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Performance Evaluation of Routing Protocols in Mobile Ad hoc Networks (MANETs)

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Abstract

The IETF MANET working group mandate was to standardise IP routing protocols in MANETs. The RFC 2501 specifies the charter for the working group. The RFCs still has unanswered questions concerning either implementation or deployment of the protocols. Nevertheless, the working group identifies the proposed algorithms as a trial technology.

Aggressive research in this area has continued since then, with prominent studies on routing protocols such as AODV, DSR, TORA and OLSR. Several studies have been done on the performance evaluation of routing protocols using different evaluation methods. Different methods and simulation environments give different results and consequently, there is need to broaden the spectrum to account for effects not taken into consideration in a particular environment. In this project, we evaluate the performance of AODV, OLSR, DSR and TORA ad hoc routing protocols in OPNET. We simulate a Mobile ad hoc network with all nodes in the network receiving FTP traffic from a common source (FTP server). In this way, the results of this analysis would also represent a situation where the MANET receives traffic from another network via a common gateway. In addition, the mobile nodes were randomly placed in the network to provide the possibility of multihop routes from a node to the server. The performance of these routing protocols is evaluated with respect to routing overhead, throughput, end-to-end delay and packet delivery ratio.

In this study, results show that OLSR floods the network with the highest amount of routing traffic followed by TORA, AODV and DSR. All the protocols exhibit a low packet delivery ratio of maximum 59%. This degradation is expected due to huge retransmissions in the network because of using TCP traffic. OLSR outperforms AODV, DSR and TORA in terms of end-to-end delay and throughput. Varying traffic volumes or speeds in the network, leaves OLSR superior in terms of end-to-end delay and throughput. OLSR build and maintains consistent paths resulting in low delay. The results in this study also confirm TORA’s inability to handle rapid increases in traffic volumes. TORA performs well in networks where the volume of traffic increases gradually.

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To my wife, Yvonne, and my son, Wanga Thanthwe Mwanza, you bring love and joy to my life. The sacrifices you made during the period of my absence helped me complete my studies successfully. I will always cherish your love and commitment and will always love you. To my parents, my brothers and my cousin, Bwalya, without you people life would be meaningless.

- *Jason Mwanza.*

To my dear Wife Angela and my darling daughter, Temwani Zunguya Nyirenda, I say your sacrifice was immeasurable and greatly appreciated. Being without daddy and husband must have been difficult for you but you stood firm. Thank you and I shall forever be grateful.

To God who strengthens me be all the glory.

- *With Love, Bained Zunguya Nyirenda.*

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- *Bained & Jason*

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Acronyms

AODV	Ad hoc On-Demand Distance Vector
DAG	Directed Acyclic Graph
DES	Discrete Event Statistics
DSN	Destination Sequence Number
DSR	Dynamic Source Routing
IETF	Internet Engineering Task Force
IMEP	Internet MANET Encapsulation Protocol
IP	Internet Protocol
MANET	Mobile Ad Hoc Network
MPR	Multi-Point Relay
OLSR	Optimised Link State Routing
PDR	Packet Delivery Ratio
RERR	Route Error
RFC	Request For Comment
RREP	RREP
RREQ	Route Request
TC	Topology Control
TORA	Temporally Ordered Routing Algorithm
TTL	Time-To-Live
WiMAX	World-wide Interoperability for Microwave Access
WRP	Wireless Routing Protocol
ZRP	Zone Routing Protocol

Chapter 1

1 Introduction

MANET stands for Mobile Ad hoc Network. It is a robust infrastructureless wireless network. A MANET can be formed either by mobile nodes or by both fixed and mobile nodes. Nodes randomly associate with each other forming arbitrary topologies. They act as both routers and hosts. The ability of mobile routers to self-configure makes this technology suitable for provisioning communication to, for instance, disaster-hit areas where there is no communication infrastructure, conferences, or in emergency search and rescue operations where a network connection is urgently required. The need for mobility in wireless networks necessitated the formation of the MANET working group within The Internet Engineering Task Force (IETF) for developing consistent IP routing protocols for both static and dynamic topologies.

After years of research, MANET protocols do not have a complete formed Internet standard. There is only been an identification of experimental Request For Comments (RFCs) since 2003 [1]. At this stage, there is an indication that questions are unanswered concerning either implementation or deployment of the protocols but the proposed algorithms are identified as a trial technology and there is a high chance that they will develop into a standard [1]. Aggressive research in this area has continued since then with prominent studies on Ad hoc On-demand Distance Vector (AODV), Dynamic Source Routing (DSR), Temporally Ordered Routing Algorithm (TORA) and Optimised Link State Routing (OLSR) [1].

1.1 Research Questions and Problem Statement

There are several IP routing protocols, with competing features, developed for wireless ad hoc networks. These protocols have varying qualities for different wireless routing aspects. It is due to this reason that choice of a correct routing protocol is critical. In this research, we address three main questions. The first is ‘Which routing protocol provides a better performance in Mobile Ad hoc Networks?’ This question addresses the overall performance of each routing protocol investigated in this thesis. The second question addresses the factors that influence the performance of these routing protocols. Finally yet importantly, we address the major differences in the routing protocols under study. In trying to answer these questions, we modelled MANET scenarios with varying traffic loads and mobility scenarios and evaluated the performance of AODV, DSR, OLSR and TORA with respect to throughput, packet delivery ratio, end-to-end delay and routing overhead.

The premise in this research is that no single routing protocol among AODV, DSR, OLSR and TORA is clearly superior to the others in terms of overall network performance. One protocol may be superior in terms of average end-to-end delay while another may perform better in terms of routing overhead and throughput. The performance of the routing protocol will greatly depend on various factors such as network load and mobility effects.

1.2 Scope of Thesis

Routing protocols are classified either as reactive or proactive. Ad hoc routing protocols that are a combination of both reactive and proactive characteristics are referred to as hybrid. In this thesis, we considered four routing protocols. Three of these are reactive: AODV, TORA and DSR, and one is proactive: OLSR. As briefly stated in the preceding section, in this thesis, we evaluate the behaviour (how these protocols affect network performance) of these protocols when implemented in a network. We do not address in depth the design of these algorithms. We briefly mention and explain the design of these protocols in the subsequent chapters to help explain their effects on a network. Furthermore, we did not consider the effects of varying pause time of the mobile nodes. The pause time was kept constant in all the scenarios. The energy consumption of the routing algorithms was also not considered.

1.3 Thesis Outline

This document is divided into seven main chapters. Chapter 1 introduces the topic in question. It gives a brief description of what MANETs are and presents the research questions and the problem statement for this study. Chapter 2 presents the background of our work and a brief insight into related work. Chapter 3 reviews the state of the art. This chapter presents the theoretical concepts of the ad hoc routing protocols considered in this thesis. In chapter 4, we have defined the performance metrics: routing overhead, packet delivery, throughput and end-to-end delay, of the protocols considered in this paper. Chapter 5 presents the results and an analysis of the routing protocols with respect to the four performance metrics considered in our study. Chapter 6 presents the conclusion and finally, Chapter 7 presents future work of this study.

Chapter 2

2 Background and Related Work

In this chapter, we present the background to our work and provide an insight into some related work of the performance of routing protocols in MANETs. We also present an overview of MANETs and examples of their application.

2.1 Background

The dynamic nature of mobile ad hoc networks makes them ideal candidates for a number of applications. These networks are quick to deploy and require minimal configuration thus making them suitable for emergencies such as natural disasters. MANETs are also used to extend service coverage in cost effective ways. As technology advances in the development of devices such as Wi-Fi capable laptops, mobile phones and other portable devices, MANETs are increasingly becoming popular.

Research has been conducted on the performance evaluation of routing protocols mainly using the NS2 network simulator. Different methods and different simulation environments give different results and there is therefore need to broaden the spectrum to account for effects not taken into consideration in a particular environment. In this project, we evaluate the performance of AODV, OLSR, DSR and TORA ad hoc routing protocols in OPNET [2] under varying network load and mobile speeds. Most comparison studies have used constant bit rate sources [3]. In this project, we use TCP traffic to study the effects of the ad hoc protocols. Our goal is to provide an additional source of comparison statistics with a unique combination of commonly used wireless routing protocols carrying TCP traffic. Our simulations do provide a link between the theoretical concepts associated with ad hoc routing protocols and the expected performance in practical implementations.

2.2 Related Work

A performance comparison of DSDV, AODV, DSR and TORA is undertaken in [3] using the NS2 platform and it is concluded that AODV generally outperforms DSR and TORA. Another study was conducted in [4] on the performance of a simple link state protocol, AODV and DSR, The authors conclude that AODV and DSR perform well when the network load is moderate while link state outperforms the reactive protocols when traffic load is heavy. Authors in [5] provide an analysis of DSR and DSDV to study the effect of a real simulation environment on their performance.

In [1], the performance evaluation of on-demand protocols AODV and DSR is undertaken using the Glomosim simulator [6]. The authors provide an interesting conclusion on the performance of the protocols. They conclude that with sources sending data to different destinations, AODV outperforms DSR. However, when the sources send the traffic to a common destination, they conclude that AODV suffers massive degradation in the average packet delivery rate. They mention that this may cause problems when using common gateways, and thus they propose some solutions to mitigate this effect. In this project, we analyse a similar situation where the nodes in the MANET send traffic to a common destination. We do not intend to dispute or concur with the conclusion drawn by the authors as we are performing the simulations in different environments. However, we draw our own conclusions of the situation.

2.3 An Overview of Mobile Ad hoc Networks

The IETF MANET working group was tasked with standardisation of routing protocols in MANETs. RFC 2501 specifies the charter for the working group [7].

An ad hoc network is a wireless network characterised by the absence of a centralised and fixed infrastructure. The absence of an infrastructure in ad hoc networks poses great challenges in the functionality of these networks. We refer to a wireless ad hoc network with mobile nodes as a Mobile Ad Hoc Network (MANET).

As MANETs are characterised by node mobility and limited bandwidth, there is need to take into account the energy efficiency of the nodes, topology changes, unreliable communication and limited bandwidth in their design. In a MANET, mobile nodes have the ability to accept and route traffic from their neighbours towards the destination, i.e., they act as both routers and hosts. As the network grows, and coupled with node mobility, the challenges associated with self-configuration of the network become more pronounced. More frequent connection tearing and re-associations place an energy constraint on the mobile nodes.

Ad hoc routing protocols are developed with mechanisms to cope with the dynamic nature of MANETs. The efficiency of a routing protocol is determined among other things by its battery power consumption of a participating node and routing of traffic into the network. How fast the routing protocol adapts to the connection tearing and mending is also considered paramount. Examples of ad hoc routing protocols include AODV, OLSR, DSR, TORA, Wireless Routing Protocol (WRP) and the Zone Routing Protocol (ZRP). A detailed presentation of OLSR, AODV, DSR and TORA is given in chapter 3 of this report.

2.4 MANET Application Example

The versatility of MANETs makes them ideal candidates for a wide-range array of applications. They can be used during natural disasters where there is no communication infrastructure, as an extension of service coverage such as in airport hotspots and in normal enterprise deployment. A common use of MANETs is during group communications in conferences. The key attributes that make MANETs ideal candidates for such applications are their quick self-configuration and low cost of deployment.

In case of a natural disaster, a radio link such as a WiMAX radio link may be established to one area and then a MANET access network established to provide coverage extension to the areas that would otherwise be impossible to cover. In this situation, the nodes further away from the base station will rely on intermediate nodes for communication. This provides an important communication network used in such situation. Figure 1 illustrates the deployment of a MANET over a WiMAX backbone.

