A Scalability Study of Mobile Ad Hoc Networks Routing Protocols

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***Abstract*-Mobile ad hoc networks are self-organizing data networks, which perform routing at each end-user node rather than using the services of a centralized controller. This allows them to be employed in areas where an infrastructure (or a coordinator) is not available, such as the dynamic battlefield and disaster relief environments. One challenge in such networks is to develop a routing strategy, which performs consistently under different network scenarios, such as different levels of traffic, mobility and different number of nodes. A number of different routing protocols have been proposed. These protocols are based on the traditional Link-State and Distance Vector algorithms. Other strategies have also been proposed which use the services of a GPS to help in performing route discovery. In this paper, we investigate the behavior of a number of different routing protocols under different network scenarios. We also discuss which protocols will scale better in large networks and suggest a number of different improvements, which can further increase the scalability.**

I. INTRODUCTION

Mobile Ad Hoc networks are considered to be useful in areas where an infrastructure is not available or cannot be used. Two examples of such places are disaster relief and the battlefield environment. In disaster relief areas, the emergency search and rescue team may need to coordinate their efforts to rescue the victims of disasters as quickly possible. Similarly, in the battlefield environment, a coordinated effort between different types of forces is required in order to implement a successful striking strategy. In both examples, discussed above, mobile ad hoc networks can be used to achieve the coordination required in order to provide efficient communication between all users in the network [1].

However, before mobile ad hoc networks can be successfully implemented in the scenarios described above, a number of critical issues need to be resolved. Mobile ad hoc networks have a number of limitations when compared to fixed or wired networks. These limitations include: Bandwidth, Power supply and Storage space. Other constraints, which need to be addressed in mobile ad hoc networks include: QoS, Security, Dynamic topology and Scalability.

The aim of this paper is to investigate the scalability of mobile ad hoc networks under different network conditions. The experiments conducted will investigate the effect of increasing the network traffic and the number of intermediate nodes in the network under a number of different routing protocols. The obtained results will illustrate which routing strategies will perform consistently as the size and the density of traffic and nodes increase. This will then highlight a number of desirable routing characteristics for designing a scalable routing protocol for mobile ad hoc networks.

This paper is organized as follows. The following section describes the different routing strategies introduced for mobile ad hoc networks. Section III describes the functionality of the routing protocols used in the simulation. Section IV describes the simulation environment used. Section V presents the simulation results and their interpretation. This is then followed by the conclusions of the paper.

II. ROUTING STRATEGIES

The limited resources in mobile ad hoc networks has made designing of an efficient and reliable routing strategy a very challenging problem. An intelligent routing strategy is required to efficiently use the limited resources while at the same time being adaptable to the changing network conditions such as: network size, traffic density and network partitioning. In parallel with this, the routing protocol must provide different levels of QoS for different types of applications and users.

A number of routing protocols have been designed for mobile ad hoc network to address these issues. These protocols can be classified into three categories: Table-Driven, On-demand and Hybrid routing protocols. In Table-Driven (or proactive) protocols each node attempts to maintain routing information to each node in the network. The routing information is stored in different routing tables and updated based on the updating strategy employed. A number of different updating strategies have been introduced for Table-Driven routing protocols. Some common updating strategies include:

- Global & Periodic
- Localized & Periodic
- Mobility Based
- Conditional (or event triggered updates)

The first generation of Table-Driven routing protocols were derived from the traditional LinkState and Distance Vector algorithms, which were designed for wired networks. These protocols maintained and periodically updated their routing tables by exchanging globally propagating control messages. Such protocols include: DBF and DSDV[2]. In order to minimize the number of globally propagated routing packets, Localized updating strategy was introduced in protocols such as GSR[3] and FSR[4]. In GSR, each node exchanges routing information with their neigbours only and in FSR the routes in the fisheye scope [4] are refreshed at a higher frequency than the remote ones. Mobility based updates were introduced in DREAM [5] in an effort to eliminate periodic route updates. This was achieved by making the rate at which the route updates occur proportional to the speed at which each node travels. The advantage of this is that in networks with low mobility this updating strategy may produce lower overhead than the periodic routing update approach. A more recent updating strategy first introduced in STAR [6] is known as conditional (or event-based). With this method, updates are sent only if a certain event occurs. For example when a link becomes invalid or a when new node joins the network.

