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AN INVESTIGATION INTO THE ADVANTAGES, MECHANISMS, AND DEVELOPMENTAL CHALLENGES OF SCRIPTED MOBILE ROUTING

THESIS

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AFIT/GCS/ENG/08-13

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THESIS

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In Partial Fulfillment of the Requirements for the

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Captain, ROKA

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AN INVESTIGATION INTO THE ADVANTAGES, MECHANISMS, AND DEVELOPMENTAL CHALLENGES OF SCRIPTED MOBILE ROUTING

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AFIT/GCS/ENG/08-13

Abstract

Mobile Ad Hoc Network (MANET) routing protocols provide routing solutions in mobile wireless networks, without assuming any prior knowledge of topology nor any prediction of future topology. However, the resulting routes suffer from delay and consume precious bandwidth. Perfectly scripted routing could theoretically be optimal, (i.e., introduce no delay and cost no additional bandwidth), but would naturally be very fragile. This thesis explores a merging of these approaches, following a routing script if and when available, but reverting to a robust recovery approach otherwise.

Script-Assisted Ad Hoc On-demand Distance Vector (S-AODV) routing protocol is designed to take advantage of prior knowledge of topology to improve performance in a MANET, better utilizing available bandwidth. S-AODV uses pre-simulation to build a script to substitute for the route discovery process, avoiding delay and bandwidth penalties. Before sending any Route Request Packets (RREQs) to find a route, S-AODV consults the script. If the data exists, it updates the routing table. If not then it broadcasts RREQs like AODV routing protocol. Using this approach, S-AODV enjoys reduced routing traffic and route discovery times.

S-AODV is compared with Ad Hoc On-demand Distance Vector (AODV) routing protocol. S-AODV provides better performance in reducing routing traffic, route discovery time, and end-to-end delay. Also, S-AODV has better throughput in most scenarios except the environment in fast movement or heavy traffic loads.

Acknowledgments

First, I would like to give thanks to GOD for blessing me with my completion of my work. Second, I offer my thanks to my family. The love and support was always shown regardless of the long physical distance. Lastly, I am thankful to my thesis advisor, Maj. Scott Graham for his support, guidance, and advice. Without his support, this work would not have been completed.

Boyeon Jang

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AN INVESTIGATION INTO THE ADVANTAGES, MECHANISMS, AND DEVELOPMENTAL CHALLENGES OF SCRIPTED MOBILE ROUTING

I. Introduction

1.1. Background and Motivation

Wireless communication frees nodes from a wire tether, allowing mobility. Network access may be provided through a fixed infrastructure, wherein mobile nodes must be in the transmission range of an access point, which is fixed. If the node goes out of range of one access point, it connects with another access point within transmission range. If it cannot connect with any access point, then it cannot transfer data to any node. Therefore, a node may only move within the range of access points.

Mobile ad hoc networks (MANETs) discard the access points. Instead, each node is expected to provide routing services. In theory, if a path can be constructed between the mobile nodes, messages can be delivered without any fixed infrastructure allowing MANET's to be deployed anytime and anywhere with just the nodes themselves.

This research focuses on better utilizing the limited bandwidth available in most MANETs. Because MANET's suffer changing connections, or topology, the routing must continually be established via control packets which are transferred between nodes and which consume bandwidth. Most MANET routing protocols attempt to reduce routing traffic. This research proposes a routing protocol called “Script-assisted AODV (S-AODV) routing protocol” which, through knowledge of an existing plan, is able to function with lower routing traffic than a typical ad hoc routing protocol.

Military operations typically follow a detailed plan, which could be used to produce a prescribed plan for routing, avoiding the need for nodes to "discover" the routing information during the operation. For this research, the routing "plan" was constructed by "pre-simulation" in which a typical on-demand protocol, Ad hoc On demand Distance Vector routing (AODV) [2] was used to construct routing paths, which were then captured for later use in the actual network simulation experiments.

To verify the effectiveness of this routing protocol, the performance of S-AODV was compared with AODV routing protocol.

1.2. Research Objectives

The objective of this research is to evaluate the effectiveness of S-AODV routing protocol compared to AODV routing protocol with respect to throughput, routing traffic, route discovery time, and end-to-end delay in various network configurations.

1.3. Approach

To avoid the use of unnecessary routing control traffic, the S-AODV routing protocol incorporates an additional process beyond the AODV routing protocol, inserted immediately before the route discovery process. This step searches the "script", a previously prepared routing database to look up the routing data from the plan before running the expensive route discovery process. To do this, the S-AODV routing protocol requires a plan, which in this research is obtained via pre-simulation. We run a simulation once, using straightforward AODV, but with a traffic generation scheme designed to discover all available topology and routing information. The results from that pre-simulation effort become the plan, or script, for running S-AODV. It is understood that this approach is sub-optimal, and imperfect. Hence, when in the real simulation there is no appropriate data for the requested route, a node simply performs the routing discovery process exactly as in the standard AODV routing protocol.

The effectiveness and performance can be evaluated in many ways. To evaluate the performance of S-AODV routing protocol, we collected statistics including end-to-end delay, data traffic arrived, route discovery time, route traffic received, and traffic load.

1.4. Summary

This research compares the performance of the S-AODV routing protocol to the AODV routing protocol. The performance of the routing protocol is examined via multiple scenarios and using several different statistics.

The remainder of this paper is organized as follows. Chapter 2 presents a literature review of MANET routing protocols and the AODV routing protocol. Chapter 3 provides an outline of the methodology for this research's experiments. Chapter 4 presents the results of this research, detailed analysis of the S-AODV routing protocol, and conclusions regarding the S-AODV routing protocol. Chapter 5 summarizes this research and offers suggestions for future research.

II. Literature Review

2.1. Overview

This chapter provides an introduction to the scheme of MANET routing. Section 2.2 presents features of MANET and routing protocol. Section 2.3 introduces basic AODV concepts and routing process.

2.2. Mobile ad hoc networks (MANETs)

2.2.1. Overview

Wireless networks have become popular with the advancement of computer and wireless communication technology. Also the mobility became available with the wireless communication capability. To guarantee the quality of wireless network, Mobile Ad-hoc Networks (MANETs) has been formed by the Internet Engineering Task Force (IETF) [3].

MANETs is known as the infrastructureless mobile network which has no fixed routers. In MANETs, all nodes have a capability of mobility and can form the dynamic topology without any infrastructure (i.e., fixed and wired gateways) [5]. The major goal of MANETs is to provide the efficient function in the mobile network.

2.2.2. Characteristics of MANETs

MANETs have several features [4]: First, they have dynamic topologies: The network topology may change randomly and rapidly because nodes in MANETs can move arbitrarily. Second, they have bandwidth-constrained links: The capacity of wireless link is typically lower than the capacity of a wired links. Also the throughput of wireless network suffers from fading, noise, and interference conditions. Third, MANET nodes are typically energy-constrained: Usually nodes in MANETs rely on batteries or other exhaustible means. Thus the energy conservation is a big issue to optimize the system. Lastly, the MANETs typically have limited physical security: The physical security threat level of MANETs is higher than the one of wired networks due to the wireless character. Also an attacker from inside or outside can easily exploit the network because there is no centrally administrated node [6].

2.2.3. Type of Routing

Routing protocols generally use either distance-vector or link-state routing algorithms [7]. In distance-vector routing, each node keeps vectors that contain the cost and path between all possible destination nodes and itself in their routing table. To exchange the routing information the node sends all or some portion of its routing table to its neighbors periodically. Bellman Ford algorithm is used to calculate the shortest cost path [14].

With link-state routing, each node generates a link state packet (LSP) which consists of a list of names and cost for neighbors. Each node broadcasts a LSP to all nodes. Based on the information of LSPs the node builds a map of the entire network in its routing table using a shortest path algorithm (i.e. Dijkstra's shortest path algorithm [13]) [8].

2.2.4. Routing Protocol

There are a lot of routing protocols for wireless ad hoc networks. The goals of all these protocol are the same as finding and maintaining the routes efficiently for data transfer. The difference among the protocols is a methodology for accomplishing their goals. MANET routing protocols can be categorized into three based on their methodologies: flat routing, hierarchical routing and geographic position assisted routing [1] [15].

(1) Flat routing: The node which adopts a flat routing scheme plays on an equal level with other nodes during a routing process. There are two categories for flat routing: proactive and on-demand routing. Usually routing protocols use either link-state or distance-vector algorithms. Typically many proactive routing protocol uses link-state routing. The nodes in the link-state routing scheme flood the routing information periodically to others. On the other hand, reactive routing protocols only initiate routing process when it is needed. Thus there is no routing flooding without demand [1] [17].

(2) Hierarchical routing: The nodes in hierarchical routing play different roles. There are two way to build the hierarchy. One is to group nodes geographically close to each other into clusters. The leading node of a cluster communicates to other nodes instead of other nodes in the cluster. The other is to build implicit hierarchy. In this scheme, each node has a local scope. The routing protocol of inside scope is different from the one of outside scope. The communication between two other clusters is available using the overlapping scopes [16].

(3) Geographic position assisted routing: This routing scheme is developed after the development of GPS. GPS provides the location information and universal clock. Geographic position assisted routing protocol considers this physical position and time [18].

2.2.5. Disadvantages of MANETs

(1) Scalability problem: In the big network, the routing overhead and route table becomes bigger. Also the route failure will occur more often because the protocol can not propagated through the whole network immediately [19].

(2) Overhead: The rapid topology change might cause the huge control message which could overwhelm the network bandwidth. The excess messaging overhead will decrease the throughput of wireless network [20] [21].

(3) Delay: The delay may cause due to route discovery process [21].

2.3. Ad hoc On-Demand Distance Vector Routing

2.3.1. Overview

The ad hoc on-demand distance vector (AODV) routing is a pure on-demand routing protocol. It means that the nodes in this routing scheme do not perform any route discovery mechanism until the route is needed by the nodes or packets. The nodes that are not on active path do not maintain any routing information and do not participate in routing table exchanges. Instead of creating all possible routes, AODV creates only the route which is currently needed by itself or another node wishing to route through this node to some distant node. Hence AODV routing protocol can reduce the amount of control traffic overhead [12].

AODV routing protocol uses a broadcast route discovery mechanism. It is similar to the Dynamic Source Routing (DSR) algorithm [9]. However the routes in AODV are based on the dynamic routing table entries which are maintained at intermediate nodes.

In AODV routing, the local "hello" messages are used to determine or maintain the local connectivity. This exchange can reduce the response time to the route request and also trigger updates when it is necessary.

The AODV routing protocol utilizes a table-driven method. Each node which is on a particular route can maintain a valid routing table entry in its routing table. But the node can maintain only one route entry per destination in its routing table.

2.3.2. Path Discovery

Path discovery process is initiated when there is no route entry from the source to the destination in the routing table. When the new route is requested the source node generates and broadcasts a route request (RREQ) packet. [2] The format of a route request packet is shown in Figure 2.1.

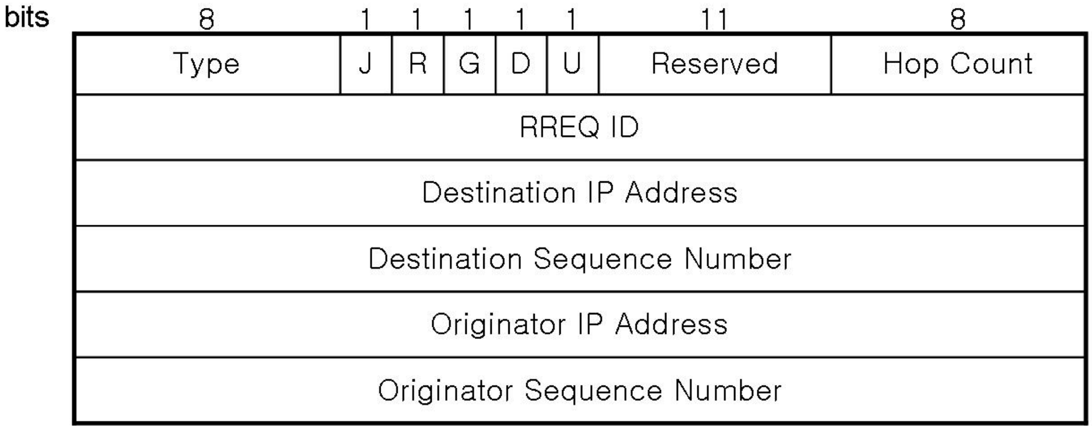

Figure 2.1: Route Request Packet Format

The RREQ packet is uniquely identified by originator IP address and RREQ ID which is maintained in each node. The RREQ ID is incremented whenever the originator generates a new RREQ. The destination sequence number is copied from the node's routing table or is set as invalid.

