Performance Study of Ad Hoc Routing Protocols with Gossip-Based Approach

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Abstract

A variety of ad hoc routing protocols based on a simple flooding routing method have been developed under the constraints of the limited transmission range of wireless network interfaces and other limited mobility resources in MANETs. In this paper we discuss the performance of a gossip-based routing and flooding protocol based on ad hoc on-demand routing protocols in order to identify the strengths and weaknesses of each protocol and suggest appropriate MANET environments for each routing protocol. To accomplish our goals, we selected six performance metrics: packet delivery fraction, average end-to-end delay of data packets, routing overhead, normalized routing load, throughput, and average node energy used. We performed simulations of three ad hoc routing protocols: AODV+G, AODV, and DSR, using the ns-2 network simulation tool.

1. INTRODUCTION

A Mobile Ad Hoc Network (MANET) is a self-configuring network of mobile nodes connected by wireless links to form an arbitrary topology without the use of any existing infrastructure or centralized administration. In such an environment, each node performs as a router and a host, and forwards packets to other nodes by discovering multiple hop paths. Many ad hoc routing protocols have been designed to efficiently establish routes and deliver packets between mobile nodes with minimum communication overhead while ensuring high throughput and low end-to-end delay in MANETs. Early researchers have pointed out the critical performance issues, such as increasing node density and traffic in MANETs, which include an appropriate selection of routing protocols [2], [3]. It is a challenging task to determine which protocols may perform best under a number of different network scenarios, network size, and node mobility. Due to these problems, a number of routing protocols have been proposed for MANETs using a flooding strategy at each node to share its link information by periodically broadcasting routing packets to all other nodes in the network topology. However, the problem with flooding is that many routing messages are propagated unnecessarily. The worst-case of the computational complexity of this algorithm is $O(N^2)$. Therefore, the routing protocols based on the use of flooding are not efficient in large-scale MANETs when taking into consideration the constraints of available bandwidth, channel contention, and energy consumption.

In this paper, we studied a gossip-based algorithm (GOSSIP3) [13] that uses a simple concept of probability such as tossing a coin to decide whether or not to forward a packet for reducing the number of routing packets sent. We implemented the AODV+G protocol by adding the GOSSIP3 algorithm into the Ad-hoc On-Demand Distance Vector Routing protocol (AODV) [5]. AODV+G is a lightweight probabilistic broadcast protocol and is scalable because it can significantly reduce the communication overhead compared with flooding protocols in dynamic and frequently changing systems as MANETs; it reduces the number of routing packets required for getting routing information.

To evaluate the gossip-based routing protocol, we compared the performances of AODV+G, AODV, and Dynamic Source Routing protocol (DSR) [4]. AODV and DSR are reactive routing protocols; their routes are determined when they are needed (on-demand) by the source nodes using a path discovery process. The proactive protocols, such as Destination-Sequenced Distance-Vector (DSDV) [6] and the Optimized Link State Routing (OLSR) [3], determine routes by a routing table periodically maintained in all of the possible destinations within the network, which are not efficient in large-scale networks. Thus, reactive ad hoc routing protocols (on-demand) are better able to reduce routing overheads than proactive protocols [2], [3], [7-9].

The purpose of this study was to compare the performances of AODV+G, AODV, and DSR to determine which protocol performs best and to analyze the strengths and weaknesses in terms of design considerations of ad hoc routing protocols and critical performance issues. To achieve our goals, we identified six performance metrics: packet delivery fraction, average end-to-end delay of data packets, routing overhead, normalized routing load, throughput, and average node energy used, which is ignored in many previous research studies but is a very important issue in ad-hoc routing.

The rest of the paper is organized as follows: Section 2 provides an overview of each of the routing protocols used in our study. The simulation environment and performance metrics are described in Section 3 and results are presented in Section 4. Finally, Section 5 concludes the paper.

2. OVERVIEW OF ROUTING PROTOCOLS

In this section we provide a brief description of the key features of the routing protocols: DSR, AODV, and AODV+G.

2.1. Dynamic Source Routing (DSR)

DSR is an on-demand routing protocol. The motivation of DSR design is to reduce routing overheads and to avoid the routing updates necessary with conventional routing protocols such as distance vector or link state in an ad hoc network. One of the key factors of DSR is the presence of a source route in the packet's header of each sender, and another is that a route cache is maintained in each mobile node for caching the source routes learned. Thereby, DSR is capable of adapting quickly to routing changes when node movement is frequent.

