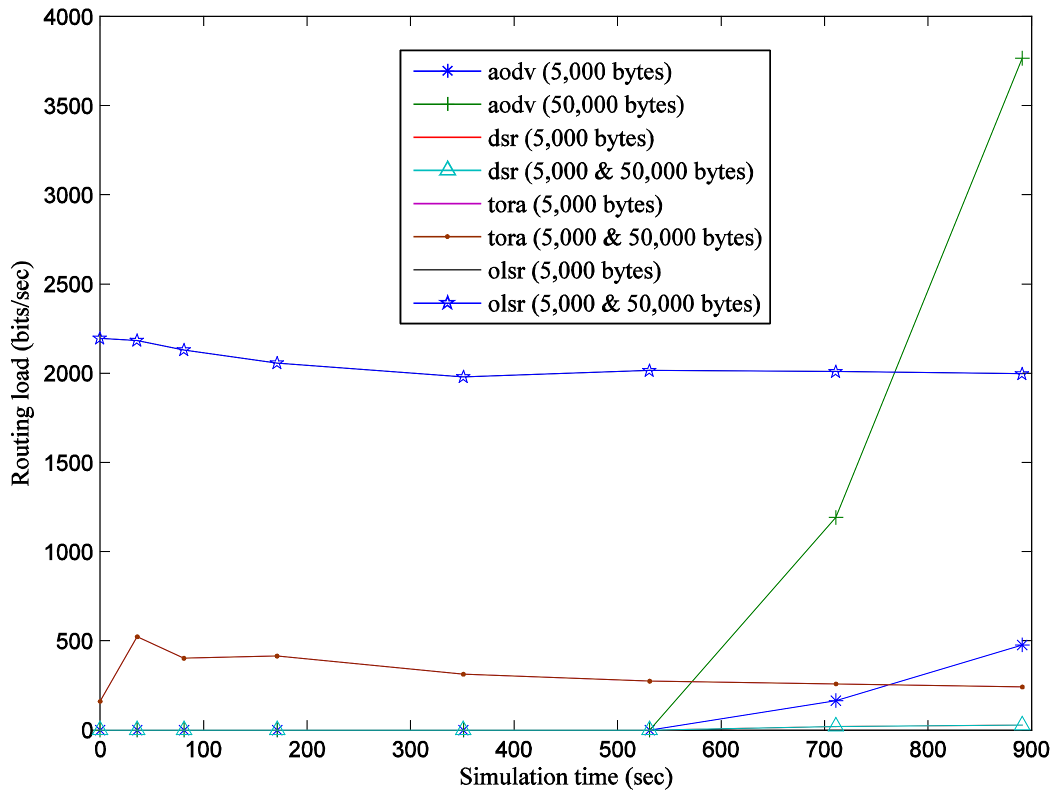

Figure 5.35: Average routing load versus simulation time (N=10, NS=30 m/s, PL = 5,000 & 50,000 bytes).

Figure 5.37 shows the average delay. DSR, in both packet lengths, maintains a low delay regardless of the increase in traffic load. OLSR likewise reacts in the same way as DSR. TORA has the second highest delay of 0.0015 sec; however, delay does not vary regardless for the two packet lengths. AODV on the other hand attains the highest delay when packet length is 50,000 bytes. AODV has a lower delay than TORA with packet length of 5,000 bytes.

OLSR, in most scenarios, maintains a lower delay. A possible reason for the achievement is the efficient route maintenance method it uses, and hence there is less likelihood of packets being sent over on invalid paths or in an event of link failure. The results also suggested that AODV is the protocol whose packet delivery rate is going to be increased as traffic load increases in small networks. Furthermore, taking into account that AODV's overhead is sharply increased therefore this resulted in a much higher delay than the other three protocols.

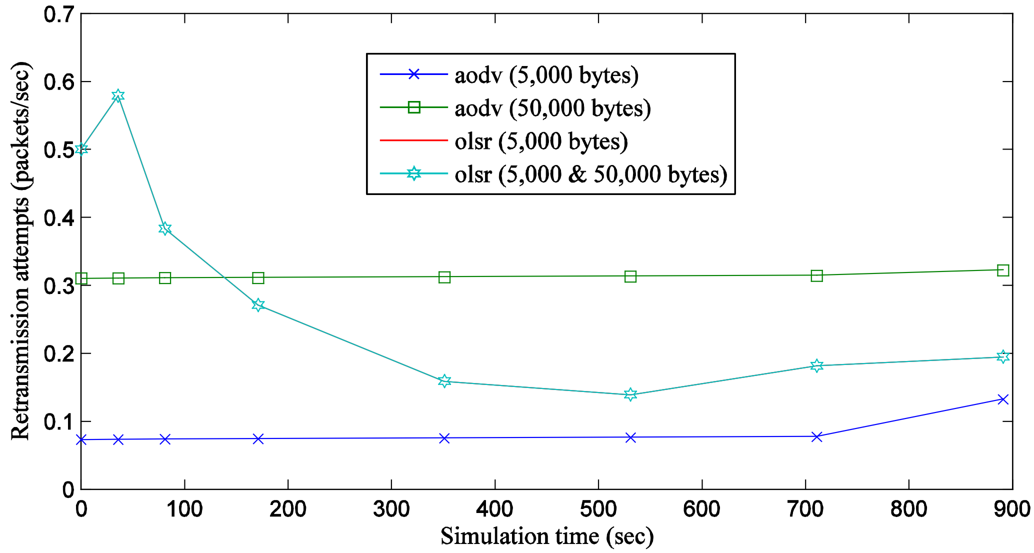

Figure 5.36: Average retransmission versus simulation time (N=10, NS=30 m/s, PL = 5,000 & 50,000 bytes).

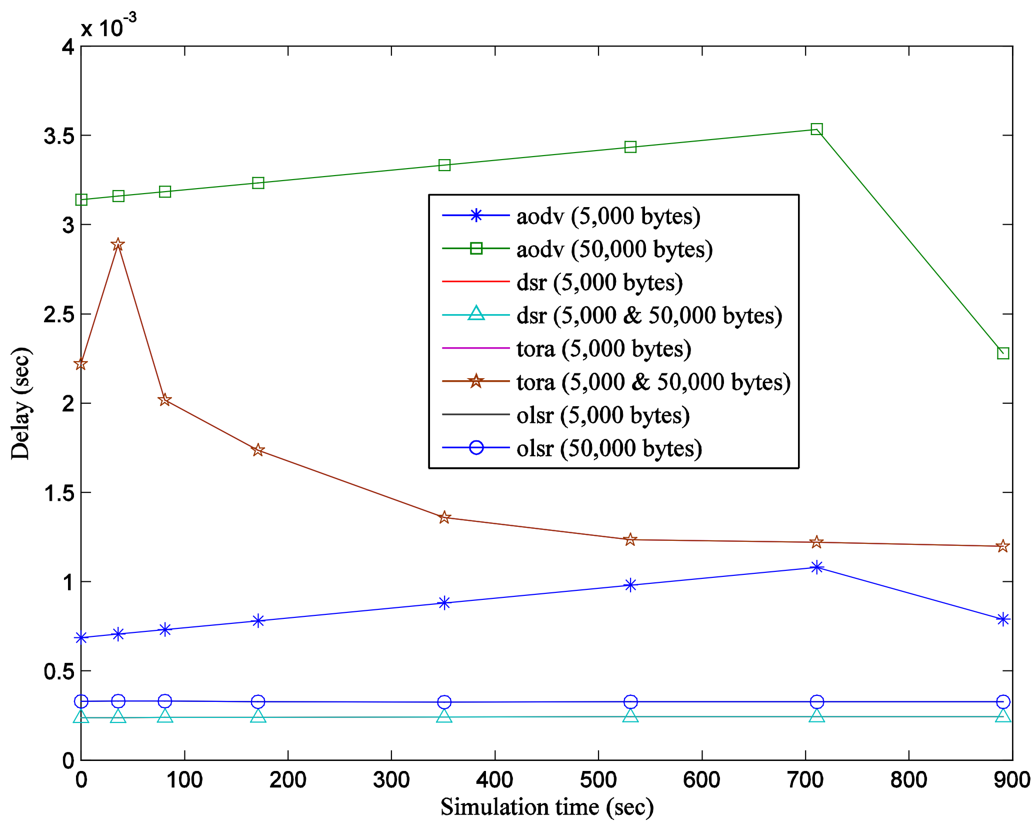

Figure 5.37: Average delay versus simulation time (N=10, NS=30 m/s, PL = 5,000 & 50,000 bytes).

In a small network where node speed is high and traffic load increases, OLSR degrades in throughput performance while AODV increases performance. DSR, the winner in small networks, maintains a low delay, however it achieves the lowest throughput in this scenario. The recommended protocols, according to the results are AODV and OLSR. In this scenario, throughput and delay does not vary with traffic load except with AODV. If a consistent traffic load is kept, with a node speed of 30 m/s, AODV is recommended, however it may not be suited for applications where delay is not acceptable.

Scenario 8: Varying traffic load in a medium sized network (N=50, NS = 30 m/s, PL = 5,000 & 50,000 bytes)

Figure 5.38 shows the throughput performance of varying traffic loads with packet lengths of 5,000 and 50,000 bytes in a medium size network (N=50 nodes). Like Scenario 7, the node speed is kept at a constant of 30 m/s. The increase in the number of nodes causes a distinguish reaction to packet lengths. OLSR performance dropped from 36,000 bits/sec to 30,000 bits/sec when traffic load increased from 5,000 to 50,000 bits/sec. TORA's reaction was different for both packet lengths. The throughput increases to 100 seconds of simulation time then decreases to 300 seconds. TORA mobilises the situation with packet length of 50,000 bytes. TORA gains throughput of 40,000 bits/sec over OLSR when packet length is 50,000 bytes. The packet length of 5,000 bytes however maintains a throughput of 10,000 bits/sec. AODV maintains the same reaction towards node mobility, as packet length increases from 5,000 to 50,000 bytes throughput increases from 5,000 bits/sec to 9,000 bits/sec respectively. DSR however differs from the pattern it used to have in a small network, without decreasing throughput as node speed increases. DSR increases throughput from 4,000 bits/sec to 8,000 bits/sec respectively when packet length increases from 5,000 to 50,000 bytes.

Figure 5.39 presents the network load. OLSR maintains a consistent network load and varies slightly when traffic load increases. TORA, AODV and DSR routing loads behave in a similar manner as their throughput performances. TORA attains routing loads of 8,000 and 37,000 bits/sec respectively. OLSR has a network load of 14,000 and 13,900 bits/sec. AODV shows a routing load of 5000 and 9000 bits/sec respectively and DSR, with 2,500 and 6,500 bits/sec achieved packet lengths of 5,000 and 50,000 bytes.

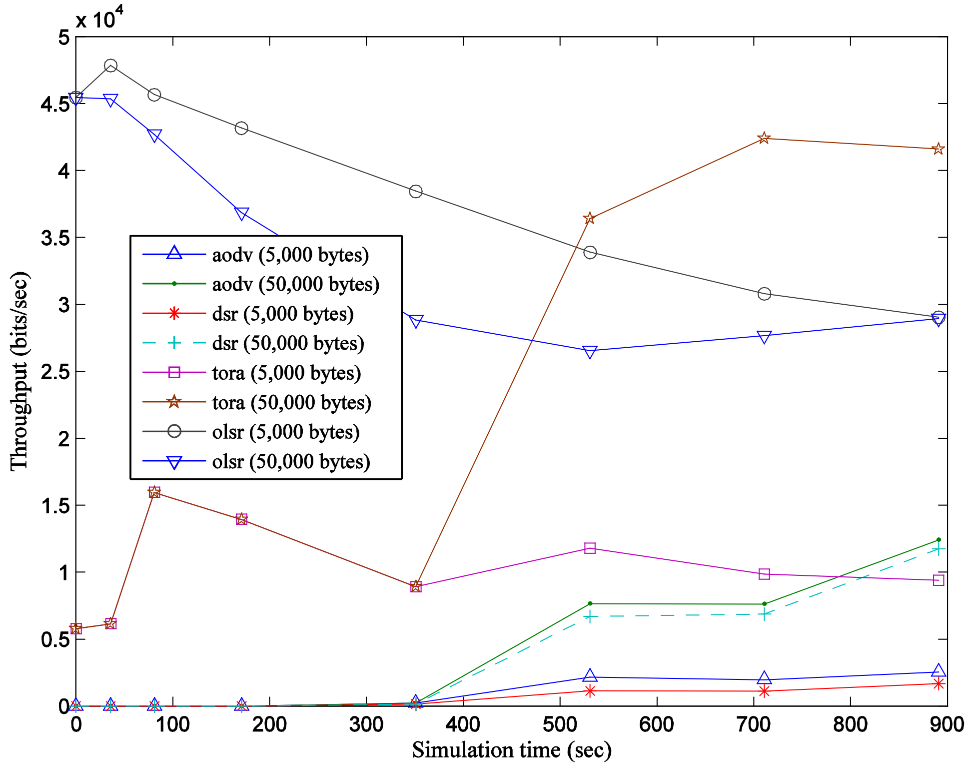

Figure 5.38: Average throughput versus simulation time (N=50, NS=30 m/s, PL = 5,000 & 50,000 bytes).