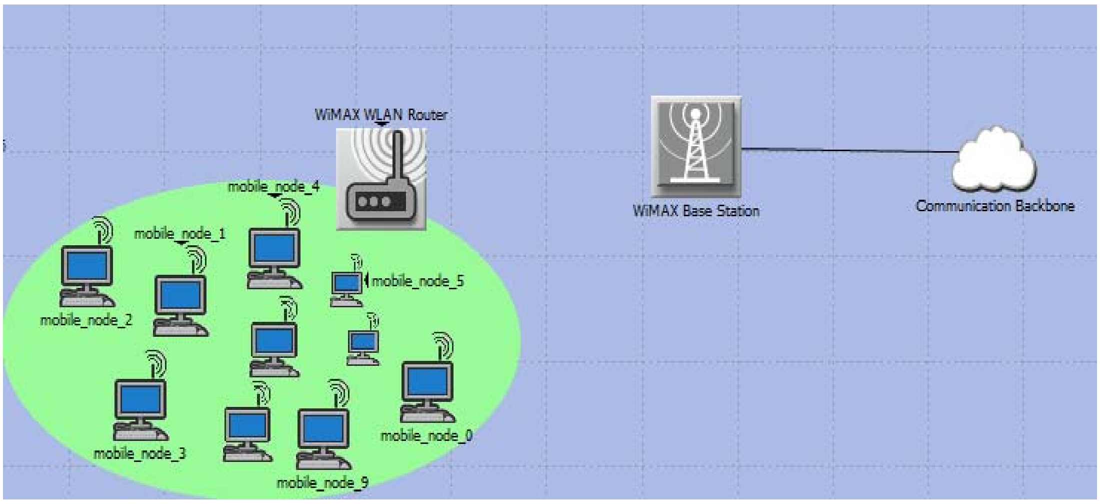

Fig. 1 MANET deployment over WiMAX

In Figure 1, the mobile nodes and the WiMAX_WLAN Router form a MANET. The WiMAX_WLAN router forms the boundary between the MANET and the WiMAX network. The router is capable of supporting translations between the ad hoc protocols and the appropriate protocols used on the WiMAX network and the communication backbone.

Chapter 3

3 Routing Protocols in MANETs

We present the theoretical concepts of ad hoc routing protocols in this chapter. We begin by describing proactive routing protocols under which OLSR is covered. We then describe reactive ad hoc routing protocols under which AODV, DSR and TORA are discussed.

An ad hoc routing protocol is a standard for controlling node decisions when routing packets traverse a MANET between devices. A node in the network, or one trying to join, does not know about the topology of the network. It discovers the topology by announcing its presence and listening to broadcasts from other nodes (neighbours) in the network. The process of route discovery is performed differently depending on the routing protocol implemented in a network.

There are several routing protocols designed for wireless ad hoc networks. Routing protocols are classified either as reactive or proactive [8]. There are some ad hoc routing protocols with a combination of both reactive and proactive characteristics. These are referred to as hybrid.

3.1 Proactive Routing Protocols

Proactive routing protocols build and maintain routing information to all the nodes. This is independent of whether or not the route is needed [9]. In order to achieve this, control messages are periodically transmitted. Proactive routing protocols are not bandwidth efficient. This is due to the control messages that are broadcasted even when there is no data flow. This type of routing protocols has its advantages and disadvantages. One of its main advantages is the fact that nodes can easily get routing information and it’s easy to establish a session. The disadvantages include: there is too much data kept by the nodes for route maintenance and it is slow to restructure when there is a failure in a particular link. OLSR is an example of a proactive routing protocol.

3.1.1 Optimized Link State Routing

OLSR is a proactive IP routing protocol for mobile ad hoc networks. It can also be implemented in any ad hoc network. Lately, it is also used in WiMAX Mesh (Backhaul). OLSR is classified as proactive due to its nature. Nodes in the network use topology information derived from HELLO packets and Topology Control (TC) messages to discover their neighbours. Not all nodes in the network route broadcast packets. Only Multipoint Relay (MPR) nodes route broadcast packets. Routes from the source to the intended destination are built before use. Each node in the network keeps a routing table. This makes the routing overhead for OLSR higher than any other reactive routing protocol such as AODV or DSR. However, the routing overhead does not increase with the number of routes in use since there is no need to build a new route when needed. This reduces the route discovery delay.

In OLSR, nodes send HELLO messages to their neighbours at a predetermined interval. These messages are periodically sent to determine the status of the links. For example, if node X and node Y are neighbours, node X sends the HELLO message to node Y. If node Y receives the message, the link is said to be asymmetric. The same holds true for the HELLO message sent by node Y to node X. If the two-way communication is possible, the link is symmetric as shown in Figure 2 below. These HELLO messages contain all the information about all their neighbours. This makes a node in the network build a table with information about its multiple hop neighbours. In addition, once these symmetric connections are made, a node chooses a minimal number of MPR nodes that broadcast TC messages with link status information at a predetermined TC interval [9]. A TC message contains information about which MPR node each node in the network has selected. TC messages also handle the calculation of routing tables.

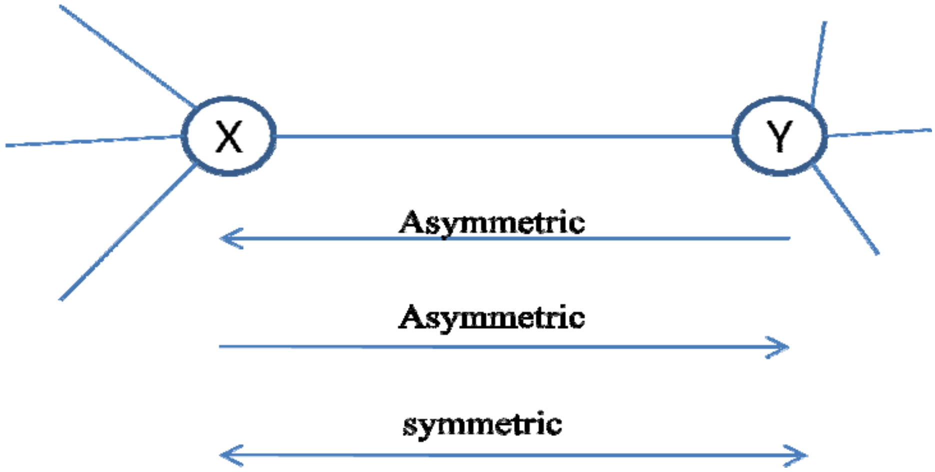

Fig. 2 HELLO messages in MANET using OLSR algorithm

3.2 Reactive Routing Protocols

Reactive routing protocols are bandwidth efficient. Routes are built as and when they are needed. This is achieved by sending route requests across the network. There are disadvantages with this algorithm. One of them is that it offers high latency when finding routes. The other disadvantage is the possibility of network clog when flooding is excessive [10]. In this thesis, we considered AODV, DSR and TORA.

3.2.1 Ad hoc On-demand Distance Vector

AODV is an on-demand routing protocol used in ad hoc networks. This algorithm, like any other on-demand routing protocol, facilitates a smooth adaptation to changes in the link conditions. In the case a link fails, notifications are sent only to the affected nodes. This information enables the affected nodes invalidate all the routes through the failed link. It has low memory overhead, builds unicast routes from source to the destination and network utilization is minimal. There is minimal routing traffic in the network since routes are built on demand. It does not allow nodes to keep routes that are not in use. When two nodes in an ad hoc network wish to establish a connection between each other, AODV will enable them build multihop routes between the mobile nodes involved. AODV is loop free. It uses Destination Sequence Numbers (DSN) to avoid counting to infinity. This is one of the distinguishing features of this algorithm. Requesting nodes in a network send DSNs together with all routing information to the destination. It also selects the optimal route based on the sequence number [11].

AODV defines three messages: Route Requests (RREQs), Route Errors (RERRs) and Route Replies (RREPs) [1]. These messages are used to discover and maintain routes across the network from source to destination by using UDP packets. When a node is requesting for a route, it uses its IP address as the source address in the message IP header and 255.255.255.255 for broadcast. The Time-To-Live (TTL) in the IP header determines the number of hops a particular routing message propagates in the ad hoc network.

Whenever there is need to create a new route to the destination, the requesting node broadcasts an RREQ. A route is determined when this message reaches the next hop node (intermediate node with routing information to the destination) or the destination itself and the RREP has reached the originator of the request [10]. Routes from the originator of the RREQ to all the nodes that receive this message are cached in these nodes. Whenever there is a link failure, an RERR message is generated. This message contains information about the nodes that are not reachable because of this failure. It also contains IP addresses of all the nodes that were using it as their next hop to the destination.

AODV is table-driven; routing information for routes in the network is stored in tables. These routing tables have the following route entries: destination IP address, DSN, flag, state, network interface, hop count, next hop, the list of precursors and lifetime.

3.2.2 Dynamic Source Routing

DSR is a reactive routing protocol for ad hoc wireless networks. It also has on-demand characteristics like AODV but it's not table-driven. It is based on source routing. The node wishing to send a packet specifies the route for that packet. The whole path information for the packet traversing the network from its source to the destination is set in the packet by the sender [1]. This type of routing is different from table-driven and link-state routing by the way routing decisions are made. In source routing, routing decisions are made by the source node.

The source node collects the addresses of all the intermediate nodes between itself and the intended destination when discovering routes. During the process of route discovery the path information collected by the source node is cached by all the nodes involved in this process. The intermediate nodes use this information to relay packets. The information in the packet traversing the network includes the IP addresses of all the nodes it will use to reach its destination. DSR uses a flow *id* to facilitate hop-by-hop forwarding of packets. Figure 3 and Figure 4 illustrate the process and sequence of route discovery in an ad hoc wireless network using DSR. When node A wishes to communicate with node F, it broadcasts RREQ packets to all its neighbours with unique *ids*. We chose to show only one route for each instance to avoid clustering.

