Performance Analysis of MANET Routing Protocols using ns-3 Mobility Models

Ms Project

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Abstract

A mobile ad hoc network commonly referred to as a MANET is made up of many nodes that can communicate to each other directly without the need of an access point or a central coordinator. Essentially all the nodes in the network can act either as an end system or an intermediate system. The nodes are also mobile and their movements and speed can be random, thus making its network topology very dynamic due to constant link breakages and formations, leading to deterioration in the performance of the MANET routing protocols. MANETs are not widely deployed and therefore mobility models are used in simulation environments to test network performance. This project uses four of the mobility models supported in the ns-3 network simulator to show the impact of mobility on MANET routing protocols. The attributes of the nodes that will be changing are velocity and node density; the performance parameters that will be evaluated are throughput, end-to-end delay, and routing overhead. The analysis will seek to answer the following questions: how does mobility and node density affect the performance of the different protocols? Does the underlying mobility model used affect protocol performance? Is there a superior protocol that performs better overall? And is there a mobility model that seems to offer better performance to all the protocols?

1 Introduction and Motivation

A mobile ad hoc network (MANET) is made up of many nodes that can communicate to each other directly without the need of an access point or a central coordinator. The nodes are mobile and their movements and speed can be random thus making its network topology very dynamic [5]. This means that the end-to-end path of two nodes in a MANET changes frequently due to link breakages and link formations by the nodes in the path from sending node to receiving node and vice-versa. The different routing protocols used in MANETs are AODV, DSR, OLSR, and DSDV. AODV and DSR are reactive protocols and routes are discovered when needed. OLSR and DSDV on the other hand are proactive protocols and routing tables in every node are periodically updated with fresh routes [6]. The movement of nodes in MANETs cause link breakages thus adversely affecting the performance of these protocols. There was therefore need to create mobility models that could be used in simulations to study to what degree mobility of nodes affects protocol performance [12]. The movement of the nodes in the mobility model should be as close as possible to the movement of the nodes that will eventually utilize the protocol being evaluated otherwise it will not accurately depict the performance of the protocol when it is finally deployed [2]. In the ns-3 network simulator, ten mobility models are defined and supported [7]. Four of these models will be used to show the impact of mobility models on MANET protocols. The attributes of the nodes that will be changing are velocity and node density; the performance parameters that will be evaluated are throughput, end-to-end delay, and overhead. All the major MANET routing protocols that is AODV, DSDV, DSR, and OLSR will be evaluated and the mobility models that will be used are: Random direction, Random walk, Steadystate Random Waypoint, and Gauss Markov, which is a model with memory [1]. Performance of a protocol in a given mobility model will then be evaluated by plotting graphs of throughput, overhead, and end-to-end delay versus velocity and node density. Analysis will then be done to find out whether a certain protocol performs well in a given mobility model and poor in another mobility model. Furthermore in our analysis we will try to determine whether there is a protocol that performs well overall regardless of the mobility model used.

2 Background

This chapter explains in details how the mobility models used operate and the mode of operation for each MANET routing protocol that will be evaluated.

2.1 MANET Protocols

MANETs are generally characterized by mobility of individual nodes leading to unreliable communication links between them. MANET protocols therefore need to maintain communication between nodes in this highly dynamic environment by continuously finding valid routes in the face of difficulties like low wireless bandwidth and low battery power of MANET nodes. Furthermore the overhead has to be kept to a minimum to prevent it from choking the bandwidth for data communication [6]. Next is a detailed description of the four major MANET routing protocols.

2.1.1 DSDV

The Destination Sequenced Distance Vector protocol is based on the Bellman Ford algorithm. It is a proactive table-driven protocol. This means that every node in the network has routing entries to all the nodes in the network. The tables are updated periodically or when there is a significant change in the network topology. This means that there is always a route to any destination in the network if the topology is not changing very much. To prevent routing loops due to these updates, the updates have sequence numbers that are incremented by two, meaning that it always has to be an even number. The route with the highest sequence number is the freshest route and it is the one that is used. Entries that have not been updated for a while are considered stale and thus deleted. However, if there are two entries with the same sequence number, the one with the better metric is used; DSDV uses hop count as its cost metric. If a node wants to alert the other nodes of an invalid route it sends an update with an odd sequence number and they know to delete that route from their table. DSDV uses settling time to dampen route fluctuations [9]. The periodic updates in the DSDV mode of operation is a considerable disadvantage since it consumes much of the already limited battery power of the MANET nodes, however if the topology is not changing, it can be very efficient since a route to any destination will always be present when needed.

2.1.2 OLSR

Optimized Link State Routing is a proactive table driven link-state routing protocol. Each node selects a multipoint relay set also known as an MPR set from its neighbours such that all its two hop neighbours are accessible through the MPR set. The optimizations in OLSR via the MPR set are three-fold: only MPR nodes flood broadcast messages, link state advertisements originate only from MPR nodes, and MPR nodes can choose to report only links between itself and its MPR selectors. All these optimizations serve to reduce the number of control packets in the network thus substantially reducing the overhead compared to other link state protocols. OLSR uses HELLO and topology control (TC) messages to discover and broadcast link state information throughout the network [9]. HELLO messages are periodically sent by a node to its neighbours and contain information about its MPR selector set (nodes that have chosen it as an MPR node) and it is not flooded. The topology control messages are used to advertise the MPR selector set of a node to the entire network and are flooded using the multipoint relaying system. The advantages of OLSR are that the overhead does not increase with the number of routes required in a network and that a route is always available when needed [4]. The disadvantages are that like in DSDV battery utilization in the MANET nodes is poor and MPRs are extremely useful only in dense networks otherwise its complexities would not be warranted for.

2.1.3 AODV

The Adhoc On-demand Distance Vector routing protocol is a reactive or an on-demand routing protocol. This means that routes are discovered only when needed. If a route to a destination is not found on the routing table, the source generates a route request (RREQ) packet and broadcasts it. This RREQ packet contains the source IP address, current sequence number, broadcast ID and most recent sequence number for the destination known to the source node [6]. The intermediate nodes update information about the source node and sets a reverse route entry to the source. If any intermediate node contains a route to the destination with a higher sequence number than the one in the RREQ packet, then it sends a route reply (RREP) to the source otherwise the packet is rebroadcast until it gets to the destination. On receiving the packet, the destination sends a unicast RREP back to the source using the reverse route of the RREQ and each intermediate node sets a forward route entry to the destination. Each intermediate node also takes note of the RREQ's source IP address and the broadcast ID so that it does not rebroadcast a duplicate RREQ. If there is a link breakage on an active route, the node upstream sends a route error packet (RERR) to the source to inform it that the route is invalid, thus the source can re-initiate a route discovery [10]. AODV has considerably less overhead than its pro-active counter parts since routes are discovered only when needed and performs well in high mobility scenarios. The disadvantage is that latency can be high since a packet has to wait in the send buffer for a route to a new destination to be found.