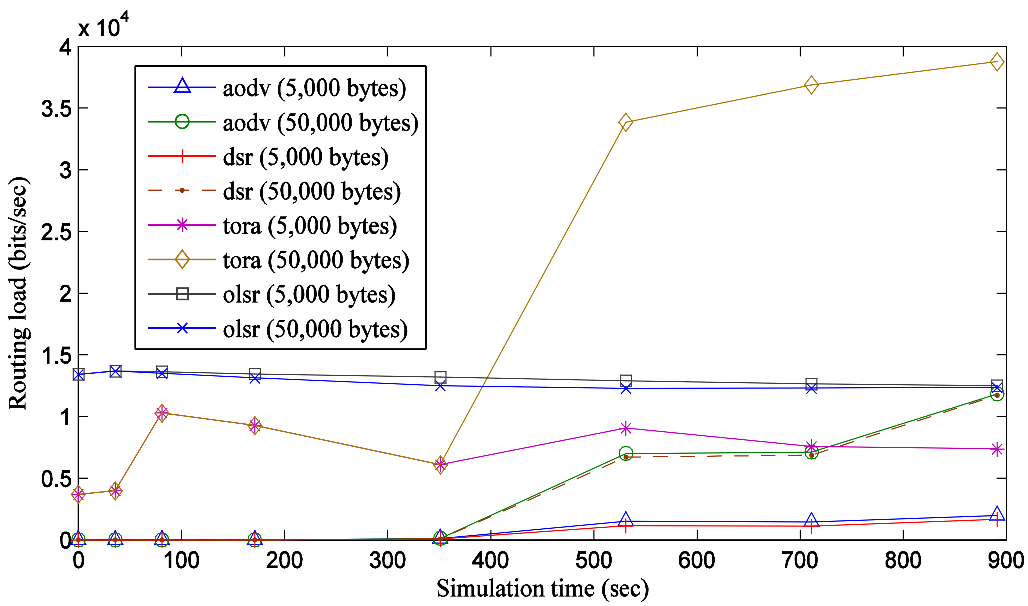

Figure 5.39: Average routing load versus simulation time (N=50, NS=30 m/s, PL = 5,000 & 50,000 bytes).

Figure 5.40 shows the retransmission attempts of the routing protocols. TORA has the highest retransmission attempts, the attempts of packet length of 50,000 bytes are less than those of the packet length of 5,000 bytes. DSR, for both packet length 5,000 and 50,000 bytes, achieves second highest however, its packet length of 50,000 bytes has a higher transmission rate than those of the packet length 5,000 bytes. AODV has a similar pattern to TORA and has the lowest retransmission rate.

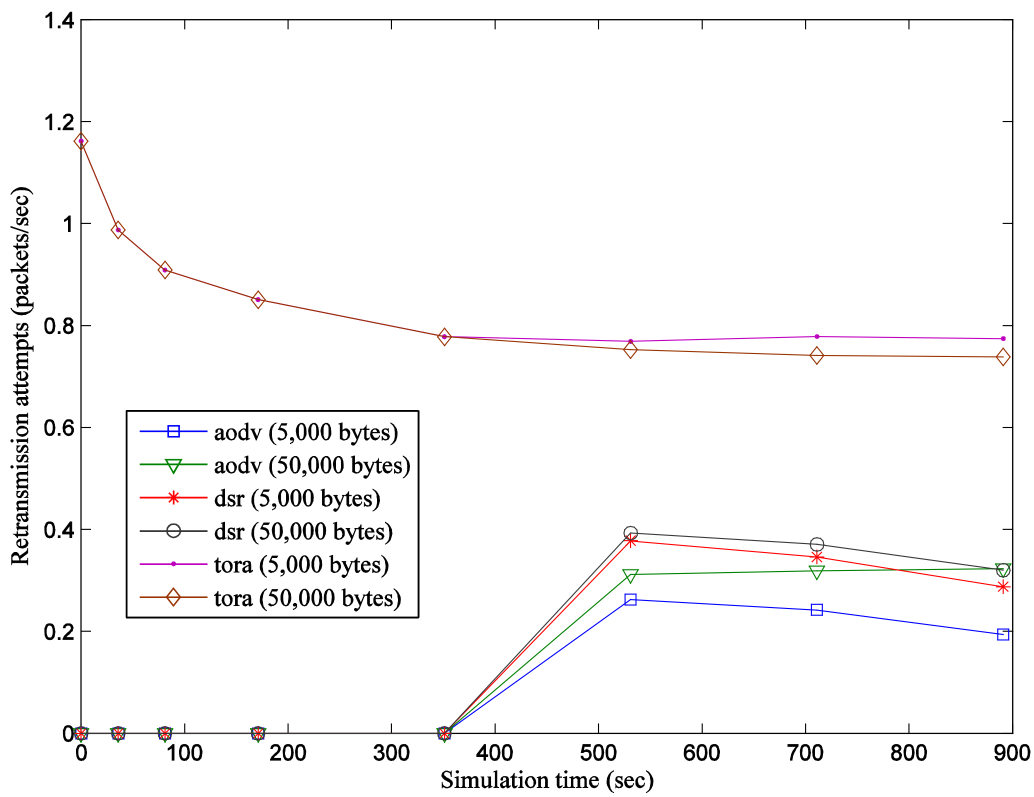

Figure 5.40: Average retransmission versus simulation time (N=50, NS=30 m/s, PL = 5,000 & 50,000 bytes).

Figure 5.41 presents the average delay of varying traffic loads. The results show that TORA has a lower delay with the packet length of 50,000 bytes than the packet length of 5,000 bytes. DSR with the packet length of 50,000 bytes has a higher traffic delay than the packet length 5,000 bytes. OLSR and AODV maintained a lower delay. AODV has a higher delay with packet length of 50,000 bytes than the packet length of 5,000 bytes.

The number of nodes in a network plays an important role towards the performance of routing protocols. DSR and AODV increase performance when traffic load increases. One possible explanation for this result is due to the increased number of nodes, data packets can use multiple routes to a destination. AODV performs better than DSR in situations with large numbers of nodes.

TORA maintains the same sensitivity to packet drop however due to its property of multiple routes to destination. It establishes a route quickly, minimising communication overheads by localising the algorithmic reaction to topological changes in a high mobility network environment. Therefore, as a result, the packet length of 50,000 bytes has a higher performance than the other protocols. TORA has a steep rise in routing load which may result in increased packet drops, causing congestion.

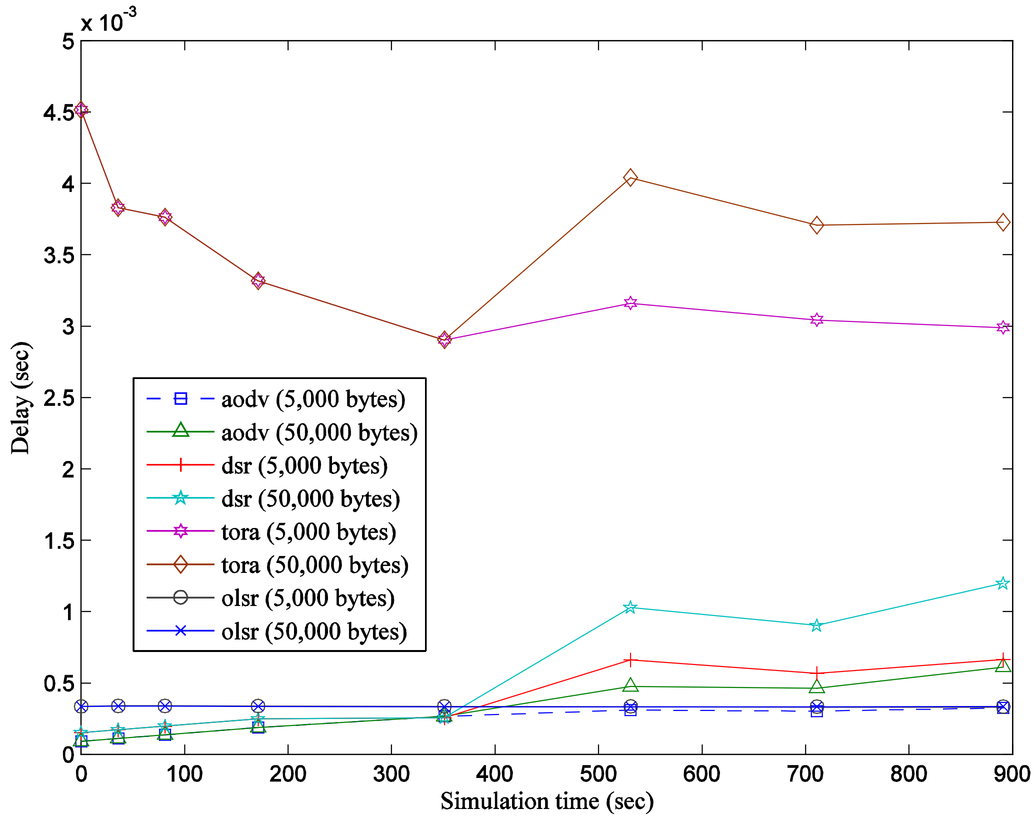

Figure 5.41: Average delay versus simulation time (N=50, NS=30 m/s, PL = 5,000 & 50,000 bytes).

In summary, the throughput results show that TORA is the recommended routing protocol to be used in varying traffic loads with high node speeds in a medium network of 50 nodes. OLSR did well in keeping a lower delay than TORA however the throughput result suggested a continuous decrease as traffic load increased. TORA behaviour not only favours mobility but also traffic load. The reactive winner of medium size networks, AODV, comes third and behaves in the same manner as TORA. Its reaction favours traffic load, however, mobility causes lowered its performance. AODV could also be well recommended as option in this scenario.

Scenario 9: Varying traffic load in a large sized network (N=100, NS = 30 m/s, PL = 5,000 & 50,000 bytes)

Figure 5.42 presents the throughput performance of varying traffic loads (packet length 5,000 and 50,000 bytes) in a large network (N=100) and node speed of 30 m/s. Throughput results show that TORA performed well in large networks with high mobility, and in higher traffic loads. As shown in Figure 5.42, DSR, with a packet length of 50,000 bytes, increases pace after 350 seconds of simulation time and increases throughput over OLSR. The presence of a large node size and mobility contribute to DSR's performance improvement. In large network DSR is capable of establish multiple routes to a destination. On the other hand DSR has a lower throughput in a lower traffic load. OLSR throughput drops and there are no differences between the packet lengths. Both packet lengths maintain the same throughput of 80,000 bits/sec. AODV responded with same throughput performance to both packet lengths. It achieves the same throughput of 70,000 bits/sec regardless of increase traffic load. TORA, with a packet length of 5,000 bytes, achieves 100,000 bits/sec and increases throughput to 230,000 bits/sec with the packet length of 50,000 bytes. DSR likewise achieves throughput of 20,000 bits/sec in a packet length of 5,000 bytes and increases throughput to 150,000 bits/sec with the packet length of 50,000 bytes.

Figure 5.43 shows the network loads for all routing protocols is similar to what is delivered to destination node as throughput. OLSR maintains a low and consistent routing load throughout simulation time.

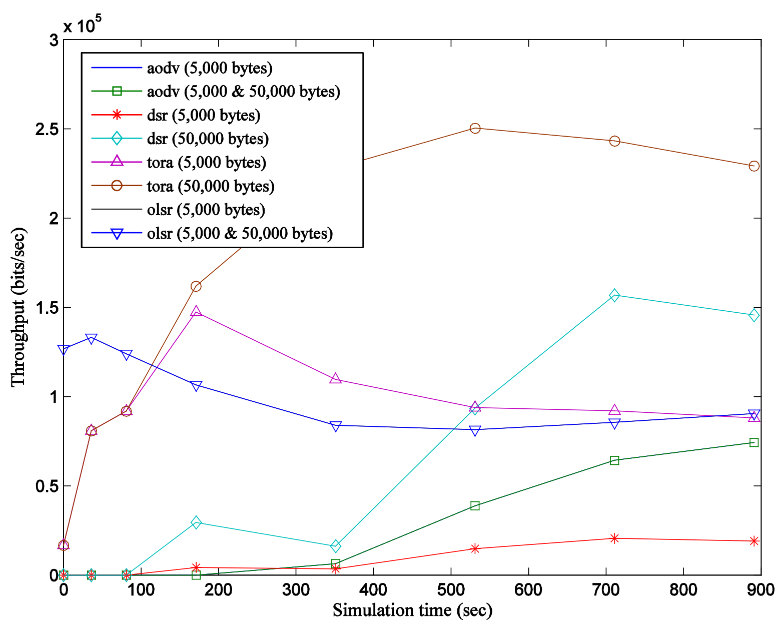

Figure 5.42: Average throughput versus simulation time (N=100, NS=30 m/s, PL = 5,000 & 50,000 bytes).