Route discovery and route maintenance are the basic operations of DSR. In route discovery, when one node sends a packet to another node, each sender first checks its route cache for a source route to the destination. If a route is found, the sender uses this route to transmit the packet; otherwise, the sender initiates a route discovery by broadcasting a *route request* packet and receiving a *route reply* packet from the desired destination node or an intermediate node that has a route for the target destination in its route cache. In route maintenance, a *route error* packet and an acknowledgement are used. A *route error* is generated at a node when either a link fails or a link can no longer be used due to a change in network topology. When the sender receives the route error packet, the sender and all the intermediate nodes remove the route link from their cache. Then, the sender can use an alternative route in its cache to the destination or can initiate route discovery again to find a new route [4].

Therefore, these two basic operations can reduce the number of overhead packets by using the route cache, which means the source node can check its route cache for a valid route before initiating route discovery, and if a valid route is found, there is no need for route discovery. It is the key advantage of DSR because intermediate nodes do not need to maintain routes in order to route the packets, which leads to less control overhead [7]. The DSR protocol does not require any periodic broadcasting or hello message exchanges for route maintenance; thus, it can save a considerable amount of bandwidth in MANETs. However, the disadvantage is that DSR will not be effectively scalable in a large mobile network and in a highly dynamic mobile network since it is based on a source routing that requires each packet to carry the full address - such as every hop in the route - from source node to the destination [3].

2.2. Ad Hoc On-Demand Distance Vector Routing (AODV)

AODV is based on combining the DSDV (Destination-Sequenced Distance Vector) and DSR algorithms. The motivation of AODV design is to use bandwidth efficiently and to be capable of scalability to large populations of nodes in dynamically changing networks. AODV uses an on-demand approach applied from DSR, and thus, a route is established only when a source node needs to send packets to some destination. In addition, AODV uses the hop-by-hop routing that relies on routing tables and the sequence numbers applied from DSDV. Hence, a node updates its route information only if the destination sequence number in the currently arrived packet is greater than the destination sequence number already stored at the node. It is to ensure all routes are loop-free routing.

To find a route from a source node to the destination, the basic operation of AODV is a similar route discovery procedure as in DSR using the three messages: a *route request* (RREQ) used to discover routes, a *route reply* (RREP) sent as an answer to a RREQ, and a *route error* (RERR) reporting the new unreachable destinations. However, unlike DSR, the AODV route discovery uses hop-by-hop routing, in which each node remembers only the next hop and not the entire route as does DSR using source routing. In route maintenance, AODV uses both a RREQ message and a HELLO message. If the source node does not receive a RREP before its route request expiration timer, then the source node rebroadcasts the RREQ message. If the source node moves, then it can reinitiate a new route to the destination. If an intermediate node moves, then the neighbors of the moved node can detect the link failure by a HELLO message broadcasted periodically within a default rate of once per second to maintain the local connectivity of a node, and sends a RREQ to its upstream neighbors until it reaches the source node that can reinitiate route discovery if still needed [5].

The key advantage of AODV is that it is adaptable to highly dynamic changing networks because AODV can reduce routing overheads by on-demand based on hop-by-hop routing that only carries the destination IP address and the destination sequence number [3]. Also, AODV has great knowledge of network connectivity by using the HELLO message [2]. However, the HELLO message leads to unnecessary bandwidth consumption. Also, flooding RREP messages in response to a single RREQ message may lead to high routing overheads and packet collisions.

2.3. Gossip-Based Ad Hoc Routing (AODV+G)

AODV+G is a lightweight probabilistic broadcast protocol based on on-demand routing in MANETs. The motivation of AODV+G is to reduce the redundant routing packets, thus reducing network bandwidth overhead and battery power usage. The AODV+G protocol implemented by our simulation test bed is based on the gossip-based algorithm that is GOSSIP3(*p*, *k*, *m*) [13]. The concept of the gossip-based routing algorithm is simple. A node broadcasts the route request to its neighbors with probability 1. When a node first receives a route request, it broadcasts the request message with probability p to its neighbors, and discards the request message with probability 1-p. If the node receives the same route request again, it discards it. Hence, the node broadcasts a received route request at most once. However, if the gossiping operates with too low a probability, the route request message may "die out" in a certain fraction of the executions.