After generating the RREQ, the source node broadcasts the RREQ packets to every node. When the intermediate node receives the RREQ packet, it looks up its own routing table and then it creates or updates a route to the previous hop without a valid sequence number because the RREQ packet doesn't have the previous hop's sequence number. After that, it checks whether it has received a duplicated RREQ packet within at least the last path discovery time. If the same RREQ has been received, the node discards the RREQ packet. If there is no duplicate RREQ packet, then it increments the hop count field in the RREQ packet by one and updates or creates its reverse route to the originator node. After setting the reverse route the node searches for the route to the destination. If the intermediate node already has the valid route then it generates the Route Reply (RREP) packet using the information of the route table and RREQ packet. If there is no valid route in the intermediate node's routing table, it just broadcasts the RREQ packet to the neighbors. When the RREQ arrives at the destination node, it generates the RREP packet and sends that packet to originator node.

(1) Reverse Path Setup

The RREQ packet has two different sequence numbers. One is the originator sequence number and the other is the destination sequence number. The node always maintains its own sequence number and it is updated whenever the node's action happens like generating RREQ or RREP packet. The originator sequence number is used to maintain the reverse route to the originator in the routing table. The destination sequence number becomes the standard to determine the route freshness.

When A RREQ packet travels from the source to the neighbor node or the destination, the nodes which received the RREQ packet automatically update their routing table to set up the reverse path to the source node. To set up the reverse path, the node creates or updates its routing entry which contains the originator IP address and originator sequence number. The reverse path is used when it received the RREP packet to forward to the destination. However, this reverse path entry can expire if it doesn't receive the RREP packet from the intermediate node or the destination node.

(2) Forward path setup

A RREP packet could be generated not only from a destination node but also from an intermediate node. When the RREQ arrives at the intermediate node which has a route entry for the destination, a destination sequence number in the RREQ packet is compared with a sequence number of the route entry in the intermediate node. If the RREQ packet's destination sequence is greater, then it doesn't use its route entry from the routing table to answer the RREQ packet. It just broadcasts the RREQ packet to other neighbor nodes. However, if the node has equal or higher destination sequence number in its route entry then it replies to the RREQ packet. The RREP packet is shown in Figure 2.2.

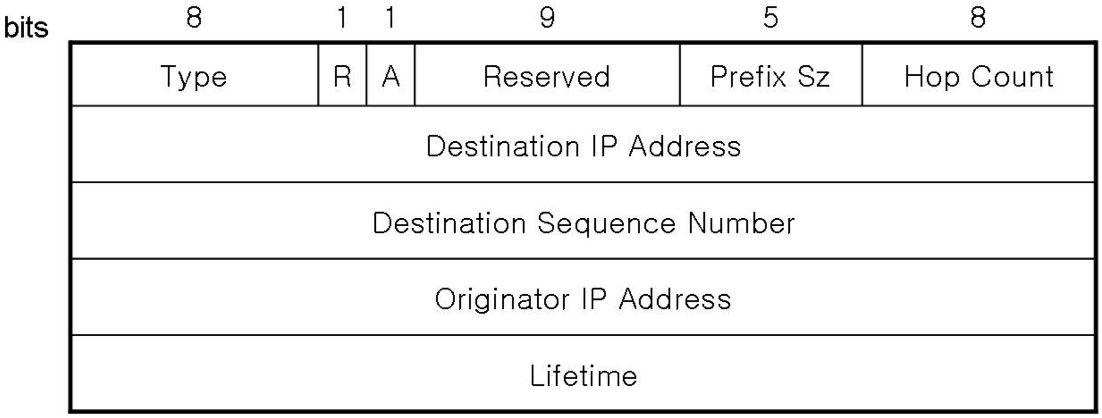

Figure 2.2: Route Reply Packet Format

The originator IP address is copied from the RREQ packet. The lifetime is a time in milliseconds. Nodes which are receiving the RREP consider the route to be valid.

Once the RREP is generated, it is unicasted to its neighbor node toward the originator node of the RREQ packet using a reverse path. When the RREP packet arrives at the intermediate nodes, each node sets up a forward path which is the route to the destination. It records the latest destination sequence number from the RREP packet and set up a timer based on the lifetime field in the RREP packet. The node which is not on the active route to the destination will timeout after ACTIVE_ROUTE_TIME (3000 msec) and the route entry will become invalid. [12]

When a node receives the another RREP packet which has the same originator and the same destination, the node updates its routing entry for the destination only when the latest RREP packet has a greater destination sequence number than the previous RREP packet or the hop count of the latest RREP packet is smaller then the previous one. The transmission from the source will begin when the RREP packet is received. If the better RREP packet is arrived, then it will update its routing entry and forward the data packet using an updated route entry.

2.3.3. Route Table Management

Every node maintains its routing table and that routing table is used for forwarding packets. When a node receives a packet from a neighbor or when it creates or updates a route entry, the routing table is used to find a route for a destination. When the node tries to update its route table, it compares the new sequence number from an old sequence number in a routing table. The route could be updated when the new sequence number is higher than the destination sequence number in the route table or when the sequence number are equal but increased hop count is smaller or equal than a existing hop count in the route.[2]

Routing table entry contains the following information: destination IP address, destination sequence number, next hop node, number of hops, active neighbors for this route, and expiration time for the route table entry.

There are three soft-state maintenances of the route table entries; active route lifetime, route request expiration timer and route caching timeout. The active route lifetime is determined from the control packet or it is initialized to ACTIVE_ROUTE_TIMEOUT. When the route is used to forward a data packet, the active route lifetime of the source, destination and the next hop on the path to the destination is updated to the current time plus ACTIVE_ROUTE_TIMEOUT.

The routing request expiration timer is used to eliminate the reverse path routing entry from the nodes that are not on the determined path between the source and the destination. It is usually determined by the net traversal time, node traversal time and the hop count.

Even though the route entry in the routing table becomes invalid, the node maintains the invalid route entry for route caching timeout. If the node tries to find the route which is invalid in the routing table, it uses the destination sequence number from the invalid route entry. However the invalid route entry is removed after route caching time out.

2.3.4. Path Maintenance

When the node moves, it could break the path from the source to the destination if that node is on the active route path. If the mobile node which is not on the active route moves, then no action will happen. When the destination node or the intermediate node which is lying along an active path moves, a RREP is sent to the source nodes. The route change will be detected by these three following cases

- Failure of periodic HELLO packets
- Failure of disconnected indication from the link level
- Failure of transmission of a packet to the next hop

Once the node detects a failure of the link to the next hop, the node generates an unsolicited RREP with the sequence number which is one greater than the sequence number of its routing entry. This odd sequence number will represent that the route is no more available. And the hop count of the RREP will be set as ∞. The RREP which is generated from the intermediate node will travel along all active paths. The node which received this RREP will update their route entry as invalid. The RREP will be forwarded until it arrived at the source node.

When source node receives this RREP, it can restart the route discovery process if the route to the destination is still needed. To determine whether a route is still needed or not, the node will check whether this route is used recently. If the node determines that the route to the destination is still needed, it will generate the RREQ with the new destination sequence number which is one greater than the RREP’s destination sequence number to find the fresh route path. Then the RREQ is broadcasted to all possible nodes.

2.3.5. Local Connectivity Management

A node can find its neighbor in two ways. Whenever a node receives any packet like RREQ, RREP, REER or data packet, it updates its local connectivity information.

The other way to find the neighbors is exchanging hello messages. If the node does not receive any packet from the neighbor within HELLO_INTERVAL (1000msec), it broadcasts a hello message to its neighbors. However, only the node which is a part of an active route can use the hello messages. The hello message has the same format as a RREP. When the node generates the hello message, the RREP message fields set as follows

- Destination IP address: The node's IP address
- Destination sequence number: The node's latest sequence number
- Number of hops: 0
- Expiration time for the route table entry: ALLOWED_HELLO_LOSS * HELLO_INTERVAL

The node's sequence numbers in the routing table and a hello message are not changed by generating a hello message. When the hello message arrives at the neighbor node, the neighbor does not rebroadcast the hello message because hello message contains a time to live (TTL) value as 1. The neighbor node just updates its local connectivity information by using a hello message's information. If the node receives the hello message or another message from new node, or it fails to receive ALLOWED_HELLO_LOSS consecutive hello message from the neighbor which is listed in its routing table, then it represents that the local connectivity has changed. Failing to receive a hello message from the node which is on the inactive path does not initiate any action. However if the node fails to receive ALLOWED_HELLO_LOSS consecutive hello message from the node which is on the active route, then the node initiates the route discovery process.

2.4. Summary

This chapter provides a mobile ad hoc routing scheme and routing protocol. The ad hoc on-demand distance vector (AODV) routing protocol is presented in detail because it is used for methodology in this research.

III. Methodology

3.1. Problem Definition

3.1.1. Goals and Hypothesis

Like other protocols MANET protocols focus on finding optimal routes between a source and a destination. During a process to find an optimal route, MANET protocols generate routing control traffic. If the network size is small then the routing control traffic overhead is minimal. However for a large network in MANET protocols, routing control traffic will be a big issue because the large network means large routing control traffic overhead, significantly reducing the useable bandwidth. A major solution for this problem is to reduce routing control traffic caused by nodes in the topology and dynamic topologies [1].

To reduce the routing control traffic we created the S-AODV routing protocol. The S-AODV protocol relies on a fundamentally different routing paradigm. S-AODV assumes existence of a plan, known in advance, which is used to determine much, if not all, of the routing information. For purposes of this research, the plan was created by an additional routing discovery step from AODV. The plan consists of the routing data extracted from the pre-simulation run, and now stored in the router. If it cannot find the data, then it initiates the original AODV route discovery process.

The primary goal of this research is to analyze the performance of such a routing scheme, known here as S-AODV.

S-AODV certainly ought to have better performance, given that it enjoys more information. First, it is expected that fewer routing discovery processes will be performed than in the original AODV protocol. Since the S-AODV protocol has a pre-simulated plan and will update a routing entry before it initiates the routing discovery process, it is expected to decrease Routing Request Packets (RREQs). This decrease has ramifications for routing traffic. Reduced RREQs will cause less Route Reply Packets (RREPs) or Route Error Packets (RERRs). Hence, the total routing traffic will be decreased.

Second, route discovery times will be shortened. For the AODV protocol, the routing discovery process is always performed (unless cached from a recent discovery process). The route discovery process ends only when it receives the RREP or it fails to receive RREP for certain time [2]. So it usually takes certain amount of time based on the circumstance of network topology and traffic load. However, for the S-AODV routing protocol, if routing data exists for the destination in question, then it can be updated to the routing table immediately, requiring only the time to finding and updating data, which is minimal compared to the time spent waiting for RREP's.

The S-AODV routing protocol suffers from some limitations. First, a plan routing table, or script, must be created in advance. A companion problem, not covered in this research, is how to efficiently prepare the "script" given that node locations are known in advance. The sheer volume of data required developing and maintaining such a script requires that some form of compression be used, but no such attempt was accomplished as part of this research. In this case, it is generated by "pre-simulation" and the routing information is thus collected before the actual simulation. To obtain the routing data, we simulated the original scenario with AODV protocol and collected every routing update action.

Second, the router has to have sufficient memory to store the pre-simulated data. Much effort will be required to determine how to efficiently distribute and maintain the scripted information. (Memory requirements for this large data set hampered efforts to run larger scenarios for longer periods of time.)