On-demand (or reactive) routing protocols were introduced to reduce the routing overhead associated with table-driven protocols by determining routes when they are required. When a node requires a route to the destination, it initiates a route discovery procedure, which may send a globally propagating route request packet through the network. Once a route to the destination is found a route reply is sent back to the source. The source selects its route to the destination based on the route selection criteria employed. Some of the currently proposed route selection criteria include:

- Shortest path (DSR [7])
- First fit (CBRP [8])
- Associativity based (ABR [9])
- Signal strength (SSR [10])

In shortest path routing, the source node will select and use the shortest available path to the destination. With first fit route selection, the first available route is chosen. In associativity based route selection, the node with the strongest associativity are chosen in the preferred path to the destination and with signal strength route selection, the intermediate node with strongest signal-to-noise ratio is chosen in the preferred path to the destination.

Hybrid routing protocols behave both reactively and proactively at different times. Two examples of such protocols are ZRP [11] and ZHLS [12]. In these protocols, the network is made up of a number of zones. The network with in each zone is maintained proactively and the routes between zones are determined reactively.

III. DESCRIPTION OF SIMULATED ROUTING PROTOCOLS

In this section, we describe the characteristic features of the FSR, DSR, AODV and LAR1 routing protocols used in our simulations.

A. Fish-Eye State Routing (FSR)

The FSR routing protocol is a direct descendent of the GSR protocol. The improvement offered by the FSR is that it improves the scalability of GSR by updating network information for nearby nodes at a higher frequency than the remote ones. The updating procedure scans through the update message received from the neighbouring nodes and removes the entries that are outside the fisheye scope. Fig. 1 illustrates a typical fisheye scope.

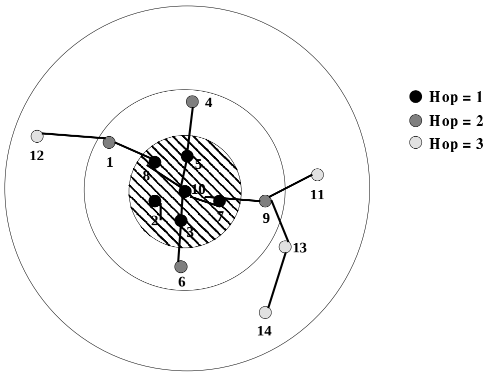


Fig. 1. Fisheye scope

The fisheye scope defines a set of nodes that can be reached within a certain number of hops from the central node [4]. The central node can select the update message from the nodes with the smallest (or given) number of hops and disseminate them into the network. The update messages with greater hop counts are sent at a lower frequency [7].

B. Dynamic Source Routing (DSR)

DSR is based on source routing, where each packet to be sent carries the full address to the destination in its header. Each node along the path towards the destination simply forwards the packets to the next hop indicated in the packet header. All nodes maintain a route cache, where they store the route they have learned. These entries are continually updated, as new routes are discovered [7].

DSR is made up of two phases: route discovery and route maintenance. When a node has data to send, it first checks its route cache to see if it has a route to the required destination. If a route is found, it uses the route to forward the packet to the destination, otherwise it initiates the route discovery mechanism. In route discovery, the source broadcasts a Route Request packet to its neighbours, which contains: the destinations id, source address (own address), and a unique ID. Each node receiving this route request checks its own route cache for a route to the required destination. If it does not know of any routes to the destination, it appends its own address to the route record of the route request packet and broadcasts the query to its outgoing links.

To limit the number of route request propagated, each node only forwards the route request if it already has not seen the packet and its address does not appear in the route record [7].

A route reply is generated when the route request reaches the destination or a node with an unexpired route to the destination in its route cache (in this case the route to the destination is appended to the route record). The route reply can be sent back to the source in one of two ways: If symmetric links are supported, the node can reverse the route in the route record. Otherwise, if symmetric links are not supported, then the responding node initiates its own route discovery procedure and piggy back the route reply on its route request towards the source node [7].