To avoid the die-out problem, GOSSIP3(*p, k, m*) was developed by Hass et al. [13]. The concept of GOSSIP3(*p, k, m*) is that if the message does not die out, the node assumes that all its neighbors would get the same message as well, and thus, if the gossip probability is p, it should receive pn messages for ($m <= pn$) from its n neighbors. This algorithm function stipulates that at the beginning, a node broadcasts the request message to its neighbors with probability 1 for the first k hops and with probability p for the rest; if a node with n neighbors receives a message and does not broadcast it, but then does not receive the message from at least m neighbors within a reasonable timeout period, it broadcasts the message to all its neighbors with probability 1. We used the heuristic values of p = 0.65, k = 1, m =1 for GOSSIP3(0.65, 1, 1) based on the experiments of Hass et al.[13], which showed a reduction of message overhead up to 35% compared to flooding, and applied it to our AODV+G approach. Therefore, AODV+G provided significant performance improvements in large-scale networks, especially reducing the number of routing messages sent unnecessarily. The basic differences of the above three routing protocols are listed in Table 1.

Table 1. Comparison of Routing Protocols

Parameter	**DSR**	**AODV**	**AODV+G**
Classification	Proactive	Proactive	Proactive
Routing	Source	Hop-by-hop	Hop-by-hop
Broadcasting method	Flooding	Flooding	Gossiping
Route maintained in	Route cache	Route table	Route table
Periodic updates	No, as required in routing	No, as required in routing	No, as required in routing
Hello messages	No	Yes	Yes
Loop free	Yes	Yes	Yes
Suitable network	Small networks	Large networks & dynamically changing	Large networks & dynamically changing
TC	$O(2D)$	$O(2D)$	$O(\log D)$
CC	$O(2N)$	$O(2N)$	$O(\log N)$
Advantages	Reduce route discovery overhead	Adaptable to large & highly dynamic topologies	Reduce number of routing packets sent & small delays
Disadvantages	Large delays	Large delays	Reliability depends on probability

D = diameter of the network
N = number of nodes in the network
p = probability
Small networks = up to few hundred nodes (< 200 nodes) in MANETs

Time complexity (TC) is defined as the time required for the number of steps to perform a protocol operation, and communication complexity (CC) is defined as the number of messages exchanged in performing a protocol operation [14]. Route discovery in on-demand routing protocols usually occurs by flooding a route request message through bi-directional links or by piggy-backing the route in a route reply packet via flooding [3]. Thus, DSR and AODV have relatively the same time complexity = $O(2D)$ and communication complexity = $O(2N)$. Gossip-based routing protocol is based on the percolation theory [16], where in each step, a mode chooses a random node to forward messages uniformly with probability p. Thus, the time complexity needed for all nodes in a diameter of the network with size D is $O(\log D)$, and the communication complexity is $O(\log N)$ [17]. Therefore, a gossip-based routing protocol is more efficient and scalable than flooding-based ad hoc routing protocols by reducing the communication overhead. For reliability, gossip-based routing protocols depend on the gossip probability p. If p is equal to 1, its performance is equivalent to flooding routing as almost all nodes get the message in almost all executions, but if p is below 0.59, then the gossip dies out in almost all executions [13].

3. SIMULATION AND PERFORMANCE METRICS

Our simulations were performed using the ns-2 network simulator with version ns-2.32 [12] over IEEE 802.11b. The details of our basic ad hoc mobile simulation scenarios are as follow.

3.1. Traffic Models

The application traffic is CBR (constant bit rate). The source-destination pairs are spread randomly over the network. We generated two traffic models: 50 nodes as a small network scenario and 150 nodes as a large network scenario. There are maximum connections of 30 nodes with a sending rate of 2 packets per second. The data packet size is 512 bytes.

3.2. Mobility Models

The mobility model uses the Random Waypoint model in a rectangular field of 1500m x 300m with 50 nodes, and in a rectangular field of 3300m x 600m with 150 nodes. In this mobility model, each node starts its journey from a random location to a random destination with the speeds of nodes randomly distributed between 0 to 20m/s. Once the destination is reached, another random destination is chosen after a pause time. Simulations run for 525 seconds for both the 50 nodes and 150 nodes with changes in pause time, as from 0 to 500 seconds, by 100–second increases. At 0 pause time, nodes are kept moving until 525 seconds simulated time; at 500 pause time, nodes halt until end of simulation time. For fairness, identical mobility and traffic scenarios are used across protocols. Simulation parameters are listed in Table 2.