2.1.4 DSR

The Dynamic source routing protocol is an on-demand protocol based on the source routing concept [3]. It has two main mechanisms: route discovery and route maintenance. When a node wants to send packets to a particular destination, it checks its route cache to find a route and if it is not found it initiates a RouteRequest. The RouteRequest is flooded in the network and each intermediate node that receives it rebroadcasts it provided it has not done this already and the time to live for the RREQ is not expired. Each RREQ is given a sequence number by the source which is used by the intermediate nodes to prevent forwarding of duplicate RREQs. The intermediate nodes between source and destination attach their IP addresses to the RREQ and thus it contains the path it has traversed. On reaching the destination, a RouteReply is sent back to the source using the reverse path in the RREQ and each node along the way caches this information. Every data packet sent contains the path to be traversed in its header therefore DSR is a beaconless routing protocol [8]. When a path fails, the node at which it fails generates a RouteError packet and sends it back to the source thus alerting it to look for an alternative path in its cache or initiate a route discovery. The intermediate nodes along the path of the RERR also delete the failed route from their caches. The advantages of DSR are that routes are found only when needed thus avoiding unnecessary overhead and that several routes to one destination can be cached thus if one fails the other route can be used. The disadvantage is the set up delay can be quite high especially in high mobility scenarios since DSR will try all the routes in its cache before initiating a route discovery and they might all be invalid.

2.2 Mobility Models

As mentioned earlier, MANETs have not been widely deployed so they are normally studied in simulation environments. Since the nodes in a MANET are mobile, evaluation of the network performance needs a mobility model whose node movements closely relates to or mimics the node movements in a real network [5]. This poses great challenges in the analysis of protocols that are used in MANETs because the realistic motion scenarios are many and vary from each other. For example in a war zone, nodes might move in relation to a central node which might be the commander's control station co-ordinating the movement of the soldiers. Also some soldiers might be on foot and others in vehicles introducing different node speeds [5]. On the other hand, in a conference meeting, the nodes would be expected to move only within a certain area and most probably at the same speed with the distances between them being small. Clearly different mobility models would be needed to evaluate the routing protocols in order to decide which one would be best for each scenario. For my study four mobility models that have been implemented in ns-3 will be used for performance comparisons of MANET protocols and their operation is described in detail below.

2.2.1 Random Walk

In random walk mobility model, the nodes can change direction after traveling for a specified amount of time or after traveling for a certain distance. They then choose a random direction and repeat the process again; if the node reaches the simulation boundary it bounces off at an angle that is determined by the incoming direction. Figure 1 shows a pyviz (ns-3 visualizer) [7] snapshot of 40 nodes travelling at a speed of 10m/s in time mode. They travel for 50 seconds before changing direction. The snapshot was taken at half time in a simulation running for 300 seconds and serves to show the distribution of nodes in the simulation area.

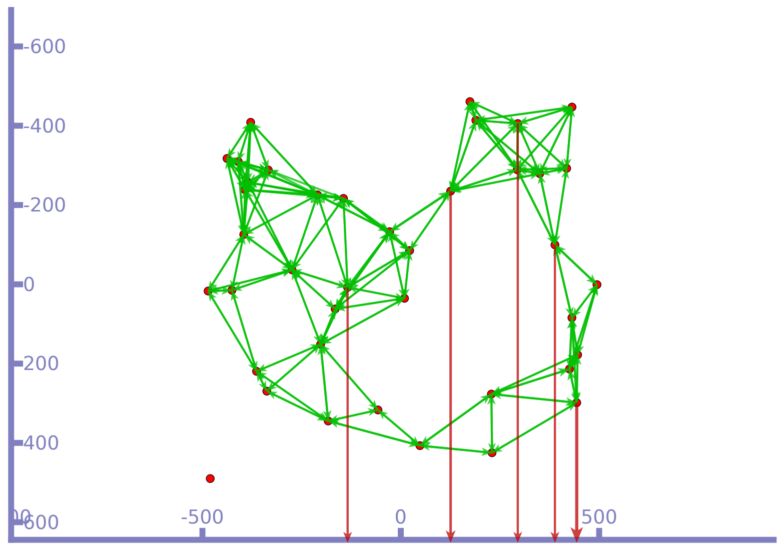

Figure 1: Pyviz snapshot of RW with 40 nodes

2.2.2 Steadystate Random Waypoint

The Steadystate Random waypoint mobility model is a modification of random waypoint mobility model that is the most commonly used mobility model in MANET simulation environments. A node chooses a random speed from a specified range, a random destination and a pause time which is specified in seconds. The node then moves towards the chosen destination with the specified speed and pauses for the required amount of time before repeating the whole process over and over until the simulation time expires. Both a maximum and minimum speed are explicitly defined for the nodes ensuring that the nodes achieve a steady state speed while travelling from one waypoint to another. Furthermore minimum and maximum pause times are defined in this model. Figure 2 shows a pyviz snapshot of 40 nodes travelling at a minimum speed of 9m/s, a maximum speed of 10m/s and having pause times between 30 and 35 seconds.

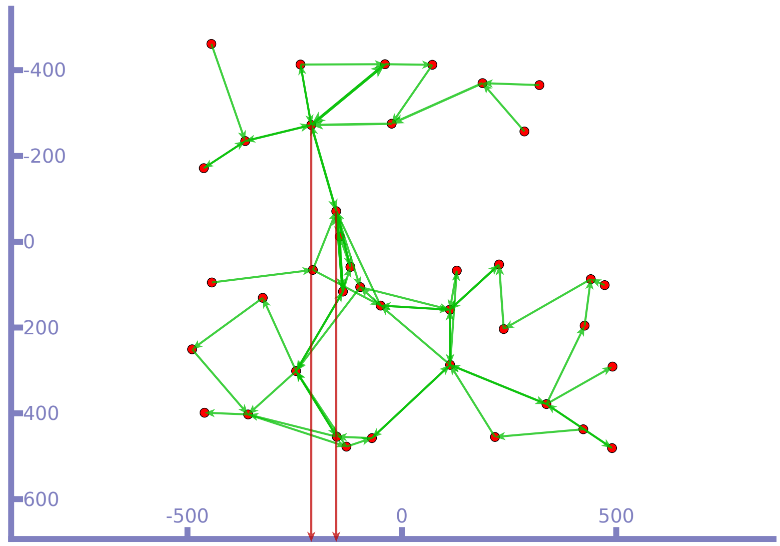

Figure 2: Pyviz snapshot of steadystate RWP with 40 nodes

2.2.3 Random Direction

The Random Direction Mobility Model is designed as an improvement for Random Way Point Mobility Model to overcome a density wave that is the clustering of all nodes in one part of the simulation area mostly the center for RWP. In the random direction mobility model, the nodes choose a random direction and travel at a specified speed along this direction until it reaches the simulation boundary where it pauses for a specified amount of time before randomly choosing an angular direction between 0 and 180 degrees and repeating the process again. This ensures that a node has a very high probablity area of traversing the whole simulation area. Figure 3 shows a pyviz snapshot of 40 nodes travelling at a speed of 10m/s and having pause time of 10 seconds.