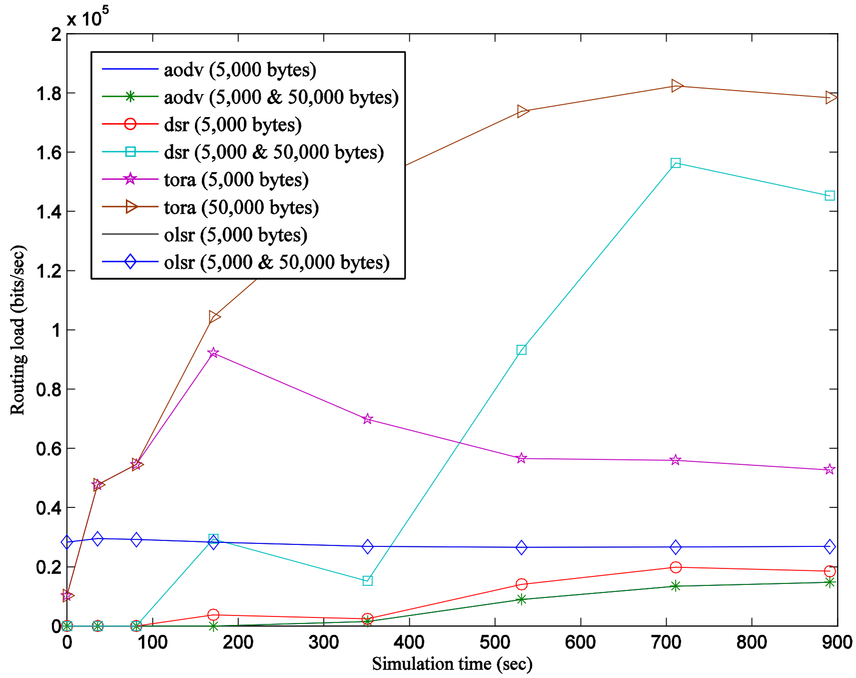

Figure 5.43: Average routing load versus simulation time (N=100, NS=30 m/s, PL = 5,000 & 50,000 bytes).

Figure 5.44 shows TORA and DSR to have retransmission attempts. TORA has higher retransmission attempts than DSR. TORA has a lower retransmission rate at a packet length of 50,000 bytes than the packet length of 5,000 bytes. Likewise DSR, with the higher packet length (50,000 bytes) produces more retransmission than a lower packet length.

The delay performance in Figure 5.45 shows TORA with higher delays than other routing protocols. TORA, with a packet length 5,000 bytes produces a higher delay than the delay of packet length 50,000 bytes. This shows that as load and node mobility increases, the delay of TORA should decrease further. DSR delay, on the other hand, behaves differently to TORA, it increases delay as traffic load increases. OLSR has a low delay and is consistent in both packet lengths. AODV shows a lower delay than OLSR and maintains same delay for both packet lengths.

TORA continues to maintain the reaction discussed in Scenario 8, where routes are established quickly in a large network and in the presence of high node mobility. There is no impact in increasing the traffic load for AODV. DSR may have a lot of stale routes in its cache; however results depicted a good throughput when mobility and traffic load is high in a large network. The result suggests that DSR can have a good scalability for node mobility in a large network with regards to message overhead. This means the control packets will not increase sharply when mobility increases as shown in Fig 5.37.

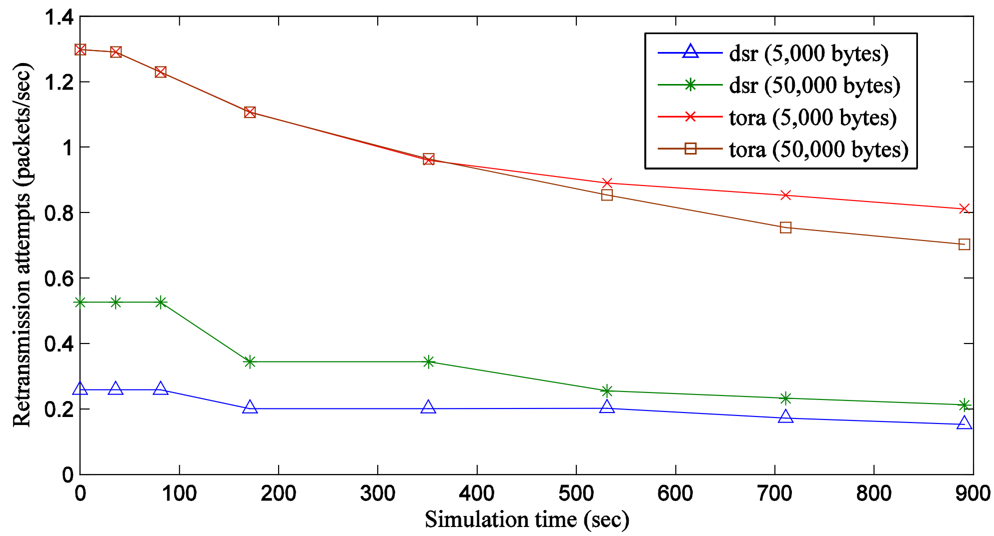

Figure 5.44: Average retransmission versus simulation time (N=10, NS=30 m/s, PL = 5,000 & 50,000 bytes).

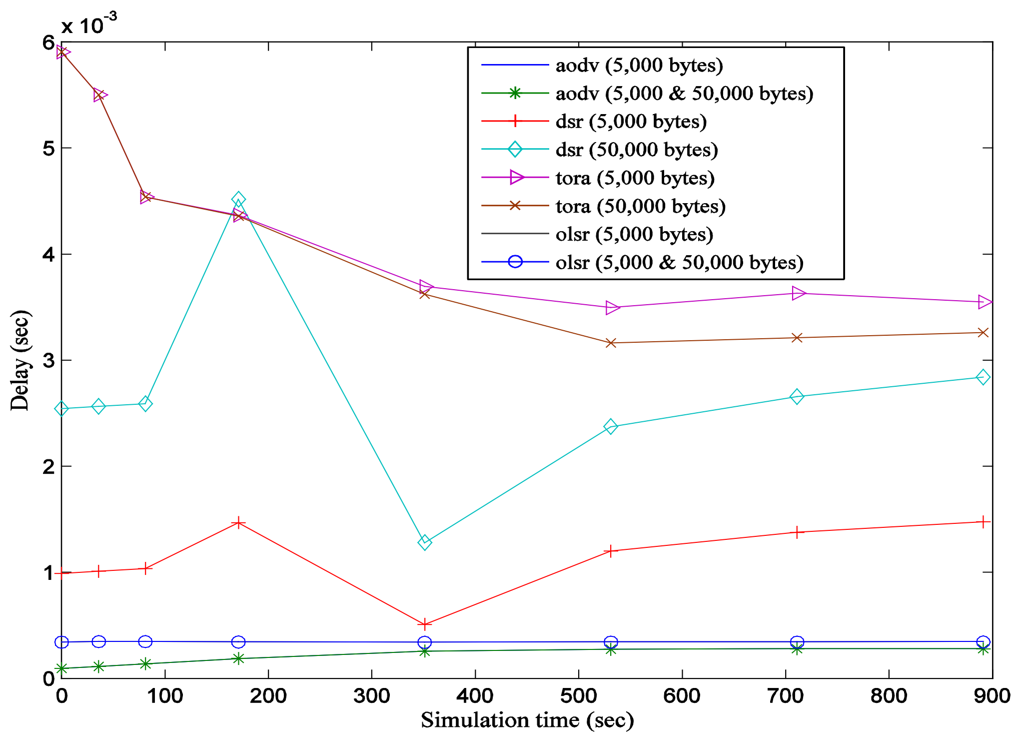

Figure 5.45: Average delay versus simulation time (N=10, NS=30 m/s, PL = 5,000 & 50,000 bytes).

In summary, TORA performed well in a large network and under high node mobility and traffic load conditions. DSR on the other hand can be used as results depicts. TORA and DSR reacted well to traffic load and mobility in large network however OLSR and AODV have no significant difference in varying traffic loads.

5.1.6 Summary of traffic load

This section present the summary results on the impact of routing protocols with varying traffic load in different network sizes. The summary graph presented three network sizes (N=10, 50,100) and the two node speed (20, 30 m/s). The averages of the results are presented from the simulation time of 900 seconds. The results in Figure 5.46 shows the effect of traffic load on network sizes where routing protocol TORA and DSR performed well in large network (N=100) and in higher node mobility. AODV and OLSR performed well in small network (N=10) however as network size increases TORA outperformed AODV in medium network (N=50). In large network OLSR and AODV where outperformed by TORA and DSR. TORA continues to perform well when traffic load increases. DSR has the greater impact in large network and larger traffic load with a light node speed of 5 m/s. A large network with available nodes for data to route from source to destination and given the right speed DSR can perform well as TORA. TORA increases throughput performance as traffic load increases in a large network. The delay of TORA in large network is lowers as compared to those of lower traffic load. A further explanation on the effects of traffic load on routing protocols is discussed in Section 5.2.

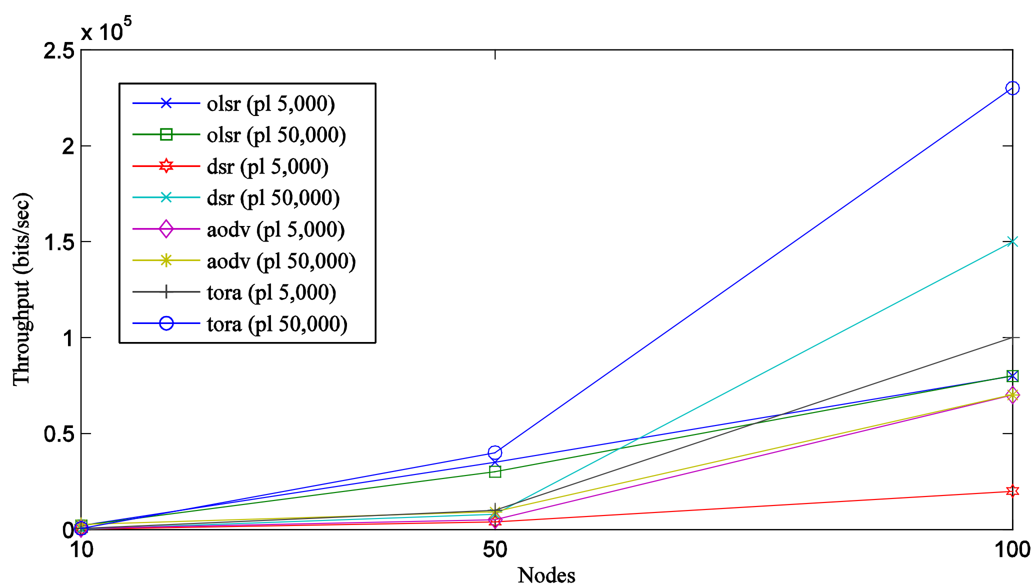

Figure 5.46: Average throughput versus network size with varying traffic load (PL-5,000, PL-50,000)

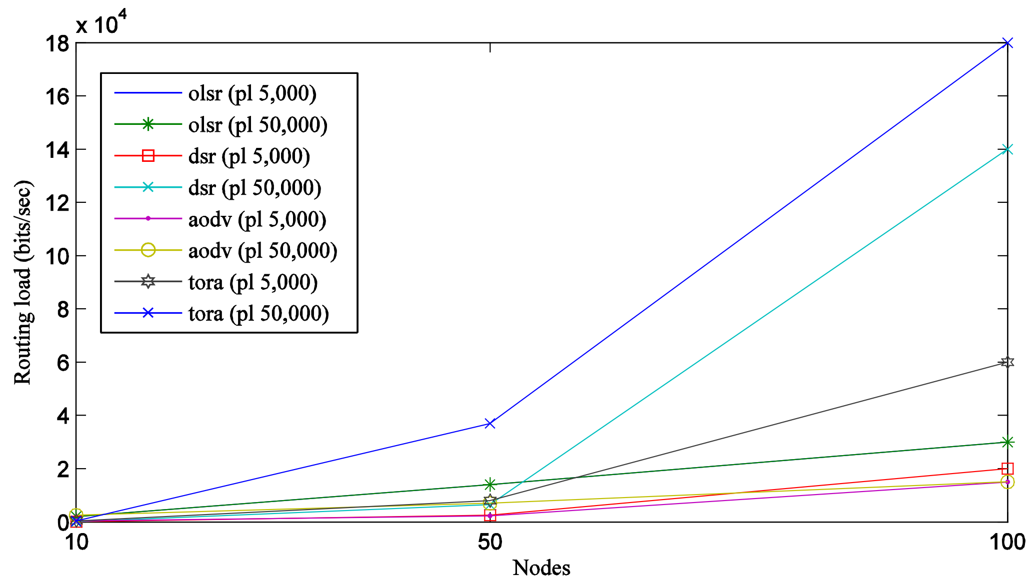

Figure 5.47: Average routing load versus network size with varying traffic load (PL-5,000, PL-50,000)