Table 2. Simulation Parameters

Parameters	Value
Studied protocols	DSR, AODV, and AODV+G
Number of nodes	50/150 nodes
Simulation time	525 seconds
Simulation area	1500m x 300m for 50 nodes, 3300m x 600m for 150 nodes
Node movement model	Random waypoint
Traffic model	CBR (UDP)
Speed of nodes	0-20 m/s
Packet size	512 bytes/packet
Packet rate	2 packet/sec for 30 connections
Node pause time	0-500 by 100–second increases
Physical layer	IEEE 802.11b
MAC layer	IEEE 802.11b
Bandwidth	11 Mb/s
Gossip probability	0.63

3.3. Performance metrics

For performance comparison, we considered six performance metrics [1], [7-8] for our evaluation. They are as follow.

Packet Delivery Fraction: The ratio of data packets delivered to the destinations to those generated by the CBR sources.

Average end-to-end delay: This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC layer, propagation time, and transfer time.

Routing overhead: The total number of routing packets transmitted during the simulation. For packets sent over multiple hops, each transmission of the packet counts as one transmission. In our simulations, packets are counted both in the MAC layer or RTR layer transmissions.

Normalized routing load: The number of routing packets transmitted per data packet delivered at the destination. Each hop-wise packet transmission is counted at in the RTR layer as one transmission.

Throughput: A dimensional parameter that gives the fraction of the channel capacity used for useful transmission, such that the total number of delivered data packets divided by the total duration of simulation time is the throughput.

Average node energy used: The average amount of energy used by nodes, in Joules, from a given initial amount of energy to each node.

4. SIMULATION RESULTS

To compare the performance of three protocols with respect to six performance parameters, we present six pair graphs. Each pair group shows the performance results for both the small size (50 nodes) and the large size (150 nodes) of network for different traffic pause times. Figure 1 (a) and (b) show the packet delivery fractions of the routing protocols dependant on the network size. Figure 1(a) shows that AODV and AODV+G have similar performances and high packet delivery between 70% and 90% from 0 to 500 pause times for 50 nodes. However, in the large network size (150 nodes), Figure 1(b) shows that AODV outperforms both AODV+G and DSR. DSR has a lower packet delivering rate: about 47% in the small network and 9% in the large network at higher mobility as 0 pause time. DSR packet delivery rate, at higher mobility rate when pause time is 0, drops about 69% and 97% for the small and the large networks, respectively. As AODV+G broadcasts packets with probability 0.65, it shows a good performance in the small network and it outperforms DSR in the large network. DSR drops about 96% packet delivery rate at the interface queue (IFG) compared with AODV+G dropping about 27%, which is much lower than DSR's packet dropping. The major reason for packet dropping in DSR is that the IFG is full due to carrying full routing information for each packet's header file; hence, a number of incoming packets will be dropped. However, AODV and AODV+G drop packets mostly at the RTR layer and MAC layer, about 40% and 15% respectively at higher mobility.