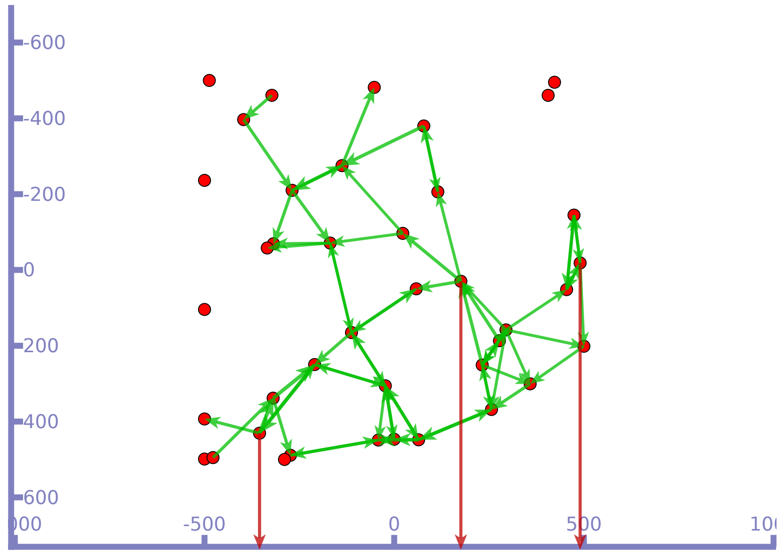

Figure 3: Pyviz snapshot of Random direction with 40 nodes

2.2.4 Gauss-Markov

The Gauss-Markov Mobility Model is a memory-based mobility model. Every node begins at a random initial point and travels for a specified time interval known as a time step before changing speed and direction. The next speed and direction is then calculated based on the previous ones. The 3-D version of this model under ns-3 was designed and developed by Dan Broyles of University of Kansas [1]. It was designed primarily to improve the accuracy of simulation in comparison with real world situations. Gauss Markov Mobility Model is a synthetic model and it combines random movements with memory unlike the other mobility models which tend to produce straight-line node movement due to lack of memory [1]. Originally it was designed to simulate 3-D wireless environment, however it will be used in 2-D for my study of MANET protocol performance comparisons since the other mobility models are in 2-D. Figure 4 shows a pyviz snapshot of 40 nodes travelling at a speed between 10m/s and 20m/s and having time step intervals of 10 seconds.

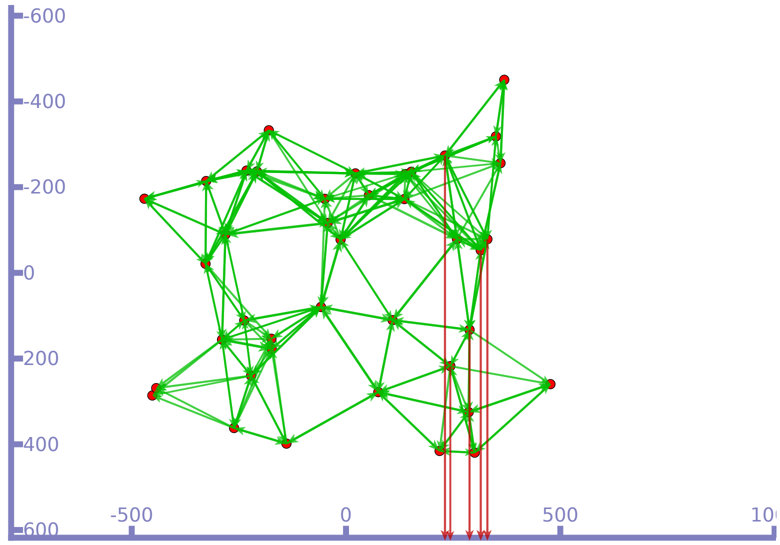

Figure 4: Pyviz snapshot of Gauss Markov with 40 nodes

3 Simulation Environment

The simulations were run in the ns-3 network simulator and the results were averaged over 10 runs. A different seed was used for each run to ensure variability of the results. 95 percent confidence interval bars were used to indicate the reliability of the results. At the start of the simulation the nodes are randomly positioned in the simulation area. The performance metrics that were evaluated were PDR which is the number of packets received divided by the number of packets sent by the application, overhead which is the fraction of bytes used by the protocols for control messages and delay which is the time taken by the packet to reach the destination from the source [9]. The table below shows a summary of the simulation parameters used in the simulations, some of which were chosen from previous analysis of MANET protocols.

Parameter	**Scenario**	**value**
area	varying speed varying nodes	1000×1000 m 500×500 m
application data rate		4 pkt/s
data packet size		64 bytes
wifi mode		802.11b
transmission range		250 m
simulation time		1000 s
propagation loss model		range propagation loss model
traffic		CBR
node speed	varying network size	2 m/s
number of nodes	varying speed network	50
pause time	stationary RWP random direction	100 s 10 s
node traversal time	aodv	2 μs
enable buffering periodic update interval settling time	dsdv	false 15 s 6 s

Table 1: Simulation table

4 Results and Analysis

As mentioned earlier the performance metrics that were evaluated are PDR, delay and overhead. These metrics were evaluated using the four mobility models chosen under both varying speed of the nodes and network size. Speed was varied from 0.2 m/s to 40 m/s and the number of nodes varied from 10 nodes to 50 nodes in an area of 500 by 500 meters as shown in the previous table of simulation parameters. The analysis of the protocols is done in the following sub-sections grouped by the performance metric.

4.1 Packet Delivery Ratio (PDR)

As can be seen from the graphs (Figure 5 to Figure 8), PDR of the protocols decreased with increasing velocity across all the mobility models. When the nodes move at a higher speed, the topology of the network constantly changes thus the routes in the cache become invalid and thus most packets transmitted at the application layer never get to the destination due to lack of end to end route leading to a low PDR. DSDV and OLSR performance suffer the most from increase in mobility. This can be attributed to the fact that routes are pro-actively found and thus when a packet finds no route to the destination when it is transmitted it is immeadiately dropped. AODV degradation in performance with increasing mobility is not as severe as in its pro-active counterparts and the reason for this is that routes are found when needed and thus it suffers less from the invalid route in cache problem even with rapid topology changes [11]. The performance of the pro-active protocols seem to have a marked improvement when steadystate random waypoint mobility model is used as can be observed in figure 8. For example there is a 25 percent improvement in performance for DSDV at 15 m/s as compared to its performance in random direction mobility model and 30 percent improvement when compared to random walk mobility model. This can be attributed to the fact that in steadystate random waypoint the nodes pause randomly for a period of 100 seconds and thus the topology is not changing as rapidly as in the other mobility models like random walk where nodes are moving constantly. From Figures 9 to 12, PDR increases with increase in the number of nodes and then it starts to drop as the network gets congested. At first the nodes in the network are fewer increasing the chances that nodes will move out of the transmission range of each other leading to network partitioning thus low PDR. As the nodes increase however, connectivity improves leading to a higher PDR but at about 30 nodes for AODV and 40 nodes for OLSR and DSDV, the network becomes too congested and packets are dropped thus PDR drops. AODV performs worse with increase in nodes and this can be attributed to the fact that it involves all the nodes in the network when finding a route thus leading to a long delay causing packets to be dropped in buffers. OLSR performance does not drop with increase in node size, its multi point relaying system works even better in a larger network ensuring that increase in network traffic does not cause increase in overhead thus PDR remains about the same even with increase in the number of nodes in the network.