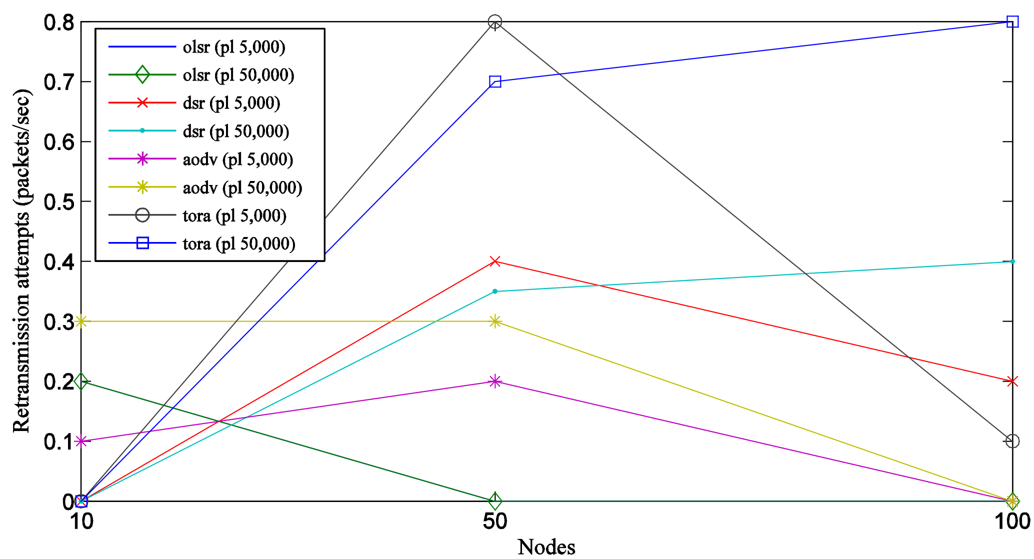

Figure 5.48: Average retransmission attempts versus network size with varying traffic load (PL-5,000, PL-50,000)

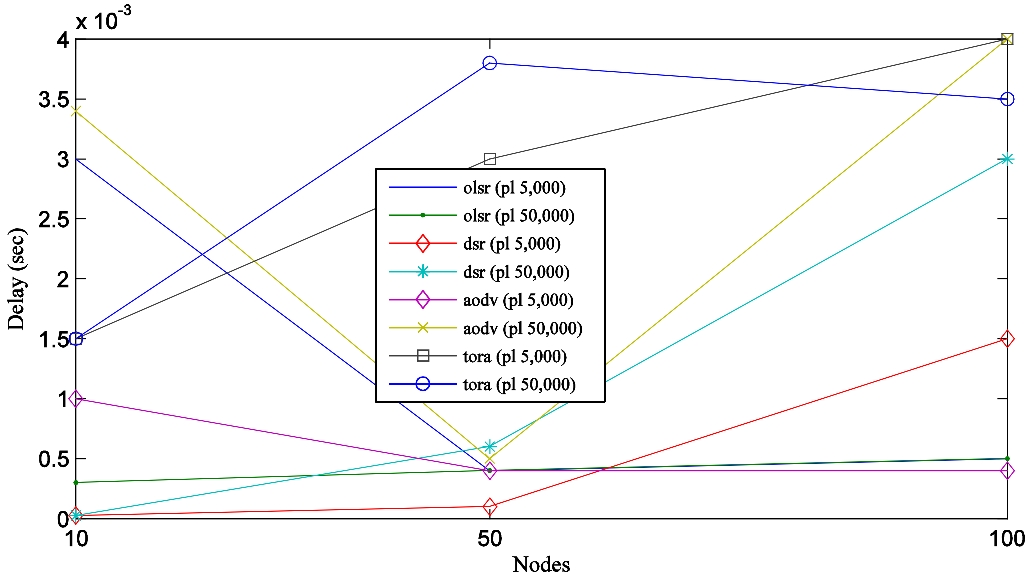

Figure 5.49: Average delay versus network size with varying traffic load (PL-5,000, PL-50,000)

Figure 5.50 presents a summary of the well performed routing protocols in the experimental results discussed in Section 5.2. The summary of routing protocols is divided in to three columns; 1) the performance metrics, 2) scenarios and 3) the recommended routing protocol identified by the evaluation of performance metrics of a scenario. Figure 5.50 also presents a guideline to follow when selecting a routing protocol to be used in a similar scenario setting as those used in this research.

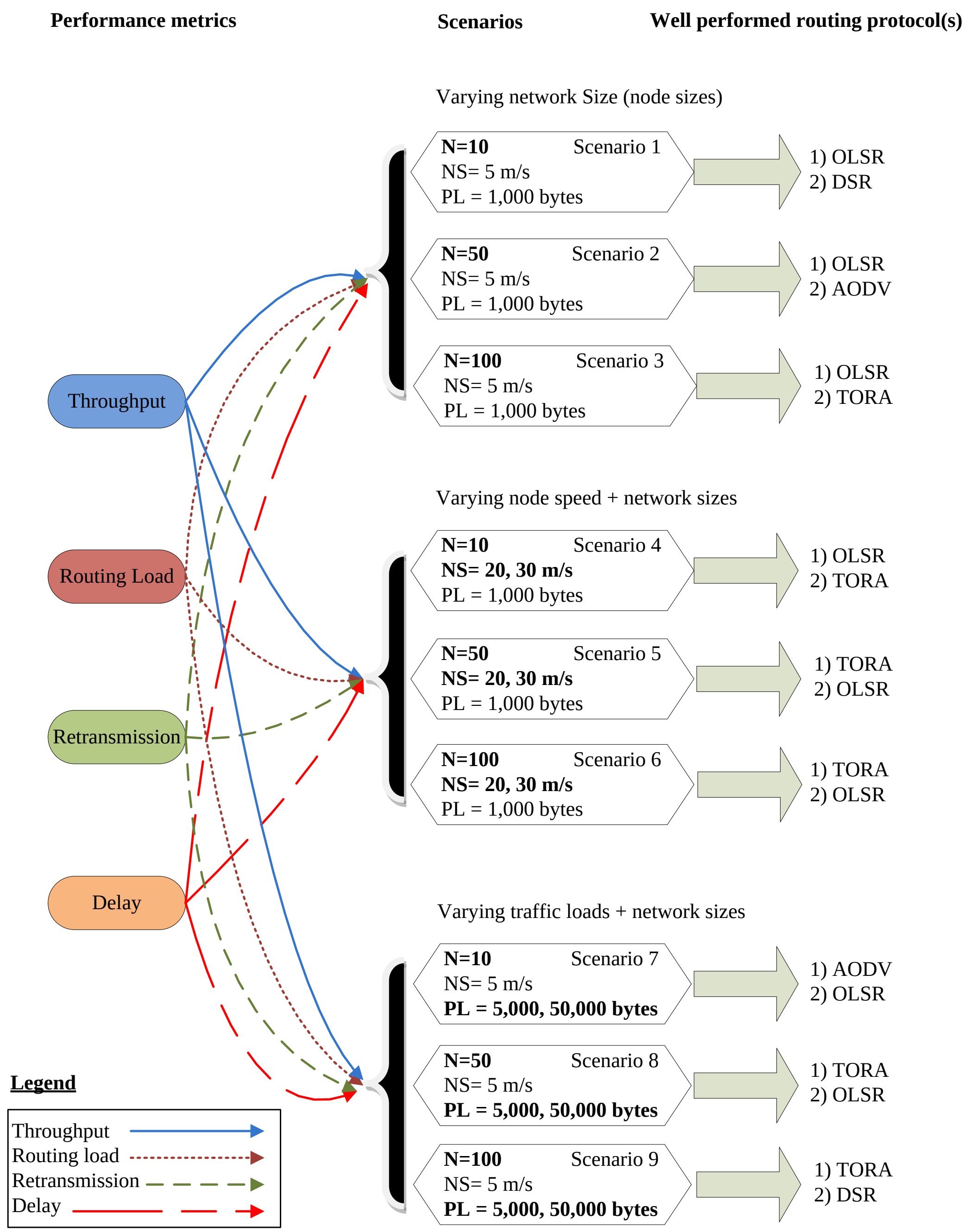

Figure 5.50: Summary of results.

5.2 Overall observation and network performance

The simulation results gave important characteristics and findings, those which have impacted routing protocols performance. The presence of node mobility, network size and traffic load implies a variety of reactions to OLSR, DSR, AODV and TORA routing algorithms. The different properties each routing protocol has lead to a variety of differences in performance. The experimental results, discussions and summary results in Section 5.1 lead to the following categorization of effects. These are; the effect of networks sizes, the effect of node mobility and the effect of packet lengths (effect of traffic loads).

5.2.1 Effect of network size

To some routing protocols the network size, in terms of the number of nodes in a network when increased, is considered as an advantage while to others is a drawback. The summary figures namely Figures 5.14, 5.15, 5.16 and 5.17 shows the reaction of routing protocol to MANET's performance in different network sizes. A more detail effect on each network is presented in Scenarios 1, 2 and 3.

Scenario 1 portrayed that in small networks [N=10] proactive routing protocols like OLSR performed well. By keeping a routing table, valid routes can be found, accessed easily, and used. OLSR by using MPR nodes, has an advantage in slow motion environments, therefore, has a high probability of maintaining a valid route [29]. DSR, amongst other reactive protocols also performed well in small networks by easily establishing routes. It is recommended to be used in low density network [29]. However, since all experiments in this research are done using mobile nodes, it is considered as a factor that caused a high delay that impacted on DSR performance. Detailed discussion on node mobility will be covered in the next section. As network size increase DSR become more aggressive in its caching, therefore, delay increases producing a lower throughput performance. DSR higher delay is shown in Figure 5:17 in network size of 100 nodes. In large network routes become larger, therefore the probability of getting a stale route and a route error is high.

The medium size network [N=50] results in Scenario 2 show OLSR performing well however it started decreasing towards the end of simulation period. AODV performed well in a medium network (N=50) by having a prior knowledge of neighbours, hence preventing loops and determining the freshest routes. AODV also has a lower delay rate due to its proactive nature. Another factor why AODV has a lower delay than DSR is the RREQ mechanism. In DSR when a RREQ message is send, a destination replies to all REEQ it receives therefore results in difficulty in determining the least congested route where as in AODV a destination replies only to the first RREQ it receives [3].

Figure 5.14, show that OLSR performed well in large network (N=100) followed by TORA. OLSR performance in large network is due to its proactive nature and by forwarding requests immediately when received. OLSR is support to work best in large network size [63]. TORA has an advantage over other reactive protocols in high density network due to its routing properties by providing multiple routes and supporting multicast environment giving a higher probability of establishing a valid route [20]. In a large network, nodes mostly communicate to a nearby node for possible route paths and hops. If local communication predominates, the paths will remain constant as the network grows. Constantly using the same path in a large network, nodes in the paths becomes denser therefore has a higher probability for a link failure to occur. This is also considered as an influential factor towards protocols performances.

5.2.2 Effect of node mobility

Mobility imposes a stress to routing protocols due to link breakages and subsequent route discovery cost. Link failure is caused by invalid routes (from nodes that disappear from network) or stale routes (nodes with expired routes). When a link failure occurs, data packet messages also increase therefore increasing network traffic load. Additionally some routing protocols may not deal well with different traffic patterns. This adds a substantial burden which causes performance to degrade significantly during node mobility. Node mobility does play an important role in determining the performance of routing protocols. In the presence of mobility, failure of links does happen therefore it requires retransmission. The accumulation of retransmission increases network load causing overhead which lead to a less throughput and performance. When node speed is high, link failure occurs and route discoveries are initiated more frequently.

In small network (N=10) outlined in Scenario 4 and Figures 5:30-5.33 shows that OLSR and TORA did performed well than AODV and DSR. AODV’s properties causes more overhead when dealing with link failures and route discoveries. DSR, on the other hand, maintains a lower route discovery due to large cache therefore less retransmission in most cases, however, due to mobility the probability of getting a stale route in its cache is very high. As a result, DSR in Scenarios 4, 5, 6 and Figure 5.30 shows lowest in throughputs. Figure 5.30 shows that DSR performs poorly in high mobility than AODV. A prior knowledge of neighbouring nodes allows AODV to perform better than DSR in all network sizes when mobility increases. DSR replies heavily on route cache to determine a valid route, which is prone to be stale with the increase in node mobility.