All existing routing protocols are reactive in the sense that they "discover" topology in an existing network through message passing. The inherent delays in doing so make it impossible to create "perfect" time phased routing tables. That is, the pre-simulated routing information collected is not necessarily optimal. Specifically, AODV does not produce a perfect record of network topology. Latencies in the RREQ and RREP processes prevent such a perfect record. Moreover, as it is on-demand, not all possible connections are discovered. In an effort to minimize this, we send many very small packets (minimal load) throughout the network during pre-simulation, to try to stimulate the best record of the network topology possible.

3.1.2. Approach

To achieve the research goal, we simulated a given mobile scenario with AODV protocol to gather routing table information of all nodes in the network. After obtaining all routing data from the previous scenario result, the same mobile scenario was simulated with S-AODV routing protocol. It is crucial that the pre-simulation scenario match the actual simulation very closely, or the "planned" routing information is not valid.

The protocol developed for these experiments is able to handle scripted route failures, but was not yet specifically tested in this capacity.

The S-AODV routing protocol performs the following process to send the packets.

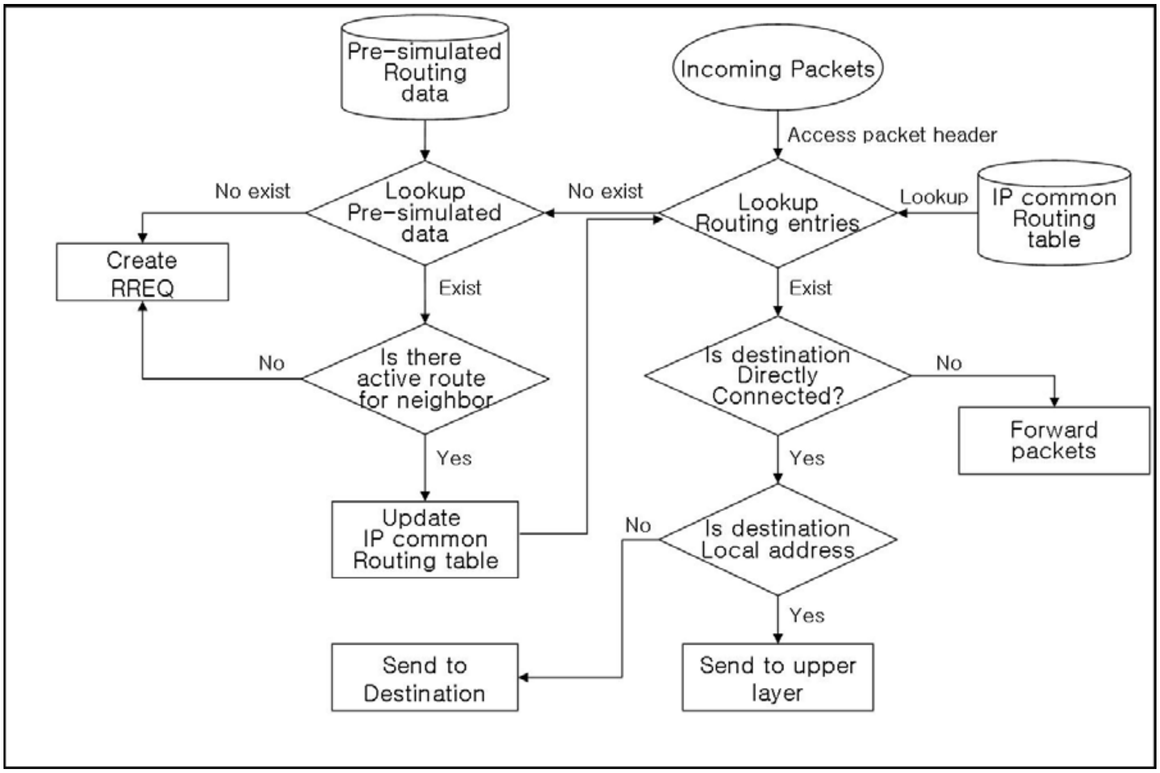

Figure 3.1: The S-AODV Routing Process Flowchart

3.2. System Boundaries

The system under test (SUT) for this research consists of the following components.

(1) Mobile Nodes

(2) Operation Area

(3) Mobility

(4) Routing Algorithms

3.3. System Services

One of the main services of the system is data transfer. This service enables the packet to be delivered to the destination. The failure of this service implies packet transmission failure, which could be caused by many factors. First, the data cannot be transferred if the neighbor node is out of the transmission range. This is most common in wireless networks because the wireless nodes have limited transmission power and they are mobile. Second it may be caused because of the limited bandwidth. If the traffic load is high, the packet could be dropped.

Another service is the route discovery. This service is a process to find the path between source and destination. The service failure means that the source cannot find any valid route to the destination. It may be caused when the destination is unreachable due to a connectivity problem or a routing problem.

The third system service is a local repair. The local repair is initiated when an intermediate node doesn’t have a valid route anymore for the incoming packet. If the local repair is enabled then the intermediate node broadcasts a hop-limited RREQ packet for that destination [2], in the hope that a neighbor has some routing information regarding the destination node.

3.4. Workload

The workload of this system is the data transferred between mobile nodes in a simulation. This data includes the actual data packets which have the information to be transferred and excludes the routing control packets that are generated by the routing protocol.

This workload can have an effect on the system in many ways. First, transferring data may cause the route discovery process. If there is no route to the destination when a packet arrives, the node will initiate the route discovery process. Also data transfer rate may also affect the route lifetime. With regular data transmission, the route's lifetime will be extended. However, if the interval between data packets increases, the active route may expire.

Furthermore, the workload will affect the overall network system. If the workload is too high then the efficiency of the network will be low because the network cannot afford to transfer the all data because of the limited bandwidth. Also the end-to-end delay will increase due to the congestion process on the network.

3.5. Performance Metrics

The S-AODV routing protocol is evaluated by the following performance metrics.

(1) Throughput: This metric is the number of bits which is successfully transmitted divided by the total simulated time. Throughput is defined as $Throughput\ (bits) = \frac{B_{rx}}{T}$, where B_{rx} is the number of data bits received successfully and T is the elapsed time.

(2) End-to-End Delay: End-to-End delay is the time required to transmit the packet from the source node to the destination node. This performance metric

includes processing, queuing, and transmission delay in each intermediate node, as well as propagation delay between the nodes.

(3) Route discovery time: Route discovery time is the time from the initiation of route demand until a useable route is discovered.

(4) Routing traffic received rate (bits/sec): The routing traffic received rate is defined as the ratio of the total number of bits in received routing control packets received from all nodes per second. Routing control packets include RREQ, RREP, and RRER packets.

3.6. Parameters

3.6.1. System Parameters

(1) Number of nodes: The network size, measured in number of nodes affects the level of connectivity. If the system has higher connectivity level, then that system is likely to have more reliable route because it has more available route. Various sizes between 30 nodes and 90nodes are selected in this simulation. Also 100~150 nodes are used for extra data.

(2) Operation Area: The operational area was selected to maintain a somewhat constant density. While the area is changing it is not a factor in this study and is merely changed to accommodate a changing number of network nodes,

without also affecting the network density. Actual operational area is changed based on the network size as below.

Table 3.1. Operation Area

Number of Nodes	Operation Area	Number of Nodes	Operation Area
30 nodes	660m * 600m	90 nodes	1980m * 600m
40 nodes	880m * 600m	100 nodes	2200m * 600m
50 nodes	1100m * 600m	110 nodes	2420m * 600m
60 nodes	1320m * 600m	120 nodes	2640m * 600m
70 nodes	1540m * 600m	130 nodes	2860m * 600m
80 nodes	1760m * 600m	140 nodes	3080m * 600m

(3) Mobility: The mobility of nodes in this simulation will follow the random waypoint model [11]. The random waypoint is characterized by two factors, pause time and maximum speed (a uniform distribution chooses the actual speed per node, between 0 and the maximum specified speed). In this simulation we fixed the pause time as 0 second. The mobility will affect the network topology changes. If the mobility is higher, then the network topology changes more rapidly. Higher mobility results in larger routing overhead and lower throughput. Mobility was only varied as a specific test of 70 nodes (with four levels varying from 10-70 meters per second). Otherwise, the maximum speed was fixed at 10 meters per second.

Table 3.2. Node Mobility

Number of Nodes	Node Speed	Number of Nodes	Node Speed
30 nodes	10 m/s	90 nodes	10 m/s
40 nodes	10 m/s	100 nodes	10 m/s
50 nodes	10 m/s	110 nodes	10 m/s
60 nodes	10 m/s	120 nodes	10 m/s
70 nodes	10 m/s, 20m/s, 30m/s, 40m/s, 50m/s, 60m/s, 70ms	130 nodes	10 m/s
80 nodes	10 m/s	140 nodes	10 m/s

(4) Routing Protocol: Performance test of the S-AODV routing protocol is the goal of this research. Thus the simulation runs the original AODV routing protocol as a baseline (and to obtain the data necessary to build the script required by S-AODV) and then runs the S-AODV routing protocol to compare the performance of the two routing schemes.

(5) Transmission Range: The node’s transmission range is depends on the transmit power. The transmit power is 0.0025W in simulations and the transmission range is 250meters.With the bigger transmission range, the mobile mode is less affected by the node’s mobility [10]. This parameter was held constant throughout the experiment.

3.6.2. Workload

(1) Number of source nodes: The number of source nodes affects the total received data packet in the network. And it also affects the performance of the network.

(2) Packet inter-arrival time: Packet inter-arrival time means how frequently data packet is transmitted at the source node. By varying this parameter, we can very the network workload.

(3) Packet size: Packet size of data traffic is 512 bytes. Routing control packet size are various based on the packet format. AODV routing control packet sizes are defined in [2].

3.7. Factors

(1) Routing protocol
    i. AODV: This routing protocol is the basic protocol of the simulation.
    ii. S-AODV: This protocol is designed to use pre-simulated data to update routing table before route discovery process is initiated.

(2) Number of Nodes
    i. Network sizes are from 30 nodes to 90 nodes for 900 second simulation time. Network size from 100 nodes to 140 nodes is used for 300 second simulation time. The simulation is unable to run longer with more nodes due to memory constraints.

(3) Ratio of moving nodes to stationary nodes.

    i. The ratio of the moving nodes to stationary nodes is fixed - half of the total nodes are mobile.

(4) Node speed

    i. For the 70 node network, node speed has seven levels as 10m/s, 20m/s, 30m/s, 40m/s, 50m/s, 60m/s, and 70m/s. Otherwise, all scenarios have a node speed of 10 m/s.

(5) Traffic load

    i. Four different traffic load levels (0.25pps, 0.5pps, 1pps, and 2pps) are used for 70 nodes.
    ii. Total 50 pps traffic load is used for various network sizes.
    iii. 1pps is used for various network sizes.

3.8. Evaluation Technique

This research used a simulation model as an evaluation technique among measurement, simulation and analytical model. The most accurate evaluation technique is the measurement model but it is infeasible to build such a network for purposes of this research. Moreover, it is difficult to measure accurate results because of many environmental factors. Analytical models are infeasible for this level of complexity. Thus, the simulation model is the most adequate evaluation technique. This research is evaluated using OPNET version 12.0.

OPNET has MANET protocol models like AODV, DSR, and TORA. Among the MANET models we used AODV model, although it is assumed that any other MANET protocol would be suitable for this comparison, provided a scripted version of the protocol could be constructed, as was done in the case of AODV by extending the AODV model. The S-AODV routing protocol follows most of the AODV protocol model except for the additional step of building a scripted plan and avoiding route discovery and hello message exchanges as much as possible.

3.9. Experimental Design

Usually full factorial experiment design is used to verify the research. However the full factorial experiment design is not used for this research. To get a result for one experiment scenario, it takes 1 hour for small network size and 3-5 hours for big network size. Due to this time limitation, we designed the experiment using four classes as follows: First, class A, 1pps is used for various network sizes with 10m/s node speed. Second, class B, the total network data rate is fixed as 50pps (by varying the data rate per node) in various network sizes. Third, class C, seven levels of node speed are varied (with a constant network size of 70 nodes). Fourth, class D, network size is held constant at 70 nodes, node mobility is held constant at 10 m/s, and the data rate per node is varied (0.25pps, 0.5pps, 1pps, and 2pps) to examine the effect of increasing data rate.

