PERFORMANCE COMPARISON OF AODV AND DSR ROUTING PROTOCOLS IN MANETs

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

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in

Software Engineering

By

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Certificate

I hereby certify that the work which is being presented in the thesis entitled, **"Performance Comparison of AODV and DSR Routing Protocols in MANETs"**, in partial fulfillment of the requirements for the award of degree of Master of Engineering in Software Engineering submitted in Computer Science and Engineering Department of Thapar Institute of Engineering and Technology (Deemed University), Patiala, is an authentic record of my own work carried out under the supervision of Mr. Anil Kumar Verma.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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Abstract

An ad hoc network is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. A number of routing protocols like Dynamic Source Routing (DSR), Ad Hoc On-Demand Distance Vector Routing (AODV) and Destination-Sequenced Distance-Vector (DSDV) have been proposed.

In this work an attempt has been made to compare the performance of two prominent on-demand *reactive* routing protocols for mobile ad hoc networks: DSR and AODV. A simulation model with MAC and physical layer models is used to study interlayer interactions and their performance implications. Although DSR and AODV share similar on-demand behavior, the differences in the protocol mechanics can lead to significant performance differentials.

The performance differentials are analyzed using varying network load, mobility, and network size. These simulations are carried out using the ns-2 network simulator, which is used to run ad hoc simulations. The results presented in this thesis illustrate the importance in carefully evaluating and implementing routing protocols when evaluating an ad hoc network protocol.

Keywords: DSR, AODV, DSDV, MAC, Simulation

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Chapter 1

INTRODUCTION

1.1 Background

Wireless communication[1][2] between mobile users is becoming more popular than ever before. This is due to recent technological advances in laptop computers and wireless data communication devices, such as wireless modems and wireless LANs[3]. This has lead to lower prices and higher data rates, which are the two main reasons why mobile computing continues to enjoy rapid growth.

There are two distinct approaches for enabling wireless communication between two hosts. The first approach is to let the existing cellular network infrastructure carry data as well as voice. The major problems include the problem of handoff, which tries to handle the situation when a connection should be smoothly handed over from one base station to another base station without noticeable delay or packet loss. Another problem is that networks based on the cellular infrastructure are limited to places where there exists such a cellular network infrastructure.

The second approach is to form an ad-hoc network among all users wanting to communicate with each other. This means that all users participating in the ad-hoc network must be willing to forward data packets to make sure that the packets are delivered fro m source to destination. This form of networking is limited in range by the individual nodes transmission ranges and is typically smaller compared to the range of cellular systems. This does not mean that the cellular approach is better than the ad-hoc approach. Ad-hoc networks[4] have several advantages compared to traditional cellular systems. These advantages include:

- On demand setup
- Fault tolerance
- Unconstrained connectivity

Ad-hoc networks[4][5][6] do not rely on any pre-established infrastructure and can therefore be deployed in places with no infrastructure. This is useful in disaster recovery situations and places with no n-existing or damaged communication infrastructure where rapid deployment of a communication network is needed. Ad- hoc networks can also be useful on conferences where people participating in the conference can form a temporary network without engaging the services of any pre-existing network[4].

As the nodes are forwarding packets for each other, some sort of routing protocol is necessary to make the routing decisions. Currently, there does not exist any standard for a routing protocol for ad-hoc networks, instead this is work in progress. Many problems remain to be solved before any standard can be determined. This thesis looks at some of these problems and tries to evaluate some of the currently proposed protocols.

1.2 Problem description

The objective of this thesis is to evaluate two of the proposed routing protocols[7][8][9], namely, AODV and DSR, for wireless ad-hoc networks based on performance. This evaluation should be done theoretically and through simulation[10][11][12]. The thesis also included the goal to generate a simulation environment[11][12] that could be used as a platform for further studies within the area of ad-hoc networks.

The goal of this thesis is to:

- Get a general understanding of ad -hoc networks.
- Generate a simulation environment that could be used for further studies.
- Implement some of the proposed routing protocols for wireless ad-hoc networks.
- Analyze the protocols theoretically and through simulation.
- Produce a classification of the protocols with respect to applicability in combinations of small/large networks, and mobile/semi-mobile nodes.
- Recommend protocols for specific network scenarios.

1.3 Related work

Many routing protocols have been proposed, but few comparisons between the different protocols have been made. Of the work that has been done in this field, only the work done by the Monarch1 project at Carnegie Mellon University (CMU)[13] has compared some of the different proposed routing protocols and evaluated them based on the same quantitative metrics. The result was presented in the article -“A performance comparison of multi-hop ad hoc wireless network routing protocols”[14] that was released in the beginning of October 1998. There exists some other simulation results that have been done on individual protocols. These simulations have however not used the same metrics and are therefore not comparable with each other.

1.4 Disposition

This thesis consists of 7 chapters and two appendices. Chapters 1 and 2 explain the concept of ad-hoc networks and routing in general. Chapter 3 describes the different routing protocols, analyze and compare (AODV and DSR). Chapters 4 describe the simulator and the scenarios that were considered. Chapters 5 describe results and finally Chapter 6 and 7 concludes the report by describing various observations and scope of future work. The appendices contain some terminology and abbreviations used in this work.

Chapter 2

BACKGROUND AND GENERAL CONCEPTS

The tremendous growth of personal computers and the handy usage of mobile computers necessitate the need to sharing of information between computers. At present this sharing of information is difficult, as the users need to perform administrative tasks and set up static, bi-directional links between the computers. This motivates the construction of temporary networks with no wires and no communication infrastructure and no administrative intervention required. Such an interconnection between mobile computers is called an Ad Hoc network. In such an environment, it may be necessary for the mobile computers to take help of other computers in forwarding a packet to the destination due to the limited range of each Mobile host's wireless transmission

2.1 Wireless ad-hoc networks

2.1.1 General

A wireless ad-hoc network[15] is a collection of mobile/semi-mobile nodes with no pre-established infrastructure, forming a temporary network. Each of the nodes has a wireless interface[2] and communicate with each other over either radio or infrared. Laptop computers and personal digital assistants that communicate directly with each other are some examples of nodes in an ad-hoc network. Nodes in the ad-hoc network are often mobile, but can also consist of stationary nodes, such as access points to the Internet. Semi mobile nodes can be used to deploy relay points in areas where relay points might be needed temporarily. Wireless networking is an emerging technology that allows users to access information and services electronically, regardless of their geographic position. Wireless networks[1][4] can be classified in two types: -

- ***Infrastructured networks[4][2]***

Infrastructured network consists of a network with fixed and wired gateways. A mobile host communicates with a bridge in the network (called base station) within its communication radius. The mobile unit can move geographically while it is communicating. When it goes out of range of one base station, it connects with new base station and starts communicating through it. This is called handoff. In this approach the base stations are fixed.

➢ ***Infrastructureless (Ad hoc) networks[4][2]***

In ad hoc networks all nodes are mobile and can be connected dynamically in an arbitrary manner. All nodes of these networks behave as routers and take part in discovery and maintenance of routes to other nodes in the network. Ad hoc networks are very useful in emergency search-and-rescue operations, meetings or conventions in which persons wish to quickly share information, and data acquisition operations in inhospitable terrain.

Figure 2.1 shows a simple ad-hoc network with three nodes. The outermost nodes are not within transmitter range of each other. However the middle node can be used to forward packets between the outermost nodes. The middle node is acting as a router and the three nodes have formed an ad-hoc network.

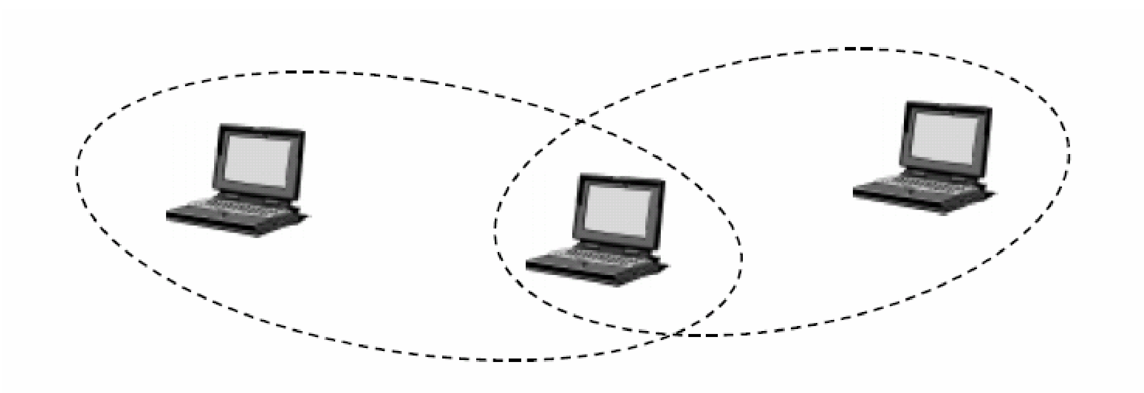

Figure 2.1: Example of a simple ad-hoc network with three participating nodes.