In medium networks (N=50) OLSR and TORA performed well over AODV and DSR. Figure 5.32 shows a variation of delay in DSR. When mobility increases in small network the delays is high and in medium networks the delay decreases and further increases as network increases. This upholds

DSR to work well in low mobility and small network size. As mobility increases in all experiment of network sizes, TORA did pick up momentum, even in a small network size, as the results depicted in Figure 5.18. In stressful situations AODV performed better than DSR, however, keeping a route table the mechanism may not be suitable for a medium size network. Figure 5.22, clearly shows that for AODV a node speed of 30 m/s may be too much to handle. TORA, on the other hand, manages well in medium and large size networks hence increases throughput when node mobility increases.

In large network (N=100), Figure 5.30 shows that as mobility increases TORA outperform OLSR. TORA is supported and recommended to be used in large network and high mobility [29]. One of the factors of TORA's advance is by providing multiple routes to destination and supports multicasting therefore its establishes routes quickly and minimising communication overheads by its localizing algorithm reaction to topological changes [20]. In all scenarios where node mobility is present, TORA performed well. On the other hand TORA causes more packet drop and a high delay (Figure 5:33) than any other routing protocol therefore has a higher delay. TORA high delay believed to be from broken links to its neighbours and the neighbour's discovery mechanism which requires each node to transmit at least one hello message per beacon period. Yet as mobility increases the delay decreases. This supports the theory that TORA gains more throughput performance in higher mobility networks [29].

OLSR performed well in all network size (Figure 5:30) and regardless of the increase in mobility. In addition OLSR has the lowest average delay. This is due to the fact that OLSR is a proactive protocol hence when a packet arrives at a node; it is immediately forwarded or dropped. Buffering enables OLSR to have a higher throughput than reactive protocols. Another obvious reason was that TCP traffic require route from both the source to destination and destination to source, which is demanding more from reactive protocols. Such routes are provided by OLSR [63].

5.2.3 Effect of packet length

Data traffic flow in the form of packet lengths plays an effective role towards scalability of routing protocols. The varying traffic load and the presences of high mobility do have an impact on routing protocols performance in many ways. Results in Scenarios 7, 8 9 and Figures 5.46-5.49, shows that not all routing protocol reacted as much, to varying traffic loads as to node mobility.

In a small network (N=10) Figure 5.46 showed AODV and OLSR to have performed well. In an in-depth perspective in Scenario 7, OLSR, TORA and DSR did not react to varying packet lengths. AODV, however, does react by increasing in throughput. The reaction is favoured towards mobility since AODV behaves in the same manner as TORA by increasing performance when node speed increases. AODV, being an improvement from DSR and DSDV, turns out to be a highly versatile protocol in such environment. Furthermore AODV outperforms other routing protocols including DSR, in heavy traffic load situations and in small networks [16]. AODV has difficulty when nodes are moving at a fast pace, as stated in [30], however in small network where nodes are moving fast with a heavy traffic load AODV performs better.

In medium network (N=50) the performance is different, TORA and OLSR showed higher performance. Due to the impact of the number of nodes and mobility present in the network, all routing protocol reacted to data traffic. TORA and AODV, increase performance as traffic increases, while DSR and OLSR, decrease performance as traffic load increases. In Scenarios 8 and 9, the combination of factors, node mobility and traffic load has affected routing protocols performance. While mobility does not favour both DSR and OLSR, adding more traffic load to the protocol decreases performance further.

On the other hand DSR properties resulted in a higher throughput performance of in a large network (N=100) and in a high mobility situation. Figure 5.46 shows that TORA and DSR performed well in large network as traffic load increases. DSR responded well to higher traffic load and higher mobility than those of lower traffic load. Two subjects that would favour this reaction are 1) when connections are established it ensures that the packets are delivered to the destination. 2) Being in a large network, and in a confined space, keeping an alternative route always pays off since there will always be a node (route) available to transfer data packets.

TORA and AODV are in favour of mobility therefore when the packet length increases, performance also increases. Since TORA supported multiple routes and multi casting allows TORA to performed well in high traffic network [17]. OLSR on the other hand maintain a linear performance and a lower delay in all network size. This would be of the same reason as mention in Sections 5.2.2 concerning TCP traffic and OLSR support both traffic from source to destination and destination to source.

Figure 5.49 shows a variation in delay respectively. Delay in a medium size network for TORA is different from the delays in a large network. A difference noted is that in a medium size network the delay increases as traffic load increases and in a large network delay decreases as throughput increases. AODV however, kept a lower delay as routing load increases. This suggests that TORA may not be too suitable for a medium network as AODV.

5.3 Validation of simulation results

The technique used in validating simulation results is the technique of graphical comparison and results output from previous results in literature [52]. Additionally each experiment is replicated and run on different machines following the guidelines outline in [62]. Each replication provides the same or similar graphical results, that when interpreted and analysed led to the same conclusion.

In small networks, with lower node mobility, the results obtained favoured the used of OLSR and DSR. This is supported by Broch et al. [64] in an experimental research using nodes of 10, 20 and 30 with node speed of 1 m/s. Comparing AODV, DSR, TORA and DSDV, DSR turns out to be the outright winner in small networks. In another study Khan et al. [12] used NCTUns, to compare performance of AODV, DSR and DSDV. The results output favoured the reactive protocols DSR and AODV. DSR works best in less stressful situations especially in small networks. A comparative study in [3] on AODV, DSR and OLSR, using OPNET modeler with CBR traffic shows that in small networks OLSR is considered very reliable.

In a medium network the results identified the use of OLSR and AODV. In a study untaken with a simulation of 40 nodes [13], the results uphold AODV stating it worked well in medium networks. In a more stressful situation (with node speed of 20 m/s) AODV performs better as nodes size increases [12]. The findings show that DSR could no longer perform when network size is greater than 20 nodes. AODV has a high performance rate at around 30 to 55 nodes. According to Huhtonen [4] OLSR also performs well in high density and highly sporadic traffics.

In a large network, the experimental results show TORA as the recommend routing protocol with high throughputs. DSR and OLSR are optional that are likely to be considered for usage in large networks. OLSR however decreases throughput. The results of [11] stated that OLSR degrades performance in large networks and when mobility increases. In other study [38] using NS2 the result affirm TORA having as higher throughput performance and good scalability in large networks.

Mobility network size and traffic load have a great impact on a routing protocol performance. The results of this experiments show that the effects of node mobility and traffic load, in terms of packet length does, have an impact on determining a protocol’s performance in small, medium and large networks.

5.4 Proposal for an improved routing protocol

To find an optimal routing protocol for all situations may not seem viable as it requires vast and substantial research into the behaviour of routing algorithms. In this research extensive and simulation experiments have been conducted to find the most suitable and reliable routing algorithms for a given situation. Node mobility, network sizes and network loads are contributing factors towards the behaviour of a routing protocol. In a dynamic changing topology TORA and AODV, in most cases, performed well while in less stressful situations OLSR and DSR perform better.

This research is centred on node mobility therefore recommendations and amendments will focus on TORA and AODV. According to the results TORA performs well in large networks and when node mobility is high. When mobility is low, TORA delay increases hence the proposed recommendation would be to look at ways of reducing the delay in large network when medium mobility of nodes exists.

AODV also performs in the same manner as TORA, however, the increase in mobility does not increase throughput in medium networks as it did for small networks. AODV is better than TORA keeping delay as low as possible, however, as mobility increases, link failures occur frequently causing a high overhead, which therefore increases delay in medium networks. Another cause of the increased delay in AODV is, because it maintains a routing table and uses the shortest and freshest route available during high node mobility. The shortest routes may not be viable when nodes are moving at a high speed. This resulted in more broadcast message initiated, therefore increasing overhead and delay impacting of the overall throughput performance.

One possible way to quantify AODV's delay and overheads in medium size networks is by proposing amendments to AODV algorithm and adopting some features of TORA. The question may arise; in what ways can the AODV overhead be defeated? The answer is to look at ways to keep the routes from constantly breaking by considering route lifetime, multiple paths and density of nodes.

Using multiple paths will allow the AODV algorithm to trigger the source node to use the next shortest possible path to the destination when alternative routes in a local route repair are not found in neighbouring nodes. Instead of initiating a broadcast message to update the routing table, the alternative path should be triggered when there are no possible routes in the neighbouring nodes routing tables during a local route repair. The risk here is that it may end up waiting too long for a response therefore more messages are sent, overloading the network. The advantage here is that the network may not be that overloaded as compared to initiating broadcast messages for route updates when there is a link failure, or there are no alternative routes found in neighbouring nodes.

The use of route lifetime will allow predetermination of the next available route when the current route is reaching its expiry date. Hence the probability of getting link failures and stale routes is lowered. The downside of a route life time is that a route may still be valid for some longer period than predicted. However, to be on the safe side rather than to trigger unwanted broadcast messages and overloading the network, the next shortest possible route should be used.

As network nodes increases some routes are used more frequently than others. Due to limited resources in MANET, the density of node plays an important role in distributing the load over the network. When one route's density becomes very high, the alternative shortest route is used. The risk involved here is that stale routes and longer paths in alternative routes may occur. The advantage is seen in balancing the load so that the shortest and freshest route is not overloaded and becomes expired sooner than its expected lifetime.

Figure 5.51 presents the proposed amendments to AODV called Priority –AODV (P-AODV). The flow chart shows the use of the alternative shortest path. The paths are considered after the topology is generated. A timer is set to keep track of a route lifetime; the timer is also influenced by the speed of the node to calculate the expiry time. Priority used paths are those with shortest path and freshest route to a destination. If a route expires or is used heavily the alternative route is trigged. Both routes should be capable of establishing connections to send data packets from a source to a destination node. When a route failure occurs, local route repair is initiated. If no possible routes are available in neighbouring nodes the alternative shortest route is triggered, however, if the alternative route has been used, the global route repair is then initiated. This research only specifies the proposed algorithm in a flow chart. The implementation of the algorithm is proposed in this research as future work.

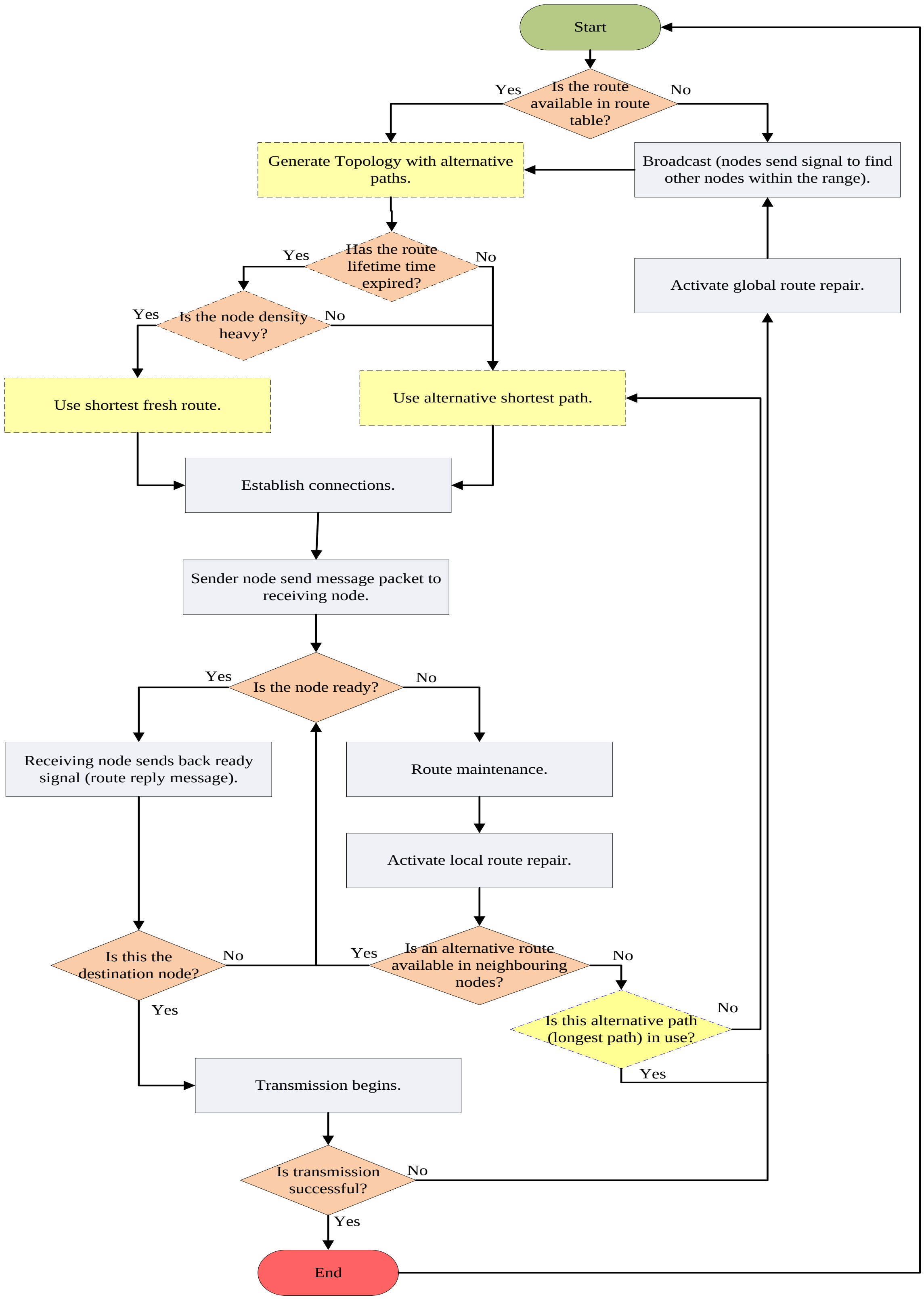

Figure 5.51: Proposed P-AODV algorithm.