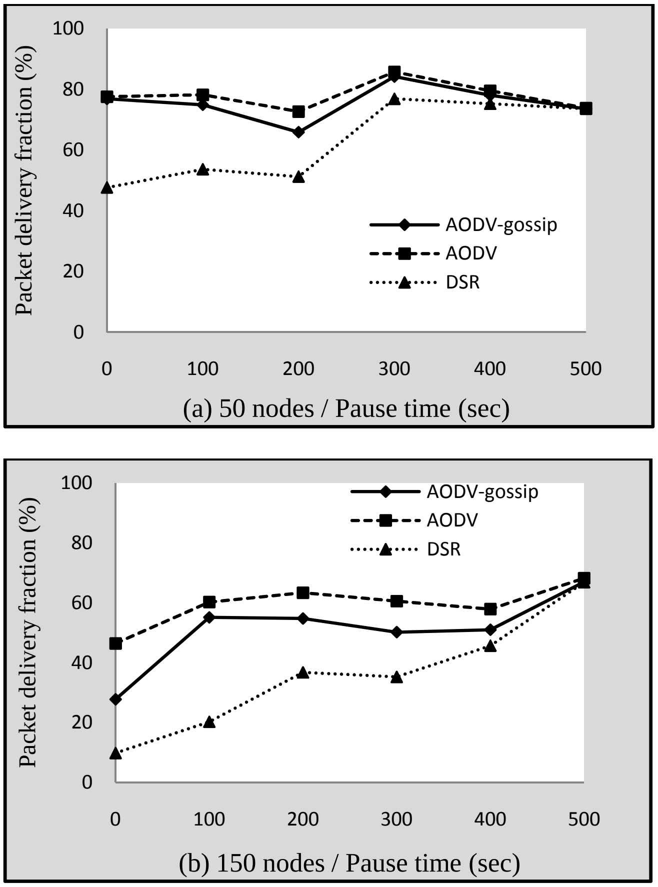


Figure 1. Packet delivery fractions for 50 nodes and 150 nodes at a variety of pause times.

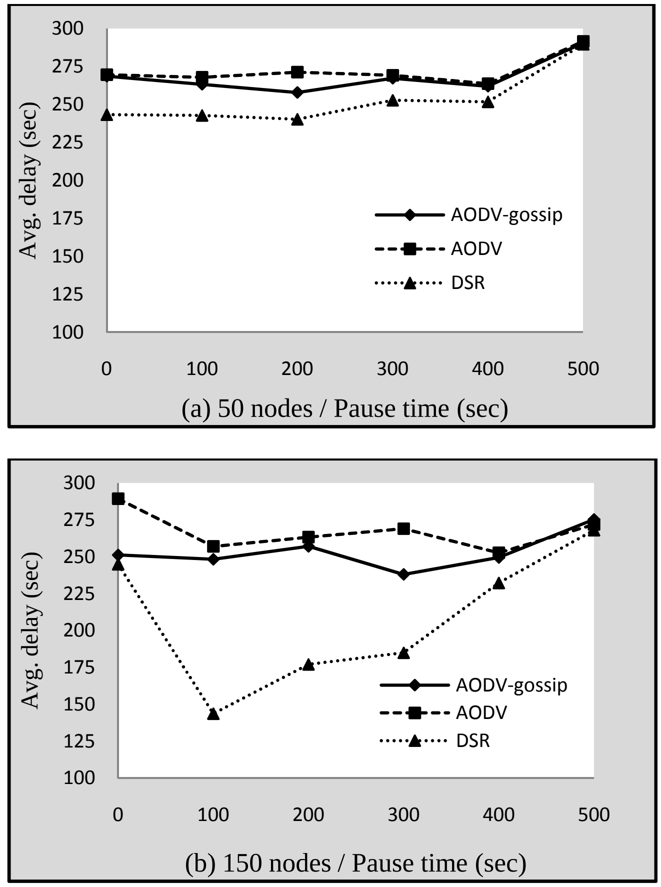


Figure 2. Average end-to-end data packet delays for 50 nodes and 150 nodes at a variety of pause times.

The average end-to-end delays are shown in Figure 2 (a) and (b), the small network and large network, respectively. DSR has less delay compared to AODV and AODV+G, especially in the large network; from 100 to 300 pause time, DSR demonstrates significantly lower delay than AODV and AODV+G. DSR has a low packet collision, about 70% to 80% lower than other protocols, which means DSR uses its route cache for route maintenance. In the large network (see Figure 2(b)), AODV+G performs about 13% better than AODV at high mobility as 0 pause time because AODV has to keep flooding packets to broadcast its neighbors for exchanging RREQs and RREPs messages until it discover a route.

The routing overheads are shown in Figure 3 (a) and (b), the small network and large network, respectively. AODV clearly has the highest overhead at all traffic mobility in both the small network and the large network from 200 to 500 pause time because packets are kept flooding due to exchanging RREQs and RREPs. DSR has a significantly high routing overhead at high mobility as 0 pause time. The reason is that DSR routing requires each packet to carry the full address from source node to the destination. Hence, we can expect that DSR is not good for large-scale networks. AODV+G performs about 13% better than AODV and much more than DSR at high mobility in the large network because DSR suffers heavy routing load at the RTR layer, about 72% more than AODV+G.