Each experiment requires three simulation executions; First to create the "script" data, then baseline AODV, and finally S-AODV. Thus total 87 experiments have to be run. Tables 3 and 4 illustrate how these various experiments are grouped into the 4 classes. An “X” indicates that an experiment is part of that class.

Table 3.3. Experiment Design

Number of Nodes	Simulation Time	Node speed	Data Packet Rate per Node (Packets per Second)	A	B	C	D
30	900 seconds	10m/s	1 pps	X			
			1.667 pps		X		
40	900 seconds	10m/s	1 pps	X			
			1.25pps		X		
50	900 seconds	10m/s	1 pps	X			
60	900 seconds	10m/s	1 pps	X			
			0.833 pps		X		
70	900 seconds	10m/s	0.25 pps				X
			0.5 pps				X
			0.714 pps		X		
			1 pps	X		X	X
			2 pps				X
		20m/s	1 pps			X	
		30m/s	1 pps			X	
		40m/s	1 pps			X	
		50m/s	1 pps			X	
		60m/s	1 pps			X	
		70m/s	1 pps			X	
80	900 seconds	10m/s	1 pps	X			
			0.625 pps		X		
90	900 seconds	10m/s	1 pps	X			
			0.556 pps		X		
100	300 seconds	10m/s	0.5 pps		X		
110	300 seconds	10m/s	0.455 pps		X		
120	300 seconds	10m/s	0.417 pps		X		
130	300 seconds	10m/s	0.385 pps		X		
140	300 seconds	10m/s	0.357 pps		X		

Table 3.4. Experiment Classes

Class	Mobility	Network Size	Network Data Rate
A	Equivalent	Increasing	Increasing
B	Equivalent	Increasing	Constant
C	Increasing	Constant	Constant
D	Equivalent	Constant	Increasing

3.10. Summary

There are many MANET routing protocols to reduce the routing traffic and increase the throughput. The Scripted Assisted Ad-hoc On-Demand Distance Vector routing protocol is designed to solve this problem using pre-simulated data during routing discovery process. Adding extra step for routing discovery process, S-AODV attempts to reduce the routing discovery time and routing traffic. Also it is expected that the overall throughput is improved.

In this chapter, we outlined the methodology which is used to test the performance of S-AODV compared with AODV. The system boundary, performance matrix, parameters and factors are identified. Also the experiment design for this research is detailed.

IV. Analysis and Results

4.1. Overview

This chapter presents the results and performance analysis of the AODV and S-AODV routing protocols. Section 4.2 shows the validation of the S-AODV routing protocol compared with the AODV routing protocol, and the data collection methods of the experiments. Section 4.3, 4.4, 4.5, and 4.6 analyze the results of this research for route discovery time, routing traffic received, throughput, end-to-end delay, and good-put ratio. Section 4.7 introduces the simulation constraints.

4.2. Routing Protocol Validation / Data Collection Method

To validate the Script-assisted AODV (S-AODV) Routing Protocol we compared the performance with the Ad Hoc On-Demand Distance Vector Routing Protocol. The experiments were simulated with the OPNET 12.0 module.

To run the S-AODV routing protocol a pre-simulated plan has to be obtained. To get the pre-simulated plan, we run a scenario with AODV protocol and collect the routing data. To collect the data, the hello inter-arrival time is modified from a uniform distribution (1, 1.1) to (0.5, 0.6) to get more explicit data. The parameters of AODV routing protocol and S-AODV routing protocol are all the same.

The experiments are designed based on four factors. The first factor is the protocols which are AODV and S-AODV (all experiment classes). The second is the network sizes which are 30, 40, 50, 60, 70, 80, and 90 nodes (experiment classes A and B). The third factor is node speed (only varied for networks of size 70 nodes, experiment class C). 10m/s, 20m/s, 30m/s, 40 m/s, 50 m/s, 60 m/s and 70 m/s speed are used for node in this research. Next, the levels for offered load are varied (0.25, 0.5, 1, and 2 packets per second (pps), experiment class D). The results for route discovery time, routing traffic received, throughput, end-to-end delay, and good-put ratio are collected and compared in the experiments.

4.3. Route Discovery Time Analysis

The route discovery is the time from the point of route need to the point of starting sending packets after route protocol updates its routing table. In this context of this research, shorter route discovery time implies better performance. S-AODV and AODV routing protocol are analyzed for each factor.

It is expected that the route discovery time for S-AODV would be shorter than the route discovery time for AODV in all scenarios. The expectation can be explained by the fundamental concept of S-AODV routing protocol. The route discovery time is the time from when a route to a given destination is needed at a given node to the moment at which packets begin to be sent to that destination after the routing protocol updates the local routing table. To find the route, AODV routing protocol performs the route discovery process if there is no route to a destination in its routing table. However, S-AODV routing protocol looks up in the scripted plan first to find a route if there is no route in its routing table. If there is an appropriate scripted path and the required next hop neighbor node is available, then it updates its routing table. It does take only little time in this process because every event is taken only in the node’s memory. Thus the S-AODV has less route discovery time than the AODV routing protocol if S-AODV has appropriate pre-simulated plan.

4.3.1. Route Discovery Time vs Maximum Node Speed

As expected, S-AODV enjoys significantly shorter route discovery times than AODV as demonstrated in Figure 4.1. The figure, derived from class C experiments, indicates that at each speed level S-AODV has a lower average route discovery time.

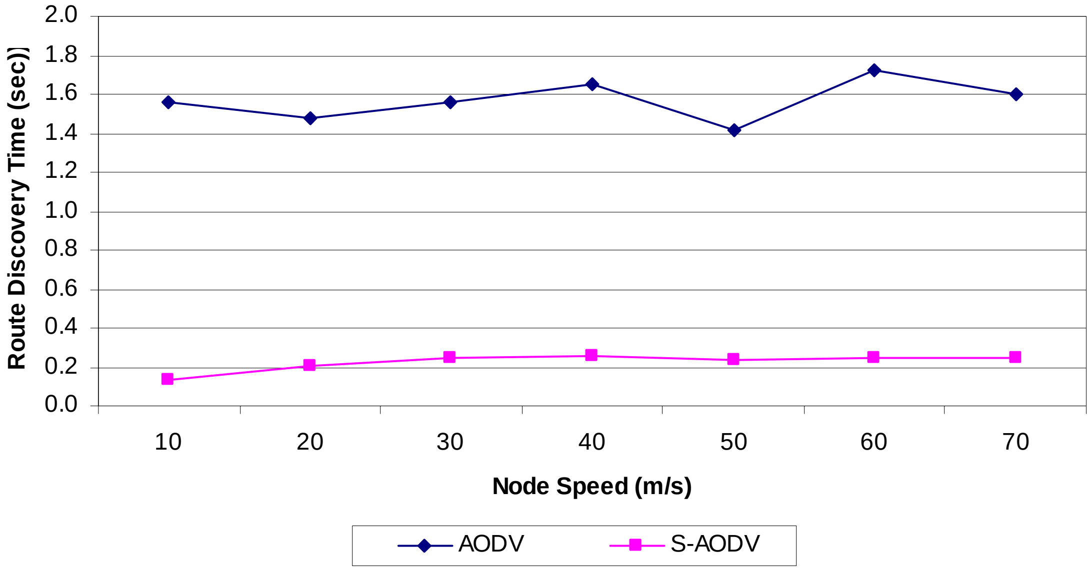

Figure 4.1: Route Discovery Time vs Node Speed

4.3.2. Route Discovery Time vs Offered Load

Figure 4.2, constructed from class D experiments, shows that S-AODV has good performance in various offered load levels. Also the figure indicates that the difference of route discovery time between two routing protocol becomes bigger when the offered load increases. If there are more packets to transmit destined different nodes, more route discovery processes will be performed. That’s why the overall route discovery time in both routing protocol increases when there are more traffic packets to send. However, when there are more route discovery processes the S-AODV routing protocol would take an advantage of its unique step for route discovery process. That's why the difference between two routing protocol becomes bigger in bigger offered load.

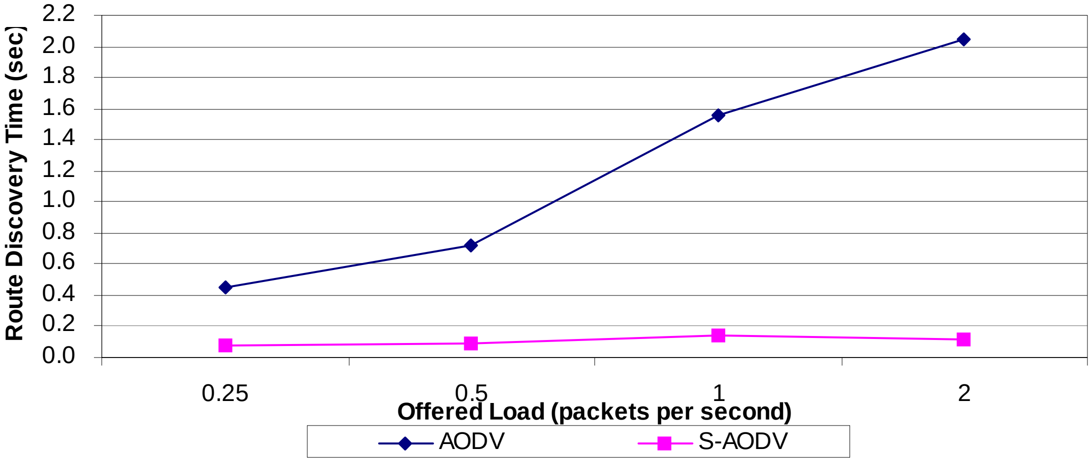

Figure 4.2: Route Discovery Time vs Offered Load

4.3.3. Route Discovery Time vs Network Size-varying Traffic Load

It was expected that S-AODV would enjoy lower route discovery times than the AODV routing protocol under any circumstance. Figure 4.3, displaying results from class A experiments, supports this expectation.

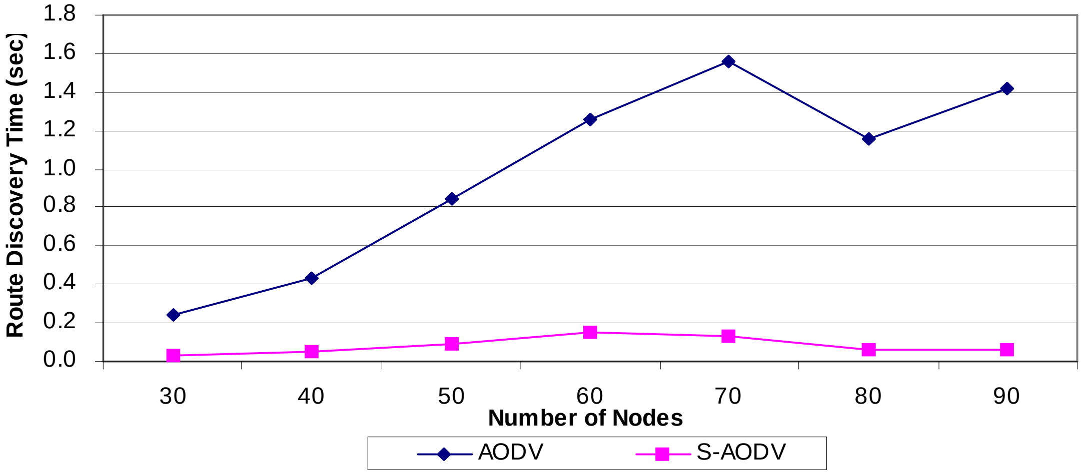

Figure 4.3: Route Discovery Time vs Network Size-varying Traffic Load

Increasing network size appears to require longer route discovery time in AODV. However S-AODV remains relatively constant. Figure 4.3 shows an anomaly at 80 nodes which can be explained by simply having a single lucky mobility scenario. Additional experiments utilizing differing mobility patterns ought to smooth out a graph like that shown in Figure 4.3.