5.5 Summary

This chapter presented the simulation experiment results of a mobile ad hoc network with varying node sizes, node mobility and traffic loads. The results obtained show that mobility is one of the contributing factors affecting the routing protocol's performance. Network size is the other factor that also plays an important role in the overall performance. The last factor looked at is the traffic load. In the presence of node mobility routing protocols have mixed reactions. The throughput performance of routing protocol varies from one scenario to another. Figure 5.50 summarises the recommended routing protocols, those that performed well in the given experimental scenarios and Figure 5.51 presents the proposal for an improved routing protocol.

Chapter 6

Summary and Conclusions

A deeper understanding of the impact of routing protocols on a typical MANET performance has been obtained by conducting various simulation experiments in this study. The preliminary results gave a clear indication of which routing protocols perform best in a given situation. These results not only help by doing a comparative analysis but also an insight into the variables that are affecting routing performances and a better judgment of which routing protocol is to be used in a similar situation in the future.

The results provide a significant input towards implementing a protocol, for instance; in particular AODV can perform well in stressful situation and in medium size networks. The results suggest it may not perform well when node mobility is too high and data traffic increases. Likewise TORA may also be considered to be used in small networks when node mobility is high and in medium size networks when mobility and traffic load is high.

In any network size where low mobility exists, OLSR performs well in most cases. One of the contributing factors towards such result could be due to the type of data traffic used. It is highlight that OLSR performance extremely well with CBR traffics. In the experiments CBR traffic is the only traffic used. In terms of reactive routing protocols, according to the results, DSR is best recommend for small networks, AODV for Medium networks and TORA for large networks. While OLSR seems to be dominating in all networks sizes with low node mobility, the effects of mobility and traffic load degrades OLSR performance.

Mobility is a contributing impact on protocol performance. Mobility findings show that when increasing mobility in small network OLSR and DSR decrease performance, and TORA and AODV increase performance. TORA then becomes a recommended routing protocol in small networks where higher mobility exists. In medium networks AODV reacts in the oppose direction as it did in small networks. As mobility increases performance decreases, the same way as DSR and OLSR. TORA however reacted favourably with an increase of mobility. The higher the mobility and network size TORA's performance increases while its delay decreases. TORA reacts in the same manner in large networks. AODV reacts the same way as TORA and therefore has a high throughput performance when mobility increases.

The traffic load impact on small networks shows that AODV reacted accordingly to changes in traffic load while TORA, DSR and OLSR maintained the same throughput. In medium networks, due to the number of nodes and higher mobility, all routing protocols reacted to traffic load. TORA and AODV increased performance when traffic load increased while DSR and OLSR reduced performance as traffic load increased. In large networks TORA and DSR increased performance while AODV and OLSR decreased performance.

Chapter 1 introduced the basis of this research, outlined the motives, aims and organizational structure of this research.

Chapter 2 reviewed routing protocols, algorithms and the behaviour that differentiates one routing protocol from another. A good understanding of how routing protocols behave, the influential factors and performance issues that stimulate or cause a drawback is required to identify areas of improvement in routing algorithm. While there is no universal routing protocol that works best in all situations, desirable properties can be considered in general while making amendments or developing routing protocols. The flow charts and contributions by researches helped to isolate the gap where improvement is required.

Chapter 3 unfolded the methodology used in this study. To gain accurate and realistic results of the impact on routing protocols performances, the computer simulation approach is the methodology used to abstract performance measurements for a particular protocol. Other useful methodologies exist like real experiments and analytical modelling, however, they would be difficult to use since the drawbacks are higher than those of computer simulation experiments

In Chapter 4, the detailed experimental design and investigation are presented. The tables in Chapter 4 describe clearly the parameters used in the configuration of the experiments and the numbers of experiments conducted in a particular scenario.

The generated experimental results on the performance of routing protocols are discussed in Chapter 5. The performance measurement of a routing protocol is considered by the four performance metrics; throughput, routing load, retransmission attempts and delay. The results are classified into three scenarios, varying network size, varying mobility and varying data traffic load. The four routing protocols OLSR, DSR, AODV and TORA are examined in each category. In each category there are three scenarios. The scenarios are determined by network size, node speed and data traffic in terms of packet length. The results confirm that there is no protocol that best suits all scenarios. In small networks where node mobility is low OLSR and DSR are recommended to be used. In Medium networks the identified routing protocols are OLSR and AODV, while in large networks the identified routing protocols are OLSR and TORA.

As mobility and traffic load increases the protocols reaction vary according to the situation. In most cases, AODV and TORA favour mobility. AODV however changes its behaviour in medium networks when mobility and traffic load increases causing a lower performance level. A proposed modified version of AODV is discussed and presented in Figure 5.51. This concluding chapter closed this dissertation by looking at the implication it has towards deployment of protocols in MANETs, including what has been left out and those identified as potential research towards further investigation in this area.

6.1 Future research

The experimental research focuses on three factors: node mobility, network size and network traffic load. Mobility is considered the most impacting factor and is by default deployed in all scenarios. FTP is the only type of data traffic application used in all scenarios. There are other areas left that may have significant impact on a protocols performance. Other types of data traffic like email, database, http and real time traffics are possibilities to include in future research scenarios. Additionally the experimental scenarios and findings could also be verified by using other simulation tools like Network Simulator 2. The following identified areas are considered as possible future research.

1) Implementation of the proposed priority AODV routing protocol (P-AODV).

The proposed improved routing algorithm in Figure 5.51 could further be developed into a program and implemented using OPNET. The simulation tool OPNET has robust features allowing coding and object development for a new or amended protocol. Perform the comparison of the proposed improved routing protocol with DSR, OLSR, AODV and TORA in the same or similar environmental settings as those carried out in this research.

2) Concurrent setups of DSR and TORA in a mobility environment.

As the results depicted, DSR has a high probability of performing well at higher node speeds, traffic loads and large networks. TORA also performed well in large networks and in stressful situations; however it is very sensitive to packet drop. DSR always has a lower delay therefore a concurrent setup in a mobility environment, especially in medium and large networks are possible future research areas. Nodes configured with TORA are position closer to the destination node and DSR further from the destination node is also a suggested future research. A comparison of the concurrent setup with performances of other routing protocols will help evaluate and raise the possibility of amendments to routing properties or a new protocol evolving.

References

[1] M. Abolhasan, T. Wysocki, and E. Dutkiewicz, "A review of routing protocols for mobile ad hoc networks," *Ad Hoc Networks*, vol. 2, no. 1, pp. 1-22, 2004.

[2] X. Hong, K. Xu, M. Gerla, and C. A. Los Angeles, "Scalable routing protocols for mobile ad hoc networks," *Network, IEEE*, vol. 16, no. 4, pp. 11-21, 2002.

[3] C. Mbarushimana and A. Shahrabi, "Comparative study of reactive and proactive routing protocols performance in mobile ad hoc networks," presented at the 21st International Conference on Advanced Information Networking and Applications Workshops (AINAW '07), 2007, pp. 679-684.

[4] A. Huhtonen, "Comparing AODV and OLSR routing protocols," presented at Telecommunications Software and Multimedia, 2004, pp. 1-9.

[5] M. Benzaid, P. Minet, and K. Al Agha, "Integrating fast mobility in the OLSR routing protocol," presented at the fourth IEEE Conference in Mobile and Wireless Communications 2002, pp. 1-5.

[6] Z. Ren, Y. Zhou, and W. Guo, "An adaptive multichannel OLSR routing protocol based on topology maintenance," presented at the Mechatronics and Automation, 2005 IEEE International Conference, 2005, pp. 2222-2227.

[7] A. Kumar, L. c. Reddy, and P. S. Hiremath, "Performance comparsion of wireless mobile ad hoc network routing protocols," *International Journal of Computer Science and Network Security (IJCSNS)*, vol. 8, no. 6, pp. 337-343, 2008.

[8] Z. Chang, G. Gaydadjiev, and S. Vassiliadis, "Routing protocols for mobile ad-hoc networks: current development and evaluation," 2005, pp. 489-494.

[9] G. Fang, L. Yuan, Z. Qingshun, and L. Chunli, "Simulation and analysis for the performance of the mobile ad hoc network routing protocols," presented at the 8th International Conference on Electronic Measurement and Instruments (ICEMI'07), 2007, pp. 2-571 - 2-575.

[10] A. K. Pandey and H. Fujinoki, "Study of MANET routing protocols by GloMoSim simulator," *International Journal of Network Management*, vol. 15, no. 6, pp. 393-410, 2005.

[11] F. D. Rango, J. C. Cano, M. Fotino, C. Calafate, P. Manzoni, and S. Marano, "OLSR vs DSR: A comparative analysis of proactive and reactive mechanisms from an energetic point of view in wireless ad hoc networks," *Computer Communications*, vol. 31, no. 16, pp. 3843-3854, 2008.

[12] K. U. R. Khan, R. U. Zaman, and A. V. Reddy, "Performance comparison of on-demand and table driven ad hoc routing protocols using NCTUns," presented at the Tenth International Conference on Computer Modeling and Simulation (UKSIM'08), 2008, pp. 336-341.

[13] H. Jiang, J. J. Garcia-Luna-Aceves, and E. California Univ Santa Cruz Dept Of Computer, "Performance comparison of three routing protocols for ad hoc networks," presented at the Tenth International Conference on Computer Communications and Networks, October, 2001, pp. 547–554.

[14] C. E. Perkins, E. M. Royer, S. R. Das, and M. K. Marina, "Performance comparison of two on-demand routing protocols for adhoc networks," *Personal Communications, IEEE [see also IEEE Wireless Communications]*, vol. 8, no. 1, pp. 16-28, 2001.

[15] N. Taing, S. Thipchaksurat, R. Varakulsiripunth, and H. Ishii, "Performance improvement of dynamic source routing protocol for multimedia services in mobile ad hoc network," presented at the 1st International Symposium on Wireless Pervasive Computing, 2006, pp. 1-5.

[16] G. Jayakumar and G. Gopinath, "Performance comparison of two on-demand routing protocols for ad-hoc networks based on random way point mobility model," *American Journal of Applied Sciences*, vol. 5, no. 6, pp. 659-664, 2008.

[17] E. M. Royer and C. K. Toh, "A review of current routing protocols for ad hoc mobile wireless networks," *Personal Communications, IEEE [see also IEEE Wireless Communications]*, vol. 6, no. 2, pp. 46-55, 1999.

[18] H. Pucha, S. M. Das, and Y. C. Hu, "The performance impact of traffic patterns on routing protocols in mobile ad hoc networks," *Computer Networks*, vol. 51, no. 12, pp. 3595-3616, 2007.

[19] S. Giannoulis, C. Antonopoulos, E. Topalis, and S. Koubias, "ZRP versus DSR and TORA: A comprehensive survey on ZRP performance," presented at the 10th IEEE Conference on Emerging Technologies and Factory Automation (ETFA '05), 2005, pp. 1-8.

[20] S. R. Chaudhry, A. Al-Khwildi, Y. Casey, H. Aldelou, and H. S. Al-Raweshidy, "A performance comparison of multi on demand routing in wireless ad hoc networks," presented at the IEEE International Conference on Wireless And Mobile Computing, Networking And Communications (WiMob'05), 2005, pp. 1-8.

[21] X. Zou, B. Ramamurthy, and S. Magliveras, "Routing techniques in wireless ad hoc networks-classification and comparison," presented at the Sixth World Multiconference on Systemics, Cybernetics, and Informatics (SCI '02), Florida, US, 2002, pp. 1-6.

[22] R. Bai and M. Singhal, "DOA: DSR over AODV routing for mobile ad hoc networks," *IEEE Transactions on Mobile Computing*, no. 1403-1416, 2006.