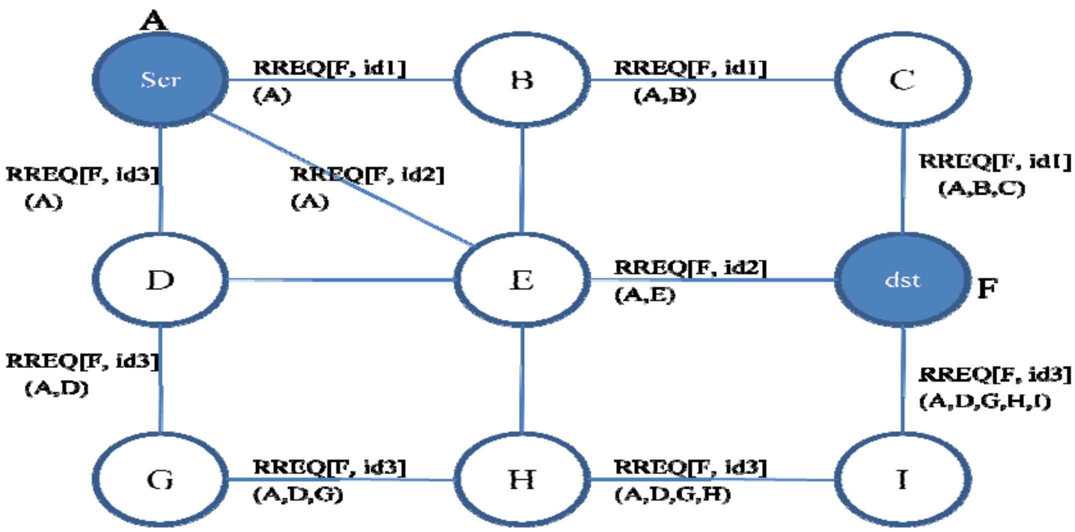

Fig. 3 **DSR route discovery process**

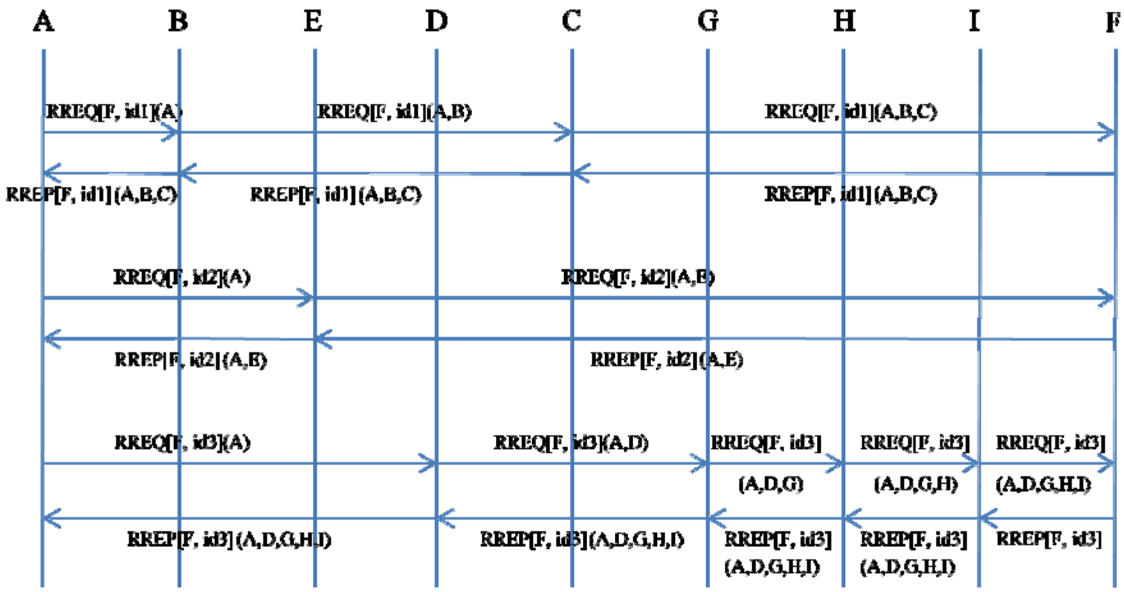

Fig. 4 **DSR route discovery sequence**

In DSR, only the destination node sends the RREP. It is only sent when the RREQ message reaches the intended destination node. The destination uses the cached routing information to traverse the RREP message to the sender. If the cached information is not sufficient, the destination node will use the information in the RREP message header. Route maintenance starts when a fatal transmission occurs. The node causing the fatal transmission is removed from the route information cached by nodes in the network. Then route discovery begins again to establish the most reliable route.

The absence of periodic table-update messages in DSR makes it bandwidth efficient. DSR does not use periodic HELLO messages. Instead it floods the network with RREQ packets when establishing a route. When a destination node receives the RREQ packet it responds with a RREP packet. It carries the same information as in the RREQ packet about the route it traversed. When an intermediate node receives a RREQ packet, as long as it's not a duplicate RREQ packet and its TTL counter is not exceeded, it rebroadcasts it to all its neighbours. And the sequence number in the RREQ packet helps to avoid packets from looping. All duplicate RREQ packets are dropped.

3.2.2.1 Advantages and Disadvantages

One of DSR main advantages is the fact that it is a reactive (on-demand) protocol hence it does not flood the network with routing updates even when the link is not in use. A route is only determined when needed. There is no need to discover routes to all the nodes in the network. And the cached information in the intermediate nodes is used to reduce routing overhead.

The disadvantage is that failed routes are not repaired locally. The cached information in the nodes may result in building inconsistent routes during reconstruction. There is high setup latency compared to the table-driven protocols. DSR is well suited for static and low-mobility networks. High mobility reduces its performance.

3.2.3 Temporally-Ordered Routing Algorithm

TORA as its name suggest, is a routing algorithm. It is mainly used in MANETs to enhance scalability. TORA is an adaptive routing protocol. It is therefore used in multi-hop networks. A destination node and a source node are set. TORA establishes scaled routes between the source and the destination using the Directed Acyclic Graph (DAG) built in the destination node [12]. This algorithm does not use 'shortest path' theory, it is considered secondary. TORA builds optimised routes using four messages [12]. Its starts with a Query message followed by an Update message then Clear message and finally Optimisation message. This operation is performed by each node to send various parameters between the source and destination node. The parameters include time to break the link (t), the originator id (oid), Reflection indication bit (r), frequency sequence (d) and the nodes id (i). The first three parameters are called the reference level and last two are offset for the respective reference level. Links built in TORA are referred to as 'heights', and the flow is from high to low. At the beginning, the height of all the nodes is set to NULL i.e. (-,-,-,-,i) and that of the destination is set to (0,0,0,0,dest). The heights are adjusted whenever there is a change in the topology.

A node that needs a route to a destination sends a query message with its route-required flag. A query packet has a node id of the intended destination. When a query packet reaches a node with information about the destination node, a response known as an Update is sent on the reverse path [12]. The update message sets the height value of the neighbouring nodes to the node sending the update. It also contains a destination field that shows the intended destination. This process is expressed in Figure 5 below.

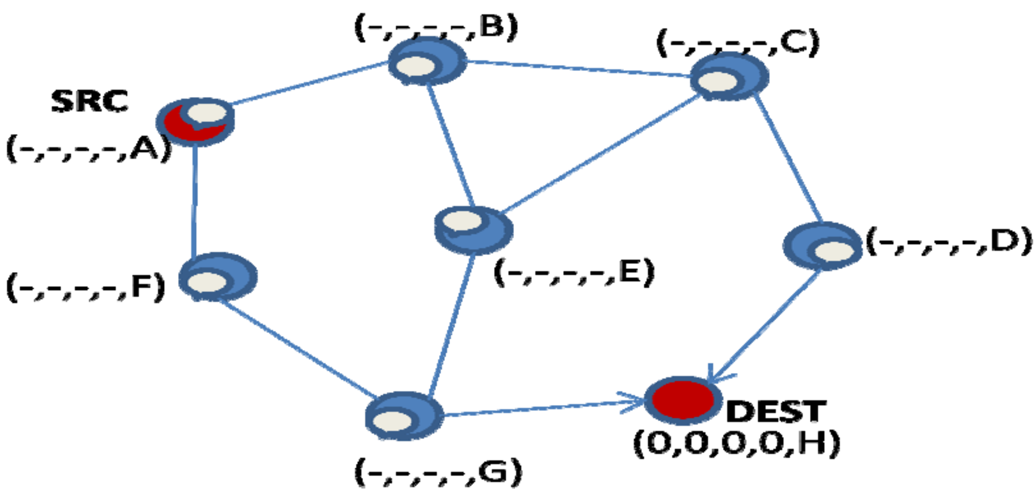

Fig. 5 **Route discovery in TORA – QRY message**

In Figure 5, node A is the source and node H is the destination. Node A broadcasts a query message across the network. Only one-hop neighbours to the destination reply to a query. When the query reaches a node with information about the destination, this node sends back an update. In this case, node D and node G are one hop away from the destination. Therefore, they will propagate Updates as shown in Figure 6.

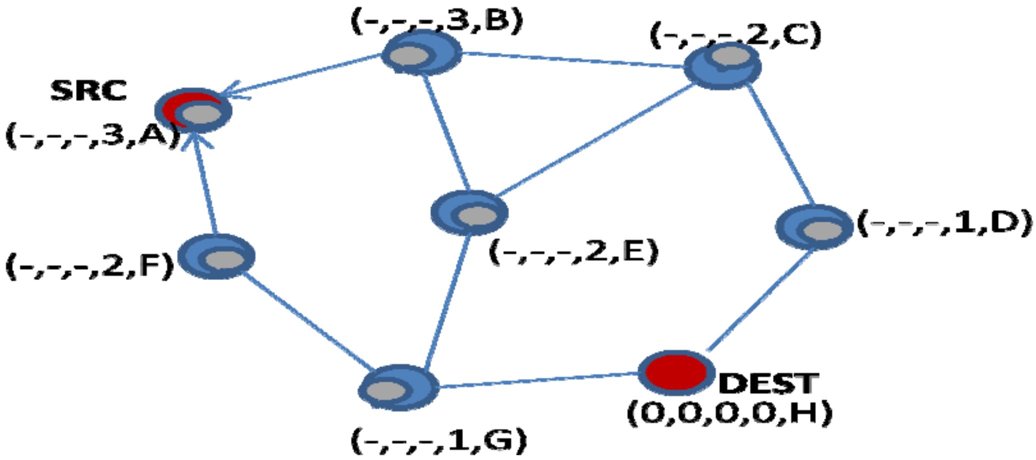

Fig. 6 Route discovery in TORA – Update message

There are flaws in this type of algorithm. The main one is that it is highly dependent on the number of nodes activated at initial set up [13]. The flaw is that the reaction to traffic demands is not independent. It is dependent on the rate of change of the amount of traffic (number of nodes) in the network. If the traffic volume in the network increases with a steep positive gradient, TORA would not be a good choice for this particular network.

TORA is layered over Internet MANET Encapsulation Protocol (IMEP) [13]. This is to ensure reliability in the delivery of control messages and notifications about link status.

Chapter 4

4 Performance Evaluation and Design

In this chapter, we present the design parameters of our system and the various metrics considered in the performance evaluation of the routing protocols. We begin by presenting an overview of the performance metrics considered in the comparisons. We then briefly present the software platform used in the simulations and lastly we present the simulation design.

4.1 Performance Metrics

Different performance metrics are used in the evaluation of routing protocols. They represent different characteristics of the overall network performance. In this report, we evaluate four metrics used in our comparisons to study their effect on the overall network performance. These metrics are routing overhead, packet delivery ratio, packet end-to-end delay and network throughput.

4.1.1 Routing Overhead

Mobile ad hoc networks are designed to be scalable. As the network grows, various routing protocols perform differently. The amount of routing traffic increases as the network grows. An important measure of the scalability of the protocol, and thus the network, is its routing overhead. It is defined as the total number of routing packets transmitted over the network, expressed in bits per second or packets per second.

Some sources of routing overhead in a network are cited in [14] as the number of neighbours to the node and the number of hops from the source to the destination. Other causes of routing overhead are network congestion and route error packets.

Mobile nodes are faced with power constraints and as such, power saving is a major factor to consider in implementation of MANETs. Furthermore, radio power limitations, channel utilisation and network size are considered. These factors limit the ability of nodes in a MANET to communicate directly between the source and destination. As the number of nodes increases in the network, communication between the source and destination increasingly relies on intermediate nodes. Most routing protocols rely on their neighbours to route traffic and the increase in the number of neighbours causes even more traffic in the network due to multiplication of broadcast traffic.

Contention for transmission slots among various nodes in a MANET also become more pronounced as the network grows. The frequency of broadcasts is increased due to frequent link failures caused by node mobility. How effective a routing protocol is in dealing with these challenges under the constraints of network congestion and low bandwidth is therefore paramount in MANETs. Routing overhead is thus used as a measure to gauge the effectiveness of routing protocols.

4.1.2 Packet Delivery Ratio

Packet Delivery Ratio (PDR) is the ratio between the number of packets transmitted by a traffic source and the number of packets received by a traffic sink. It measures the loss rate as seen by transport protocols and as such, it characterises both the correctness and efficiency of ad hoc routing protocols. It represents the maximum throughput that the network can achieve. A high packet delivery ratio is desired in a network.

4.1.3 Packet End-to-End Delay

The packet end-to-end delay is the average time that packets take to traverse the network. This is the time from the generation of the packet by the sender up to their reception at the destination's application layer and is expressed in seconds. It therefore includes all the delays in the network such as buffer queues, transmission time and delays induced by routing activities and MAC control exchanges.