An ad-hoc network uses no centralized administration. This is to be sure that the network won't collapse just because one of the mobile nodes moves out of transmitter range of the others. Nodes should be able to enter/leave the network as they wish. Because of the limited transmitter range of the nodes, multiple hops may be needed to reach other nodes. Every node wishing to participate in an ad-hoc network must be willing to forward packets for other nodes. Thus every node acts both as a host and as a router. A node can be viewed as an abstract entity consisting of a router and a set of affiliated mobile hosts (Figure 2.2). A router is an entity, which, among other things runs a routing protocol. A mobile host is simply an IP-addressable [1] host/entity in the traditional sense.

Ad-hoc networks are also capable of handling topology changes and malfunctions in nodes. It is fixed through network reconfiguration. For instance, if a node leaves the network and causes link breakages, affected no des can easily request new routes and the problem will be solved. This will slightly increase the delay, but the network will still be operational.

Wireless ad-hoc networks take advantage of the nature of the wireless communication medium. In other words, in a wired network the physical cabling is done a priori restricting the connection topology of the nodes. This restriction is not present in the wireless domain and, provided that two nodes are within transmitter range of each other, an instantaneous link between them may form.

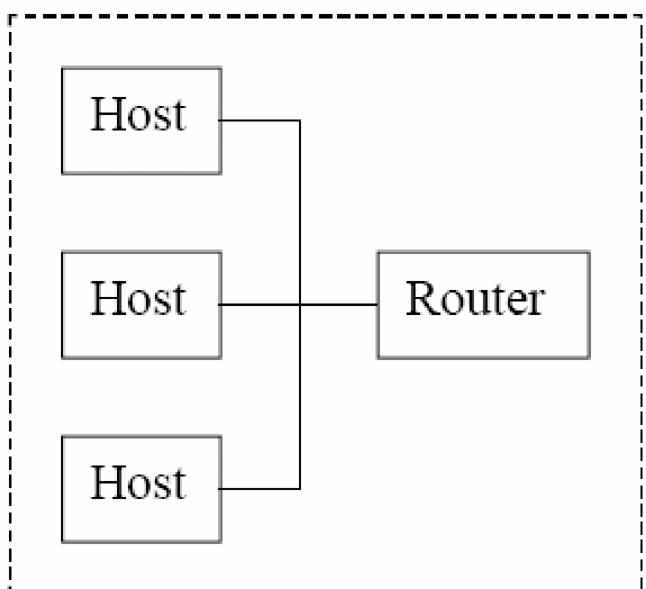

Figure 2.2: Block diagram of a mobile node acting both as hosts and as router.

2.1.2 Usage

There is no clear picture of what these kinds of networks will be used for. The suggestions vary from document sharing at conferences to infrastructure enhancements and military applications.

In areas where no infrastructure such as the Internet is available an ad-hoc network could be used by a group of wireless mobile hosts. This can be the case in areas where a network infrastructure may be undesirable due to reasons such as cost or convenience. Examples of such situations include disaster recovery personnel or military troops in cases where the normal infrastructure is either unavailable or destroyed.

Other examples include business associates wishing to share files in an airport terminal, or a class of students needing to interact during a lecture. If each mobile host wishing to communicate is equipped with a wireless local area network interface, the group of mobile hosts may form an ad-hoc network.

Access to the Internet and access to resources in networks such as printers are features that probably also will be supported.

2.1.3 Characteristics

Ad-hoc networks are often characterized by a dynamic topology due to the fact that nodes change their physical location by moving around. This favors routing protocols that dynamically discover routes over conventional routing algorithms like distant vector and link state. Another characteristic is that a host/node have very limited CPU capacity, storage capacity, battery power and bandwidth, also referred to as a “thin client”. This means that the power usage must be limited thus leading to a limited transmitter range.

The access media, the radio environment, also has special characteristics that must be considered when designing protocols for ad-hoc networks. One example of this may be unidirectional links. These links arise when for example two nodes have different strength on their transmitters, allowing only one of the host to hear the other, but can also arise from disturbances from the surroundings. Multihop[17][16][18] in a radio environment may result in an overall transmit capacity gain and power gain, due to the squared relation between coverage and required output power. By using multihop, nodes can transmit the packets with a much lower output power.

2.2 Routing

Routing[19] *is the* act of moving information across an internetwork from a source to a destination. Along the way, at least one intermediate node typically is encountered.

Routing protocols[6][7][8] are protocols that implement routing algorithms. Put simply, routing protocols are used by intermediate systems to build tables used in determining path selection of routed protocols. The routing protocol also specifies how routers in a network share information with each other and report changes. The routing protocol enables a network to make dynamic adjustments to its conditions; so routing decisions do not have to be predetermined and static.

The routing protocol has two main functions, selection of routes for various source-destination pairs and the delivery of messages to their correct destination. The second function is conceptually straightforward using a variety of protocols and data structures (routing tables).

2.3 Conventional protocols[2][5]

If a routing protocol is needed, why not use a conventional routing protocol like link state or distance vector? They are well tested and most computer communications people are familiar with them. The main problem with link-state and distance vector is that they are designed for a static topology, which means that they would have problems to converge to a steady state in an ad-hoc network with a very frequently changing topology.

Link state protocol[6] and distance vector protocol[6] would probably work very well in an ad-hoc network with low mobility, i.e. a network where the topology is not changing very often. The problem that still remains is that link-state and distance-vector are highly dependent on periodic control messages. As the number of network nodes can be large, the potential number of destinations is also large. This requires large and frequent exchange of data among the network nodes. This is in contradiction with the fact that all updates in a wireless interconnected ad hoc network are transmitted over the air and thus are costly in resources such as bandwidth, battery power and CPU. Because both link-state and distance vector tries to maintain routes to all reachable destinations, it is necessary to maintain these routes and this also wastes resources for the same reason as above

Another characteristic for conventional protocols are that they assume bi-directional links, e.g. that the transmission between two hosts works equally well in both directions. In the wireless radio environment this is not always the case. Because many of the proposed ad-hoc routing protocols have a traditional routing protocol as underlying algorithm, it is necessary to understand the basic operation for conventional protocols like distance vector, link state and source routing.

2.3.1 Link State[6]

In link-state routing, each node maintains a view of the complete topology with a cost for each link. To keep these costs consistent; each node periodically broadcasts the link costs of its outgoing links to all other nodes using flooding. As each node receives this information, it updates its view of the network and applies a shortest path algorithm to choose the next-hop for each destination.

Some link costs in a node view can be incorrect because of long propagation delays, partitioned networks, etc. Such inconsistent network topology views can lead to formation of routing-loops. These loops are however short-lived, because they disappear in the time it takes a message to traverse the diameter of the network.

2.3.2 Distance Vector[6]

In distance vector each node only monitors the cost of its outgoing links, but instead of broadcasting this information to all nodes; it periodically broadcasts to each of its neighbors an estimate of the shortest distance to every other node in the network. The receiving nodes then use this information to recalculate the routing tables, by using a shortest path algorithm.

Compared to link-state, distance vector is more computation efficient, easier to implement and requires much less storage space. However, it is well known that distance vector can cause the formation of both short-lived and long-lived routing loops. The primary cause for this is that the nodes choose their next-hops in a completely distributed manner based on information that can be stale.

2.3.3 Source Routing[6]

Source routing means that each packet must carry the complete path that the packet should take through the network. The routing decision is therefore made at the source. The advantage with this approach is that it is very easy to avoid routing loops. The disadvantage is that each packet requires a slight overhead.

2.3.4 Flooding[6]

Many routing protocols uses broadcast to distribute control information, that is, send the control information from an origin node to all other nodes. A widely used form of broadcasting is flooding and operates as follows. The origin node sends its information to its neighbors (in the wireless case, this means all nodes that are within transmitter range). The neighbors relay it to their neighbors and so on, until the packet has reached all nodes in the network. A node will only relay a packet once and to ensure this some sort of sequence number can be used. This sequence number is increased for each new packet a node sends.

2.4 Need of new routing protocols

In Ad Hoc networks, we need new routing protocols because of the following reasons:

1. Nodes in Ad Hoc networks are mobile and topology of interconnections between them may be quite dynamic.
2. Existing protocols exhibit least desirable behavior when presented with a highly dynamic interconnection topology.
3. Existing routing protocols place too heavy a computational burden on each mobile computer in terms of the memory-size, processing power and power consumption.
4 Existing routing protocols are not designed for dynamic and self-starting behavior as required by users wishing to utilize Ad-Hoc networks.
5 Existing routing protocols like Distance Vector Protocol take a lot of time for convergence upon the failure of a link, which is very frequent in Ad Hoc networks.
6. Existing routing protocols suffer from looping problems either short lived or long lived.
7. Methods adopted to solve looping problems in traditional routing protocols may not be applicable to Ad Hoc networks.