The normalized routing loads are shown in Figure 4 (a) and (b), the small network and large network, respectively. AODV+G outperforms both AODV and DSR at high mobility in the small network, and the routing load performance of AODV and AODV+G is close to each other for most mobilities in the large. Also, we found that DSR's normalized routing load is increased significantly at high mobility in the large network because it depends on the packet delivery fraction and the node movement.

The throughputs are shown in Figure 5 (a) and (b). The comparison between the routing protocols is based on throughput measured in Kbits/second using different mobilities. DSR has high throughputs at 0, 200, and 400 pause times. In the small network, AODV+G performs fairly consistently for most all mobilities (as from 100 to

500 pause time). In the large network, however, AODV+G performs its throughput about twice better than AODV's throughput at high mobility as 0 pause time because AODV has more packet flows than AODV+G, which makes for heavier work of the routing layer and congestion of the network.

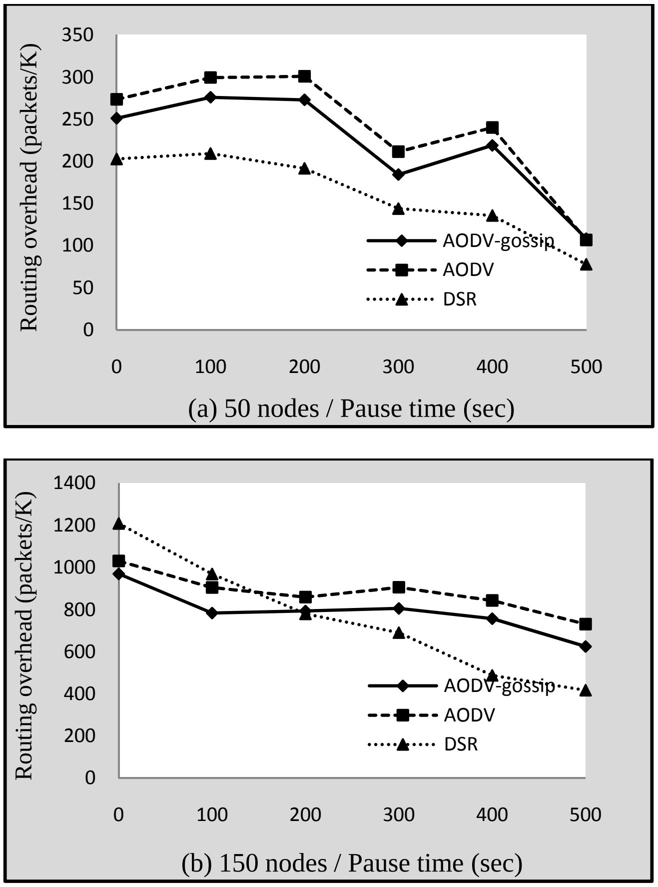


Figure 3. Routing overheads for 50 nodes and 150 nodes at a variety of pause times.

Figure 6 (a) and (b) show the average used node energies of the routing protocols for both the small and large networks, and which heavily depends on the routing overhead performance. In the small network, the three protocols consume similar levels of energy. However, in the large network, DSR consumes almost 100% energy at high mobility as 0 and 100 pause times due to its high routing overhead. Additionally, to show concrete evidence of the relationship between overall routing overhead and energy consumption for each size of network, we compared the performance of these three protocols in a high traffic model based on a sending rate of 4 packets per second in the large network (150 nodes). The results are shown in Figure 7 (a) and (b). For the routing overhead, AODV+G has less than both AODV and DSR, as shown in Figure 7(a). For the average used node energy, AODV+G also consumes less, and it is fairly stable as is AODV with increasing node mobility from low movement (500 pause time) to high movement (0 pause time), as shown in Figure 7(b). Hence, we can expect that AODV+G may be the most efficient routing protocol in large-scale MANETs.