Various applications require different levels of packet delay. Delay sensitive applications such as voice require a low average delay in the network whereas other applications such as FTP may be tolerant to delays up to a certain level. MANETs are characterised by node mobility, packet retransmissions due to weak signal strengths between nodes, and connection tearing and making. These cause the delay in the network to increase. The end-to-end delay is therefore a measure of the how well a routing protocol adapts to the various constraints in the network and represents the reliability the routing protocol.

4.1.4 Throughput

The ratio of the total amount of data that reaches a receiver from a sender to the time it takes for the receiver to get the last packet is referred to as throughput [15]. It is expressed in bits per second or packets per second. Factors that affect throughput in MANETs include frequent topology changes, unreliable communication, limited bandwidth and limited energy [15]. A high throughput network is desirable.

4.2 Software Platform

The software used in this study is OPNET modeler 14.5. OPNET is a network and application management software designed and distributed by OPNET Technologies Inc [2]. Among other things OPNET Technologies Inc, model communication devices, technologies, protocols, and architectures, and provide simulation of their performance in a dynamic virtual network environment [2].

OPNET Technologies through its R&D provides solutions that help in academic research in the following areas: Evaluation and enhancement of wireless technologies e.g., WIMAX, Wi-Fi, UMTS, evaluation and design of MANET protocols, analysis of optical network designs, enhancements in the core network technologies such as IPv6, MPLS, and power management schemes in sensor networks [2]. OPNET Modeler 14.5 System Requirements are presented in Appendix B.

OPNET is a useful tool in research. Its use can be broken down in four major steps. The first step is modelling (creating network nodes). Then choose statistics, run simulations and finally view and analyse results.

4.2.1 Modelling

The first step when creating a network is to create a blank scenario. This is done using the start-up wizard. This opens a project editor workspace in which network design is performed. The design is done either automatically or manually. It is done either by automatically generating topologies using rapid configuration or manually by dragging objects from the object palette to the project editor workspace. Pre-defined scenarios can also be imported if they suit user requirements. However, wireless networks cannot be designed by importing scenarios [16]. After the network is designed, nodes must be configured. Configuration is also performed either manually or by using pre-defined parameters in the workflow.

4.2.2 Collecting Statistics and Viewing Results

There are two types of statistics, Objet statistics and Global statistics that can be collected in OPNET**.** Global statistics are collected from the entire network while object statistics are from individual nodes. When desired statistics are chosen, run the simulation to record the statistics. After running the simulation, the collected results are viewed and analysed. This is done by either right clicking in the project editor workspace and choosing 'View Results' or by clicking on 'DES', 'Results' then 'View Results'. A results browser then pops up as shown in Figure 7 below.

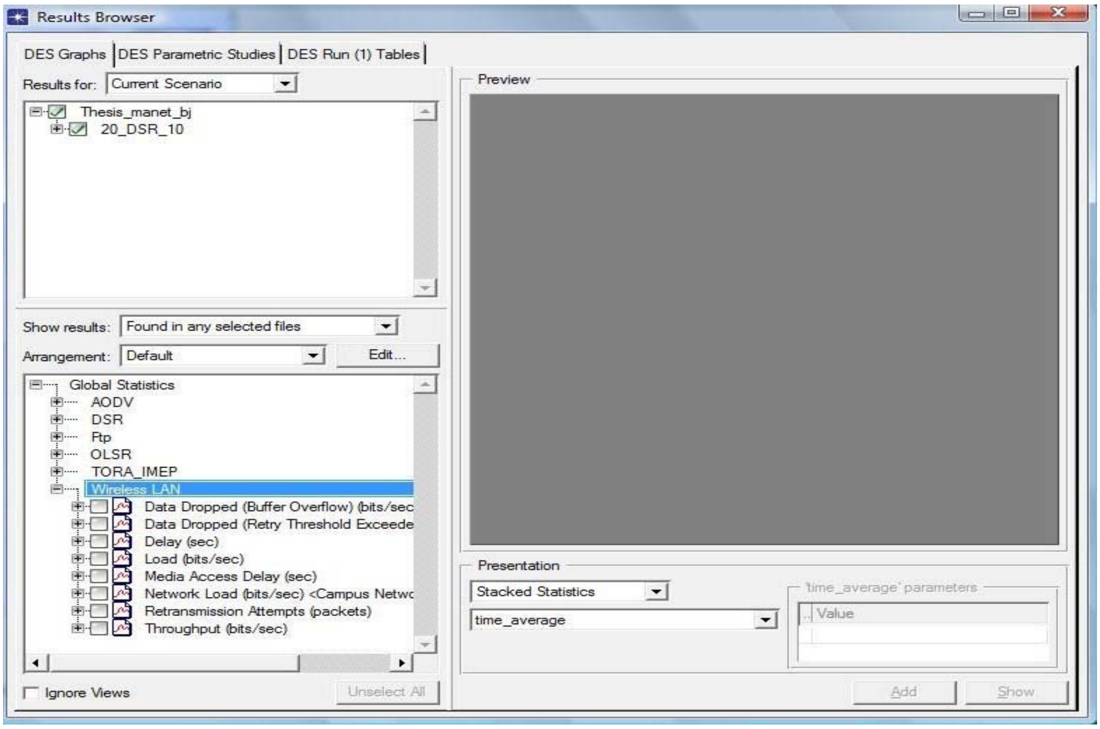

Fig. 7 OPNET results browser

4.3 Simulation Setup

We employed OPNET Modeller 14.5 in our simulations. Figure 8 shows the simulation setup of one scenario comprising 20 nodes with the mobile nodes moving at a speed of 10 m/s. A systematic procedure for the simulations is presented in Appendix A - a guide for the reader wishing to follow through the simulations. In this section, we provide the key parameters for the simulations.

We grouped the simulations into six categories, namely:

- Category I – Light load and medium speed, comprising 5 mobile nodes moving at a constant speed of 10 m/s

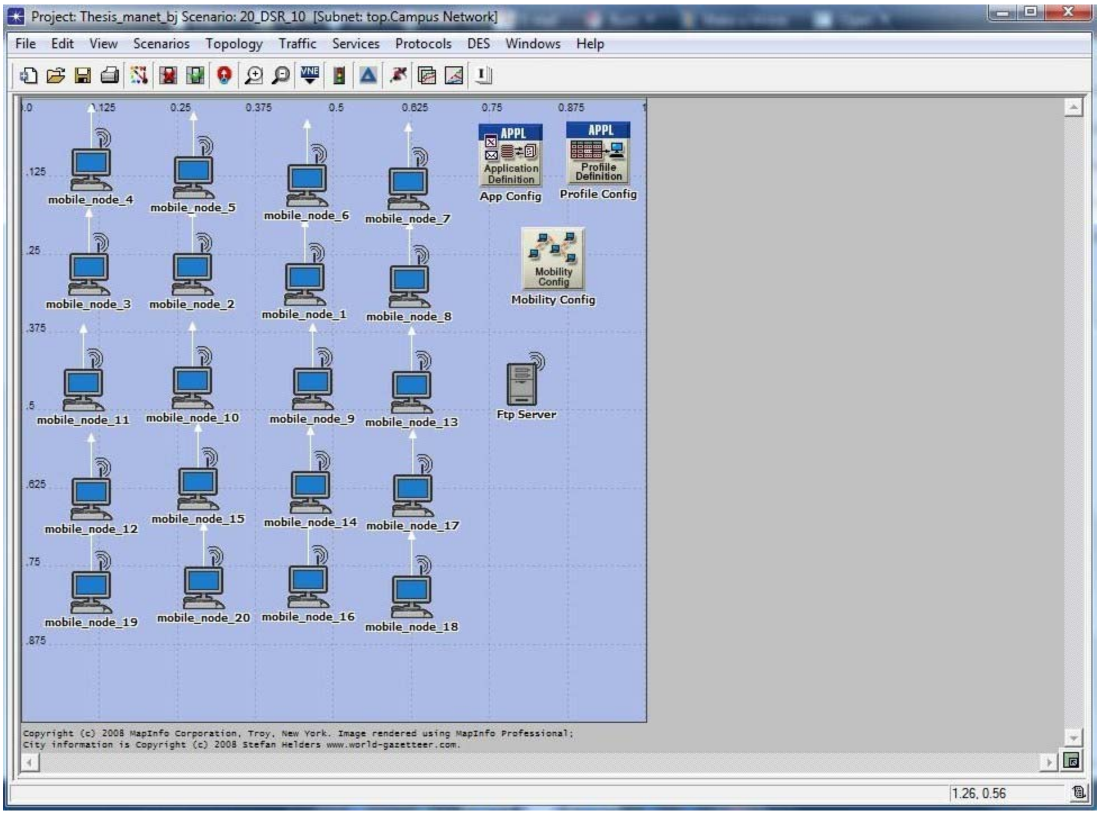

Fig. 8 Simulation setup

- Category II – Light load and high speed, comprising 5 nodes moving at a constant speed of 28 m/s
- Category III – Medium load and medium speed, comprising 20 nodes moving at a constant speed of 10 m/s
- Category IV – Medium load and high speed, comprising 20 nodes moving at a constant speed of 28 m/s
- Category V – Heavy load and medium speed, comprising 50 nodes moving at a constant speed of 10 m/s
- Category VI – Heavy load and high speed, comprising 50 nodes moving at a constant speed of 28 m/s

Twenty-four scenarios were simulated and we ran simulations for each scenario at 3,600s (simulation time). Simulations were performed repeatedly to verify the reliability of our results. The results of the repeated simulations are however not part of this report as the simulations showed consistency in the overall performance. Under each category, we simulated the behaviour of TORA, AODV, OLSR and

AODV. Our goal was to model the behaviour of the routing protocols under varying network loads and speeds. We collected global discrete event statistics (DES) on each protocol and wireless LAN. We therefore examined average statistics of the throughput, delay, packet delivery ratio and routing overhead for the entire MANET.

We modelled a campus network with an area of dimensions 1 km x 1 km. The mobile nodes and the server were spread randomly within the geographic area. In the simulations, the mobile nodes received traffic from a common source. Most comparison studies have used constant bit rate sources [3]. In this project, we used TCP traffic to study the effects of the ad hoc protocols. This will enable an evaluation of the performance of the protocols in TCP based applications such as web and file transfer. We configured one profile with heavy FTP application for our study. The nodes were WLAN mobile clients with a data rate set at 11 Mbps operating with a default power of 0.005 watts. The destination was a WLAN server also with a data rate of 11 Mbps and transmitting with 0.005 watts power.

We used the random waypoint mobility model commonly used in simulations. It is a simple and widely accepted mobility model to depict more realistic mobility behaviour [17]. The nodes move at a constant speed of 10 m/s or 28 m/s. When the node reaches its destination, it pauses for 300 seconds and then chooses a new random destination.

Chapter 5

5 Results and Analysis

In this chapter, we discuss and analyse the results of our simulations. We begin our discussion by analysing the routing overhead of the network. We then analyse the packet delivery ratio, packet end-to-end delay and lastly the throughput of the network. We defined these parameters in section 4.1 of this report. We collected global statistics for the entire network and present average values in this report.

We were not able to collect statistics for TORA with higher traffic sources, i.e. 50 nodes. TORA performs well with a gradual injection of traffic as it has a problem of counting to infinity. In our simulations, all the traffic sources were active at the initial setup. This caused TORA to overrun the computer memory during the simulations.