4.3.4. Route Discovery Time vs Network Size-uniform Traffic Load

Figure 4.4, collected from class B experiments, shows the route discovery time versus network size while maintaining a constant total network traffic load. The total traffic load of each network is same as 50 packets per second. The route discovery time of S-AODV is always smaller than the route discovery time of AODV as expected.

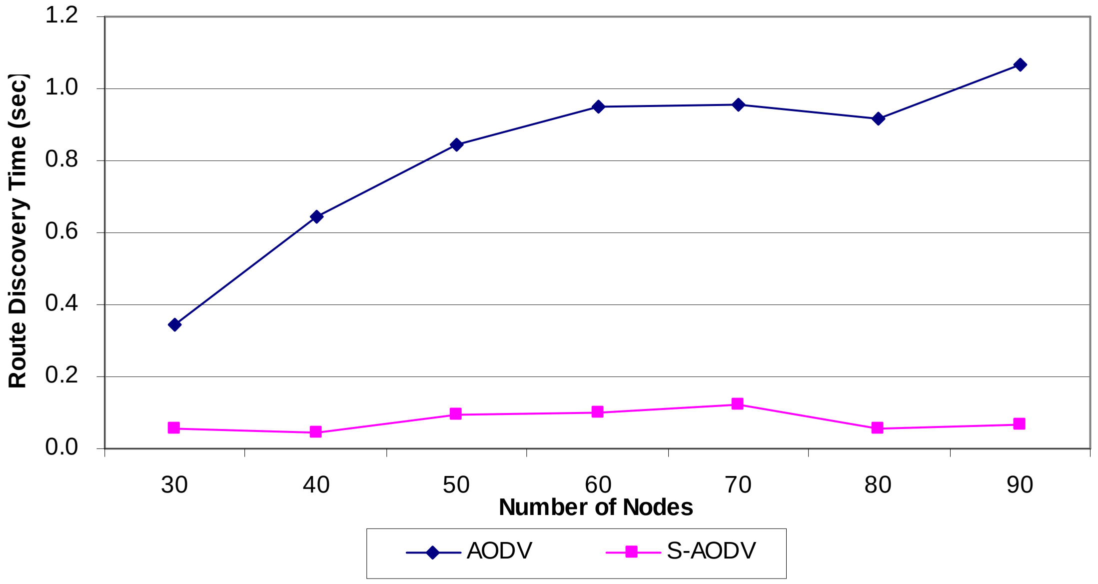

Figure 4.4: Route Discovery Time vs Network Size-uniform Traffic Load

4.4. Routing Traffic Analysis

Also, the similar trend is seen in route traffic analysis. S-AODV has fewer route request needs because it has pre-simulated plan to find the requested route first. Less route discovery process will cause less routing traffic included Route Request Packets (RREQs) and Route Reply Packets (RREPs). So the S-AODV routing protocol has less overall routing traffic than AODV routing protocol. This advantage can be bigger in MANET environment because the MANETs have a limited bandwidth and less routing traffic implies more room for bandwidth of data traffic packets.

4.4.1. Routing Traffic Received Rate vs Maximum Node Speed

It is expected that the routing traffic for S-AODV would be smaller than that for AODV. Also more routing traffic for both routing protocols is expected in faster network environment. Figure 4.5 supports the first claim. However it also indicates that a faster network environment doesn’t imply more routing traffic. The results show that the routing traffic received data rate remains relatively constant in various nodes speeds.

The unexpected result can be explained by the routing traffic load. For AODV routing protocol, the routing traffic is already fully loaded in slow speed network which has 10500 packets/sec routing traffic rates. Thus the routing traffic received rate doesn’t change much when the topology changes rapidly.

Figure 4.5 indicates that S-AODV may be more sensitive to node speed than AODV.

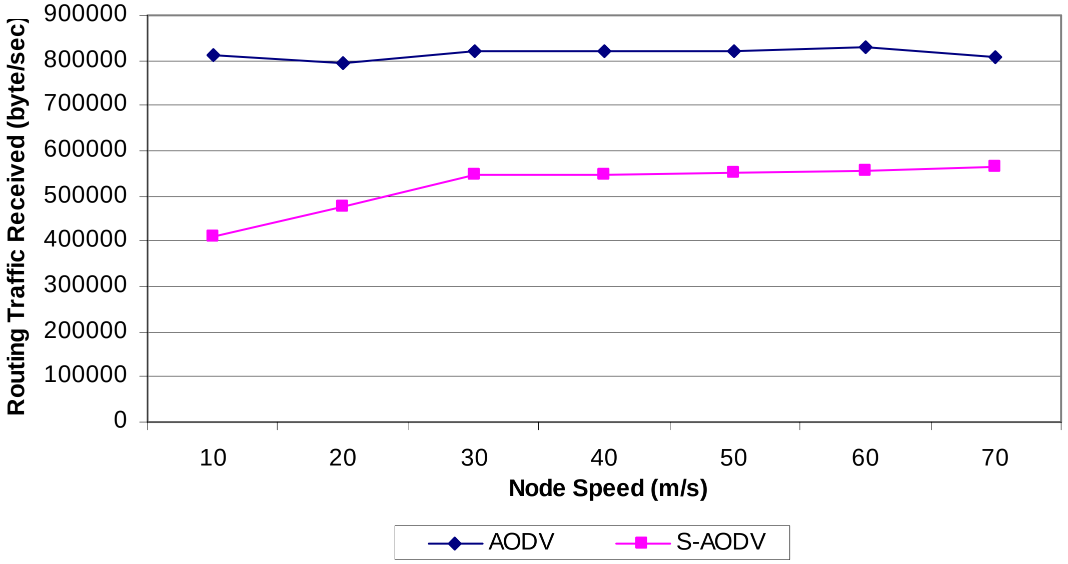

Figure 4.5: Routing Traffic Received Rate vs Node Speed

4.4.2. Routing Traffic Received Rate vs Offered Load

The routing traffic for S-AODV is always smaller than that for AODV as we expected. The offered load effects on the routing traffic however it doesn’t have simple relationship like direct proportion or inverse proportion. The routing packet received in 2pps for AODV and S-AODV is smaller than the one in 1pps and 0.5pps. This can be explained by the characteristics of AODV/S-AODV routing protocol maintenance. When the node set up the route each route has lifetime for certain period. The route is expired after lifetime period and the packet cannot use that route anymore. If there is another packet after that, then the node must initiate the route discovery process. However if there is a packet which uses that route before its expiration, then the route’s lifetime is extended. For subsequent packets, the node doesn’t have to initiate any route discovery process. In 2pps network environment, it might be enough traffic to maintain the existing routes for the future packets. And that’s why it has less routing traffic received than others.

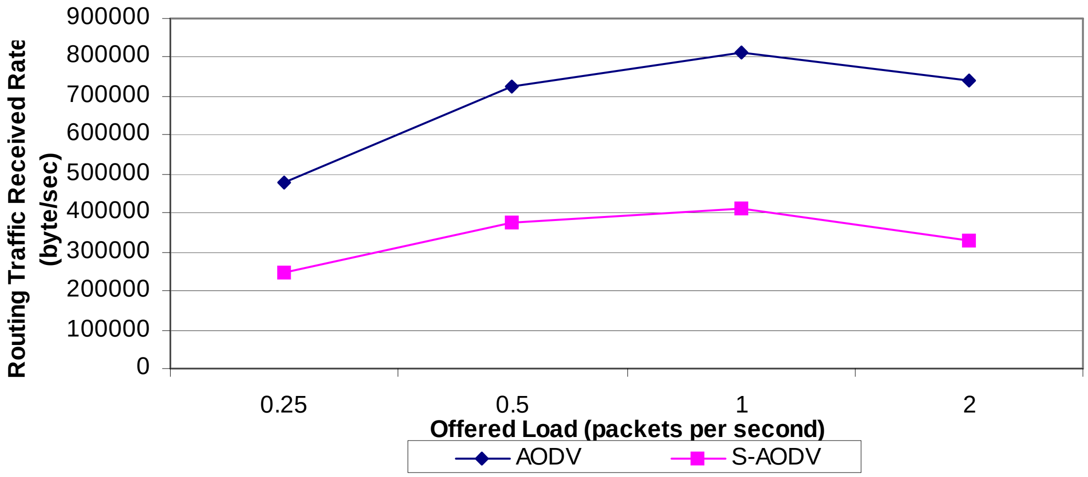

Figure 4.6: Routing Traffic Received Rate vs Offered Load

4.4.3. Routing Traffic Received Rate vs Network Size-varying Traffic Load

The result in Figure 4.7 shows that our expectation is true in various network sizes. The routing traffic for S-AODV is always lower than the routing traffic for AODV.

Figure 4.7 shows other interesting feature for both AODV and S-AODV. The routing traffic increase when the network size increases. Note that S-AODV always requires less routing traffic than AODV. The actual amount of routing traffic is somewhat dependent on the specific mobility scenario.

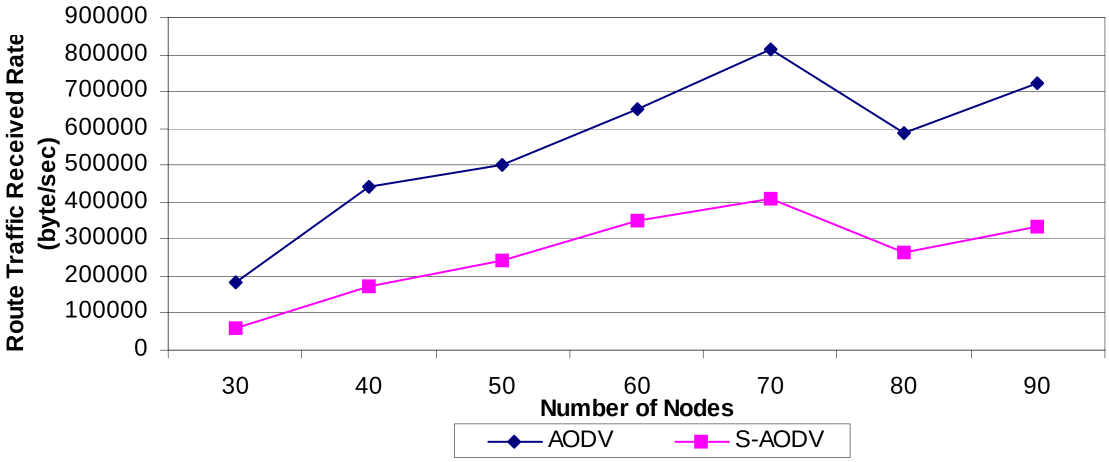

Figure 4.7: Routing Traffic Received Rate vs Network Size-varying Traffic Load

4.4.4. Routing Traffic Received Rate vs Network Size-uniform Traffic Load

S-AODV routing protocol has less routing traffic than AODV routing protocol as we expected.