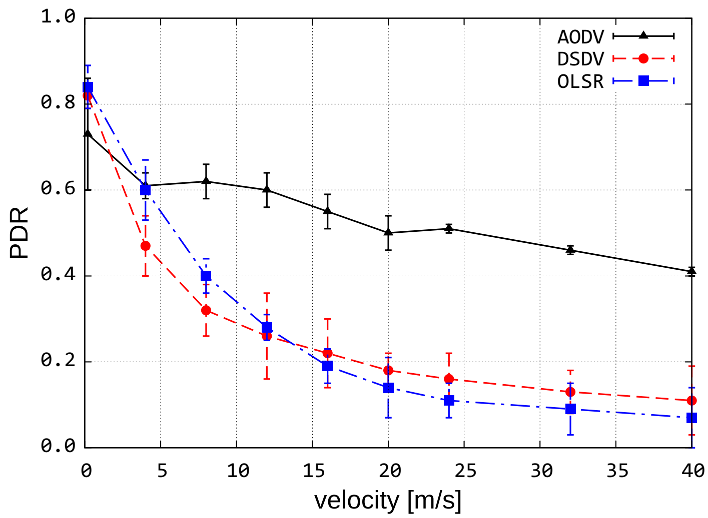

Figure 5: Random Direction PDR vs. speed of nodes

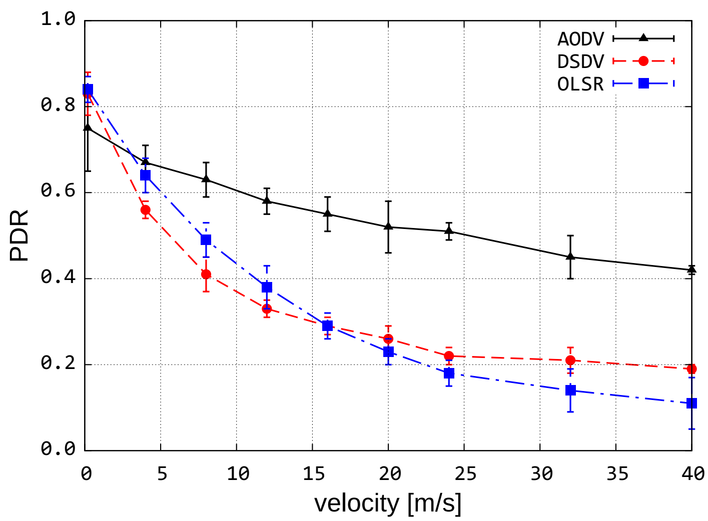

Figure 6: Random Walk PDR vs. speed of nodes

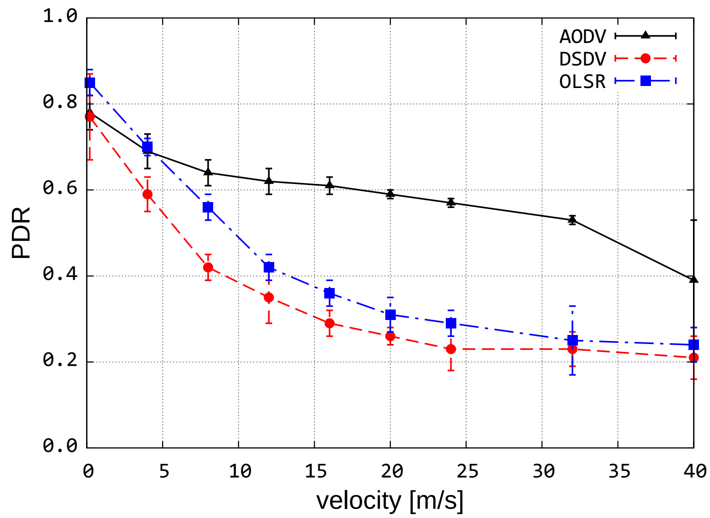

Figure 7: Gauss-Markov PDR vs. speed of nodes

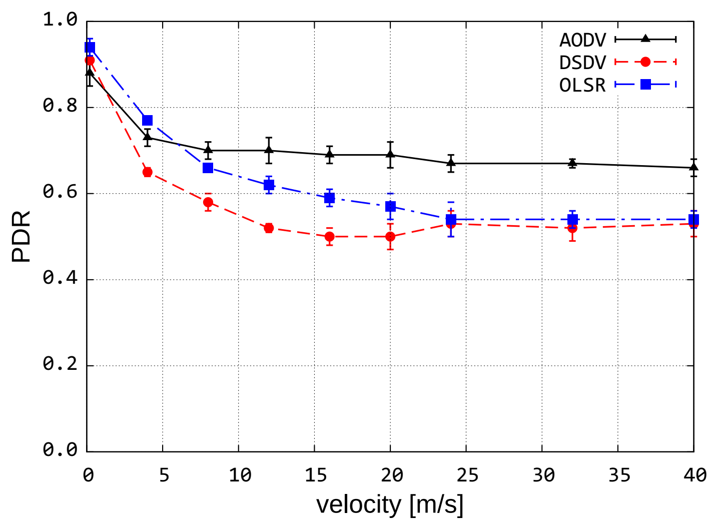

Figure 8: Steadystate Random Waypoint PDR vs. speed of nodes

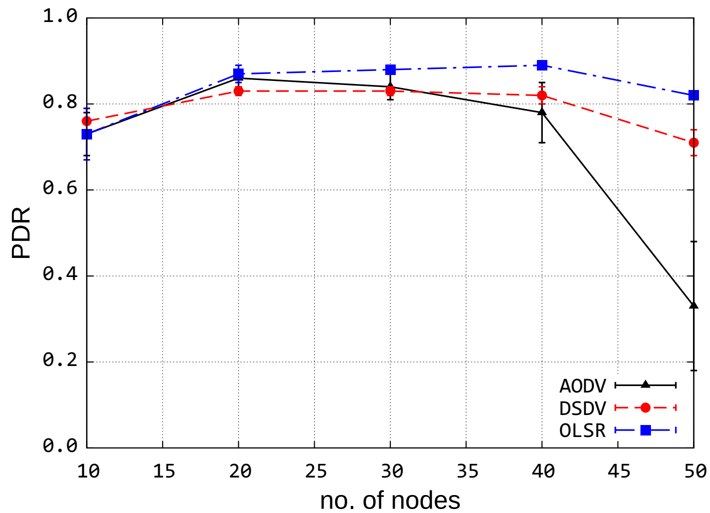

Figure 9: Random Direction PDR vs. network size

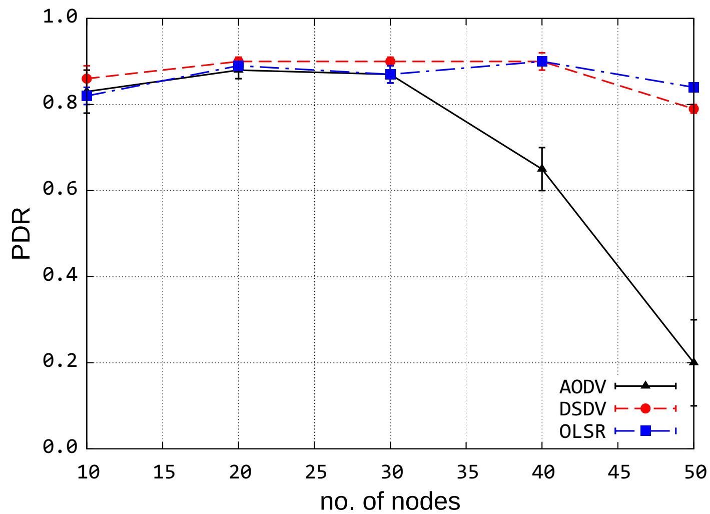

Figure 10: Random Walk PDR vs. network size

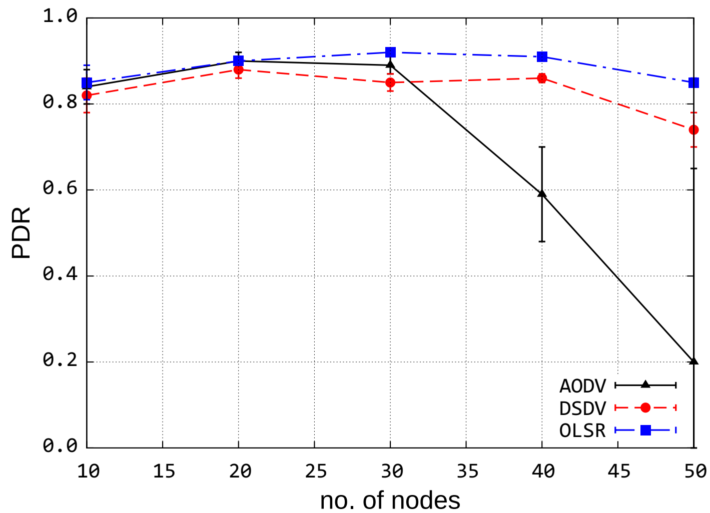

Figure 11: Gauss-Markov PDR vs. network size

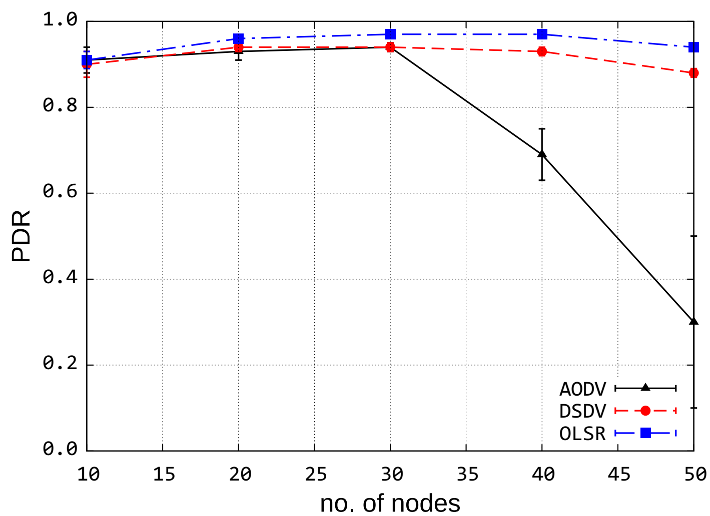

Figure 12: SteadyState Random Waypoint PDR vs. network size

4.2 Delay

Delay does not seem to vary significantly with varying velocity across all mobility models (Figure 13 to Figure 16). It was not expected to vary for the pro-active protocols since there is no buffering and thus a packet is dropped immeadiately a route is not found in the cache. It was however expected to vary for AODV, that is increase with increase in speed of the mobile nodes but it did not. This can be attributed to the fact that the network was small enough for a new or alternate route to be found without increasing the delay significantly and also packets that wait in the buffers beyond the 30 s set for maximum queueing time are eventually dropped and do not account in the delay statistics. With increasing network size, delay increased and this was most significant with AODV. Since in AODV all the nodes in the network are involved in finding a route, the packets wait longer and longer in the buffers as the number of nodes increase for a new route to be found. This is because there is a lot more route requests going around and they also have to wait longer to either be broadcasted to other nodes or to be processed for a route reply to be dispatched. The delay does not rise significantly in OLSR and DSDV because routes are found in advance and since the topology is not changing much, the probability of finding a valid route each time is very high.