5.1 Routing Overhead

5.1.1 Overall Routing Overhead Comparison

Considering the results in Figure 9 and Figure 10, we observe that OLSR sends the highest amount of routing traffic into the network followed by TORA. Following TORA is AODV and lastly DSR with the least amount of routing traffic sent. This observation is valid for all the scenarios considered, that is, a combination of 5, 20 and 50 traffic sources moving at constant speeds of 10 m/s and 28 m/s. Therefore, in terms of routing overhead, DSR outperforms AODV, TORA and OLSR as it sends the least amount of routing traffic into the network. In low resource networks, DSR would therefore perform better than the other protocols considered.

The superiority of DSR comes from the nature of its routing operation. As a reactive protocol, DSR sends routing traffic into the network only when the source has data to send thus eliminating the overhead due to unnecessary routing traffic. DSR uses source routing in its operation thereby making the source aware of the entire path the packets will flow. All intermediate nodes use cached information to relay traffic and do not send replies during route discovery. Only the destination node sends the replies to route requests. The presence of multiple routes in DSR reduces the number of route discoveries in case of link failure. These factors coupled with the absence of periodic updates in DSR, has the net effect of reducing the amount of routing traffic.

The routing overhead in AODV is slightly higher than in DSR despite both being reactive protocols. In AODV, every intermediate node sends route request replies to the source. Control overhead increases due to the multiple route replies to single route request packets. Furthermore, when a single node in the path fails, a route error message propagates to all its neighbours due to the absence of multiple paths to use as alternative routes for the traffic. This initiates a full-scale route rediscovery process thus increasing the routing overhead. TORA ranks third in the scenarios considered. The link status sensing mechanism of IMEP including the periodic beacon or HELLO packets, account for much of the routing overhead in TORA.

The worst performance in terms of routing overhead comes from OLSR. OLSR is a proactive routing protocol and as such constantly floods the network with control and routing traffic to keep its routing tables up to date. This accounts for the huge overhead in OLSR.

5.1.2 Network Load and Mobility Effects on Individual Protocols

In Figure 9 and Figure 10, we present the comparison of the performance of the individual routing protocols at various network loads and speed. Figure 9 shows the graphs for DSR and AODV while Figure 10 shows the graphs for TORA and OLSR.

5.1.2.1 Number of traffic sources and mobility effects on DSR

In Figure 9, we observe that with 5 and 20 nodes, mobility has no effect on the amount of routing traffic. In the network comprising 50 nodes, the routing overhead is consistent at the speed of 28 m/s whilst it is initially low at speeds of 10 m/s and increases as the simulation progresses. High mobility implies that there are frequent link breakages causing DSR to react more frequently, the effect of which is more pronounced as the nodes begin to pause and restart travelling after an initial period of relative stability.

5.1.2.2 Number of traffic sources and mobility effects on AODV

In Figure 9, we observe that with five and twenty nodes, mobility has no pronounced effect on the amount of routing traffic in AODV. In the network comprising fifty nodes, the routing overhead is consistent at the speed of 10 m/s whilst it is initially low at speeds of 28 m/s and increases as the simulation progresses. The routing protocols are able to adjust to the changes in the nodes pausing and restarting at low speeds whereas at high speeds, they take time to adjust and thus send traffic to stale routes. As in DSR, high mobility implies that there are frequent link failures causing AODV to react more frequently, the effect of which is more pronounced as the nodes begin to pause and restart travelling after an initial period of relative stability.

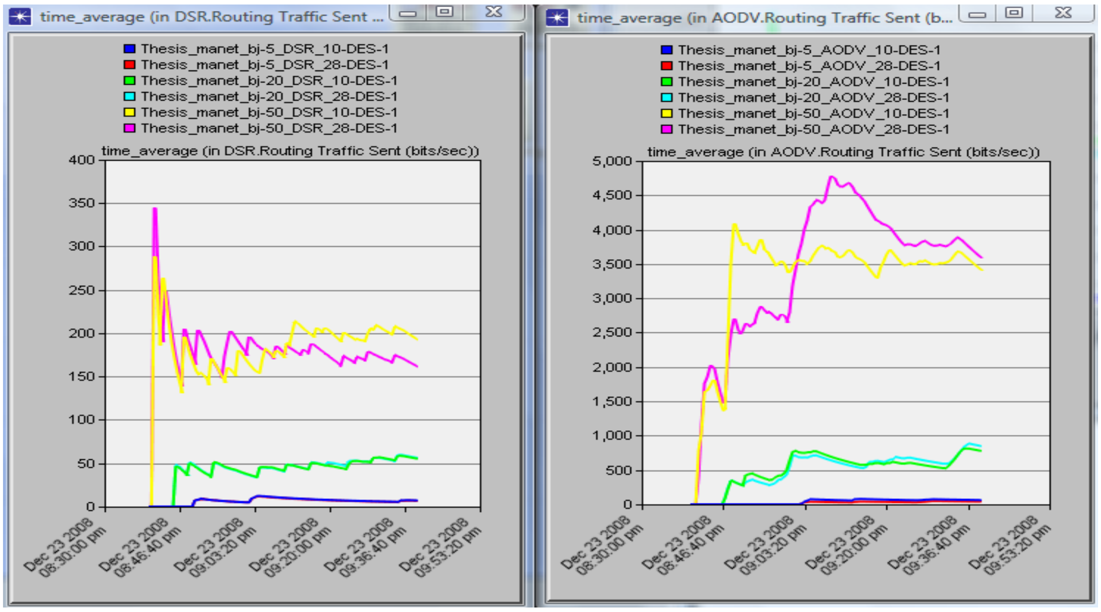

Fig. 9 Routing overhead in DSR and AODV

5.1.2.3 Number of traffic sources and mobility effects on TORA

Refer to Figure 10 for the comparison of TORA's performance at various network conditions. In the scenario with five traffic sources, we observe that increasing the speed form 10 m/s to 28 m/s does not have an effect on the amount of routing overhead in TORA. On the other hand, with twenty traffic sources, we observe that the routing overhead is lower at the higher speed of 28 m/s as compared to when the nodes are moving at 10 m/s. We can therefore conclude that in networks with large traffic sources, TORA performs better at higher than at lower mobility. The spikes at the beginning of the simulations confirm the problems associated with TORA when a lot of traffic is injected into the network at initial setup. The routing overhead increases with the increase in the number of nodes. This is an expected behaviour as more routes are injected into the network due to the increase in sources.

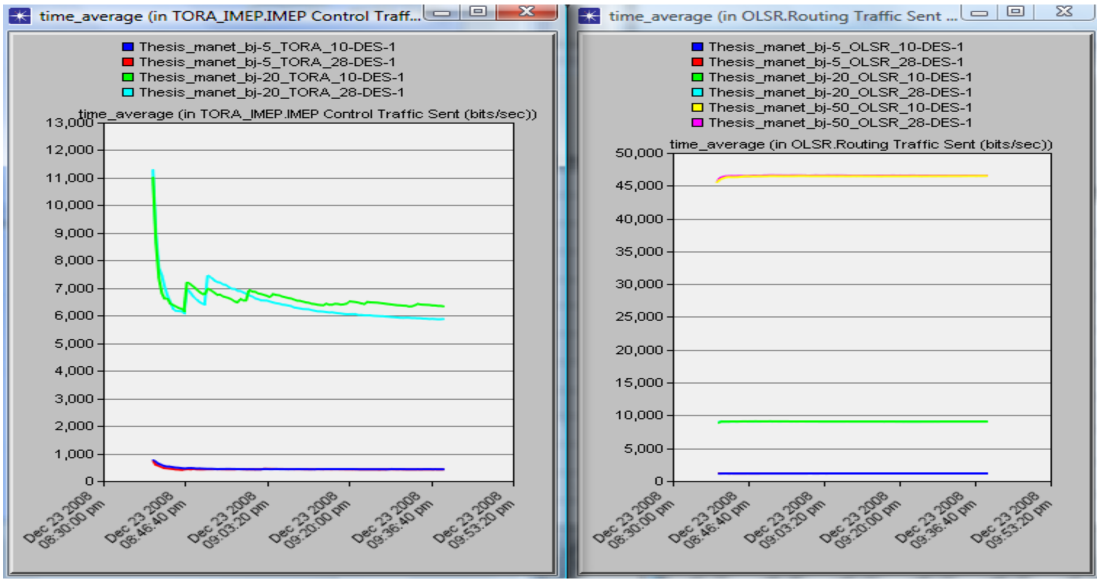

Fig. 10 Routing overhead in TORA and OLSR

5.1.2.4 Number of traffic sources and mobility effects on OLSR

Figure 10 above shows the simulations for OLSR at various network conditions. We observe that increasing the mobility has no effects on the amount of routing traffic injected into the network. The consistency in the routing overhead in OLSR is due to consistent paths it maintains owing to its proactive nature. Increasing the number of nodes has the expected effect of increasing the amount of routing traffic.

5.2 Packet Delivery Ratio

Figure 11and Figure 12 show the packet delivery ratios of the protocols at the speeds of 10 m/s and 28 m/s respectively. We observe low packet delivery ratios for all the protocols in the scenarios considered. The protocols exhibited packet delivery ratios of less than 50% except for TORA at five nodes and speed of 10 m/s. The major cause of the low packet delivery ratios exhibited is due to the use of TCP traffic. Most comparisons on the performance of ad hoc routing protocols use constant bit rate sources. TCP suffers massive degradation in its performance in ad hoc networks because of rampant retransmissions. The unstable network connections due to mobility further enhances these. Another source of massive packet drops in TCP applications is the buffer sizes of the wireless LAN MAC layers. In arriving at these conclusions, we changed the traffic type from TCP (FTP) to UDP (Video Conferencing). We observed that with lower wireless LAN MAC layer buffer sizes, both traffic types suffered massive traffic drops with UDP marginally outperforming TCP. When we increased the buffer size, UDP consistently attained packet delivery ratios of above 90% whereas TCP attained ratios of below 50%. The non-suitability of TCP in ad hoc networks brings forth the need for modifications of these protocols or the LAN MAC layer to adapt to the behaviour of TCP.

TORA delivered the highest number of packets with low speed and low number of traffic sources. However, this rapidly degraded from about 60% to about 44% when the number of sources increased to 20. Statistics for 50 traffic sources were not available due to the traffic implosion problem TORA suffers. TORA had the least packet delivery ratio when the nodes had a speed of 28 m/s with low number of traffic source. This increased as the number of nodes increased to 20.