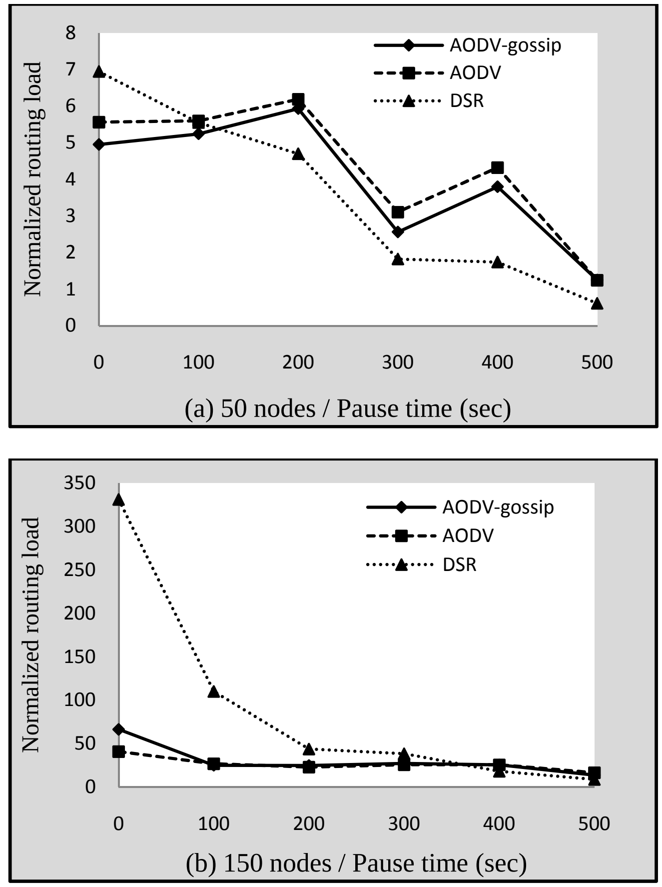
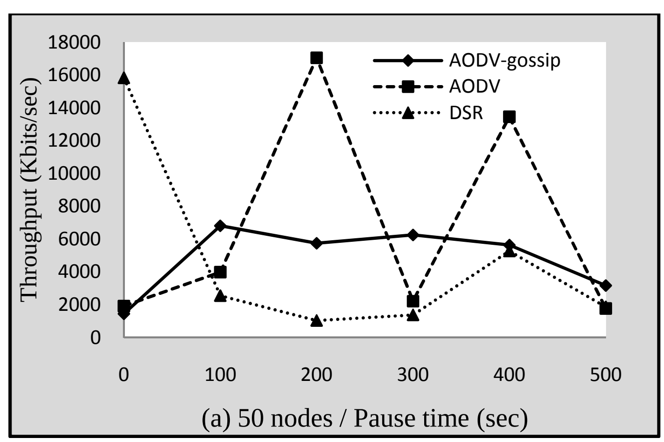


Figure 4. Normalized routing loads for 50 nodes and 150 nodes at a variety of pause times.



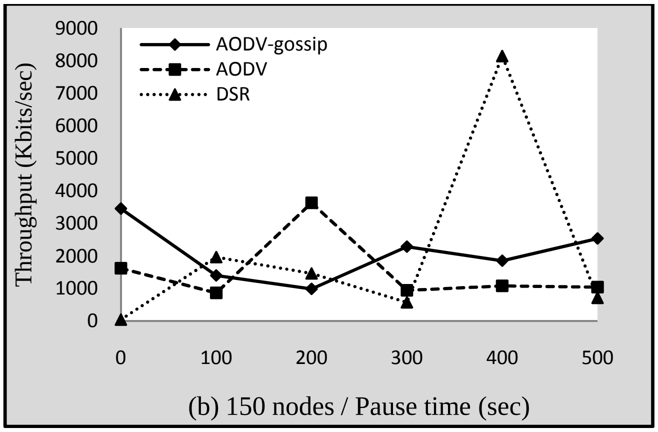
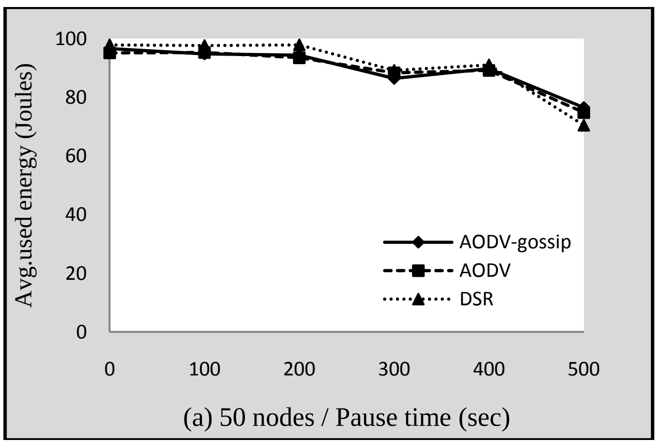


Figure 5. Throughputs for 50 nodes and 150 nodes at a variety of pause times.