2.5 Features desired for a Routing Protocol in Ad Hoc Networks

The protocols to be used in the Ad Hoc networks should have the following features:

1. The protocol should adapt quickly to topology changes.
2. The protocol should of course be distributed. It should not be dependent on a centralized controlling node. This is the case even for stationary networks. The difference is that nodes in an ad-hoc network can enter/leave the network very easily and because of mobility the network can be partitioned.
3. The protocol should provide Loop free[4] routing. To improve the overall performance, we want the routing protocol to guarantee that the routes supplied are loop-free. This avoids any waste of bandwidth or CPU consumption.

4. The protocol should provide multiple routes from the source to destination and this will solve the problems of congestion to some extent. To reduce the number of reactions to topological changes and congestion multiple routes could be used. If one route has become invalid, it is possible that another stored route could still be valid and thus saving the routing protocol from initiating another route discovery procedure. i.e. The protocol should allow for quick establishment of routes so that they can be used before they become invalid.
5. The protocol should have minimal control message overhead due to exchange of routing information when topology changes occur. To minimize the control overhead in the network and thus not wasting network resources more than necessary, the protocol should be reactive. This means that the protocol should only react when needed and that the protocol should not periodically broadcast control information.
6. The radio environment can cause the formation of unidirectional links. Utilization of these links and not only the bi-directional links improves the routing protocol performance.
7. The radio environment is especially vulnerable to impersonation attacks, so to ensure the wanted behavior from the routing protocol, we need some sort of preventive security measures. Authentication and encryption is probably the way to go and the problem here lies within distributing keys among the nodes in the ad-hoc network.
8. The nodes in an ad-hoc network can be laptops and thin clients, such as PDAs that are very limited in battery power and therefore uses some sort of stand-by mode to save power. It is therefore important that the routing protocol has support for these sleep-modes.
9. Some sort of Quality of Service (QoS)[6] support is probably necessary to incorporate into the routing protocol. This has a lot to do with what these networks will be used for. It could for instance be real-time traffic support. None of the proposed protocols from MANET[4] have all these properties, but it is necessary to remember that the protocols are still under development and are probably extended with more functionality. The primary function is still to find a route to

the destination, not to find the best/optimal/shortest-path route. The remainder of this chapter will describe the different routing protocols and analyze them theoretically.

CHAPTER 3

Description of the Ad-hoc Routing Protocols

This chapter describes the details of different ad-hoc routing protocols in general and two protocols AODV and DSR in particular.

Table-driven routing protocols attempt to maintain consistent, up-to-date routing information from each node to every other node in the network. These protocols require each node to maintain one or more tables to store routing information, and they respond to changes in network topology by propagating updates throughout the network in order to maintain a consistent network view.

A different approach from table-driven routing is source-initiated on-demand routing. This type of routing creates routes only when desired by the source node. When a node requires a route to a destination, it initiates a route discovery process within the network. This process is completed once a route is found or all possible route permutations have been examined.

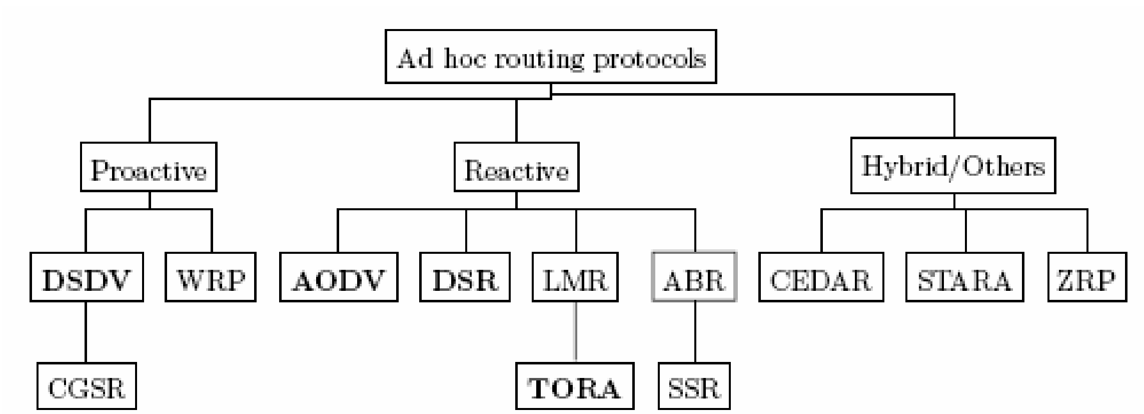

Fig 3.1 Categorization of Ad-Hoc Routing Protocol

3.1 Proactive Protocols (Table Driven Routing protocols)

3.1.1 Destination-Sequenced Distance-Vector (DSDV)

The Destination-Sequenced Distance-Vector (DSDV) Routing Algorithm is based on the idea of the classical Bellman-Ford Routing Algorithm[6] with certain improvements.

Every mobile station maintains a routing table that lists all available destinations, the number of hops to reach the destination and the sequence number assigned by the destination node. The sequence number is used to distinguish stale routes from new ones and thus avoid the formation of loops. The stations periodically transmit their routing tables to their immediate neighbors. A station also transmits its routing table if a significant change has occurred in its table from the last update sent. So, the update is both time-driven and event-driven.

The routing table updates can be sent in two ways: - a "full dump"[21] or an incremental update. A full dump sends the full routing table to the neighbors and could span many packets whereas in an incremental update only those entries from the routing table are sent that has a metric change since the last update and it must fit in a packet. If there is space in the incremental update packet then those entries may be included whose sequence number has changed. When the network is relatively stable, incremental updates are sent to avoid extra traffic and full dump are relatively infrequent. In a fast-changing network, incremental packets can grow big so full dumps will be more frequent.

3.1.2 Wireless Routing Protocol (WRP)

WRP is another protocol based on distributed Bellman-Ford algorithm (DBF)[5]. It substantially reduces the number of cases in which routing loops (count-to-infinity problem [1]) can occur. It utilizes information regarding the length and second-to-last hop (predecessor) of the shortest path to each destination.

WRP is a distance vector routing protocol. Each node maintains 4 tables:

- Distance table
- Routing table
- Link cost table Message
- Retransmission List table (MRL)[31]

The MRL contains the sequence number of the update message, a retransmission counter (how often a message is retransmitted before the connection is rebuild) and a list of updates sent in the update message.

As soon as topology changes are perceived, only the path-vector tuples (destination, distance) that reflects the update are sent. To improve reliability in delivering update messages, every neighbor is required to send ACKs for each update packet received. When no update messages have to be sent WRP periodically exchanges "HELLO" messages. When no "HELLO" message was received in a specified time period an alarm appears and it has to be checked if the link is still reachable. If the node receives a "HELLO" message from a new node, the node is added to the routing table.

WRP avoids the count-to-infinity problem by forcing each node to perform consistency check of predecessor information reported by all its neighbors.

3.1.3 Clusterhead Gateway Switch Routing (CGSR)

The Clusterhead Gateway Switch Routing (CGSR) uses DSDV as an underlying protocol Mobile nodes are partioned into clusters and a clusterhead[26][27] is elected using a distributed algorithm. All nodes in the communication range of the clusterhead belong to its cluster. A node that is in the communication range of two or more clusterheads is called a gateway node.

A clusterhead is able to control a group of ad-hoc hosts, this means that it is in charge of broadcasting within the cluster, forwarding messages and dynamic channel scheduling.

Each node maintains 2 tables:

- a cluster member table, containing the cluster head for each destination node
- a DV-routing table, containing the next hop to the destination.

The cluster member table is broadcasted periodically. A node will update the entries in its cluster member table on receiving a new one from its neighbors. Sequence numbers are used as in DSDV.

Routing in CGSR

If a node has to route a packet, it finds the nearest clusterhead along the route to the destination according to the cluster member table and the routing table. Then it will consult its routing table to find the next hop in order to reach the clusterhead selected above and transmits the packet to that node.

Thus, the routing principle looks as follows:

- Lookup of the clusterhead of the destination node
- Lookup of next hop
- Packet send to destination
- Destination clusterhead delivers packet

First, the source has to transmit the packet to its clusterhead. Then, this clusterhead sends the packet to the gateway node that connects this clusterhead and the next clusterhead along the route to the destination. The gateway sends the packet to the next clusterhead. This will go on until the destination clusterhead is reached. The destination clusterhead then transmits the packet to the destination node.