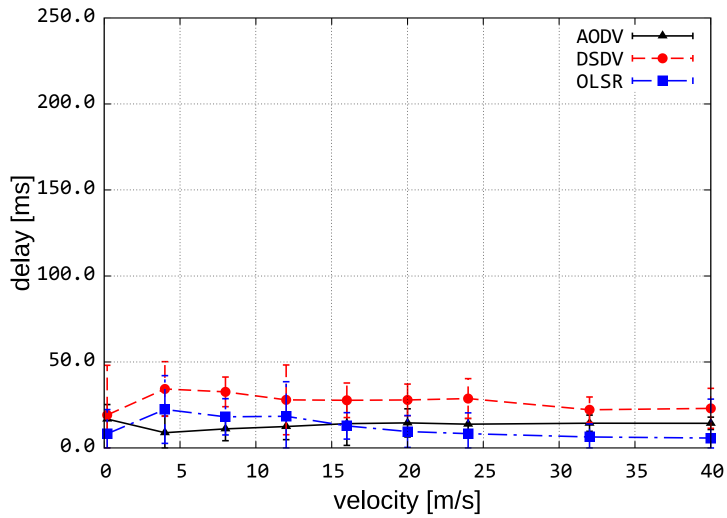

Figure 13: Random Direction delay vs. speed of nodes

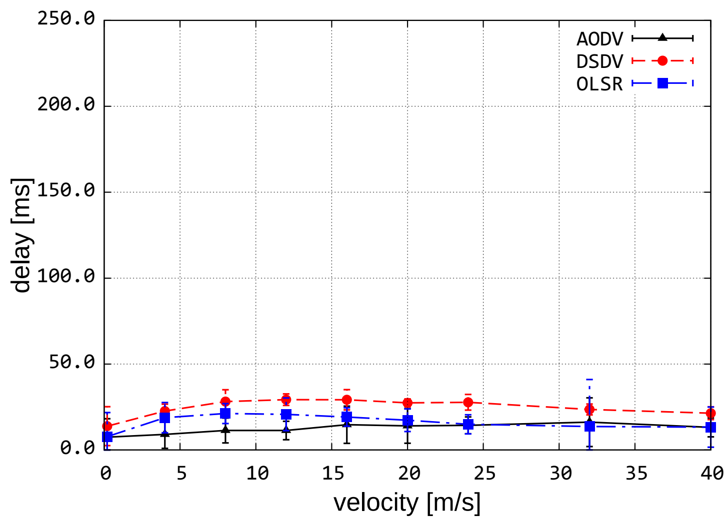

Figure 14: Random Walk delay vs. speed of nodes

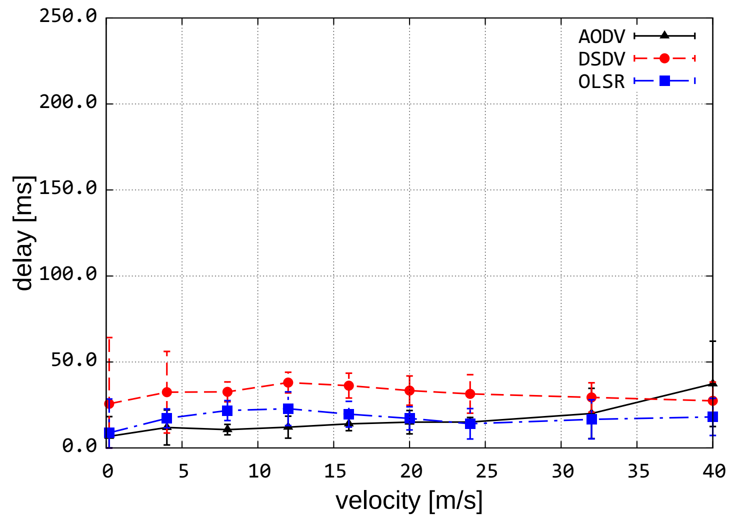

Figure 15: Gauss-Markov delay vs. speed of nodes

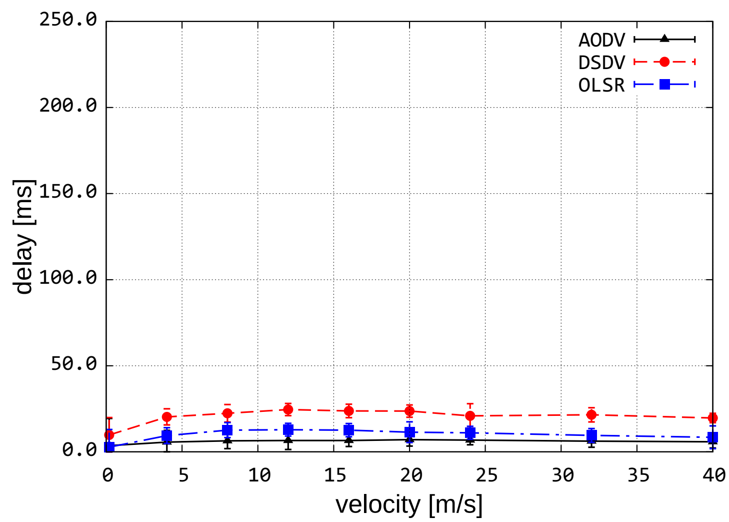

Figure 16: Steadystate Random Waypoint delay vs. speed of nodes

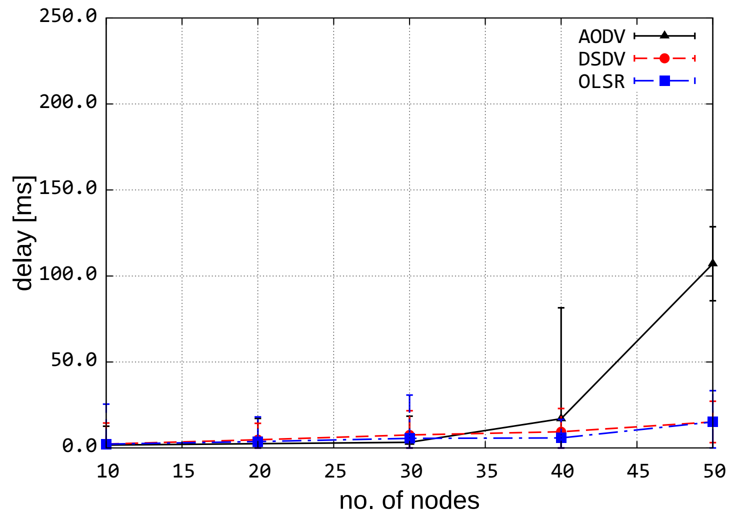

Figure 17: Random Direction delay vs. network size

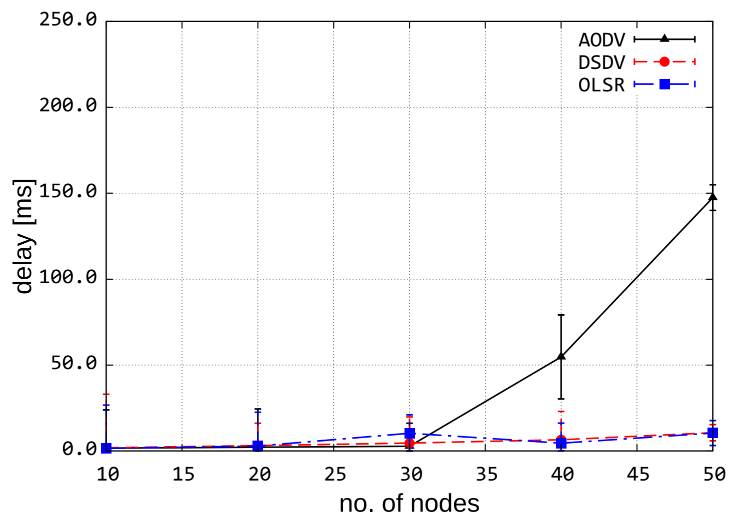

Figure 18: Random Walk delay vs. network size

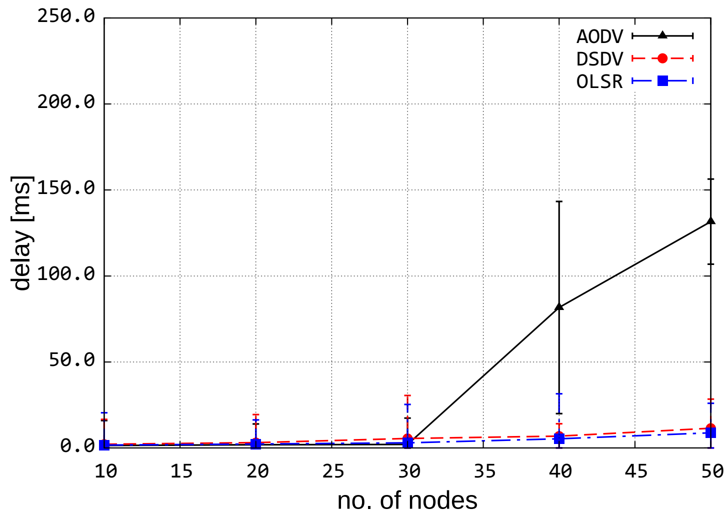

Figure 19: Gauss-Markov delay vs. network size

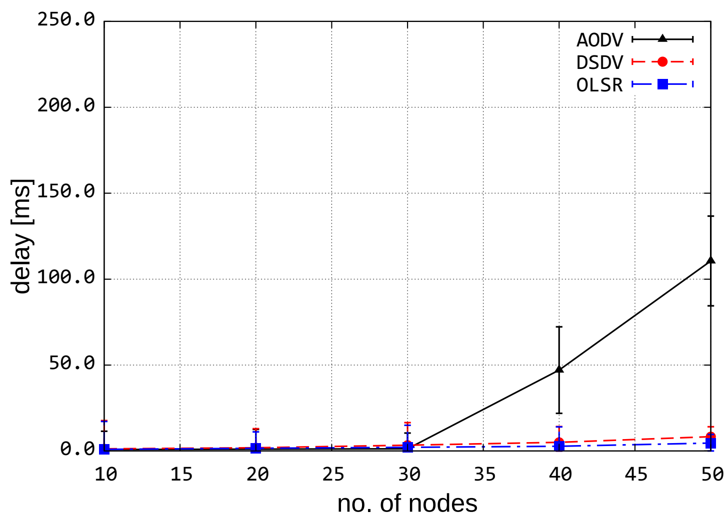

Figure 20: SteadyState Random Waypoint delay vs. network size

4.3 Overhead

The routing overhead of the proactive protocols does not change with increasing velocity and this is because routes are constantly being updated periodically whether the topology is changing or not. With AODV however as the velocity of the nodes increase the routes in the cache become more and more invalid and a route request has to be sent for almost every packet needing to be transmitted. These are in turn broadcasted all over the network thus increasing overhead with increasing velocity as can be seen in Figures 21 through 23. In Figure 24 however, AODV seems to be unaffected by increasing velocity of the nodes. This is because in the steady state random waypoint mobility model, the nodes have a pause time of 100 seconds and thus the topology is not changing as much as in the other mobility models where the nodes are in constant motion throughout the simulation period. The routing overhead for the pro-active protocols always remain steady or rise slightly with increase in network size as can be seen in Figures 25 through 28. This is obviously because the routes are found in advance using periodic updates and since the nodes are moving at a velocity of only 2 m/s the topology is not changing much increasing the probability that the route found in the cache will always be valid. The slight increase with increase in number of nodes can be attributed to the fact that more nodes are now sending these periodic updates. With AODV however, after the number of nodes in the network exceed 30, routing overhead rises exponentially. This can be attributed to the fact that AODV uses all the nodes in the network to find a route. Thus with increase in the number of nodes more routes have to be found leading to more route requests being sent and broadcasted thus more overhead