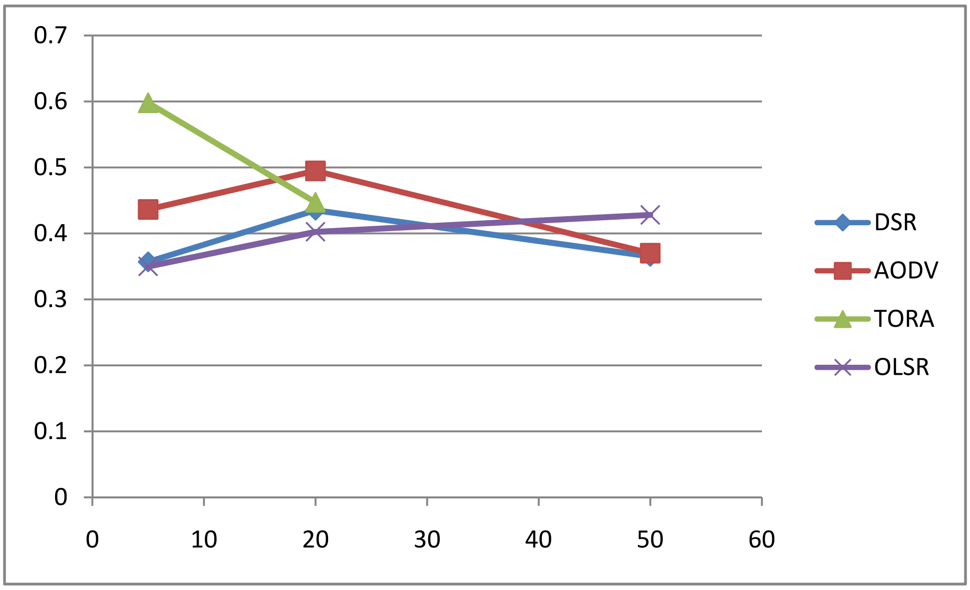

Fig. 11 Packet delivery ratios at 10 m/s

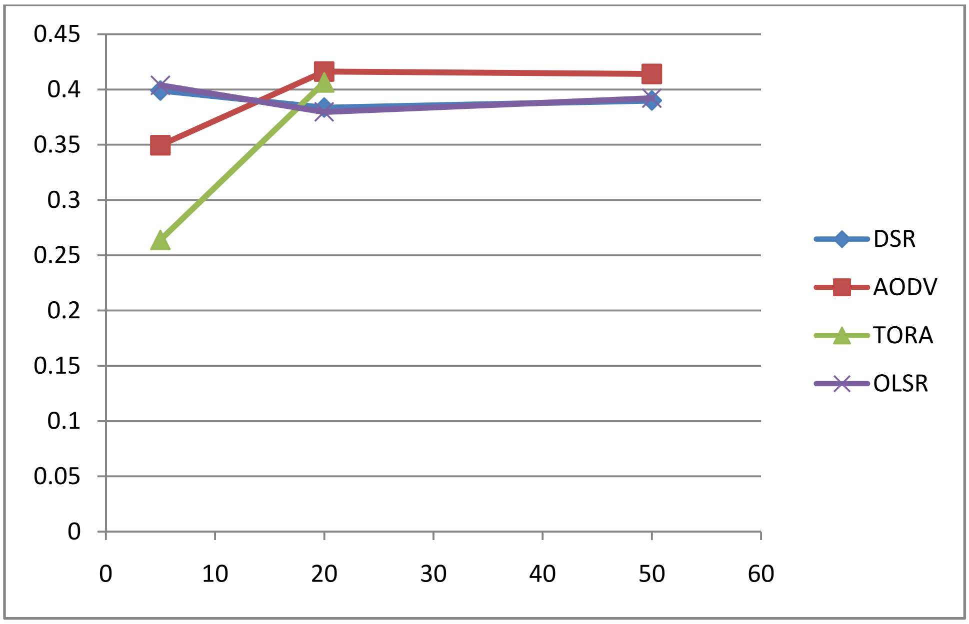

Fig. 12 Packet delivery ratios at 28 m/s

At low speeds, AODV outperformed both DSR and OLSR in the networks with 5 and 20 traffic sources. When the traffic sources increased to 50, the packet delivery ratio for AODV degraded significantly and was comparable to that of DSR. OLSR at this stage outperformed all the other protocols. We can attribute the improvement in the performance of OLSR in networks with higher number of traffic sources to its proactive nature.

AODV outperformed OLSR and DSR in the larger network when the nodes were moving at 28 m/s. In the smaller network of five nodes, DSR and OLSR outperformed AODV.

5.3 Packet End-to-End Delay

Figure 13 to Figure 15 show the average packet end-to-end delay characteristics of the protocols.

In all scenarios considered, we observe that OLSR has the lowest delay. OLSR is a proactive routing protocol, which means that routes in the network are always ready whenever the application layer has traffic to transmit. Periodic routing updates keep fresh routes available for use. The absence of high latency induced by the route discovery processes in OLSR explains its relatively low delay. With higher number of mobile nodes, the performance of OLSR competes with that of AODV. In the networks considered, OLSR had a consistent end-to-end delay due to its proactive characteristics.

In smaller networks with five traffic sources, we observe that TORA outperforms DSR by ratios of 1:3 at both low and high speeds. On the other hand, TORA competes with AODV at low speeds and is superior at high speeds. It has a consistent delay and outperforms AODV at higher speeds due to the performance degradation in AODV. When the number of nodes increased to 20, TORA suffers a significant degradation in its end-to-end delay. One reason for the degradation in the end-to-end delay of TORA at higher number of nodes is attributed to its route discovery process.

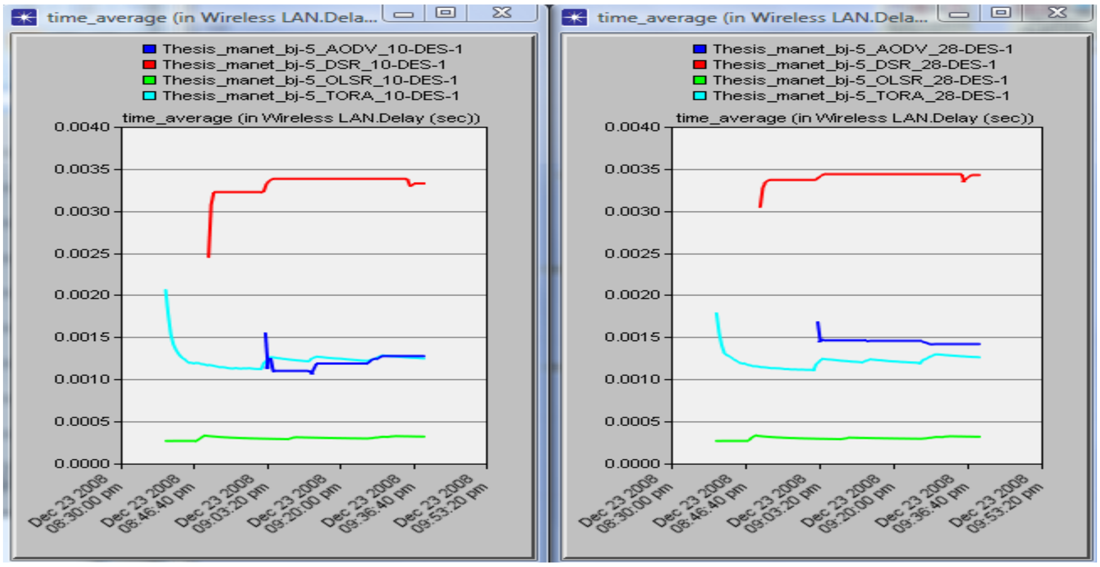

Fig. 13 End-to-end delay – 5 sources at 10m/s and 28m/s

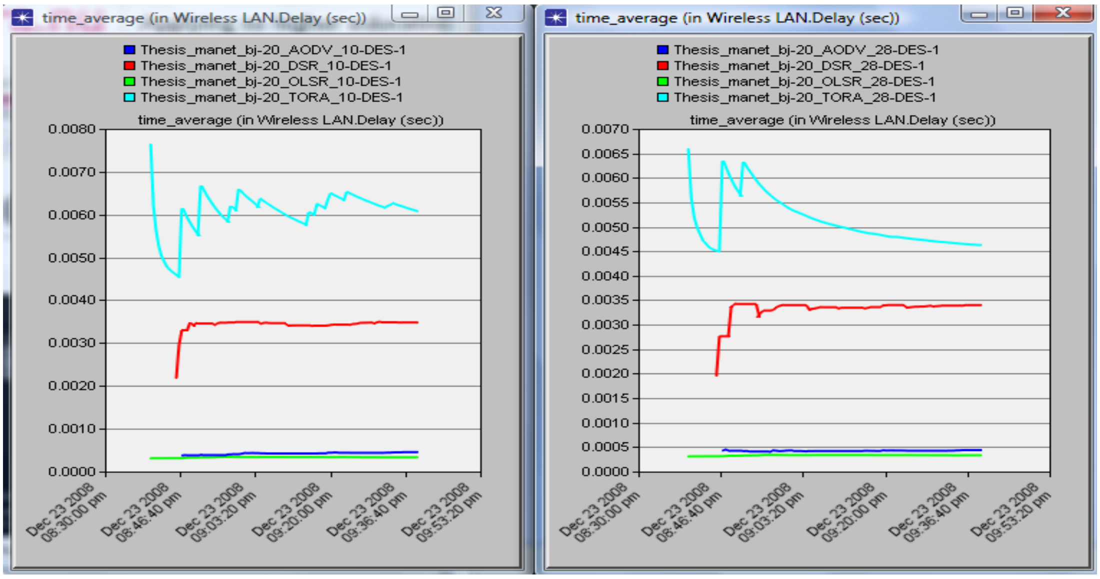

Fig. 14 End-to-end delay – 20 sources at 10m/s and 28m/s

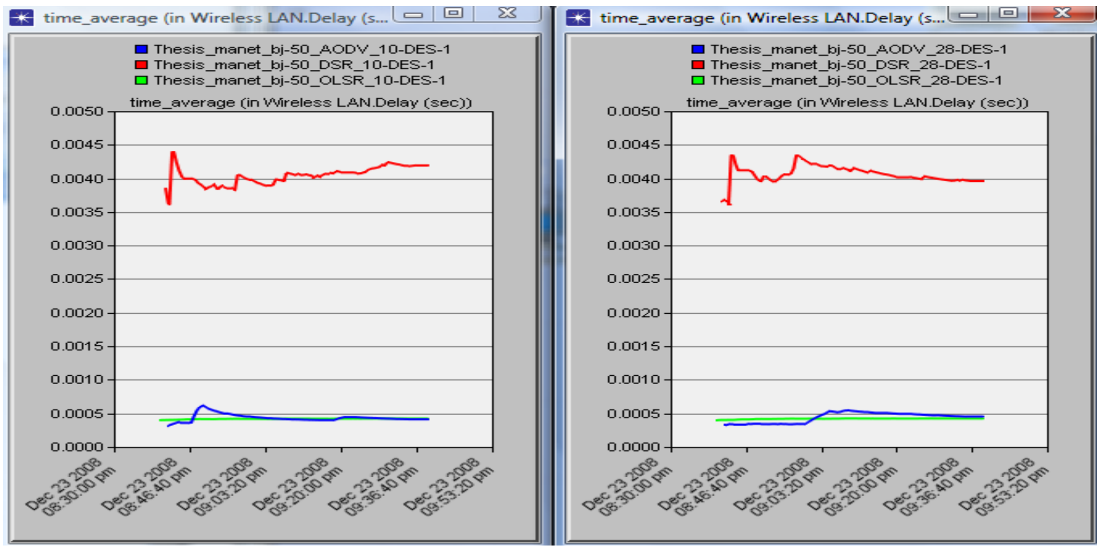

Fig. 15 End-to-end delay – 50 sources at 10m/s and 28m/s

AODV also has a very low end-to-end delay and comes second to OLSR. This is observed in all the scenarios considered except in the case of lower number of nodes and high speed where TORA outperforms it. However, we observe that the performance of AODV improves with the increase in the number of sources. The hop-by-hop initiation in AODV helps reduce the end-to-end delay.

DSR shows a more consistent end-to-end delay both at low and high speeds in networks with five and twenty nodes. With the network comprising fifty traffic sources, the end-to-end delay of DSR increases both at low and high speeds. DSR uses cached routes and more often, it sends traffic onto stale routes, which may cause retransmissions and leads to excessive delays. Thus, in networks with high traffic sources, the increase in the number of cached routes worsens the delay. On the other hand, DSR tries to minimise the effect of stale routes by use of multiple paths.

To conclude on this sub-section, we briefly recall our findings. We have observed that OLSR exhibited very low delay in all scenarios. TORA had high delay in the high traffic network, and mobility did not have an effect on the delay. AODV had an improved end-to-end delay as the network grew whereas the speed did not have a noticeable effect on delay, and lastly DSR had a consistent end-to-end delay and suffered more delay as the network grew larger but speed did not have profound effects on the performance. The three reactive protocols exhibited high delays at higher loads due to the increase in route discovery requests.