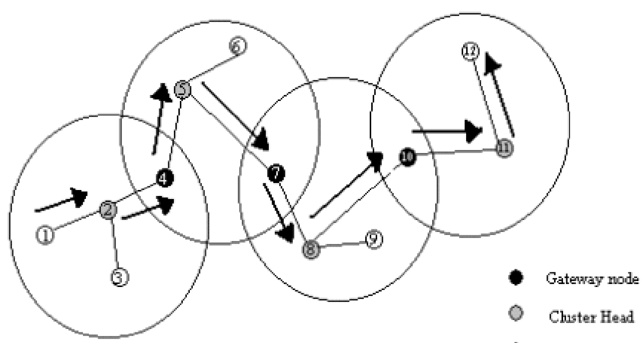

Fig 3.2 Routing in CGSR

Routing in CSGR is more effective than DSDV because it is done through the clusterheads and gateways

3.2 Reactive Protocols (On-Demand Routing Protocols)

3.2.1 Dynamic Source Routing (DSR)

The key distinguishing feature of DSR is the use of *source routin*g[25]. That is, the sender knows the complete hop-by-hop route to the destination. These routes are stored in a *route cach*e[25]. The data packets carry the source route in the packet header. When a node in the ad hoc network attempts to send a data packet to a destination for which it does not already know the route, it uses a *route discovery[25][26]* process to dynamically determine such a route. Route discovery works by flooding the network with *route request* (RREQ)[25] packets. Each node receiving an RREQ rebroadcasts it, unless it is the destination or it has a route to the destination in its route cache. Such a node replies to the RREQ with a *route reply* (RREP)[25] packet that is routed back to the original source. RREQ and RREP packets are also source routed. The RREQ builds up the path traversed across the network. The RREP routes itself back to the source by traversing this path backward. The route carried back by the RREP packet is cached at the source for future use.

If any link on a source route is broken, the source node is notified using a *route error* (RERR) packet. The source removes any route using this link from its cache. A new route discovery process must be initiated by the source if this route is still needed. DSR makes very aggressive use of source routing and route caching. No special mechanism to detect routing loops is needed. Also, any forwarding node caches the source route in a packet it forwards for possible future use.

3.2.2 Ad Hoc On-Demand Distance Vector Routing (AODV)

AODV[24] shares DSR's on-demand characteristics in that it also discovers routes on an *as needed* basis via a similar route discovery process. However, AODV adopts a very different mechanism to maintain routing information. It uses traditional routing tables, one entry per destination. This is in contrast to DSR, which can maintain multiple route cache entries for each destination. Without source routing, AODV relies on routing table entries to propagate an RREP back to the source and, subsequently, to route data packets to the destination. AODV uses sequence numbers maintained at each destination to determine freshness of routing information and to prevent routing loops. All routing packets carry these sequence numbers.

An important feature of AODV is the maintenance of timer-based states in each node, regarding utilization of individual routing table entries. A routing table entry is *expired* if not used recently. A set of predecessor nodes is maintained for each routing table entry, indicating the set of neighboring nodes which use that entry to route data packets. These nodes are notified with RERR packets when the next-hop link breaks. Each predecessor node, in turn, forwards the RERR to its own set of predecessors, thus effectively erasing all routes using the broken link. In contrast to DSR, RERR packets in AODV are intended to inform all sources using a link when a failure occurs. Route error propagation in AODV can be visualized conceptually as a tree whose root is the node at the point of failure and all sources using the failed link as the leaves.

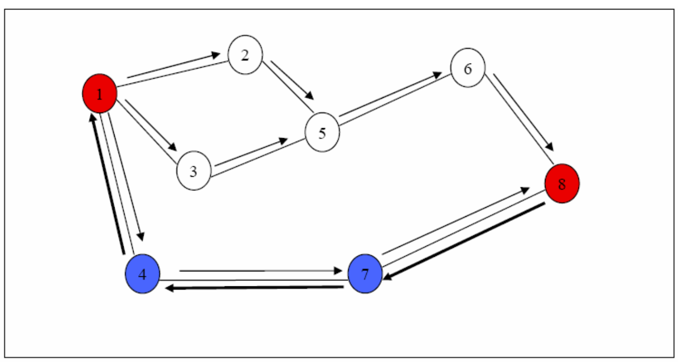

Fig 3.3 AODV route discovery

3.2.3 Temporally Ordered Routing Algorithm (TORA)

TORA[27] is a distributed routing protocol based on a "link reversal" algorithm. It is designed to discover routes on demand, provide multiple routes to a destination, establish routes quickly, and minimize communication overhead by localizing algorithmic reaction to topological changes when possible. Route optimality (shortest-path routing) is considered of secondary importance, and longer routes are often used to avoid the overhead of discovering newer routes.

The actions taken by TORA can be described in terms of water flowing downhill towards a destination node through a network of tubes that models the routing state of the real network. The tubes represent links between nodes in the network, the junctions of tubes represent the nodes, and the water in the tubes represents the packets flowing towards the destination. Each node has a height with respect to the destination that is computed by the routing protocol. If a tube between nodes A and B becomes blocked such that water can no longer flow through it, the height of A is set to a height greater than that of any of its remaining neighbors, such that water will now flow back out of A (and towards the other nodes that had been routing packets to the destination via A).

When a node discovers that a route to a destination is no longer valid, it adjusts its height so that it is a local maximum with respect to its neighbors and transmits an UPDATE packet. If the node has no neighbors of finite height with respect to this destination, then the node instead attempts to discover a new route as described above. When a node detects a network partition, it generates a CLEAR packet that resets routing state and removes invalid routes from the network.

3.3 Hybrid Protocols. (Combination of Reactive and Proactive protocols)

3.3.1 Zone Routing Protocol (ZRP)

The Zone Routing Protocol (ZRP) [29] was introduced in 1997 by Haas and Pearlman. It is either a proactive or reactive protocol. It is a hybrid routing protocol. It combines the advantages from proactive and reactive routing. It takes the advantage of pro-active discovery within a node's local neighborhood (Intrazone Routing Protocol (IARP)), and using a reactive protocol for communication between these neighborhoods (Interzone Routing Protocol(IERP)). The Broadcast Resolution Protocol (BRP)[29] is responsible for the forwarding of a route request.

ZRP divides its network in different zones. That's the nodes local neighborhood. Each node may be within multiple overlapping zones, and each zone may be of a different size. The size of a zone is not determined by geographical measurement. It is given by a radius of length, where the number of hops is the perimeter of the zone. Each node has its own zone.

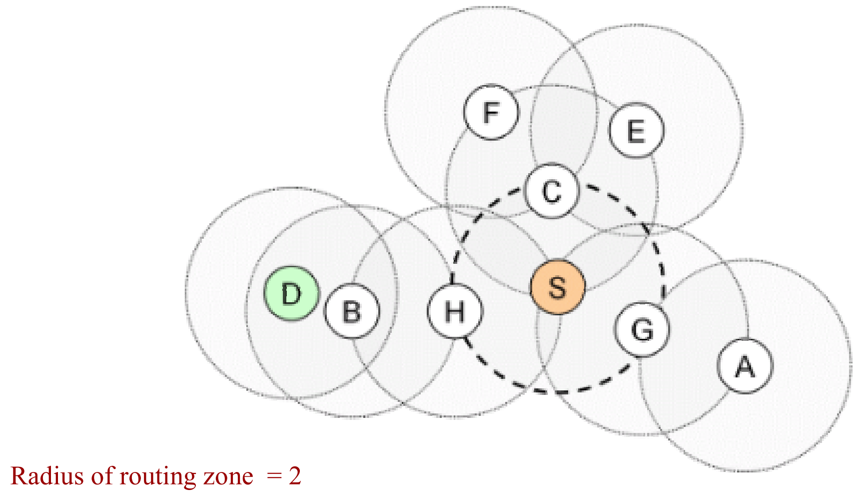

Fig 3.4 Routing in Zone Routing Protocol

3.4 Comparison of Proactive (Table-driven) and Reactive (On-demand) routing protocols

The following Table 3.1 briefly compares these routing protocols.

Table-driven	On-demand
Attempt to maintain consistent, up-to-date routing information from each node to every other node in the network.	A route is built only when required.
Constant propagation of routing information periodically even when topology change does not occur.	No periodic updates. Control information is not propagated unless there is a change in the topology.
Incurs substantial traffic and power consumption, which is generally scarce in mobile computers	Does not incur substantial traffic and power consumption compared to Table Driven routing protocols.
First packet latency is less when compared with on-demand protocols	First-packet latency is more when compared with table-driven protocols because a route need to be built
A route to every other node in ad-hoc network is always available	Not available.

Table 3.1 Comparison of Proactive and Reactive routing protocols

3.5 AODV vs. DSR

Dynamic Source Routing (DSR)[26] is commonly compared with AODV. Even though DSR is a multi-hop protocol and reactive protocol, route discovery mechanism is different. The most prominent difference is that DSR uses the source routing in which each packet contains the route to the destination in its own header. Therefore, intermediate nodes do not need to maintain up-to-date routing information in order to forward data packets. Another unique feature of DSR is packet salvaging. When an intermediate node detects the broken link to the next hop, the node begins to find an alternative route instead of discarding the data packet. In our experiments in NS2[10], we found that the packet salvaging causes the extension of end-to-end delay.