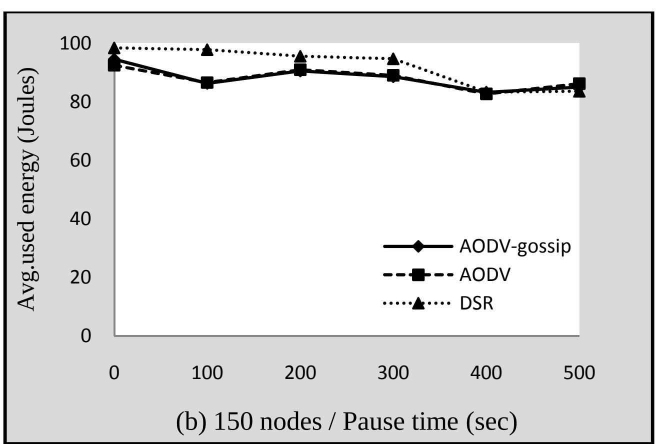
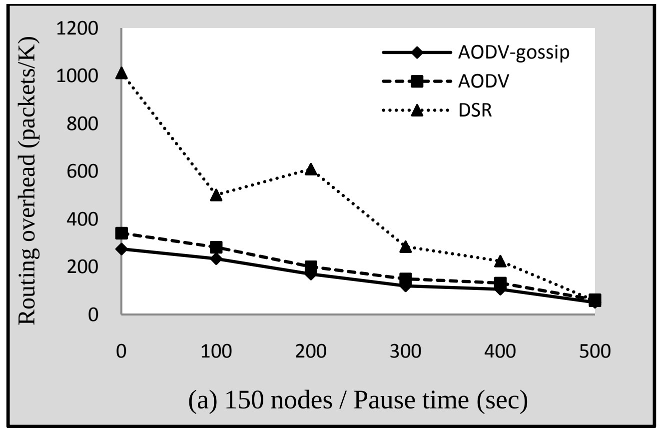


Figure 6. Average used node energies for 50 nodes and 150 nodes at a variety of pause times.



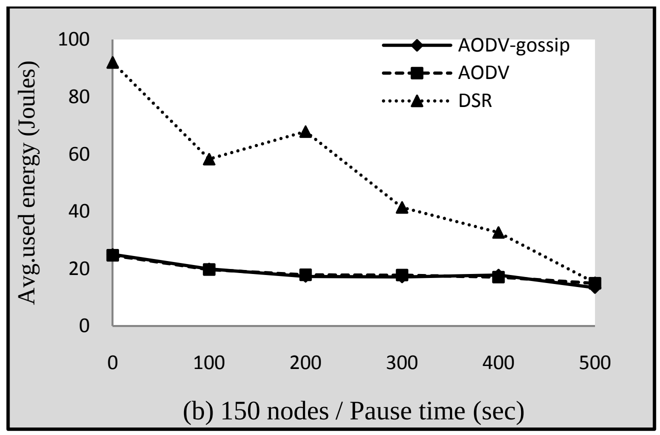


Figure 7. Routing overheads and average used node energies for 150 nodes with a higher traffic rate of 4 packets/s.

5. CONCULSION AND FUTURE WORK

The main objective of this study was to measure the performance of three ad hoc routing protocols (AODV, DSR, and AODV+G) and identify their weaknesses and strengths under two different sizes of network: a small network and a large network. To achieve our goals, we have simulated these protocols using ns-2 network simulator with version ns-2.32.

The simulation analysis results allowed us to find the following: First, DSR performs very well at most traffic mobilities in the small network, although it uses source routing. However, it is not suitable for the large-scale network with high traffic and node movement models because each packet carries full routing information. Second, both AODV and DSR use flooding packets, and they have a low end-to-end packet delay but high routing overhead. The high routing overhead makes each node consume more energy as shown in Figure 7 (b). Finally, AODV+G is a promising and efficient protocol for high traffic and node movement situations in a large-scale network like cellular phone networks. However, the

AODV+G protocol needs more improvement in its throughput in order to be widely accepted by many wireless applications.

Our immediate future improvement of this project would involve a careful review of the values of gossiping parameters to find out the optimal gossip probability so it can support higher reliability as well as higher throughput.

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Biography

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