Route maintenance is achieved by generating Route Error and Acknowledgements (ACKs). Route errors are generated when a node detects a fatal error at its data link layer. Each node receiving the route error removes the node (hop) where the error has occurred and all the routes containing that hop from its route cache. ACKs are used to verify the correct operation of the route links. This includes the passive ACKs where each node can hear the next hop forwarding the packet along the route.

C. Ad Hoc on-demand Distance Vector (AODV)

AODV is based on DSDV and DSR. It uses the hop-by-hop routing, sequence numbers and periodic beacons from DSDV while using similar route discovery and route maintenance concept as in DSR [7]. However, unlike DSR, AODV uses routing tables (one per destination) to store the routes it has already learned, and it uses hop-by-hop routing rather than source routing.

In AODV, when a node has data to send, it checks first to see if it has a valid route to the destination. If a route exists, it uses the known route to send the data to the required destination. Otherwise it initiates the route recovery process. In route discovery, the source node broadcasts a route request to its neighbours. The neighbours also broadcast this route request through their outgoing links to their neighbours. This process continues until a route request reaches the destination node or an intermediate node that has a route to the destination. Each node maintains a sequence number, broadcast ID (which is incremented for every route request generated). The sequence number is used to determine the freshest route to a destination and the broadcast ID is used with the node IP address to generate a unique route request. The sequence number, broadcast ID and the most recent sequence number of the destination are appended to the route request packets.

The intermediate nodes with an address to the required destination can only send a route reply if the sequence number associated with the required route is greater or equal to the sequence number in the route request. Each node that forwards the route request creates a reverse route for itself back to the source node. When the destination or a node with the required destination is reached, a route reply is generated which contains the number of hops required to reach the destination and the most recent sequence number seen by the node generating the reply [13].

In AODV route request are maintained by exchanging "hello" messages with intermediate nodes. For example, a node that does not receive three consecutive hello messages from one of its neighbours, will assume that it no longer has a connection with that particular neighbour. It will then send a route reply with an infinite metric to its upstream neighbours to inform them of the broken link [13].

D. Location Aided Routing 1 (LAR1)

LAR introduces a new method of routing which aims to reduce the routing overhead in the traditional flooding algorithm by using location information. The protocol assumes that each node knows its location through a GPS. Two different schemes are proposed in [14]. These are referred to as LAR scheme 1 (LAR1) and LAR scheme 2 (LAR2). The idea behind LAR1 is that if route request packets can only be seen by the nodes in the vicinity of the destination, then significant amount of routing overhead can be reduced in the network [14]. In this scheme, two different zones are defined: Expected zone and Request zone. The expected zone refers to the position of the destination node determined by the source node at a given time t_0, and the request zone refers to the area in which the destination is expected to lie after some elapsed time t_1. Note that the request zone is calculated from the average speed of each node and the time elapsed since the last known location for a given destination was recorded. Figure 2 illustrates an example of the expected zone and the request zone.

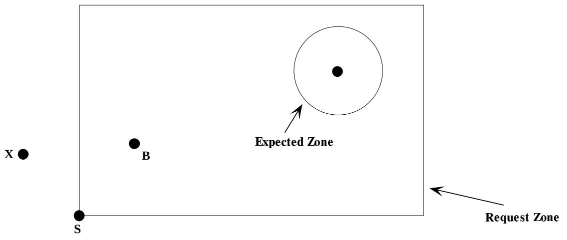


Fig. 2. Expected zones and request zone in LAR1.

In LAR1, when a node initiates route discovery, it includes the request zone in the route request message. The route request is then flooded in the same way as other flooding algorithms such as DSR (described earlier), however the route request packets can only travel through the nodes that are in the request zone (other nodes simply discard the route request). When the destination is reached it sends a route reply in a similar way as the other flooding algorithms. However it also includes its current location in the route reply packet.

IV. SIMULATION MODEL

The GloMoSim Simulation package was used to perform the simulations [15]. GloMoSim is a scalable simulation environment designed to simulate large networks. The simulation models a network of 50, 100 and 200 nodes migrating in a 1000m x 1000m and a 3000m x 3000m boundary. A Two-Ray [17] propagation characteristic was used for the propagation model. The power range was set to 15.0 dBm with antenna height of 1.5m (which corresponds to a transmission of 376m under the Two-ray model) and the data-rate was set to 2Mb/s to comply with the IEEE 802.11 radio interface specification [16]. The capture affect for the radio model was also taken into account. A random way-point mobility model was used with the node mobility ranging from 0 to 20m/s. The pause time was varied from 0 to 1800 seconds and 10 points were used for the chosen range of pause times to clearly indicate the effect of high and low mobility. The simulation was ran for 1800 seconds for every different value of pause time and each value was averaged over eight different independent simulation runs using a different seed.