[23] F. Yu, Y. Li, F. Fang, and Q. Chen, "A new TORA-based energy aware routing protocol in mobile ad hoc networks," presented at the 3rd IEEE/IFIP International Conference in Central Asia on Internet, ICI '07, 2007, pp. 1-4.

[24] E. Huang, W. Hu, J. Crowcroft, and I. Wassell, "Towards commercial mobile ad hoc network applications: a radio dispatch system," presented at the Proceedings of the 6th ACM International Symposium on Mobile Ad Hoc Networking and Computing, 2005, pp. 355-365.

[25] S. Corson and J. Macker, "RFC2501: Mobile ad hoc networking (MANET): Routing protocol performance issues and evaluation considerations," *Internet RFCs*, no., 1999.

[26] C. S. R. Murthy and B. S. Manoj, *Ad hoc wireless networks: architectures and protocols*: Prentice Hall PTR Upper Saddle River, NJ, USA, 2004.

[27] S. H. Amer and J. A. Hamilton Jr, "Performance evaluation: running DSR and TORA routing protocols concurrently," presented at the 2007 summer computer simulation conference, 2007, pp. 1-5.

[28] S. Bali, J. Steuer, and K. Jobmann, "Capacity of ad hoc networks with line topology based on UWB and WLAN technologies," presented at the Wireless Telecommunications Symposium (WTS '08), 2008, pp. 17-24.

[29] A. Zaballos, A. Vallejo, G. Corral, and J. Abella, "AdHoc routing performance study using OPNET Modeler," presented at the OPNETWORK, Washington DC (United States) August, 2006, pp.

[30] A. Boukerche, "Performance evaluation of routing protocols for ad hoc wireless networks," *Mobile Networks and Applications*, vol. 9, no. 4, pp. 333-342, 2004.

[31] E. M. Royer and C. E. Perkins, "An implementation study of the AODV routing protocol," presented at the Wireless Communications and Networking Conference, IEEE (WCNC '02), 2000, pp. 1003-1008.

[32] A. Quintero, S. Pierre, and B. Macabéo, "A routing protocol based on node density for ad hoc networks," *Ad Hoc Networks*, vol. 2, no. 3, pp. 335-349, 2004.

[33] S. Gupta. *Performance evaluation of ad hoc routing protocols using ns2 simulations.* Retrieved July 23, 2008, from http://www.cs.utk.edu/~gupta/Adhoc.doc

[34] S. R. Das, R. Castaneda, J. Yan, and R. Sengupta, "Comparative performance evaluation of routing protocols for mobile, ad hoc networks," presented at the 7th International Conference on Computer Communications and Networks (IC3N '98), 1998, pp. 153–161.

[35] T. Larsson and N. Hedman. (1998). *Routing protocols in wireless ad-hoc networks: a simulation study.*

[36] C. R. Dow, P. J. Lin, S. C. Chen, J. H. Lin, and S. F. Hwang, "A study of recent research trends and experimental guidelines in mobile ad-hoc network," presented at the 19th International Conference on Advanced Information Networking and Applications (AINA '05), 2005, pp. 1-6.

[37] Q. Biao, H. Jianhua, and Y. Zongkai, "Simulation of wireless Ad hoc routing protocols and its evaluation," *Journal - Huazhong University of Science and Technology Nature Science*, vol. 32, no. 8, pp. 66-69, 2004.

[38] L. Layuan, L. Chunlin, and Y. Peiyan, "Performance evaluation and simulations of routing protocols in ad hoc networks," *Computer Communications*, vol. 30, no. 8, pp. 1890-1898, 2007.

[39] S. R. Das, C. E. Perkins, and E. M. Royer, "Performance comparison of two on-demand routing protocols for ad hoc networks," presented at the Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM '00), 2000, pp. 3-12.

[40] S. A. Hussein, Mahmood, and Z. E. Garcia, "Factors affecting performance of AODV," *Information Technology Journal*, vol. 6, no. 2, pp. 237-241, 2007.

[41] B. Divecha, A. Abraham, C. Grosan, and S. Sanyal, "Impact of node mobility on MANET routing protocols models," *Journal of Digital Information Management*, vol. 5, no. 1, pp. 1-19, 2007.

[42] D. D. Perkins, H. D. Hughes, and C. B. Owen, "Factors affecting the performance of ad hoc networks," presented at the IEEE International Conference on Communications (ICC '02), 2002, pp. 2048-2052.

[43] M. F. Sjaugi, M. Othman, M. Rasid, and A. Fadlee, "A new route maintenance strategy for dynamic source routing protocol," presented at the International Conference on Information Networking (ICOIN'08) 2008, pp. 1-4.

[44] M. Alilou and M. Dehghan, "Upgrading performance of DSR routing protocol in mobile ad hoc networks," presented at the Third World Enformatika Conference (WEC'05) April, 2005, pp. 38-40.

[45] C. C. Yang and Y. C. Chang, "A stability-based clustering technique and routing protocol for mobile ad hoc networks," *Journal of Information Science and Engineering*, vol. 24, no. 469-481, 2008.

[46] F. Correia and T. Vazao, "Simple ant routing algorithm," presented at the International Conference on Information Networking (ICOIN '08), 2008, pp. 1-8.

[47] Y. C. Tseng, Y. F. Li, and Y. C. Chang, "On route lifetime in multihop mobile ad hoc networks," *IEEE Transactions om Mobile Computing*, vol. 2, no. 40, pp. 366-376, 2003.

[48] K. Khamforoosh, A. M. Rahmani, and A. Sheikh Ahmadi, "A new multi-path AODV routing based on distance of nodes from the network center," presented at the Mosharaka International Conference on Communications, Propagation and Electronics (MIC-CPE '08), 2008, pp. 1-5.

[49] D. Espes and Z. Mammeri, "Improvement of AODV routing in dense networks," presented at the IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM '07), 2007, pp. 1-4.

[50] J. Costa-Requena, T. Vadar, R. Kantola, and N. Beijar, "AODV-OLSR scalable ad hoc routing proposal," presented at the 1st International Symposium on Wireless Pervasive Computing, 2006, pp. 1-5.

[51] J. Liu, Y. Yougu, D. M. Nicol, R. S. Gray, C. C. Newport, D. Kotz, and L. F. Perrone, "Simulation validation using direct execution of wireless ad-hoc routing protocols," presented at the 18th Workshop on Parallel and Distributed Simulation (PADS'04) 2004, pp. 7-16.

[52] O. Balci, "Principles and techniques of simulation validation, verification, and testing," presented at Simulation Conference Proceedings, 1995. Winter, 1995, pp. 147-154.

[53] N. I. Sarkar and S. A. Halim, "Simulation of computer networks: simulators, methodologies and recommendations," presented at the 5th International Conference on Information Technology and Application (ICITA'08), Cairns, Australia, 2008, pp. 420-425.

[54] J. S. Carson, II, "Introduction to modeling and simulation," presented at the Winter Simulation Conference, 2005, pp. 16-23.

[55] R. G. Sargent, "Verification and validation of simulation models," presented at the 37th conference on Winter simulation, Orlando, Florida, 2005, pp. 130-143.

[56] A. Maria, "Introduction to modeling and simulation," presented at the 29th conference on Winter simulation, Atlanta, Georgia, United States, 1997, pp. 7-13.

[57] D. Cavin, Y. Sasson, and A. Schiper, "On the accuracy of MANET simulators," presented at the second ACM international workshop on Principles of mobile computing, Toulouse, France, 2002, pp. 38-43.

[58] P. P. Garrido, P. M. Manuel, and T. C. Carlos, "ns-2 vs. OPNET: a comparative study of the IEEE 802.11e technology on MANET environments," presented at the 1st international conference on Simulation Tools and Techniques for Communications, Networks and Systems & Workshops, Marseille, France, 2008, pp. 1-10.

[59] L. Hogie, P. Bouvry, and F. Guinand, "An overview of manets simulation," *Electronic Notes in Theoretical Computer Science*, vol. 150, no. 1, pp. 81-101, 2006.

[60] *OPNET Modeler*. Retrieved 20 Oct, 2008, from http://www.opnet.com

[61] X. Chang, "Network simulations with OPNET," presented at Simulation Conference Proceedings, 1999 Winter, 1999, pp. 307-314.

[62] K. Salah, P. Calyam, and M. I. Buhari, "Assessing readiness of IP networks to support desktop videoconferencing using OPNET," *Journal of Network and Computer Applications*, no. pp.1-23, 2007.

[63] T. Clausen, P. Jacquet, and L. Viennot, "Comparative study of routing protocols for mobile ad-hoc networks," *INRIA Research Report*, vol. 5135, no. pp.1-25, 2004.

[64] J. Broch, D. A. Maltz, D. B. Johnson, Y.-C. Hu, and J. Jetcheva, "A performance comparison of multi-hop wireless ad hoc network routing protocols," presented at the 4th annual ACM/IEEE international conference on Mobile computing and networking, Dallas, Texas, United States, 1998, pp. 85-97.

Appendices

Outlined in this section are the extra figures showing OPNET configuration parameters and the tables present the average results of all experimental simulation scenarios.

Appendix A: OPNET simulation configurations

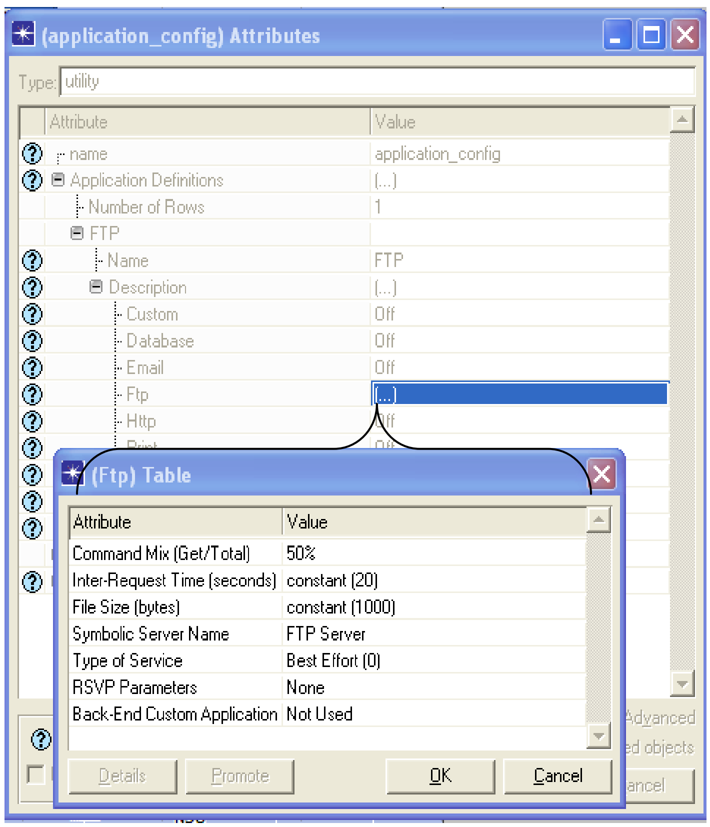

Figure A.1: Application Configuration.

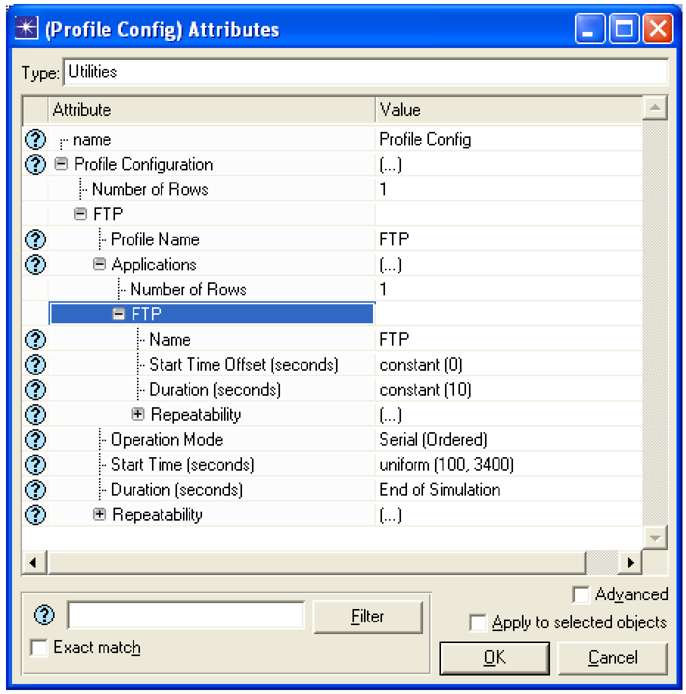

Figure A.2: FTP Profile configuration.