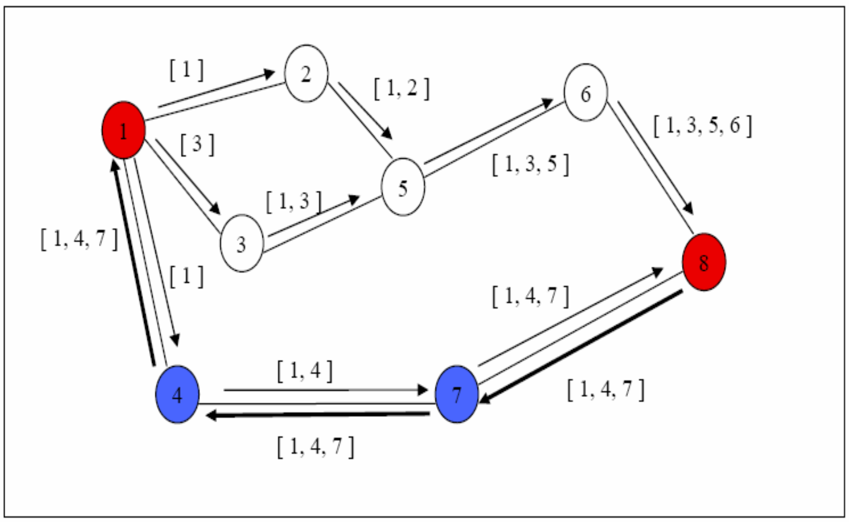

Fig. 3.5 AODV route discovery

In case of less stressed situation (i.e. smaller number of nodes and lower load and/or mobility), DSR outperforms AODV in delay and throughput but when mobility and traffic increase, AODV outperforms DSR. However, DSR consistently experiences less routing overhead than AODV.

Chapter 4

SIMULATION MODEL

4.1 Network Simulators

Nowadays, there are many network simulators that can simulate the MANET. In this section we will introduce the most commonly used simulators. We will compare their downsides and upsides and choose one to as platform to implement reactive/proactive protocol and conduct simulations in this thesis.

4.1.1 Network Simulator – ns2[12]

Ns2 is a discrete event simulator targeted at networking research. It provides substantial support for simulation of TCP, routing and multicast protocols over wired and wireless networks. It consists of two simulation tools. The network simulator (ns) contains all commonly used IP protocols. The network animator (nam) is use to visualize the simulations. Ns2 fully simulates a layered network from the physical radio transmission channel to high-level applications.

Ns2 is an object-oriented simulator written in C++ and OTcl. The simulator supports a class hierarchy in C++ and a similar class hierarchy within the OTcl interpreter. There is a one-to-one correspondence between a class in the interpreted hierarchy and one in the compile hierarchy. The reason to use two different programming languages is that OTcl is suitable for the programs and configurations that demand frequent and fast change while C++ is suitable for the programs that have high demand in speed.

Ns2 is highly extensible. It not only supports most commonly used IP protocols but also allows the users to extend or implement their own protocols. The latest ns2 version supports the four ad hoc routing protocols, including DSR. It also provides powerful trace functionalities, which are very important in our project since various information need to be logged for analysis. The full source code of ns2 can be downloaded and compiled for multiple platforms such as Unix, Windows and Cygwin.

4.1.2 GloMoSim[12]

GloMoSim is a scalable simulation environment for wired and wireless network systems. Currently it only supports protocols for a purely wireless network. It is also built in a layered approach such as OSI seven layer network architecture.

GloMoSim is designed as a set of library modules, each of which simulates a specific wireless communication protocol in the protocol statck. The library has been developed using PARSEC, a C-based parallel simulation language. New protocols and modules can be programmed and added to the library using this language. The latest version of GloMoSim has implemented DSR.

GloMoSim's source and binary code can be downloaded only by academic institutions for research purposes. Commercial users must use QualNet, the commercial version of GloMoSim.

4.1.3 OPNET Modeler [12]

OPNET Modeler is commercial network simulation environment for network modeling and simulation. It allows the users to design and study communication networks, devices, protocols, and applications with flexibility and scalability. It simulates the network graphically and its graphical editors mirror the structure of actual networks and network components. The users can design the network model visually.

The modeler uses object-oriented modeling approach. The nodes and protocols are modeled as classes with inheritance and specialization. The development language is C.

4.2 Comparison

When choosing a network simulator, we normally consider the accuracy of the simulator. Unfortunately there is no conclusion on which of the above three simulator is the most accurate one. David Cavin et al. has conducted experiments to compare the accuracy of the simulators and it finds out that the results are barely comparable. Furthermore, it warns that no standalone simulations can fit all the needs of the wireless developers. It is more realistic to consider a hybrid approach in which only the lowest layers (MAC and physical layers [3]) and the mobility model are simulated and all the upper layers (from transport to application layers) are executed on a dedicated hosts (e.g. cluster of machines).

Although there is no definite conclusion about the accuracy of the three network simulators, we have to choose one of them as our simulation environment. We compare the simulators using some metrics and the results are summarized in Table 4.1.

	Free	Open source	**Programming language**
NS-2	Yes	Yes	C++, TCL
GloMoSim	Limited	Yes	Parsec
OPNET Modeler	No	No	C

Table 4.1 Comparison of the three simulators

After comparing the three simulators, we decide to choose ns2 as network simulator in our thesis because :-

1. Ns2 is open source free software. It can be easily downloaded and installed.
2. Programming language C++ is compatible.

4.3 Mobility Models[32][33][34]

To evaluate the performance of a protocol for an adhoc network, it is necessary to test the protocol under realistic conditions, especially including the movement of the mobile nodes. A survey of different mobility models have been done. This includes the Random Waypoint Model that is used in our work.

4.3.1 Random Walk Mobility Model[34]

This model is based on random directions and speeds. By randomly choosing a direction between *0* and 2 and a speed between 0 and Vmax, the mobile node moves from its current position. A recalculation of speed and direction occurs after a given time or a given distance walked. The random walk mobility model is memory less. Future directions and speeds are independent of the past speeds and directions. This can cause unrealistic movement such as sharp turns or sudden stops. If the specified time or distance is short, the nodes are only walking on a very restricted area on the simulation area.

4.3.2 Random Waypoint Mobility Model[34]

A mobile node begins the simulation by waiting a specified pause-time. After this time it selects a random destination in the area and a random speed distributed uniformly between *0* m/s and Vmax. After reaching its destination point, the mobile node waits again pause-time seconds before choosing a new way point and speed.

The mobile nodes are initially distributed over the simulation area. This distribution is not representative to the final distribution caused by node movements. To ensure a random initial configuration for each simulation, it is necessary to discard a certain simulation time and to start registering simulation results after that time.

The Random Waypoint Mobility Model is very widely used in simulation studies of MANET. As described in the performance measures in mobile ad-hoc networks are affected by the mobility model used. One of the most important parameters in mobile ad-hoc simulations is the nodal speed. The users want to adjust the average speed to be stabilized around a certain value and not to change over time. They also want to be able to compare the performance of the mobile ad-hoc routing protocols under different nodal speeds. For the Random Waypoint Mobility Model a common expectation is that the average is about half of the maximum, because the speeds in a Random Waypoint Model are chosen uniformly between 0 m/s and Vmax. But is this the average speed really reached in simulations? Not at all, the studies in show that the average speed is decreasing over time and will approach 0. This could lead to wrong simulation results.

This phenomenon can be intuitively explained as follows. In the Random Waypoint Mobility Model a node selects its destination and its speed. The node keeps moving until it reaches its destination at that speed. If it selects a far destination and a low speed around 0 m/s, it travels for a long time with low speed. If it selects a speed near Vmax the time traveling with this high speed will be short. After a certain time the node has traveled much more time at low speed than at high speed. The average speed will approach 0 m/s. The suggestion in to prevent this problem is choosing, e.g. 1 m/s instead of 0 m/s as Vmin. With this approach the average speed stabilizes after a certain time at a value below 1/2 * Vmax.

4.3.3 Random Direction Mobility Model[34]

To reduce *density waves* in the average number of neighbors by the Random Waypoint Model the Random Direction Mobility Model was created. *Density waves* are the clustering of nodes in one part of the simulation area. For the Random Waypoint Mobility Model the probability of choosing a location near the center or a way point which requires traveling through the center of the area is high. The Random Direction Mobility Model was invented to prevent this behavior and to promote a semi-constant number of neighbors. The mobile node selects a direction and travels to the border of the simulation area. If the boundary is reached, the node pauses for a specific time and then chooses a new direction and the process goes on. Because of pausing on the border of the area, the hop count for this mobility model is much higher than for most other mobility models.

A detailed simulation model based on *ns-2* is used in the evaluation. In a recent paper the Monarch research group at Carnegie-Mellon University developed support for simulating multihop wireless networks complete with physical, data link, and medium access control (MAC) layer models on *ns*-2. The Distributed Coordination Function (DCF) of IEEE 802.11 for wireless LANs is used as the MAC layer protocol. An unslotted carrier sense multiple access (CSMA) technique with collision avoidance (CSMA/CA) is used to transmit the data packets. The radio model uses characteristics similar to a commercial radio interface, Lucent's WaveLAN. WaveLAN is modeled as a shared-media radio with a nominal bit rate of 2 Mb/s and a nominal radio range of 250 m.