Constant Bit Rate (CBR) traffic of 10 and 30 random sources was used for our simulation. We used packet sizes of 64 and 512Bytes in different scenarios and each client/server session was set to last for the duration of the simulation.

V. PERFORMANCE METRICS

To evaluate the performance of each routing protocol, the following metrics were used:

- *Packet delivery ratio*: The ratio of the number of data packets sent by the source and the data packets received by the destination.
- *Normalized Routing Load*: The ratio of routing overhead packet sent for each data packet that was successfully transmitted.

The first performance metrics is used to investigate the ability of the routing protocol to transmit data packets between the source and the destination for different values of pause time and as the number of intermediate nodes increase. The second metric is used to investigate the amount of routing overheads transmitted network wide and per data packet for each routing protocol.

VI. SIMULATION RESULTS

This section provides a discussion on the simulation results measured for the chosen routing protocols using the simulation parameters described in section IV and the performance metrics in section V.

A. Packet delivery Ratio

Figure 3 illustrates the packet delivery ratio for each routing protocol in the 1000m x 1000m boundary, to simulate a medium mobile ad hoc network. Figure 3(a) to 3(c) illustrate the performance of each routing protocol as the number of intermediate (forwarding) nodes are increased in the network. It can be seen that all on-demand routing protocol (i.e. DSR, AODV and LAR1), produce over 85 percent packet delivery for zero pause time (i.e. mobile node continually migrate), and 95 percent for 1800 second pause time (static network). However, FSR's performance degrades as the number of intermediate node increases. This is due to periodic route updating strategy used, which increase the number of routing overhead produced in the network exponentially.

Another interesting observation is that as the number of intermediate nodes is increased, more packets are being delivered. In figure 3(b) it can be seen that the number of packets delivered for all on-demand protocols is more than in figure 3(a). The increase in packet delivery ratio is due to the increase in network connectivity provided by the extra nodes.

However, as the number of intermediate nodes are further increased, it can be seen that they can have the opposite effect. To illustrate this we increased the number of CBR source/destination pairs to 30. The aim of this was to increase the effects of flooding on the network. In figure 3(f), it can be seen that for 200 nodes the performance of each protocol begins to suffer, especially in high mobility (i.e. smaller pause times). This is due to the high levels of routing overhead introduced into the network due flooding.

To investigate the behavior of the mobile ad hoc networks routing protocols in a medium to large network environment, the above protocols were also simulated in a 3000m x 3000m boundary. By increasing the boundary we will increase the number of hops between the source and the destination pairs and introduce some network partitioning, which is used to investigate which protocols will perform more efficiently when multi-hoping is increased. Fig. 4 illustrates the packet delivery ratio for the 3000m x 3000m boundary.