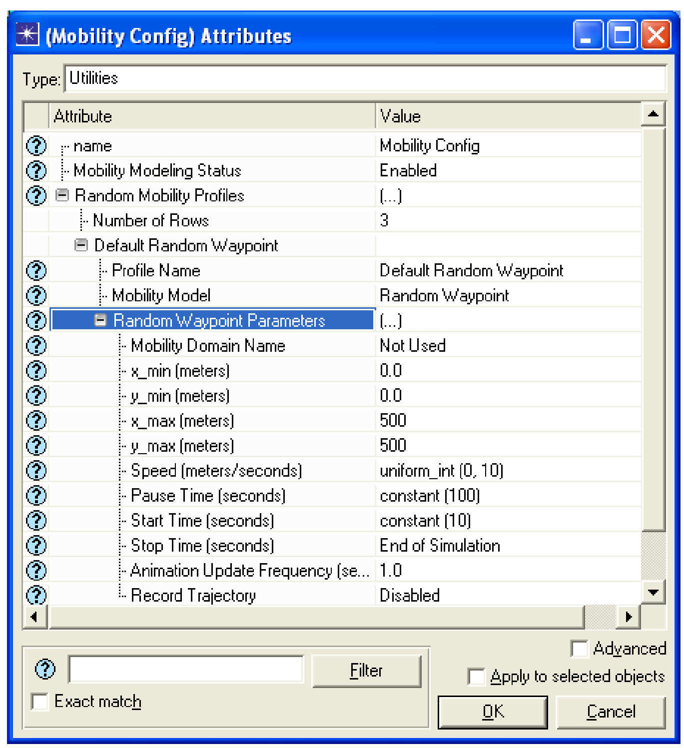

Figure A.3: Mobility configuration.

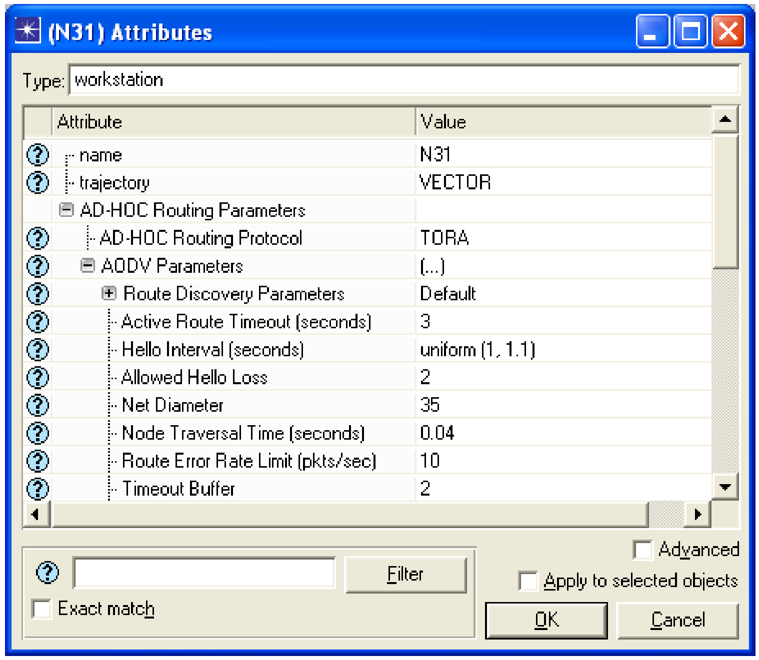

Figure A.4: Routing protocol configuration.

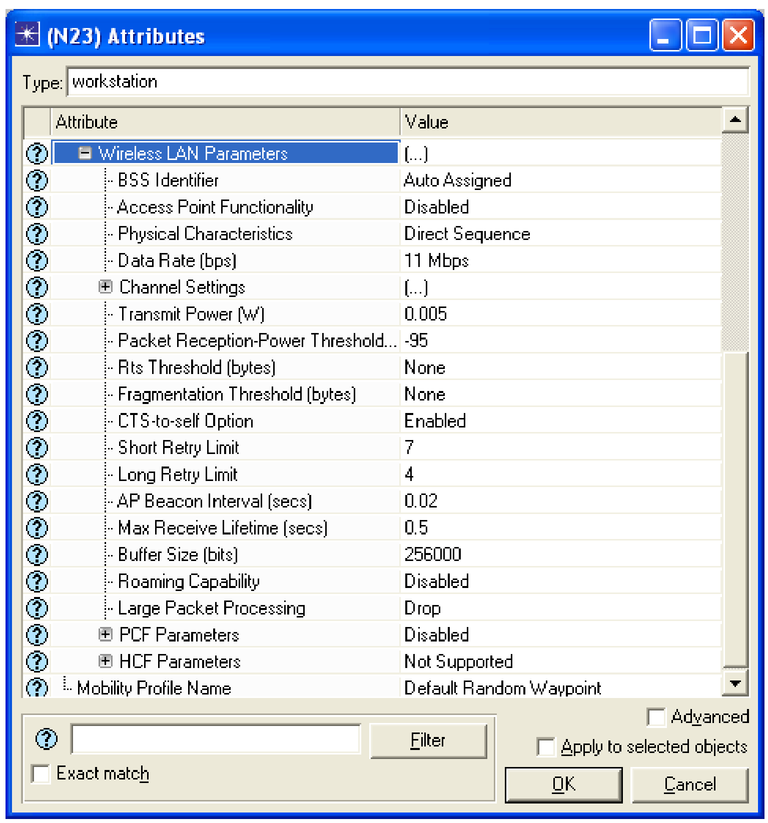

Figure A.5: Wireless and Mobility configuration.

Appendix B: Additional results for Chapter 5.

Scenario 1: Small network (N=10, NS = 5m/s, PL = 1000 bytes)				
Metrics	**Routing protocols (average results)**			
	OLSR	**DSR**	**AODV**	**TORA**
Throughput (bits/sec)	3,500	700	400	600
Routing load (bits/sec)	2,700	700	400	600
Retransmission (packets/sec)	0.45	0.05	0.15	0.6
Delay (sec)	0.00025	0.0045	0.0005	0.0015

Table B.1: Average results of small network (N=10, NS = 5m/s, PL = 1000 bytes).

Scenario 2: Medium network (N=50, NS = 5m/s, PL = 1000 bytes)				
Metrics	**Routing protocols (average results)**			
	OLSR	**DSR**	**AODV**	**TORA**
Throughput (bits/sec)	44,000	5,000	12,500	7,000
Routing load (bits/sec)	14,000	5,000	6,000	7,500
Retransmission (packets/sec)	0	0.2	0.19	1.2
Delay (sec)	0.001	0.0055	0.0012	0.003

Table B.2: Average results of medium network (N=50, NS = 5m/s, PL = 1000 bytes).

Scenario 3: Large network (Node=100, NS = 5m/s, PL = 1000 bytes)				
Metrics	**Routing protocols (average results)**			
	OLSR	**DSR**	**AODV**	**TORA**
Throughput (bits/sec)	12,0000	20,000	25,000	30,000
Routing load (bits/sec)	27,000	22,500	15,000	17,000
Retransmission (packets/sec)	0	0.6	0.2	1.4
Delay (sec)	0.0004	0.036	0.005	0.0039

Table B.3: Average results of large network (N=100, NS = 5m/s, PL = 1000 bytes).

Scenario 4: Small network + Varying mobility (N=10, NS = 20 & 30 m/s, PL = 1000 bytes)				
Metrics	**Routing protocols (average results)**			
Mobility 1 (20 m/s)	**OLSR**	**DSR**	**AODV**	**TORA**
Throughput (bits/sec)	2,700	200	100	400
Routing load (bits/sec)	2,200	100	75	500
Retransmission (packets/sec)	n/a	n/a	n/a	0.4
Delay (sec)	0.0004	0.0014	0.0004	0.002
Mobility 2 (30 m/s)				
Throughput (bits/sec)	2,000	50	300	500
Routing load (bits/sec)	2,200	25	250	400
Retransmission (packets/sec)	n/a	n/a	0.05	0.25
Delay (sec)	0.0004	0.0003	0.0003	0.0014

Table B.4: Average results of small network (N=10, NS = 20 & 30 m/s, PL = 1000 bytes).

Scenario 5: Medium network + Varying mobility (N=50, NS = 20 & 30 m/s, PL = 1000 bytes				
Metrics	**Routing protocols (average results)**			
Mobility 1 (20 m/s)	**OLSR**	**DSR**	**AODV**	**TORA**
Throughput (bits/sec)	37,000	2,000	2,500	10,000
Routing load (bits/sec)	13,500	1,000	1,600	7,000
Retransmission (packets/sec)	n/a	n/a	n/a	0.8
Delay (sec)	0.0004	0.0002	0.0005	0.0025
Mobility 2 (30 m/s)				
Throughput (bits/sec)	30,000	1,000	2,000	12,000
Routing load (bits/sec)	12,000	700	1,800	8,000
Retransmission (packets/sec)	n/a	0.3	0.18	0.7
Delay (sec)	0.0004	0.0005	0.0002	0.003

Table B.5: Average results of medium network (N=50, NS = 20 & 30 m/s, PL = 1000 bytes).

Scenario 6: Large network + Varying mobility (N=100, NS = 20 & 30 m/s, PL = 1000 bytes)				
Metrics	**Routing protocols (average results)**			
Mobility 1 (20 m/s)	**OLSR**	**DSR**	**AODV**	**TORA**
Throughput (bits/sec)	110,000	10,000	20,000	90,000
Routing load (bits/sec)	29,000	7,000	15,000	60,000
Retransmission (packets/sec)	n/a	0.7	0.3	1.2
Delay (sec)	0.0035	0.001	0.0035	0.0035
Mobility 2 (30 m/s)				
Throughput (bits/sec)	80,000	8,000	60,000	130,000
Routing load (bits/sec)	28,500	5,000	10,000	70,000
Retransmission (packets/sec)	n/a	0.2	n/a	1
Delay (sec)	0.0035	0.001	0.0002	0.004

Table B.6: Average results of large network (N=100, NS = 20 & 30 m/s, PL = 1000 bytes).

Scenario 7: Small network + Varying traffic load (N=10, NS = 30 m/s, PL = 5,000 & 50,000 bytes)				
Metrics	**Routing protocols (average results)**			
Traffic load 1 5,000 bytes/packet	**OLSR**	**DSR**	**AODV**	**TORA**
Throughput (bits/sec)	2,000	100	500	500
Routing load (bits/sec)	2,000	100	400	400
Retransmission (packets/sec)	0.2	n/a	0.1	n/a
Delay (sec)	0.003	0.000025	0.001	0.0015
Traffic load 2 50,000 bytes/packet				
Throughput (bits/sec)	2,000	100	2,500	500
Routing load (bits/sec)	2,000	100	2,500	400
Retransmission (packets/sec)	0.2	n/a	0.3	n/a
Delay (sec)	0.0003	0.000025	0.0034	0.0015

Table B.7: Average results of small network (N=10, NS = 30 m/s, PL = 5,000 & 50,000 bytes).

Scenario 8: Medium network + Varying traffic load (N=50, NS = 30 m/s, PL = 5,000 & 50,000 bytes)				
Metrics	**Routing protocols (average results)**			
Traffic load 1 5,000 bytes/packet	**OLSR**	**DSR**	**AODV**	**TORA**
Throughput (bits/sec)	35,000	4,000	5,000	10,000
Routing load (bits/sec)	14,000	2,500	2,250	8,000
Retransmission (packets/sec)	n/a	0.4	0.2	0.8
Delay (sec)	0.0004	0.0001	0.0004	0.003
Traffic load 2 50,000 bytes/packet				
Throughput (bits/sec)	30,000	8,000	9,000	40,000
Routing load (bits/sec)	14,000	6,500	7,000	37,000
Retransmission (packets/sec)	n/a	0.35	0.3	0.7
Delay (sec)	0.0004	0.0006	0.0005	0.0038

Table B.8: Average results of medium network (N=50, NS = 30 m/s, PL = 5,000 & 50,000 bytes).

Scenario 9: Small network + Varying traffic load (N=100, NS = 30 m/s, PL = 5,000 & 50,000 bytes)				
Metrics	**Routing protocols (average results)**			
Traffic load 1 5,000 bytes/packet	**OLSR**	**DSR**	**AODV**	**TORA**
Throughput (bits/sec)	80,000	20,000	70,000	100,000
Routing load (bits/sec)	30,000	20,000	15,000	60,000
Retransmission (packets/sec)	n/a	0.2	n/a	0.1
Delay (sec)	0.0005	0.0015	0.0004	0.004
Traffic load 2 50,000 bytes/packet				
Throughput (bits/sec)	80,000	150,000	70,000	230,000
Routing load (bits/sec)	30,000	140,000	15,000	180,000
Retransmission (packets/sec)	n/a	0.4	n/a	0.8
Delay (sec)	0.0005	0.003	0.004	0.0035

Table B.9: Average results of large network (N=100, NS = 30 m/s, PL = 5,000 & 50,000 bytes).