5.4 Throughput

Figure 16 to Figure 18 show the performance of the protocols in different scenarios. We observe that OLSR by far outperforms all the other protocols in all the scenarios considered. As OLSR is a proactive routing protocol, paths are readily available for traffic. OLSR maintains consistent paths in the network causing a low delay. Since throughput is the ratio of the total amount of data that a receiver receives from the sender to the time it takes for the receiver to get the last packet, a low delay in the network translates into higher throughput.

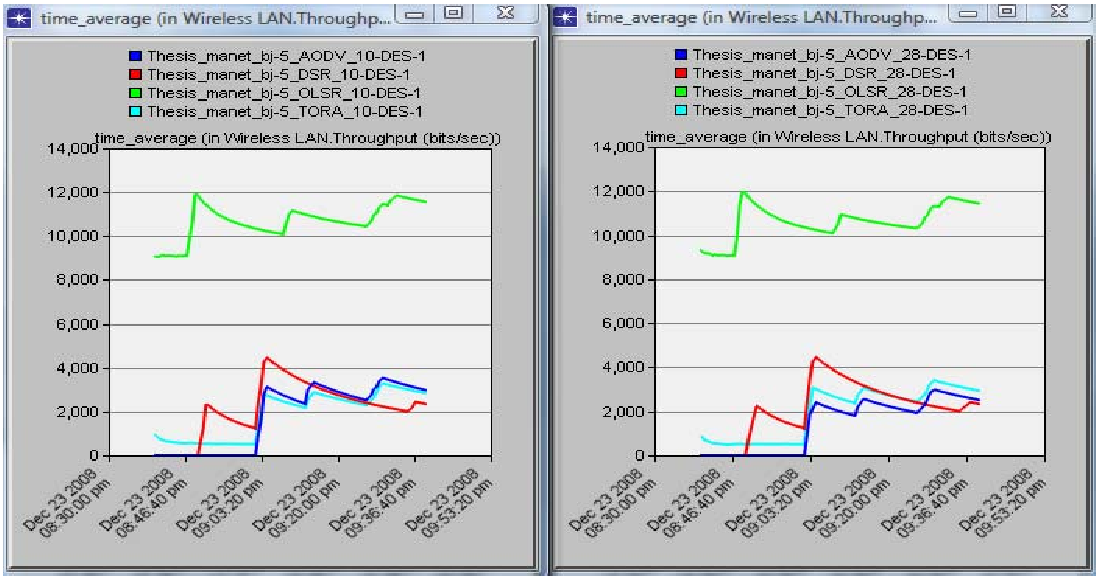

Fig. 16 Throughput – 5 sources at 10m/s and 28m/s

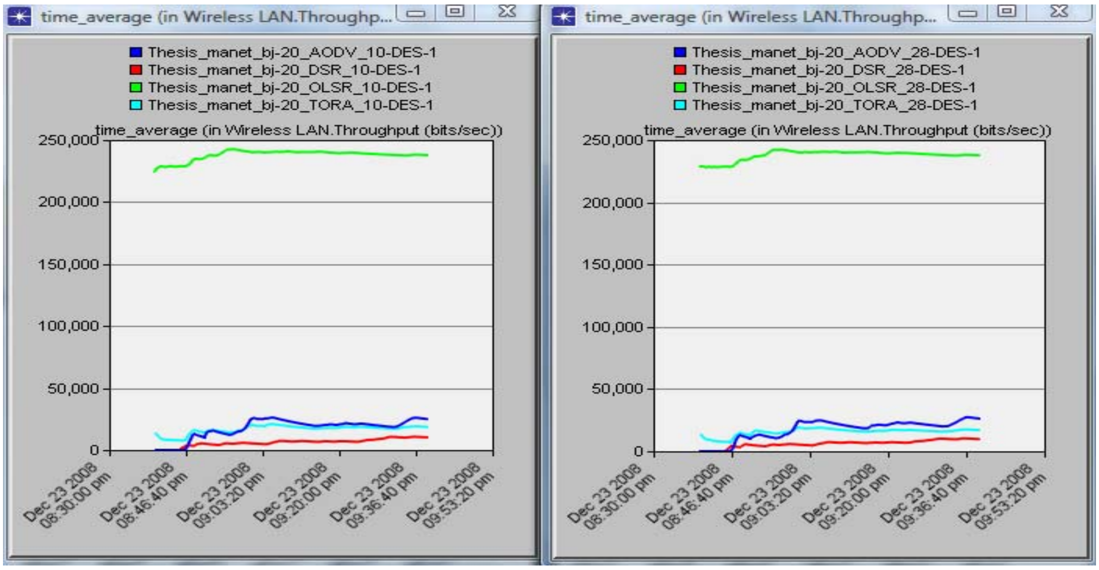

Fig. 17 Throughput – 20 sources at 10m/s and 28m/s

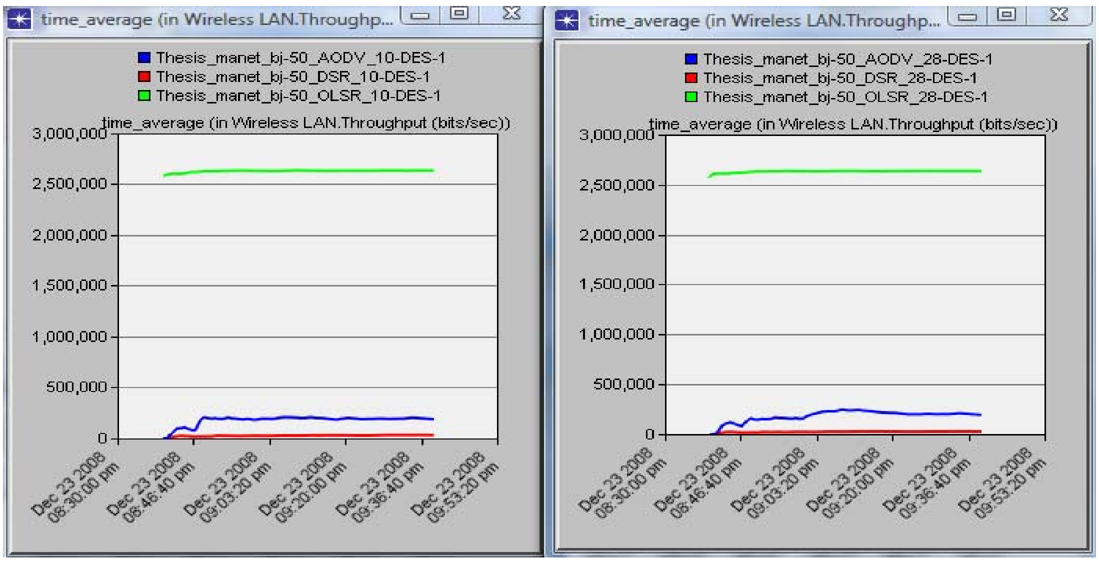

Fig. 18 Throughput – 50 sources at 10m/s and 28m/s

In the network with five traffic sources, DSR marginally outperformed TORA and AODV at 10 m/s and 20 m/s speeds despite having higher delay. Refer to Figure 16. This deviation can be explained by observing the routing overhead. DSR has the least amount of routing overhead. Since the network is small, the prevalence of link failures and other factors such as the hidden terminal problem and congestion do not come much into play. Therefore, throughput is more a factor of routing traffic than delay at low network loads.

As the number of traffic sources is increased, problems of congestion, hidden terminal and network degradation come more into effect. These problems cause the protocols to start reacting differently to the varying conditions and delay becomes an important factor in determining the network throughput. Refer to Figure 17 and Figure 18. We observe that the performance of DSR degrades in the networks with 20 and 50 nodes. From these observations, we can conclude that DSR outperforms AODV and TORA in smaller networks both in low and high-speed scenarios. The opposite holds true for AODV. It outperforms DSR as the network grows. The throughput performance of TORA at high network load cannot be conclusive as there was no data available for comparison.

When we compare the performance of individual protocols under varying speeds and network loads, we observe no effect of speed on the performance of DSR in the network with five nodes. On the other hand, we observe marginal deviations at higher speeds with DSR performing slightly better at lower speed than at higher speed.

AODV had a higher throughput when the nodes were moving at lower speed in the network with a small number of nodes, whereas it had higher throughput at higher speed in the larger networks. It is concluded from the observations that AODV performs better in networks with relatively high number of traffic sources and higher mobility.

OLSR had a consistent throughput at both speeds. As described in section 5.1 and 5.3 of this report, OLSR being a proactive protocol has consistent routing overhead and delay. Since throughput is a function of both the delay and routing traffic, a consistent throughput was expected. This demonstrates the overall superiority of OLSR. It should however be noted that as the network grows bigger, the routing tables in OLSR may grow too large and coupled with congestion and other problems in wireless networks, the advantage in OLSR may lead to an overall degradation in performance.

Chapter 6

6 Conclusions

In this report, we have evaluated four different ad hoc routing protocols with respect to their routing overhead, packet delivery ratio, throughput and packet end-to-end delay. These performance metrics used in our evaluation represent two aspects of performance in a network. Throughput, packet end-to-end delay and packet delivery ratio addresses the reliability of the protocols. Routing overhead addresses the efficient use of network resources by the protocols. In a network, it is desirable for the protocol to be both efficient and reliable.

In this research, we used TCP (FTP) traffic with all the sources sending traffic to a common destination. Due to the use of TCP, the packet delivery ratios for all the protocols in the scenarios considered was about 50%. This demonstrated the non-suitability of using TCP with the current ad hoc routing protocols. Use of UDP traffic would result in higher packet delivery ratios.

OLSR outperforms AODV, TORA and DSR in the throughput and packet end-to-end delay performance metrics used in this research. It also outperforms all the other protocols in the packet delivery ratio when deployed in low mobility and high load networks. OLSR has the worst performance in the routing overhead. It is therefore well suited for high capacity networks. The high routing traffic in OLSR used to discover and maintain routes makes it unsuitable for low capacity networks.

One can almost be certain that DSR is an exact opposite of OLSR because of its ability to perform well in situations where OLSR does not, except in the packet delivery ratio where they had the same performance. DSR outperforms OLSR in routing overhead but it is outperformed in all other aspects that favour the use of OLSR. For example, DSR is the best candidate in low capacity links. However, it has high routing overhead in long paths since the packet traversing the network records in its header the IP addresses of all the devices in the route it uses. Therefore, the use of DSR in networks with IPv6 addressing would result in high routing overhead.

AODV outperforms DSR and OLSR in low and medium load networks with low node speeds. It also outperforms DSR and OLSR at high-speed mobility under medium and heavy network conditions. In these comparisons, TORA does not offer an overall superiority except in low load networks with low-speed mobility where it had the highest packet delivery ratio.

From this study, we conclude that among the protocols considered, there is no single one with an overall superior performance. One protocol may be superior in terms of routing overhead whilst others may be superior in terms of packet delivery ratio, packet end-to-end delay or throughput. The choice of a particular routing protocol will depend on the intended use of the network.

Factors considered in this research affecting the performance of ad hoc protocols are speed and network load. Network load has a profound effect on the performance whereas speed affects the performance only in some instances.

Finally, whether a routing protocol is proactive or reactive has profound effects on how the performance of the protocols in various scenarios. Major differences in the way route discovery and route maintenance is achieved in the protocols largely dictate their behaviour. Generally, proactive protocols perform well in high capacity links whereas reactive protocols perform better in low capacity networks.