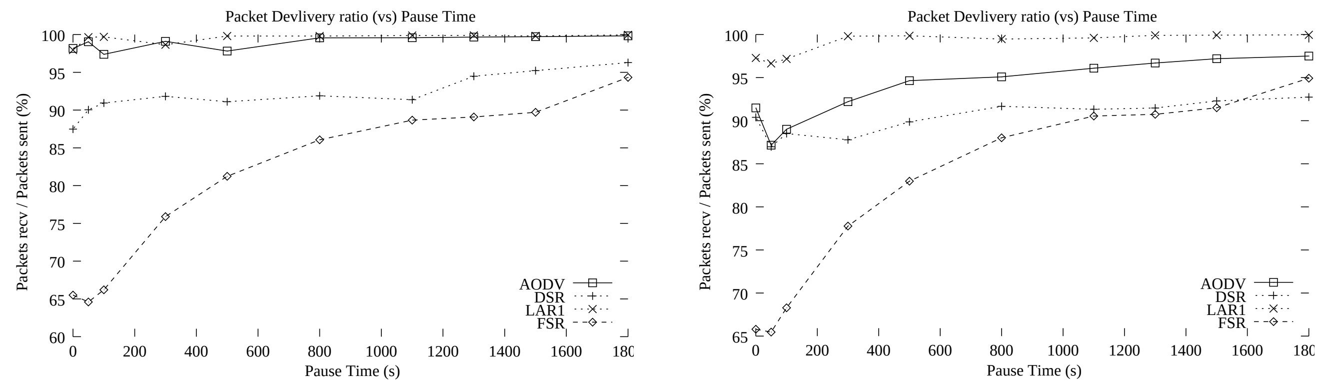
Figure 4(a) illustrates the packet delivery ratio for all routing protocols in 50 node network. The packet delivery experienced here, is far less than the 1000m x 1000m scenario. This is partly due network partitioning experienced by all nodes. This is because as the number of intermediate nodes are increased in figure 4(b) all protocols have started to show signs of improvement. However, two thing are clearly evident. Firstly AODV perform better than DSR in smaller network density, this is more evident when nodes are more mobile. AODV's advantage is due to hop-by-hop routing. This is because each neighbouring node can use a fresher route to the destination if one is available to them, where as in DSR, the route selection is static. This means, that when a route breaks, the source will have to be notified to perform another route discovery or use an alternate route if one is available. Secondly, In can be observed in LAR1, knowing approximately where to look for the destination can improve throughput. In figure 4(a) LAR1 has higher packet delivery ratio than all other protocol. However, in figure 4(b) the gab between LAR1 and AODV gets smaller. Since LAR1 is based on DSR, which means it uses source routing, the possibility of route failure in LAR1 increases by O(a.n), where a is the probability of a route failure and n is the number of nodes in the route. AODV reduces this affect by allowing the routes to be adaptable to dynamic (changing) network topology.

B. Normalized Routing Load

Fig. 5 illustrates the normalized routing load for the simulated routing protocols in the 1000m x 1000m boundary.

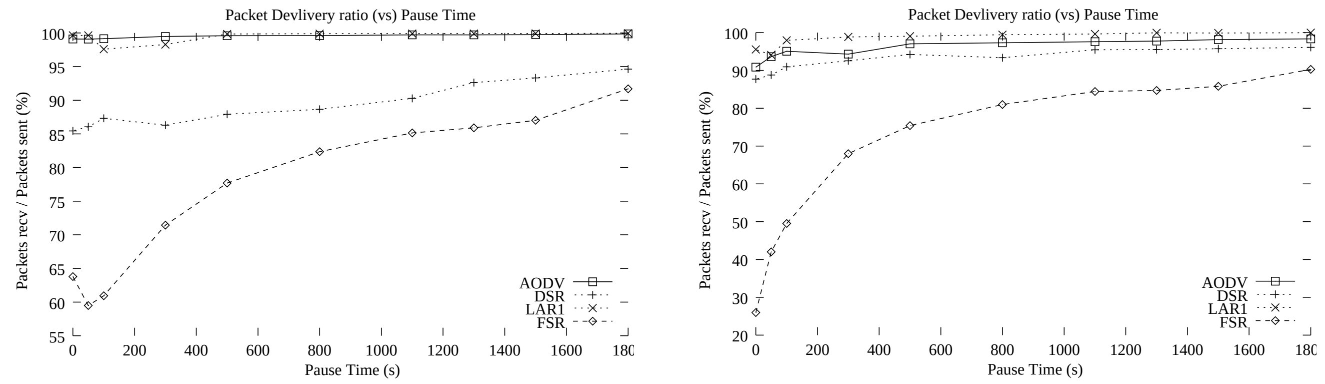
Figure 5 illustrate the overhead experienced as the number of nodes and level of traffic increases. For the 1000m x 1000m scenario it can be seen than DSR produces the least amount of overhead. This is due to the promiscuous overhearing (which is not used in LAR1) and allowing an alternate route to be used of one is available in the route cache. However, in figure 6, which represents the 3000m x 3000m scenario, it can be seen that DSR introduces more overheads than AODV. This is because AODV allows the node at each hop leading to the destination to learn and use new route information. This means that fewer route error packets will be produced than DSR due to the static nature of each route in the data packet. This extra control overhead also shows that as multi-hoping (number hops between source and destination) increases the performance of source routing strategies will begin to suffer more than hop-by-hop routing.