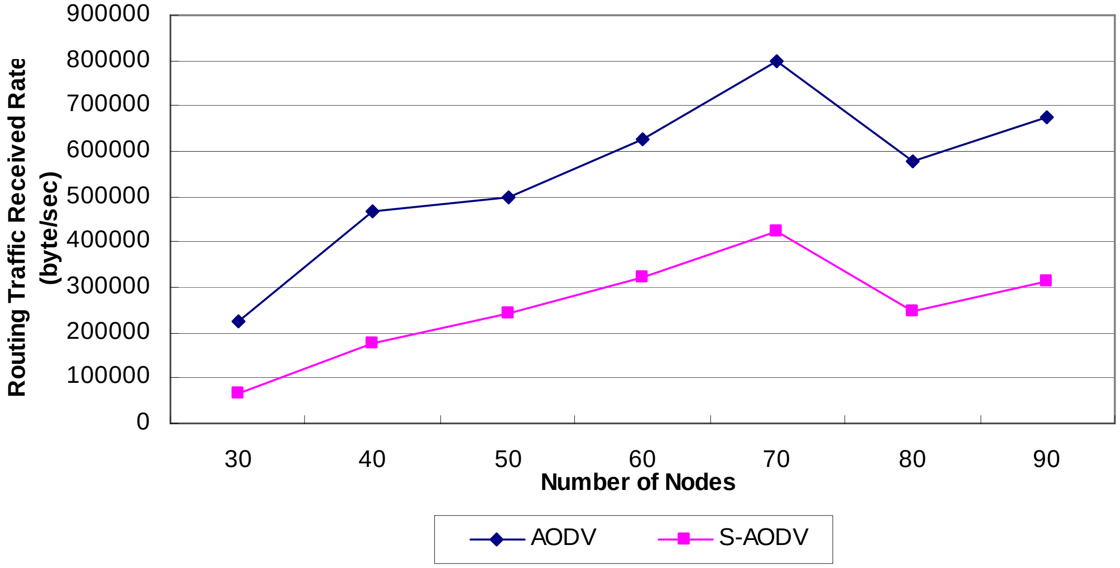

Figure 4.8: Routing Traffic Received Rate vs Network Size-uniform Traffic Load

4.5. End-to-End Delay Analysis

The route discovery time affect packet’s end-to-end delay because the end-to-end delay includes the route discovery time and total packet delivery time from a source to a destination. Thus we expected that the end-to-end delay of S-AODV protocol is lower than AODV’s one.

4.5.1. End-to-End Delay vs Maximum Node Speed

The end-to-end delay of S-AODV is smaller than the one of AODV as we expected. Also the end-to-end delay looks like increased when the speed increases except 20m/s node speed. This exception may be caused by the insufficient experiments.

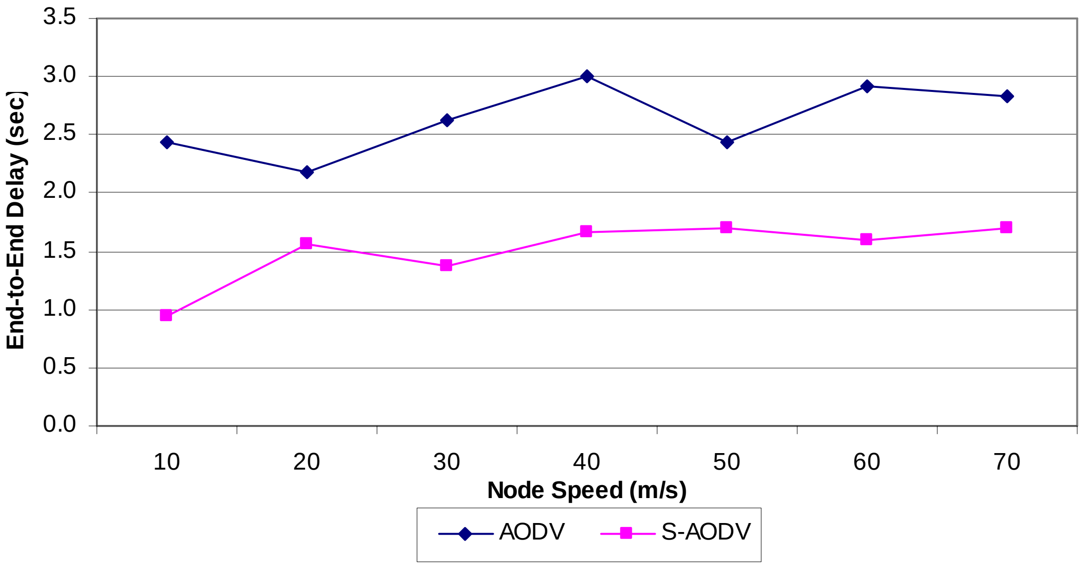

Figure 4.9: End-to-End Delay vs Node Speed

4.5.2. End-to-End Delay vs Offered Load

Figure 4.10 shows that the end-to-end delay for S-AODV routing protocol is always smaller than the end-to-end delay for AODV routing protocol. This is the result that we expected because fast route discovery time can reduce the packet's end-to-end delay.

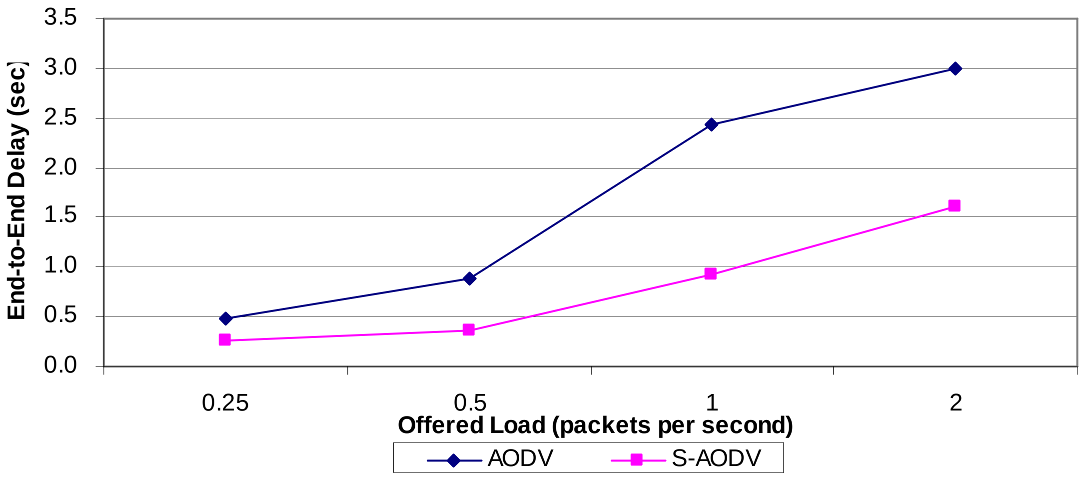

Figure 4.10: End-to-End Delay vs Offered Load

4.5.3. End-to-End Delay vs Network Size-varying Traffic Load

In Figure 4.11, the end-to-end delay for S-AODV is always smaller than the end-to-end delay for AODV. Also it shows the same trend as route discovery time in Figure 4.3. This is because that the end-to-end delay includes the route discovery time.

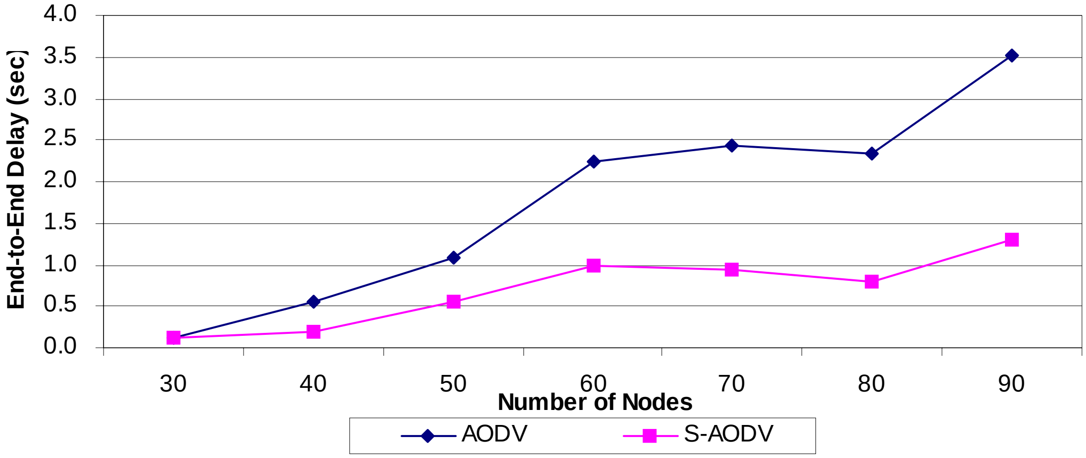

Figure 4.11: End-to-End Delay vs Network Size-varying Traffic Load

4.5.4. End-to-End Delay vs Network Size-uniform Traffic Load

The routing traffic of S-AODV is almost a half of the routing traffic of AODV. This result is expected since S-AODV reduces generating RREQs using pre-simulated data.

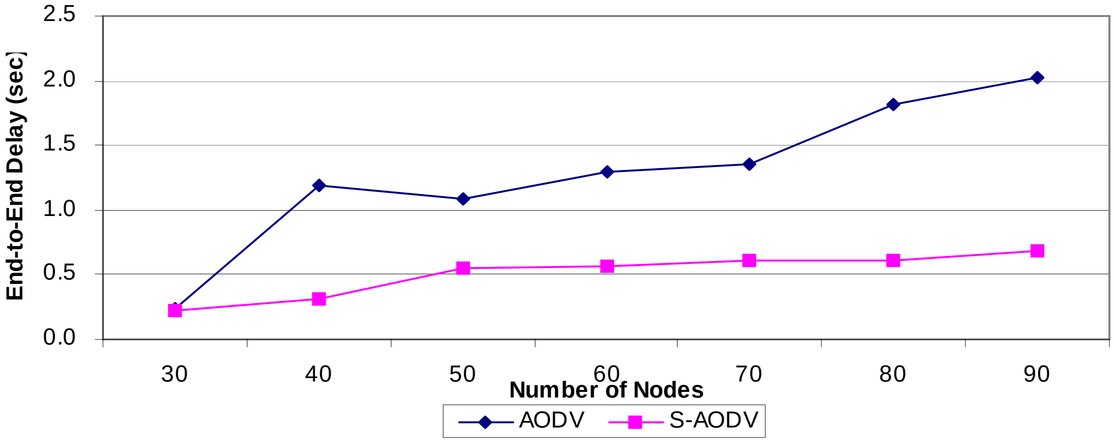

Figure 4.12: End-to-End Delay vs Network Size-Uniform Traffic Load

4.6. Throughput Analysis

The throughput for this research is measured by the number of traffic received divided by traffic sent. Lower end-to-end delay usually implies the higher throughput. If the route failures, then a node initiates a new route discovery process using local repair. During the local repair the packets is queued and this results longer delay. Thus we expected the better throughput of S-AODV routing protocol than AODV routing protocol.

4.6.1. Throughput vs Maximum Node Speed

Figure 4.13 shows that the throughput decrease when the node speed increase. Traffic received of S-AODV decreases when the speeds increase. But the traffic received for AODV decreases only a little. This can be explained by the pre-simulated plan failure. If the node speed becomes faster, then it is getting hard to catch the correct plan.

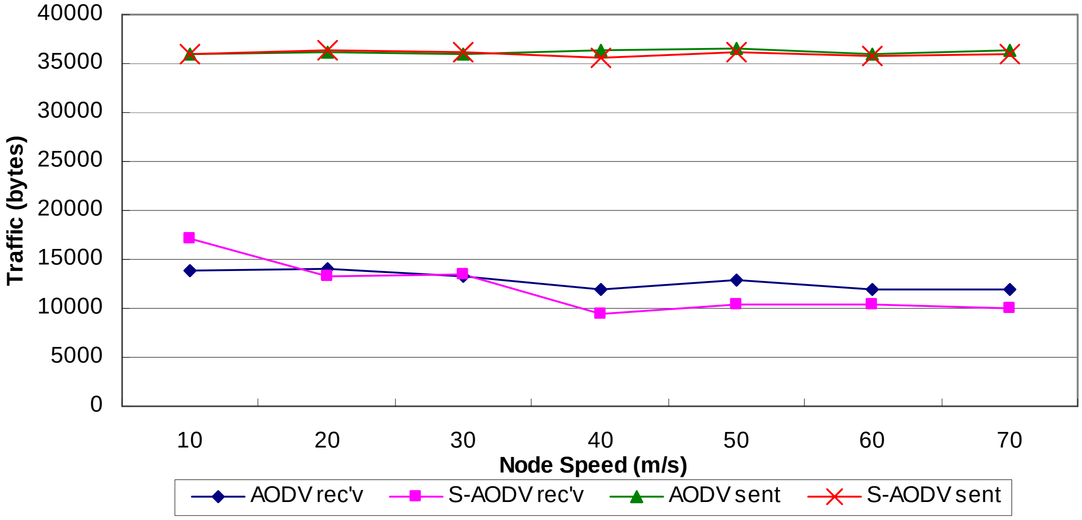

Figure 4.13: Throughput vs Node Speed

4.6.2. Throughput vs Offered Load

The throughput slightly decreased when the node speed became faster in Figure 4.14. Also figure shows that S-AODV is more responsive to the offered load than AODV.