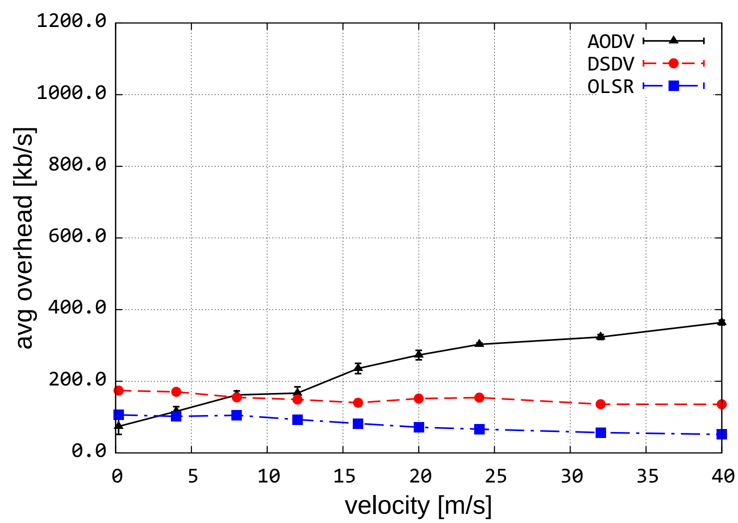

Figure 21: Random Direction overhead vs. speed of nodes

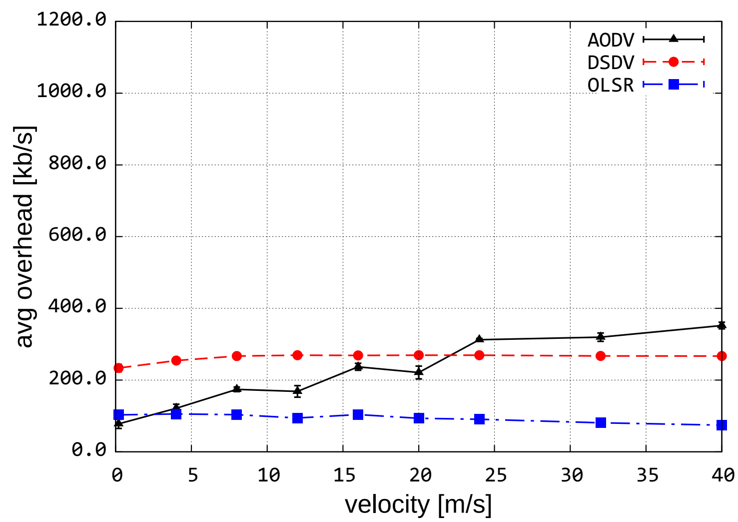

Figure 22: Random Walk overhead vs. speed of nodes

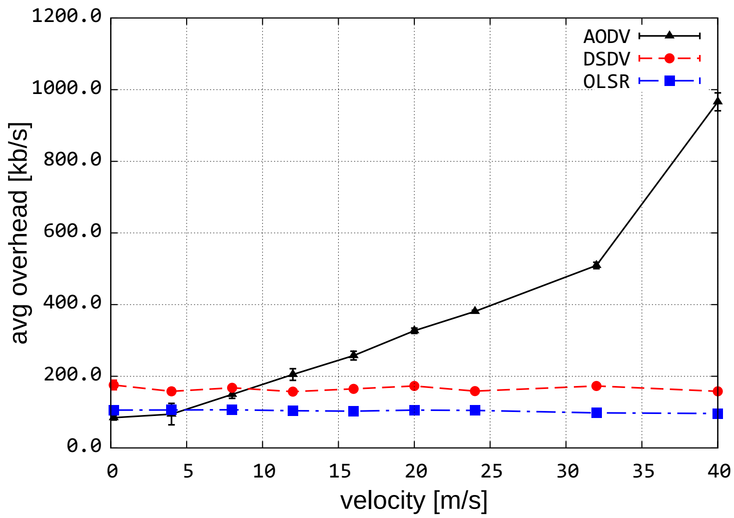

Figure 23: Gauss-Markov overhead vs. speed of nodes

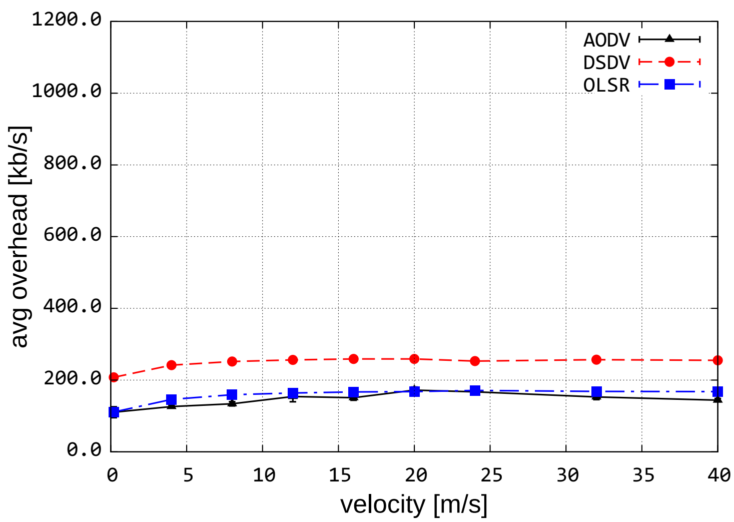

Figure 24: Steadystate Random Waypoint overhead vs. speed of nodes

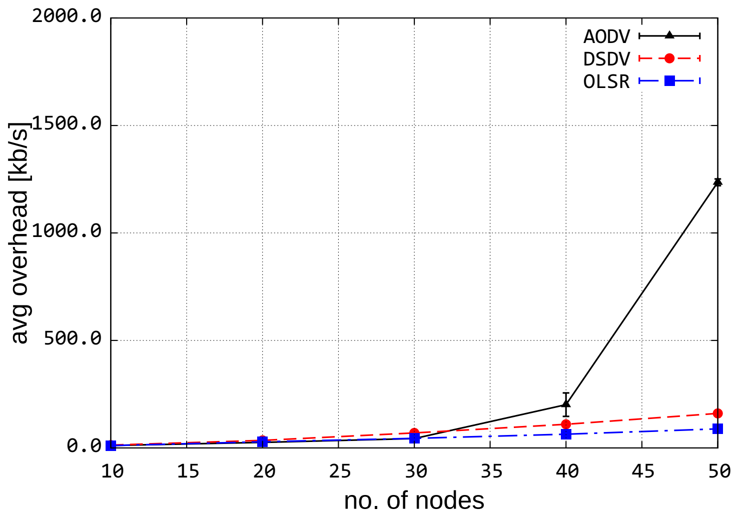

Figure 25: Random Direction overhead vs. network size

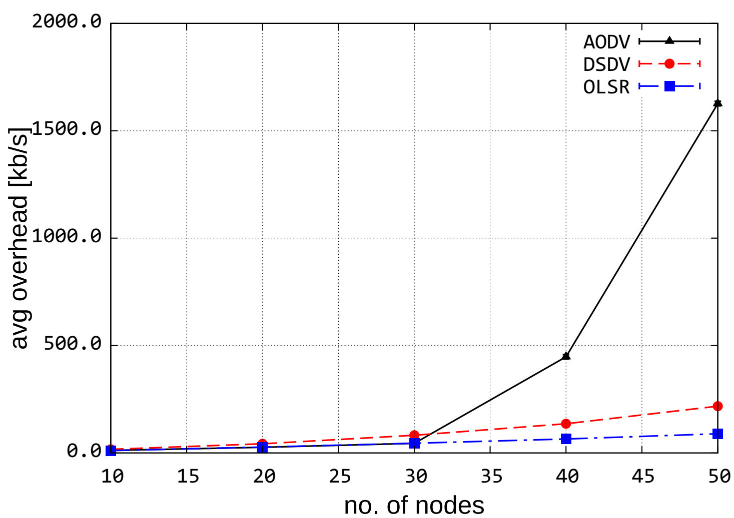

Figure 26: Random Walk overhead vs. network size

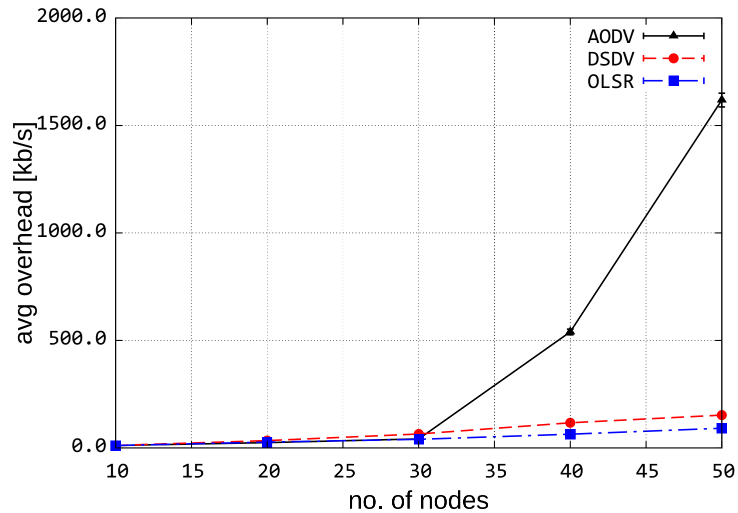

Figure 27: Gauss-Markov overhead vs. network size

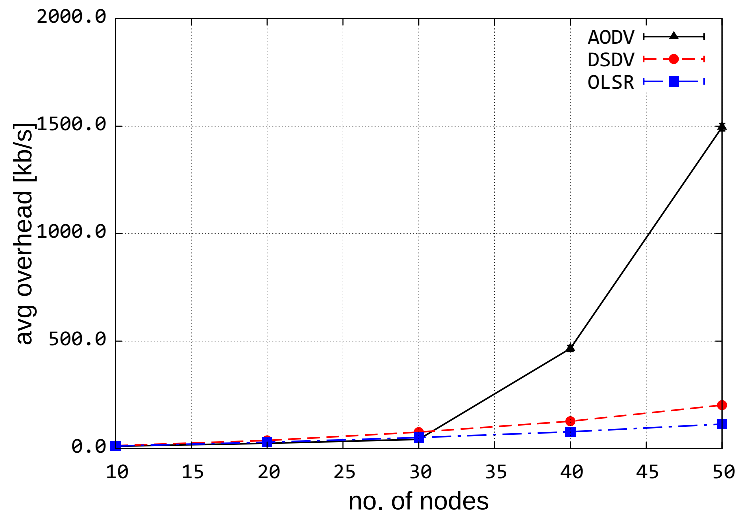

Figure 28: SteadyState Random Waypoint overhead vs. network size

5 Conclusions and Future Work

The analysis of the performance of the MANET protocols shows that the mobility model used affects protocol performance. In steadystate random waypoint mobility model, all the protocols perform far much better than in the other three mobility models used especially for the pro-active protocols. This is because the 100 seconds pause time used in the simulation runs causes the topology to be less dynamic than in the other mobility models. AODV emerges the better protocol for high velocity scenarios and OLSR followed closely behind by DSDV are better for high node density scenarios. In general however, the performance of MANET protocols drops with increasing velocity and node density. Further studies can be done on how these protocols might behave when the nodes in the network are each moving at different speeds and also it would be helpful if the analysis is done in a real life scenario instead of using the mobility models which do not truly represent real life situations.

References