In Figure 6 the amount of routing overhead produced for FSR is less than all the other protocols. This is because in this scenario (i.e. 3000m x 3000m boundary) some of the periodic routing updates sent by each node will not reach their destination (or other intermediate nodes) due to network partitioning. By increasing the number of nodes in the network in figure 6 (b) we can see that the overheads produced in FSR has increased. However, as figure 4 (b) suggests the increased in the number of nodes in FSR does not significantly increase the throughput experienced (especially during higher levels of mobility).



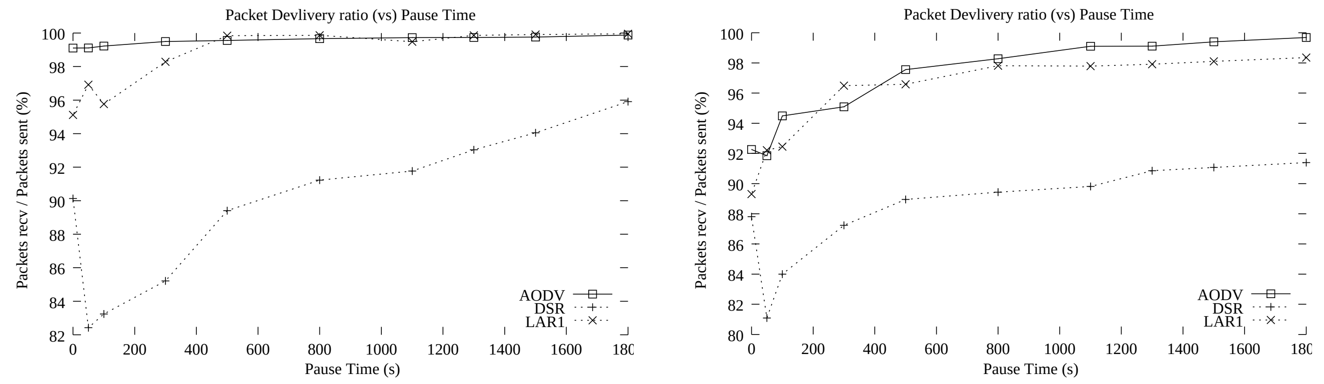
(a) Sources = 10, Nodes = 50

(d) Sources = 30, Nodes = 50



(b) Sources = 10, Nodes = 100

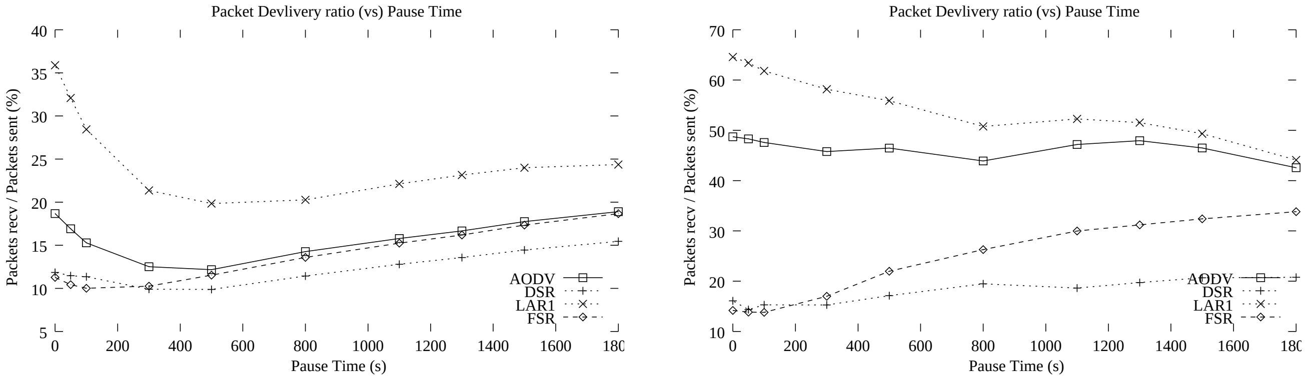
(e) Sources = 30, Nodes = 100



(c) Sources = 10, Nodes = 200

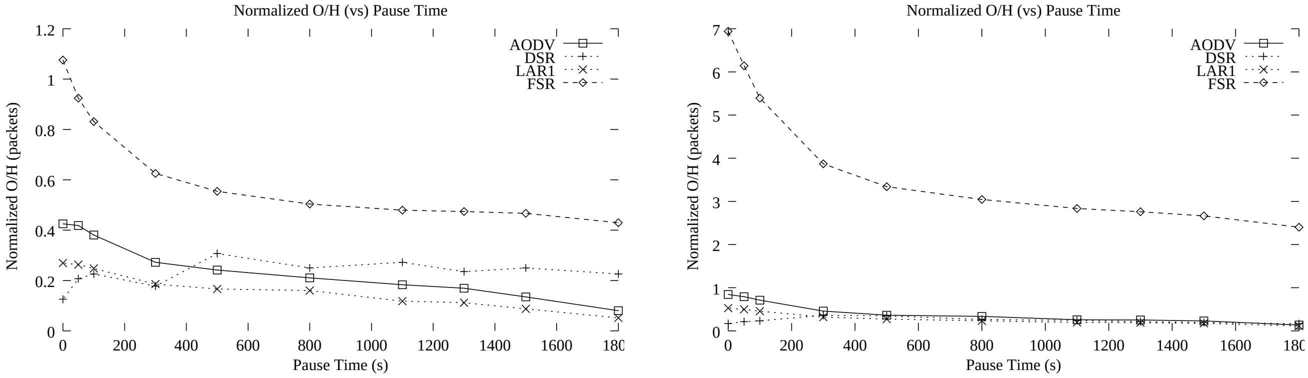
(f) Sources = 30, Nodes = 200

Figure 3: Packet delivery ratio versus pause time for the 1000m x 1000m network scenario


(a) Sources = 30, Nodes = 50

(b) Sources = 30, Nodes = 100

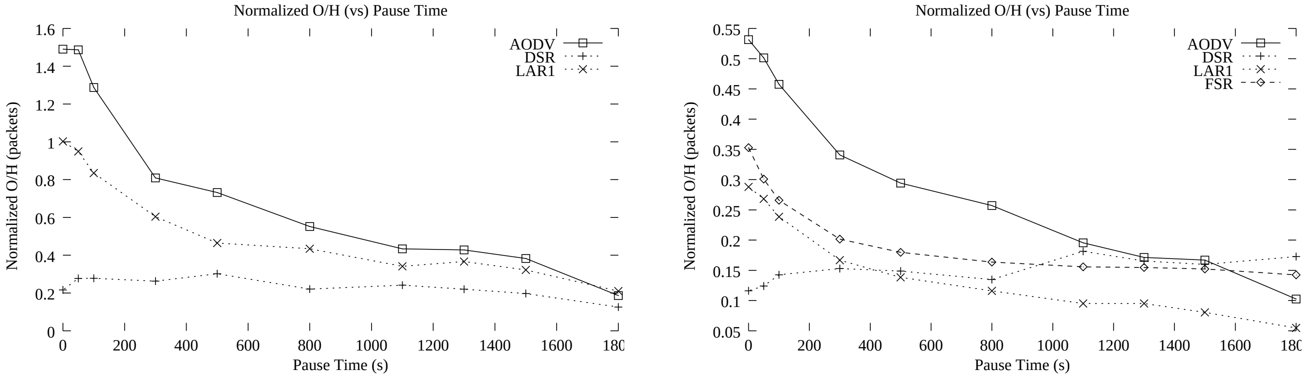
Figure 4: Packet delivery ratio versus pause time for the 3000m x 3000m network scenario