Chapter 7

7 Future Work

Future works will be to evaluate the performance of existing ad hoc routing protocols and those protocols specifically designed in the IEEE 802.16 standard in Mobile WiMAX. Mobility in WiMAX is a feature that was developed as an addition to the original IEEE 802.16 standard for WiMAX; therefore, it would be good to provide all necessary information to prospective users and hardware manufacturers about the pros and cons of the already developed standards in this area. In this research, we have seen that varying speeds does not degrade the performance of the evaluated protocols in MANETs. This shows that MANET provides the intended solution to the need for mobility by wireless nodes. A performance comparison of ad hoc routing protocols in MANETs and in mobile WiMAX would help ascertain how well mobile WiMAX has addressed the mobility problem.

The other alternative direction of this research will explore the feasibility of developing a new algorithm that will address the limitations that the ad hoc routing protocols evaluated in this research pose. For example, OLSR is superior to the other routing protocols in many aspects such as end-to-end latency but it has problems of flooding the network with routing traffic for discovery and maintenance even when a link is not in use. It is good in high bandwidth links. For instance, it outperforms DSR in high capacity links however, it is prone to network clogs in low capacity links. A new algorithm will strive to strike a balance between these discrepancies.

Appendix A – Simulation Procedure

Appendix A – Simulation Procedure

This appendix provides a systematic guide for the procedure followed in this study for those who would like to follow and repeat the experiments. There are six categories for the simulations. Each category contains four simulations, one for each of the four ad hoc protocols under consideration namely AODV, OLSR, DSR and TORA.

CATEGORY	Number of Nodes	Node Speed (m/s)
I	5	10
II	5	28
III	20	10
IV	20	28
V	50	10
VI	50	28

TABLE. 1 Simulation Categories

A. Step by step procedure

This procedure defines setting up the topology used in the simulations.

- Create a Campus network of size 1000 m x 1000 m
- Open the MANET object palette
- Drag the wlan_server (fixed node) onto the workspace
- Drag the wlan_wkstn (mobile node) onto the workspace and duplicate them to the required number according to the schedule in Table A1 above
- Click Edit → select all in subnet
- Click Protocol → IP → Addressing → Auto-assign IPv4 addresses
- Whilst all nodes are selected right click and select edit attributes
- Expand AD HOC Protocols and choose the appropriate protocol
- Tick apply to selected objects and click OK

- Save

B. Application Configuration

This procedure defines the configuration steps for setting up the application that will be deployed in the profile configuration.

- Drag the application config object from the MANET object palette onto the workspace and name it appropriately
- Right click and go to edit attributes
- Expand application definitions and enter the number of rows (1)
- Click on the row and enter the name (FTP)
- Under description choose Ftp, High load and click OK. This sets the application to model the high load FTP traffic.

C. Profile Configuration

This procedure defines the configuration of the profiles to be deployed in the MANET.

- Drag the Profile Config object from the MANET object palette onto the workspace and name it appropriately
- Right click and go to edit attributes
- Expand profile configuration and enter the number of rows (1)
- Enter the profile name
- Under applications enter the number of rows (1) and choose FTP
- Under FTP set the start time offset (seconds) to constant (0) and duration (seconds) to constant (10). This sets the time from the start of the profile to start of the application.
- Under FTP repeatability set inter-repetition time (seconds) to uniform (10, 20) and number of repetitions to constant (3). This defines when the next session of the application will start and the distribution name and parameters used for generating random session counts respectively.
- Set the start time (seconds) to uniform (100, 3400) and duration to end of simulation. This defines at what instance the profile will start from the beginning of the simulation.

- Leave repeatability at default of constant (300) for inter-repetition time and constant (0) for number of repetitions.
- Click OK

D. Deploying Traffic

To deploy the configured profile to the network, follow the following procedure.

- Protocol → Applications →Deploy Defined
- Select all mobile nodes and transfer to sources under your profile
- Select the server and transfer to server under application: FTP
- Click apply and then OK to complete the deployment

E. Mobility Configuration

Mobility Configuration defines the mobility pattern and model that the nodes will follow during the simulation. We use the random waypoint mobility model for our simulations.

- Drag the mobility config from the MANET object palette onto the workspace and name it appropriately
- Right click and edit attributes
- Expand default random waypoint
- Under random waypoint parameters set speed (meters/seconds) to constant (10). This sets the speed at which the mobile node will be moving.
- Set pause time (seconds) to constant (300). This sets the duration of the pause time for the mobile stations before changing direction to the new destination during the simulation.
- Set start time (seconds) to constant (0)
- Leave the rest as default and click OK
- To deploy the mobility profile to the MANET, Select Topology →Random Mobility→Set mobility profile
- Enter the default random waypoint profile and click OK

F. Collect Statistics

The following procedure should be followed to collect global statistics for all the nodes in the MANET.

- In the workspace, right click and choose “choose individual DES statistics”
- Expand global statistics and choose AODV, TORA_IMEP, DSR and wireless LAN
- Click OK and save

G. Duplicate Scenario

This procedure duplicates the entire scenarios to be used for comparison evaluation. Sixteen scenarios will be duplicated.

- Scenarios → Duplicate scenarios
- Enter the name of the new scenario
- Change the number of mobile nodes, AD HOC protocol and speed as appropriate according to the table above
- Save.
- Repeat the procedure for all the protocols in each category.

H. Running Simulation

- Scenarios → Manage Scenarios
- Click collect under results for all the scenarios
- Enter the appropriate sim duration for all scenarios
- Click on OK to run the simulations

I. Viewing Results

- Des → Results → Compare Results
- Select the scenarios for which you want to compare the results
- Under Global statistics, select the appropriate statistics you want to view.

Appendix B – System Requirements

Appendix B – OPNET Modeler 14.5 System Requirements

A number of Operating Systems support OPNET Modeler 14.5. Different platforms have specific requirements; they differ from one vendor to the other, as shown in, TABLE. 2, TABLE. 3 and TABLE. 4 below.

Supported Platforms

Vendor	OS	Processor
Microsoft	Windows Vista Business Windows Vista Business x64 Edition Windows 2000 Professional Windows XP Professional Windows XP Professional x64 Windows 2000 Server Windows Server 2003 Windows Server 2003 x64 Edition	x86 or EM64T (Intel Pentium III, 4, Xeon, or compatible), 1.5 GHz or better x86 AMD or AMD64, 1.5 GHz or better
Red Hat	Red Hat Enterprise Linux 3 (v2.4 Linux kernel) Red Hat Enterprise Linux 4 (v2.6 Linux kernel)	x86 or EM64T (Intel Pentium III, 4, Xeon, or compatible), 500 MHz or better
Fedora Project	Fedora Linux 3 (v2.4 Linux kernel) Fedora Linux 4 (v2.6 Linux kernel)	x86 AMD or AMD64, 500 MHz or better

TABLE. 2 OPNET Modeler Supported Platforms

- Source: OPNET Technologies [18].

Required System Patches

Vendor	OS Version	Patch Number/Name
Microsoft	Windows Vista Business	Requirement: Service Pack 1
	Windows 2000 Professional	Supports Service Packs 1, 2, and 4 but it is not required.
	Windows XP Professional	Requirement: Service Pack 1 Supported: Service Pack 2 and 3

TABLE. 3 OPNET Modeler System Patches

- Source: OPNET Technologies [18].

Hardware Requirements

RAM

512 MB required although 1 to 2 GB of RAM is recommended. Memory requirements vary depending on the size of the network and traffic demands.

System File Space

A minimum of 3 GB of hard disk space is needed. However, an addition of up to 2 GB of free disk space is required at installation

Working File Space

A minimum of 100 MB or more is required for log files

Monitor Resolution: 1024x768 minimum

Supporting software

OS	Compiler
Linux	gcc 3.4 or higher
Windows 2000, XP, Vista	Microsoft Visual Studio .NET 2002, Microsoft Visual C/C++ 6.x, Microsoft Visual Studio .NET 2003, Microsoft Visual Studio 2005, Microsoft Visual C++ 2008 Express Edition, or Microsoft Visual Studio 2008.

TABLE. 4 Supporting Software for OPNET Modeler 14.5

- Source: OPNET Technologies [18]

Browser

Any browser that supports style sheets is recommended. Mozilla Firefox 1.0.6 and Microsoft Internet Explorer 5.0 or higher are mostly used.

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References

References

[1] R. Misra and C.R. Mandal, "Performance comparison of AODV/DSR on-demand routing protocols for ad hoc networks in constrained situation" *ICPWC International Conference, IEEE,* 2005, pp. 86 – 89

[2] http://www.opnet.com/, date last viewed: 2008-12-31

[3] Vahid Nazari Talooki and Koorush Ziarati, "Performance Comparison of Routing Protocols For Mobile Ad Hoc Networks" *Asia-Pacific Conference on Communications, APCC,* 2006, pp. 1 – 5

[4] Bertocchi, P. Bergamo, G. Mazzini and M. Zorzi, "*Performance Comparison of routing protocols for Ad hoc networks," IEEE Global Telecommunications Conference, GLOBECOM,* 2003, pp. 1033 – 1037

[5] Amr M. Hassan, Mohamed I. Youssef and Mohamed M. Zahra, "Evaluation of Ad Hoc Routing Protocols in Real Simulation Environments" *The 2006 International Conference on Computer Engineering and Systems*, 2006, pp. 288 – 293

[6] The GloMoSim Simulator, http://pcl.cs.ucla.edu/projects/glomosim/, last viewed: 2008-12-27

[7] http://www.ietf.org/rfc/rfc2501.txt. date last viewed: 2008-12-31

[8] D. Kiwior and L. Lam, "Routing Protocol Performance over Intermittent Links" *Military Communications Conference, MILCOM, IEEE*, 2007, pp. 1 – 8

[9] S. Demers and L. Kant, "MANETs: Performance Analysis and Management", *Military Communications Conference, MILCOM,* 2006, pp.1 – 7

[10] A. Zahary, A. Ayesh, "Analytical study to detect threshold number of efficient routes in multipath AODV extensions", *proceedings of International Conference of Computer Engineering & Systems, ICCES,* 2007, pp. 95 – 100

[11] Lijuan Cao, K. Sharif, Yu Wang, T. Dahlberg, "Adaptive Multiple Metrics Routing Protocols for Heterogeneous Multi-Hop Wireless Networks",

proceedings for 5th CCNC Consumer Communications and Networking Conference, IEEE, 2008, pp. 13 – 17

[12] Jin Mook Kim, In Sung Han, Jin Baek Kwon, Hwang Bin Ryou, "A Novel Approach to Search a Node in MANET", *Information Science and Security, ICISS,* 2008, pp. 44 – 48

[13] S. R. Chaudhry, A. Al-Khwildi, Y. Casey, H. Aldelou, "A Performance Comparison of Multi On- Demand Routing in Wireless Ad Hoc Networks", *Wireless Network and Communications Group (WNCG), School of Engineering & Design, Brunel University, West London*

[14] Mohammad Naserian, Kemal E. Tepe and Mohammed Tarique, "Routing overhead analysis for reactive routing protocols in wireless ad hoc networks," *IEEE Conference on Wireless And Mobile Computing, Networking And Communications, WiMob*, 2005, pp. 87 – 92

[15] Uyen Trang Nguyen and Xing Xiong, "Rate-adaptive Multicast in Mobile Ad hoc Networks," *IEEE International Conference on Ad hoc and Mobile Computing, Networking and Communications, WiMob,* Montreal, Canada, 2005

[16] OPNET Modeler 14.5 Documentation

[17] Rainer Baumann, Simon Heimlicher and Martin May, "Towards Realistic Mobility Models for Vehicular Ad hoc Networks," *2007 Mobile Networking for Vehicular Environments*, 2007, pp. 73 - 78

[18] http://www.opnet.com/solutions/system_requirements/modeler/index.html, date last updated: 2008-12-31