The protocols maintain a *send buffer* of 64 packets. It contains all data packets waiting for a route, such as packets for which route discovery has started, but no reply has arrived yet. To prevent buffering of packets indefinitely, packets are dropped if they wait in the send buffer for more than 30 s. All packets (both data and routing) sent by the routing layer are queued at the *interface queue* until the MAC layer can transmit them. The interface queue has a maximum size of 50 packets and is maintained as a priority queue with two priori-ties each served in FIFO order. Routing packets get higher priority than data packets.

4.4 The Traffic and Mobility Models

Continuous bit rate (CBR)[5] traffic sources are used. The source-destination pairs are spread randomly over the network. Only 512-byte data packets are used. The number of source-destination pairs and the packet-sending rate in each pair is varied to change the offered load in the network.

The mobility model uses the *random waypoint* model in a rectangular field. The field configurations used is: 500 m x 500 m field with 50 nodes. Here, each packet starts its journey from a random location to a random destination with a randomly chosen speed (uniformly distributed between 0–20 m/s). Once the destination is reached, another random destination is targeted after a pause. The pause time, which affects the relative speeds of the mobiles, is varied. Simulations are run for 100 simulated seconds. Identical mobility and traffic scenarios are used across protocols to gather fair results.

4.5 Performance Metrics

Three important performance metrics are evaluated:

4.5.1 Packet delivery fraction — The ratio of the data packets delivered to the destinations to those generated by the CBR sources.

4.5.2 Average end-to-end delay of data packets — This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, and propagation and transfer times.

4.5.3 Normalized routing load — The number of routing packets transmitted per data packet delivered at the destination. Each hop-wise transmission of a routing packet is counted as one transmission.

The first two metrics are the most important for best-effort traffic. The routing load metric evaluates the efficiency of the routing protocol. Note, however, that these metrics are not completely independent. For example, lower packet delivery fraction means that the delay metric is evaluated with fewer samples. In the conventional wisdom, the longer the path lengths, the higher the probability of a packet drops. Thus, with a lower delivery fraction, samples are usually biased in favor of smaller path lengths and thus have less delay.

CHAPTER 5

Results and Discussions

5.1 Performance comparison of the protocols

First, an attempt was made to compare all the 4 protocols under the same simulation environment. However, simulations couldn't be successfully carried out for the TORA routing protocol, as ns-2 repeatedly gave a bus error while running the TORA simulations. For all the simulations, the same movement models were used, the number of traffic sources was fixed at 20, the maximum speed of the nodes was set to 20m/s and the pause time was varied as 0s, 10s, 20s, 40s and 100s.

Figures 5.1 and 5.2 highlight the relative performance of the two routing protocols. Both the protocols deliver a greater percentage of the originated data packets when there is little node mobility (i.e., at large pause time), converging to 100% delivery when there is no node motion.

5.1.1 Packet delivery Comparison:

The On-demand protocols, DSR and AODV performed particularly well, delivering over 85% of the data packets regardless of mobility rate.

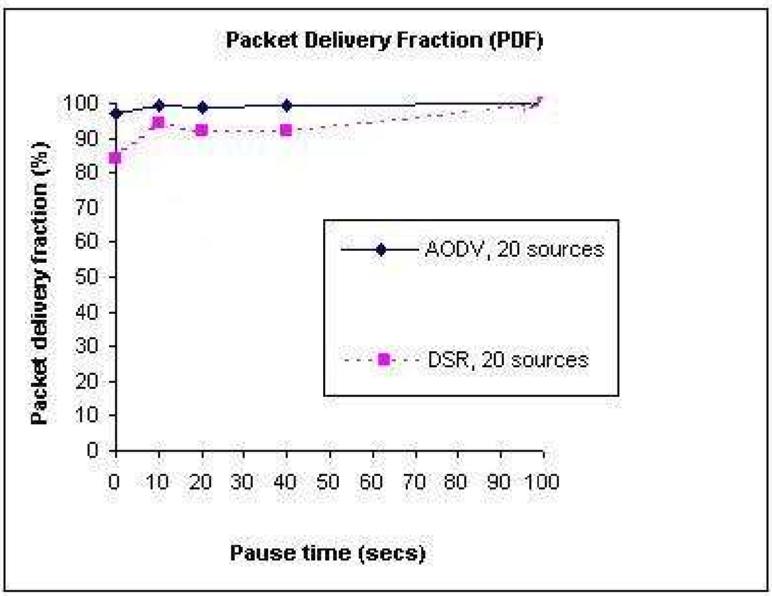

FIGURE 5.1 PACKET DELIVERY COMPARISON OF DSR AND AODV

5.1.2 Avera

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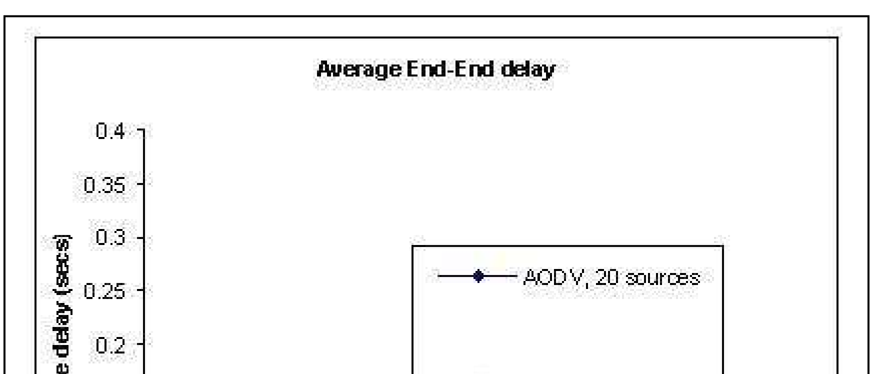
Since both erformance difference between the two by varying the Mobility pattern and Number of traffic sources.

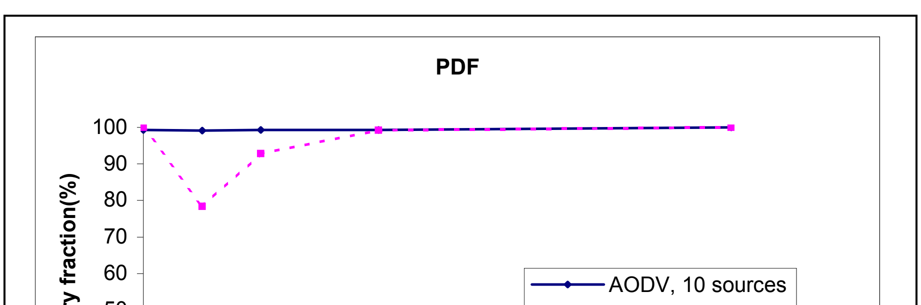


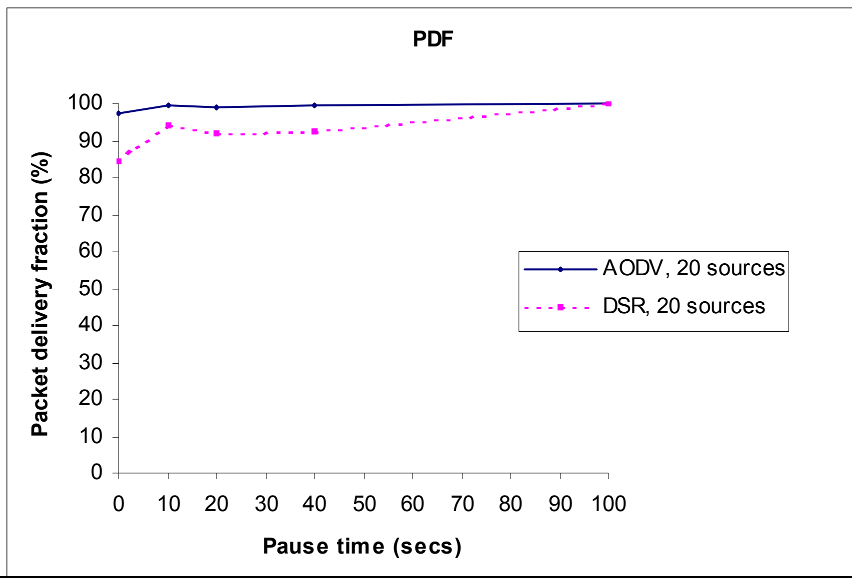
5.2 Varying Mobility and Number of Sources to see the performance difference between DSR and AODV

Now, again simulations were carried out with the number of traffic sources as 10, 20, 30 and 40. The pause time was varied as 0 (high mobility), 10, 20, 40,100 (no mobility) and the packets were sent at a rate of 4 packets/sec.

5.2.1 Packet delivery Comparison:

The packet delivery fractions for DSR and AODV are similar with 10 sources (Fig. 5.3). However, with 20, 30 and 40 sources, AODV outperforms DSR by about 15 percent (Fig. 5.5 and 5.6) at lower pause times (higher mobility).