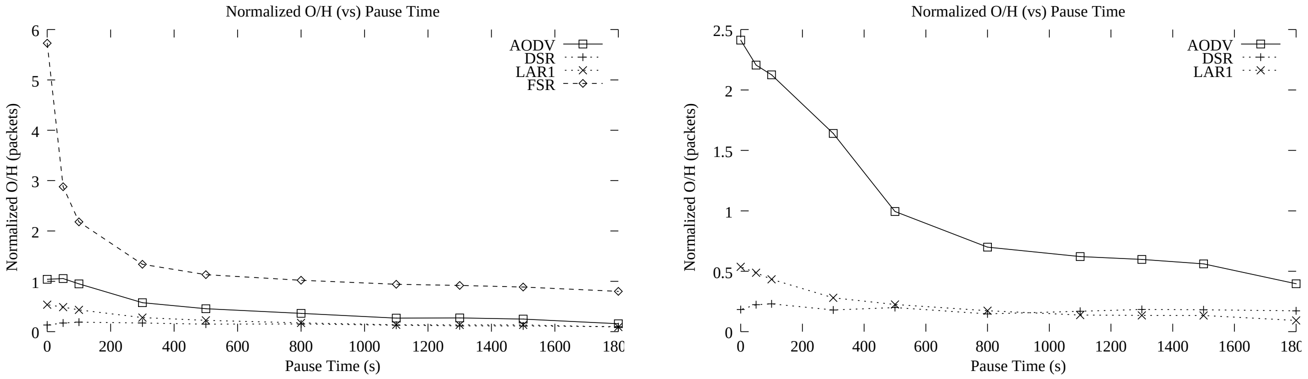

(a) Sources = 10, Nodes = 50

(b) Sources = 10, Nodes = 100

(c) Sources = 10, Nodes = 200

(d) Sources = 30, Nodes = 50

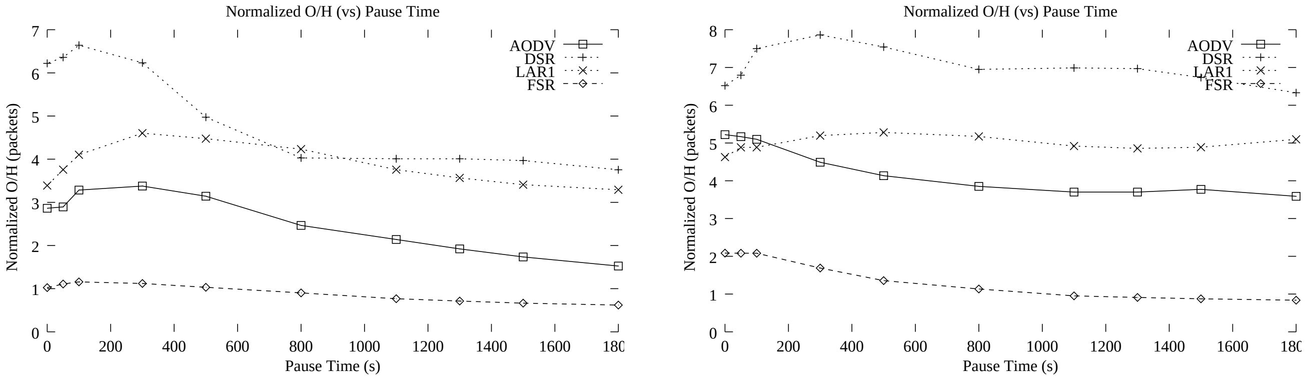




(e) Sources = 30, Nodes = 100

(f) Sources = 30, Nodes = 200

Figure 5: Normalized routing overhead versus pause time for the 1000m x 1000m network boundary



(a) Sources = 30, Nodes = 50

(b) Sources = 30, Nodes = 100

Figure 6: Normalized routing overhead versus pause time for the 3000m x 3000m network boundary

VI. CONCLUSIONS

This paper investigates the scalability of some mobile ad hoc network routing protocols. In particular, it illustrates the performance of source routing and hop-by-hop routing in different network scenarios. From the results is can be seen that source routing performs better in small to medium networks, where the source and the destination are only separated by a few nodes (i.e. one or two hops). However, as the number of hops increases, it can be seen than hop-by-hop routing produces better scalability than source routing. Furthermore, the results indicate that proactive routing strategies such as FSR will not scale as the number of nodes increases. This is because periodic routing updates produced routing overheads, which increases exponentially as the number of nodes increase in the network. The results also show that restricting the search region during route discovery will increase scalability. Therefore, localized or controlled route discovery or route maintenance is a key factor when designing a scalable routing strategy for mobile ad hoc networks. Further research is required to design net strategies to increase the scalability of hop-by-hop routing and also reduce the effect of network partitioning during data transfer.

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