[1] Dan S. Broyles. Benchmarking wireless network protocols: Threat and challenge analysis of the aerorp. Master's thesis, University of Kansas, 2011.

[2] Tracy Camp, Jeff Boleng, and Vanessa Davies. A survey of mobility models for ad hoc network research. *Wireless Communications and Mobile Computing*, 2:483–502, 2002.

[3] Yufei Cheng, Egemen K. Cetinkaya, and James P.G. Sterbenz. Dynamic source routing (DSR) protocol implementation in ns-3. In *Proceedings of the ICST SIMUTools Workshop on ns-3 (WNS3)*, pages 367–374, Sirmione, Italy, March 2012.

[4] T. Clausen and P. Jacquet. rfc3626. Project Hipercom, INRIA, October 2003. RFC for OLSR.

[5] Bai F., Narayanan Sadagopan, and Helmy A. Important: a framework to systematically analyze the impact of mobility on performance of routing protocols for adhoc networks. *INFOCOM, IEEE*, 2:825–835, July 2003.

[6] Maan F and Mazhar N. MANET routing protocols vs mobility models: A performance evaluation. *Ubiquitous and Future Networks (ICUFN), IEEE*, pages 179–184, June 2011.

[7] http://www.nsam.org.

[8] D. Johnson, Y. Hu, and D. Maltz. rfc4728, February 2007. RFC for DSR.

[9] Hemanth Narra, Yufei Cheng, Egemen K. Cetinkaya, Justin P. Rohrer, and James P.G. Sterbenz. Destination-sequenced distance vector (DSDV) routing protocol implementation in ns-3. In *Proceedings of the ICST SIMUTools Workshop on ns-3 (WNS3)*, pages 439–446, Barcelona, Spain, March 2011.

[10] C. Perkins, E. Belding-Royer, and S. Das. rfc3561, July 2003. RFC for AODV.

[11] Charles E. Perkins, Elizabeth M. Royer, Samir R. Das, and Mahesh K. Marina. Performance comparison of two on-demand routing protocols for ad hoc networks. *IEEE Personal Communications*, 2001.

[12] Liu Tie-Yuan, Chang Liang, and Gu Tian-Long. Analyzing the impact of entity mobility models on the performance of routing protocols in the manet. *Genetic and Evolutionary Computing, IEEE*, pages 56–59, February 2010.