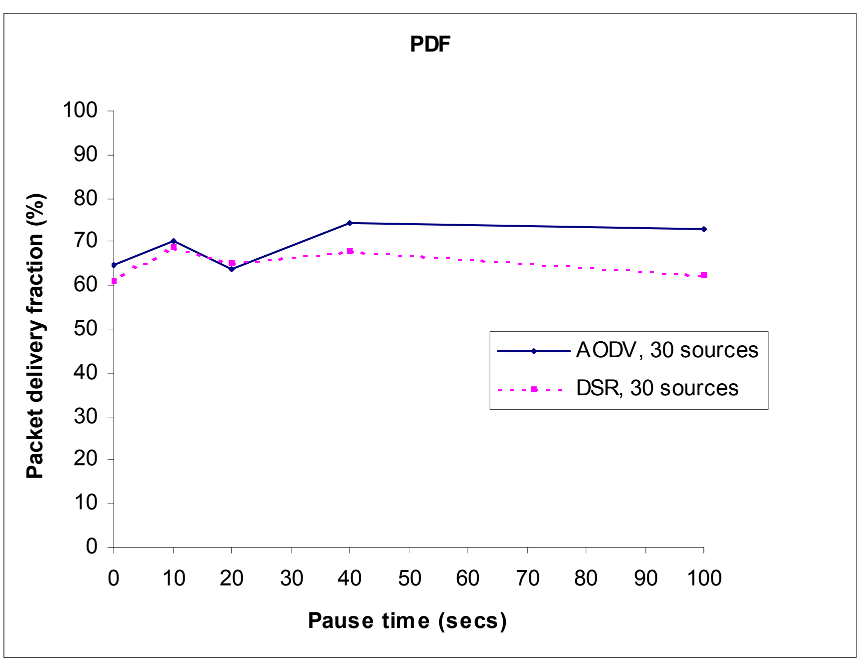


FIGURE 5.5 PACKET DELIVERY FRACTIONS FOR DSR AND AODV

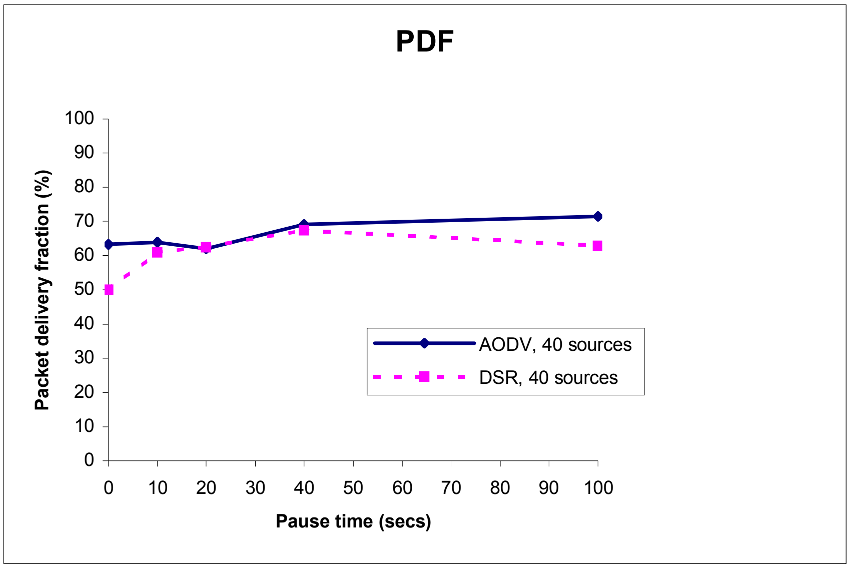


FIGURE 5.6 PACKET DELIVERY FRACTIONS FOR DSR AND AODV

5.2.2 Normalized Routing Load Comparison:

In all cases, DSR demonstrates significantly lower routing load than AODV (Fig. 5.7, 5.8, 59, 5.10), with the factor increasing with a growing number of sources.