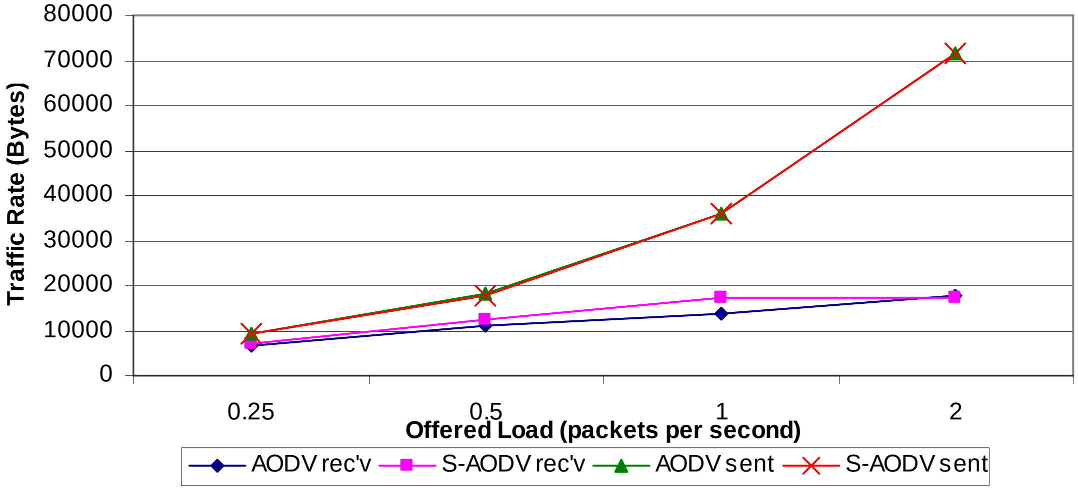

Figure 4.14: Throughput vs Offered Load

4.6.3. Throughput vs Network Size-varying Traffic Load

Figure 4.15 shows that the throughput of S-AODV is higher than the throughput of AODV. But the throughput of S-AODV is lower than the throughput of AODV in 30 nodes size though S-AODV has always lower end-to-end delay.

The reason for that is because of the failure of transmission between intermediate nodes. If the intermediate node completely fails to transmit packets to the destination or intermediate node, then this effort has no influence on the end-to-end delay. However this transmission failure is counted for the throughput. Thus we can have the results like in Figure 4.15.

The good performance of S-AODV is shown when the number of nodes becomes larger in Figure 4.15. An inefficacy of S-AODV routing protocol is that we didn’t have perfect pre-simulated plan. We didn’t build any mechanism to build the perfect plan. We just used the routing data from AODV routing protocol though it is the reactive routing protocol. The natural inefficacy of S-AODV causes the lower performance in small network. However this inefficacy is not bigger than the weakness of AODV (i.e. large routing traffic overhead and long route discovery time) in the large network.

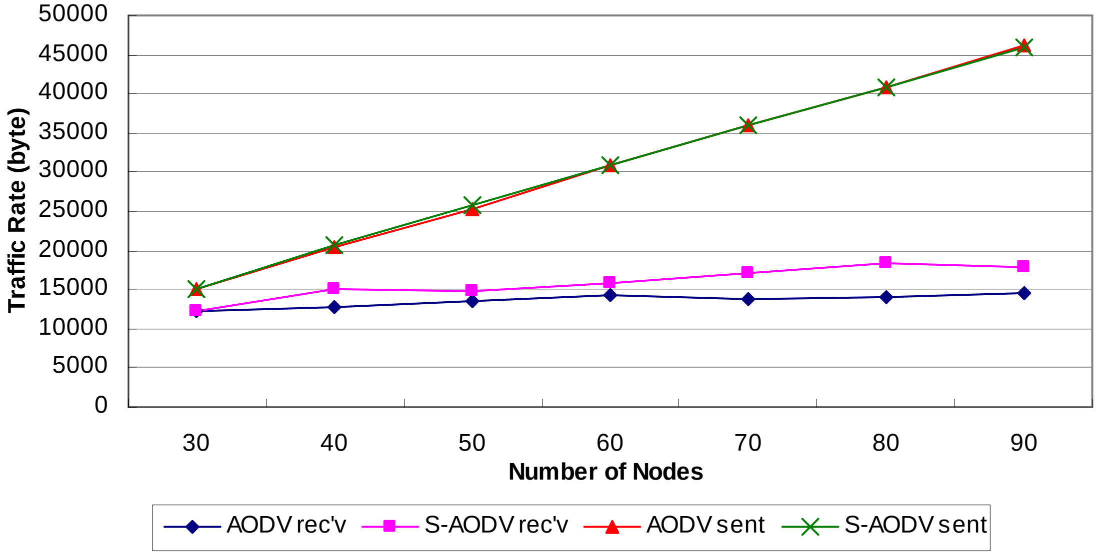

Figure 4.15: Throughput vs Network Size-varying Traffic Load

4.6.4. Throughput vs Network Size-uniform Traffic Load

The throughput of S-AODV is better than the throughput of AODV except for 30 nodes.

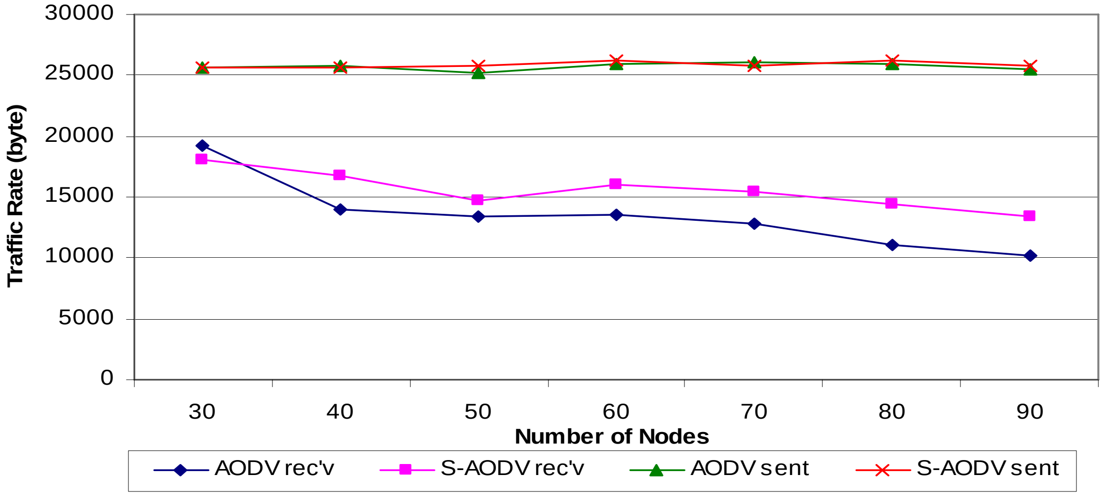

Figure 4.16: Throughput vs Network Size-uniform Traffic Load

4.7. Simulation Constraints

4.7.1. Performance Analysis of S-AODV

The experiments of this research shows that S-AODV routing protocol has better performance in route discovery time, routing traffic received, End-to-End Delay, and Throughput than AODV routing protocol.

However, the throughput performance of S-AODV was not significantly better than AODV. There are two possible reasons for this unexpected result.

One is the failure of pre-simulated plan. As I mentioned above, to obtain the pre-simulated plan we used the AODV routing protocol and collected every routing data. However AODV is an on-demand routing protocol. This means there is no path finding when there is no demand of routing. When we get a pre-simulated plan, each node generates a packet every 0.1second to random destination. But this doesn't mean that the each node have maintained every path to all possible destinations. We cannot guarantee that there was enough route demand to build the perfect pre-simulated plan. If the pre-simulated plan is not perfect, then S-AODV doesn't have the advantage of updating routing table based on the data. The inaccuracy of the plan will cause the extra route discovery time, end-to-end delay, and low throughput.

Let's assume that a source node has wrong pre-simulated plan to the destination. If the neighbor is available, then the source node will transfer the data to the neighbor node without knowing that it's wrong route. The intermediate node may send the packet to other intermediate node based on its plan. But finally the intermediate cannot send the packet to other intermediate node or a destination node because the pre-simulation is wrong. There are two penalties for this failure. First the intermediate may waste the time to transmit the packet to unavailable neighbor. Second is that the intermediate node have to initiate the local repair. Due to these two, S-AODV has inefficiency.

Second reason is the fact that the network size is not big enough. MANET routing protocol has more weakness in a big network compared with a hierarchy routing protocol. It is because of that MANET routing protocol generates more routing traffic than hierarchy routing protocol. The routing traffic of S-AODV is almost half of the routing traffic of AODV. This can be the big advantage in the big network which suffers the limitation of bandwidth. However the experiments for the big network over 90 nodes could not be simulated. The simulation time for the experiment is 900 second. But when the network size increased over 90 nodes, the system could not support the memory for the scenario which is for generating pre-simulated plan. Figure 4.17 shows the total memory used for the scenarios. The scenarios are aborted when the memory is around 2,000 MB.

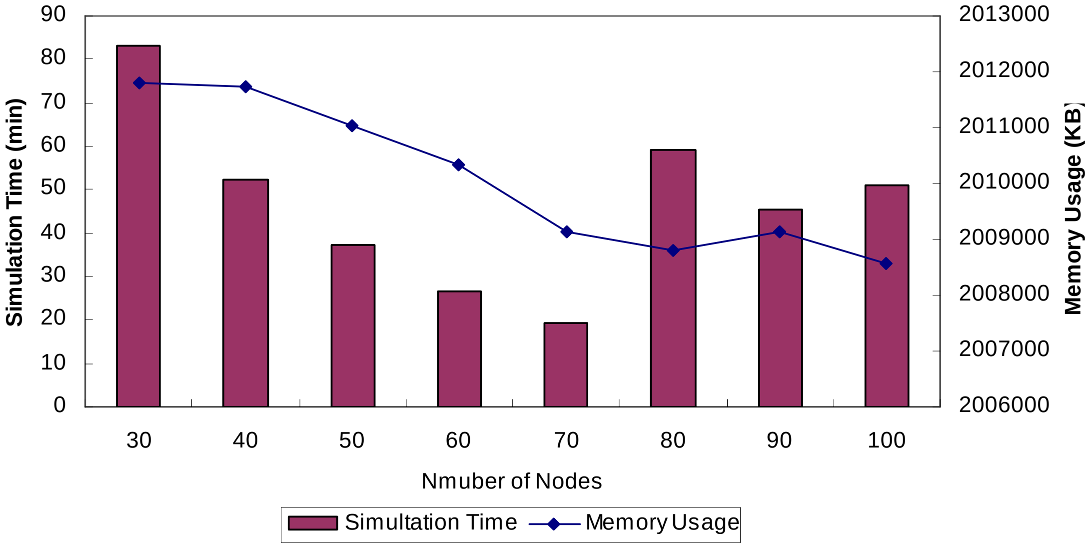

Figure 4.17: Total Memory Usage versus Number of Nodes

Due to these two possible reasons for the unexpected research result, we couldn't get outstanding throughput performance result of S-AODV and we could not simulate in a big network.

4.7.2. Result of Performance in Big Network during 300second

The scenarios over 90 nodes are simulated for 300 seconds simulation time. This short simulation time is to avoid the exhaustion of system memory.

(1) Routing Discovery Time

In Figure 4.18 the route discovery time of S-AODV is better than the route discovery time of AODV. Also over route discovery time is increased when the number of node become bigger.