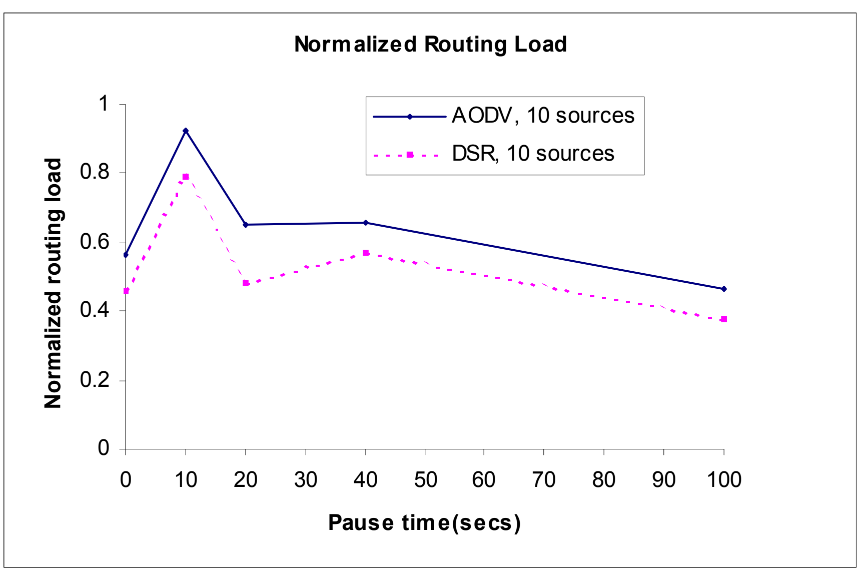


FIGURE 5.7 NORMALIZED ROUTING LOAD OF AODV AND DSR

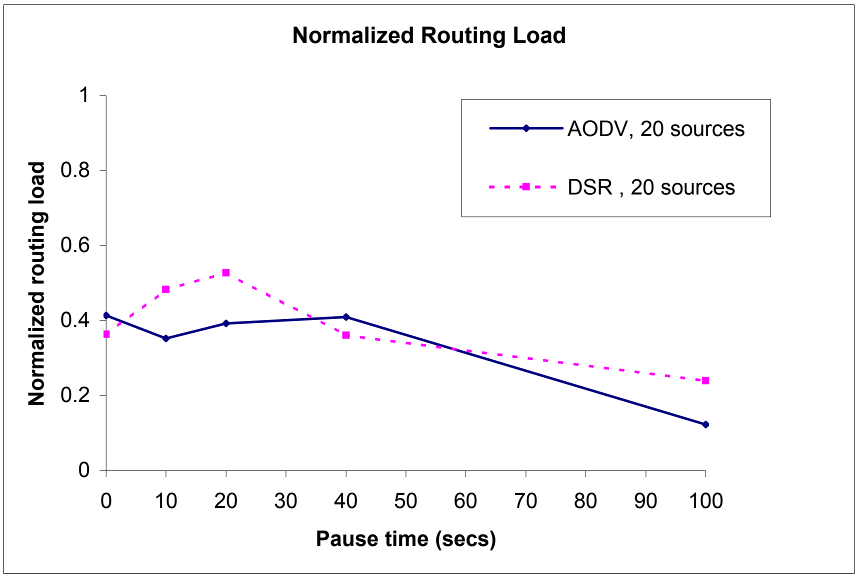


FIGURE 5.8 NORMALIZED ROUTING LOAD OF AODV AND DSR

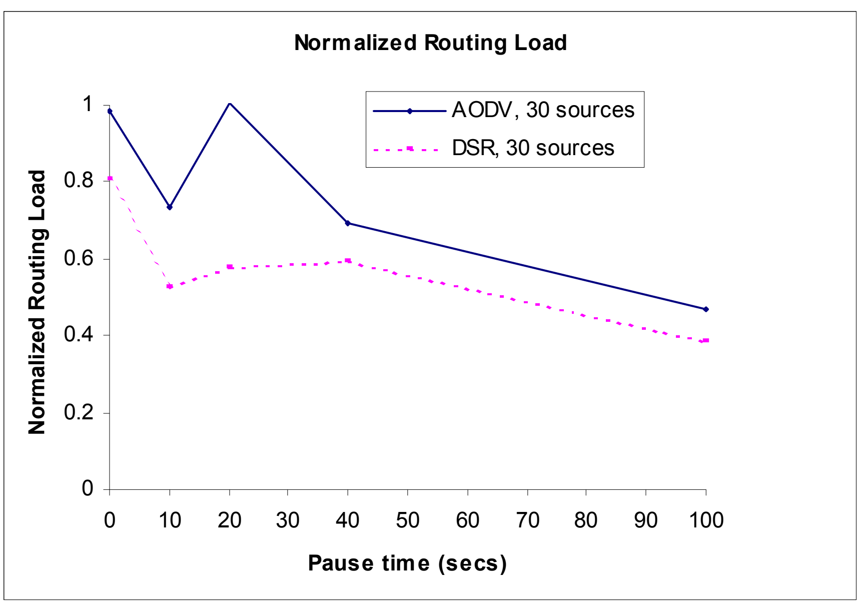


FIGURE 5.9 NORMALIZED ROUTING LOAD OF AODV AND DSR

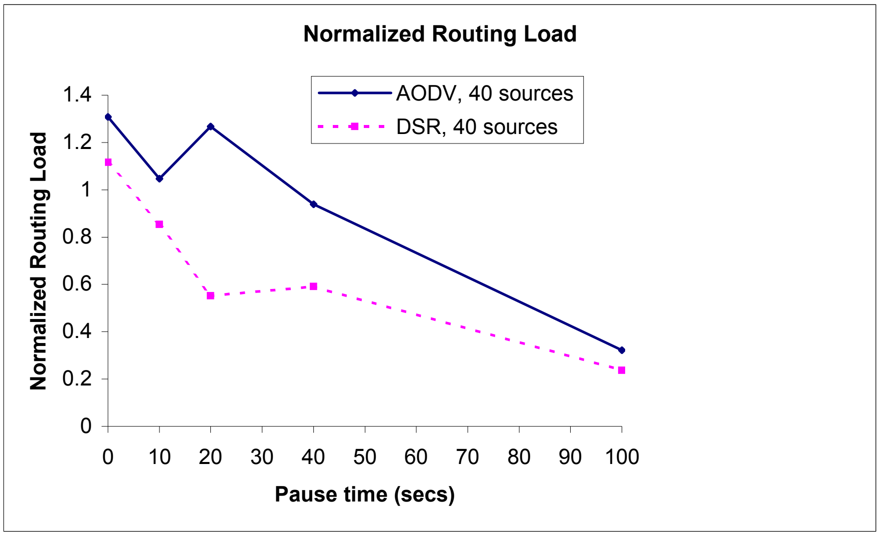


FIGURE 5.10 NORMALIZED ROUTING LOAD OF AODV AND DSR

In summary, when the number of sources is low, the performance of DSR and AODV is similar regardless of mobility. With large numbers of sources, AODV starts outperforming DSR for high-mobility scenarios. As the data from the varying sources demonstrate, AODV starts outperforming DSR at a lower load with a larger number of nodes. DSR always demonstrates a lower routing load than AODV. The major contribution to AODV's routing over-head is from route requests, while route replies constitute a large fraction of DSR's routing overhead. Furthermore, AODV has more route requests than DSR, and the converse is true for route replies.

CHAPTER 6

Observations

The simulation results bring out some important characteristic differences between the routing protocols. The presence of high mobility implies frequent link failures and each routing protocol reacts differently during link failures. The different basic working mechanisms of these protocols leads to the differences in the performance

For DSR and AODV, packet delivery ratio is independent of offered traffic load, with both protocols delivering between 85% and 100% of the packets in all cases.

The simulation results from Figure 5.1 to Figure 5.10 lead us to the following conclusions.

6.1 Effect of Mobility:

In the presence of high mobility, link failures can happen very frequently. Link failures trigger new route discoveries in AODV since it has at most one route per destination in its routing table. Thus, the frequency of route discoveries in AODV is directly proportional to the number of route breaks. The reaction of DSR to link failures in comparison is mild and causes route discovery less often. The reason is the abundance of cached routes at each node. Thus, the route discovery is delayed in DSR until all cached routes fail. But with high mobility, the chance of the caches being stale is quite high in DSR. Eventually when a route discovery is initiated, the large number of replies received in response is associated with high MAC overhead and cause increased interference to data traffic. Hence, the cache staleness and high MAC overhead together result in significant degradation in performance for DSR in high mobility scenarios[34].

In lower mobility scenarios, DSR often performs better than AODV, because the chances of find the route in one of the caches is much higher. However, due to the constrained simulation environment (lesser simulation time and lesser mobility models), the better performance of DSR over AODV couldn't be observed.

6.2 Routing Load Effect:

DSR almost always has a lower routing load than AODV. This can be attributed to the caching strategy used by DSR. By virtue of aggressive caching, DSR is more likely to find a route in the cache, and hence resorts to route discovery less frequently than AODV.

CHAPTER 7

Conclusion and Future Work

CONCLUSION

This work compared the performance of AODV and DSR routing protocols for ad hoc networks using ns-2 simulations.

AODV and DSR use the reactive On-demand routing strategy. Both AODV and DSR perform better under high mobility simulations. High mobility results in frequent link failures and the overhead involved in updating all the nodes with the new routing information less in AODV and DSR, where the routes are created as and when required.

DSR and AODV both use on-demand route discovery, but with different routing mechanics. In particular, DSR uses source routing and route caches, and does not depend on any periodic or timer-based activities. DSR exploits caching aggressively and maintains multiple routes per destination. AODV, on the other hand, uses routing tables, one route per destination, and destination sequence numbers, a mechanism to prevent loops and to determine freshness of routes. The general observation from the simulation is that for application-oriented metrics such as packet delivery fraction and delay AODV, outperforms DSR in more “stressful” situations (i.e., smaller number of nodes and lower load and/or mobility), with widening performance gaps with increasing stress (e.g., more load, higher mobility). DSR, however, consistently generates less routing load than AODV. The poor performances of DSR are mainly attributed to aggressive use of caching, and lack of any mechanism to expire stale routes or determine the freshness of routes when multiple choices are available.

Future Work

A comparison of two routing protocols, AODV and DSR, has been carried out. It is proposed to compare all other routing protocols considering the same simulation parameters so that an exhaustive comparison of various routing protocols can be made.

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Discusses Clustered Gateway Switch Routing Algorithm.

APPENDIX A – TERMINOLOGY

THIS APPENDIX CONTAINS SOME TERMINOLOGY THAT IS RELATED TO AD-HOC NETWORKS.

A.1 General terms

Bandwidth: Total link capacity of a link to carry information (typically bits).

Channel: The physical medium is divided into logical channel, allowing possibly shared uses of the medium. Channels may be made available by subdividing the medium into distinct time slots, distinct spectral bands, or decorrelated coding sequences.

Convergence: The process of approaching a state of equilibrium in which all nodes in the network agree on a consistent state about the topology of the network.

Flooding: The process of delivering data or control messages to every node within the any data network.

Host: Any node that is not a router.

Interface: A nodes attachment to a link.

Link: A communication facility or medium over which nodes can communicate at the link layer.

Loop free: A path taken by a packet never transits the same intermediate node twice before arrival at the destination.

MAC-layer address: An address (sometimes called the link address) associated with the link interface of a node on a physical link.

Next hop: A neighbor, which has been designated to forward packets along the way to a particular destination.

Neighbor: A node that is within transmitter range from another node on the same channel.

Node: A device that implements IP.

Node ID: Unique identifier that identifies a particular node.

Router: A node that forwards IP packets not explicitly addressed to itself. In case of ad-hoc networks, all nodes are at least unicast routers.

Routing table: The table where the routing protocols keep routing information for various destinations. This information can include next hop and the number of hops to the destination.

Scalability: A protocol is scalable if it is applicable to large as well as small populations.

Source route: A route from the source to the destination made available by the source.

Throughput: The amount of data from a source to a destination processed by the protocol for which throughput is to be measured for instance, IP, TCP, or the MAC protocol.

A.2 Ad-hoc related terms

Ad-hoc: "For this special or temporary purpose" or "a special case without generic support".

AODV: Ad-Hoc On-Demand Distance Vector. Routing protocol for wireless ad-hoc networks.

Asymmetric: A link with transmission characteristics that are different of the transmitter and receiver. For instance, the range of one transmitter may be much higher than the range of another transmitter on the same medium. The transmission between the two hosts will therefore not work equally well in both directions. See also symmetric.

Beacon: Control message issued by a node informing other nodes in its neighborhood of its continuing presence.

Bi-directional: refer symmetric.

CBRP: Cluster Based Routing Protocol. Routing protocol for wireless ad-hoc networks.

Cluster: A group of nodes typically in range of each other, where one of the nodes is elected as the cluster head. The cluster head ID identifies the cluster. Each node in the network knows its corresponding cluster head(s) and therefore knows which cluster(s) it belongs to.

DSDV: Dynamic Sequenced Distance Vector. Routing protocol for wireless Ad Hoc networks.

DSR: Dynamic Source Routing. Routing protocol for wireless Ad Hoc networks.

Proactive: Tries to maintain the routing map for the whole network all the time. See also reactive.

Reactive: Calculates route only upon receiving a specific request. See also proactive

RREQ: Routing Request. A message used by AODV for the purpose of discovering new routes to a destination node.

RREP: Route Reply. A message used by AODV to reply to route requests.

Symmetric: Transmission between two hosts works equally well in both directions. See also asymmetric.

TORA: Temporally Ordered Routing Algorithm. Routing protocol for wireless ad-hoc networks.

Unidirectional: see asymmetric.

ZRP: Zone Routing Protocol. Routing protocol for wireless ad-hoc networks.

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