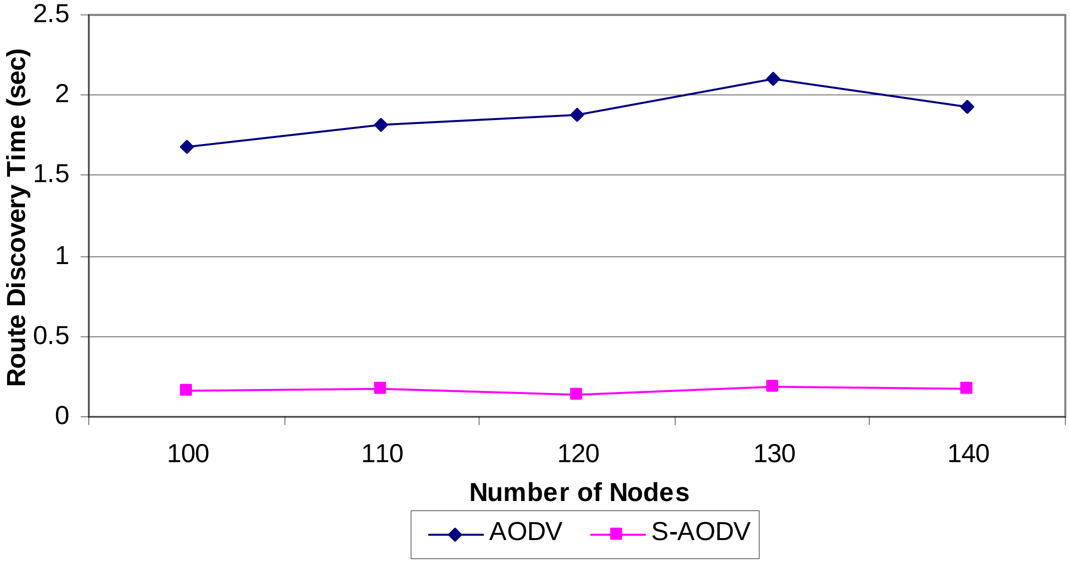

Figure 4.18: Route Discovery Time vs Network Size (Big network)

(2) Routing Traffic Received

Figure 4.19 shows that AODV generates more routing traffic than S-AODV. This result was expected in previous section and can be explained the characteristic of S-AODV.

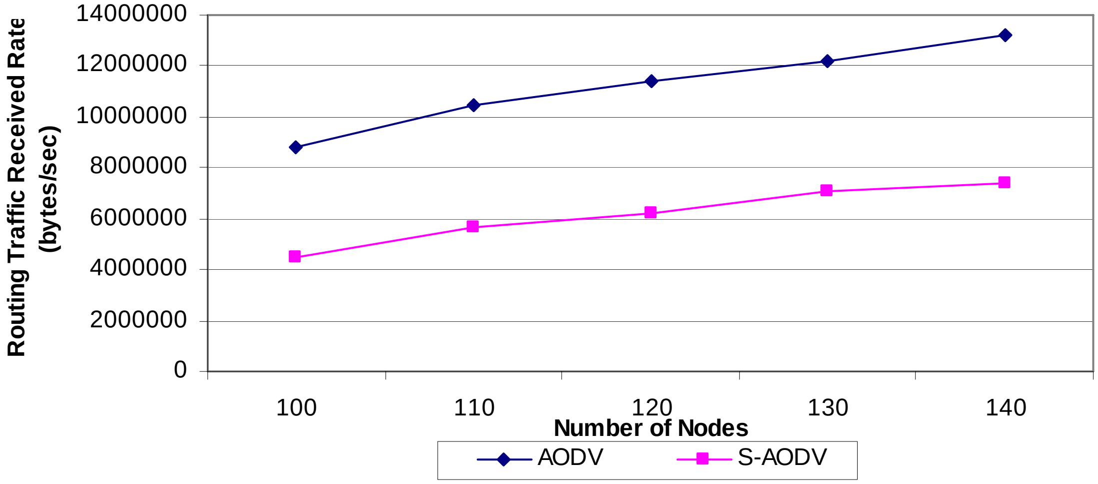

Figure 4.19: Routing Traffic Received Rate vs Network Size (Big network)

(3) End-to-End Delay

In Figure 4.20, we can figure out that S-AODV routing protocol has better performance than AODV in end-to-end delay field.

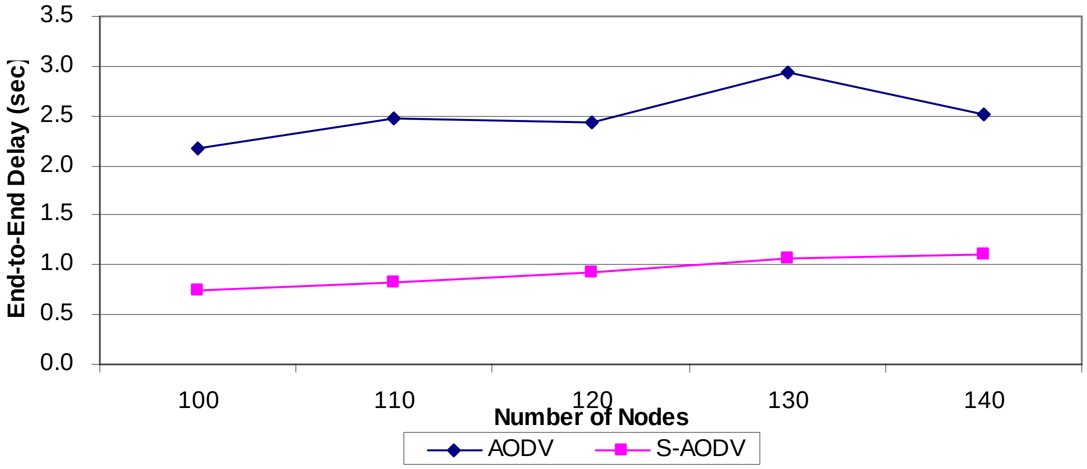

Figure 4.20: End-to-End Delay vs Network Size (Big network)

(4) Throughput

The network of S-AODV routing protocol has better throughput than the network of AODV routing protocol. Also the received traffic is slightly decreased when the number of node increase.

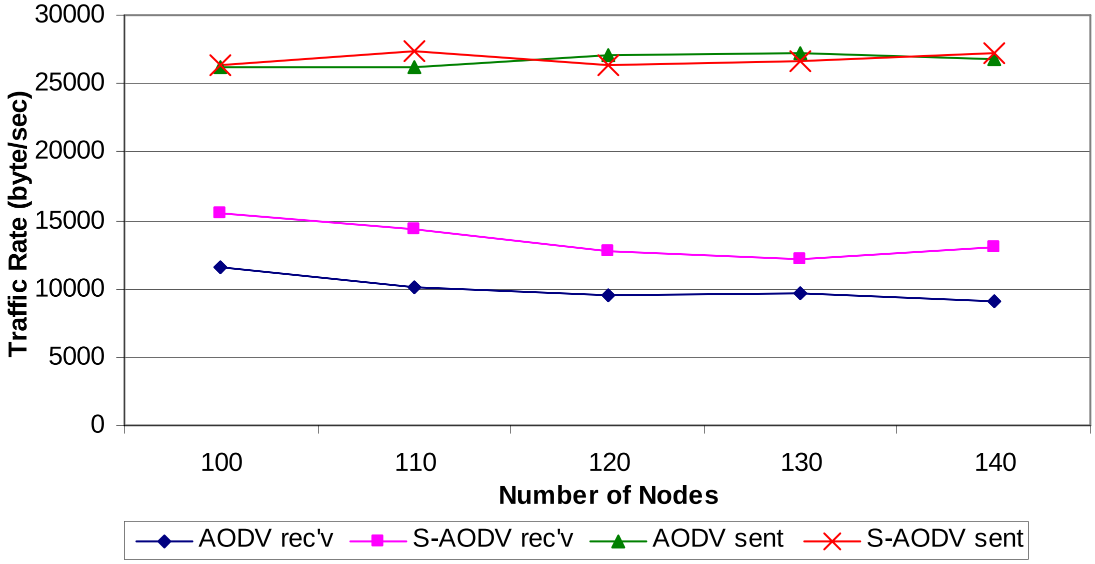

Figure 4.21: Throughput vs Network Size (Big network)

4.8. Summary

This chapter provides the results of the experiments that are defined in chapter 3. Script-assisted AODV is designed to generate lower routing traffic and to have less route discovery time than a typical Ad hoc routing protocol. The results of this research show that S-AODV has better performance for routing traffic, route discovery time and end-to-end delays than AODV though S-AODV has fewer throughputs when the data traffic increases.

V. Conclusions and Recommendations

5.1. Chapter Overview

In this chapter, we summarized the results of this research. First the conclusion of research is explained. Next the contribution of this research is outlined. Finally the recommendation for future search is detailed.

5.2. Conclusions of Research

To examine the performance of S-AODV routing protocol, we compared the statistics with AODV routing protocol. The statistics include routing traffic received rate, route discovery time, end-to-end delay and throughput.

The results of this research show that S-AODV is not efficient at throughput when the node speed increases and the traffic load increases. However S-AODV has less routing traffic, lower end-to-end delay, and lower route discovery time in every case of the experiments. Also the throughputs of S-AODV were better than AODV except some scenarios that have fast node speeds or heavy traffic loads.

5.3. Significance of Research

The primary contribution of this research is that we verify whether the concept of using pre-simulated data for route discovery is useful or not. Adapting the new concept to the existing MANET routing protocol, we obtain the better performance for routing traffic, route discovery time, and end-to-end delay. The advantage of this new concept routing protocol (S-AODV) becomes bigger in MANETs because MANETs suffer from the limitation of bandwidth and less routing traffic gives more available bandwidth of wireless network.

5.4. Recommendations for Future Research

There are some areas for future research. First, new optimal algorithm to build the efficient pre-simulated plan is needed. For this research, we used the AODV routing protocol and try to record every routing table change possible to get a pre-simulated plan. However, due to the on-demand characteristics and the latencies in the RREQ and RREP processes, AODV does not produce a perfect record for network topology change. Also, the pre-simulated plan which is used for this research has big file size (i.e. the total pre-simulated data size for 70 nodes is almost 490 MB) because no optimal process was performed. The more efficient algorithm for pre-simulated plan will give better performance to S-AODV. Also it will reduce the pre-simulated plan size.

Other area for future research is to test S-AODV routing protocol in bigger network size. S-AODV is designed to reduce the routing traffic. Thus its advantage can be bigger in the big network. However, due to the limitation of hardware memory problem the experiment over 140 nodes was not tested. If this problem can be solved by using different machine, then more reliable experiment could be performed.

5.5. Summary

Mobile Ad Hoc Networks is easy to deploy and it is the solution for mobile network. However it has bandwidth limitation due to wireless characteristics. Script-Assisted AODV routing protocol is designed to reduce this limitation by using pre-simulated plan.

Simulation results of this research reveals that S-AODV shows better performance in reducing routing traffic, route discovery time, end-to-end delay, and throughput except certain exceptional environment.

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14. ABSTRACT

Mobile Ad Hoc Network (MANET) routing protocols provide routing solutions in mobile wireless networks, without assuming any prior knowledge of topology nor any prediction of future topology. However, the resulting routes suffer from delay and consume precious bandwidth. Perfectly scripted routing could theoretically be optimal, (i.e., introduce no delay and cost no additional bandwidth), but would naturally be very fragile. This thesis explores a merging of these approaches, following a routing script if and when available, but reverting to a robust recovery approach otherwise.

Script-Assisted Ad Hoc On-demand Distance Vector (S-AODV) routing protocol is designed to take advantage of prior knowledge of topology to improve performance in a MANET, better utilizing available bandwidth. S-AODV uses pre-simulation to build a script to substitute for the route discovery process, avoiding delay and bandwidth penalties. Before sending any Route Request Packets (RREQs) to find a route, S-AODV consults the script. If the data exists, it updates the routing table. If not then it broadcasts RREQs like AODV routing protocol. Using this approach, S-AODV enjoys reduced the routing traffic and route discovery times.

S-AODV is compared with Ad Hoc On-demand Distance Vector (AODV) routing protocol. S-AODV provides better performance in reducing routing traffic, route discovery time, and end-to-end delay. Also, S-AODV has better throughput in most scenarios except the environment in fast movement or heavy traffic loads.

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