Influence of Mobility Models on the Performance of Routing Protocols in Ad-Hoc Wireless Networks

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Abstract**—The patterns of movement followed by the nodes in an Ad-Hoc Network play an important role in the performance of routing protocols. These different patterns of movement of the nodes can be classified into different Mobility Models, each of which are characterized by their own distinctive features. We have explored the influence of three such mobility models (Pursue, Column and RPGM-RW) on the performance of three well-known ad-hoc routing protocols namely DSR, AODV and DSDV. The simulation environment used for this purpose was NS-2. The significance of this study lies in the fact that there has been very limited investigation of the effect of mobility models on routing protocol performance in ad-hoc networks.**

Keywords: Mobility Models, Ad-Hoc Networks, Wireless Networks, Routing Protocols, Performance, 802.11, NS-2, Packet Delivery Ratio, Routing Overhead, Optimality, Throughput, AODV, DSR, DSDV, Pursue, Column, RPGM, Simulation.

I. INTRODUCTION

An ad hoc network may be described as a collection of wireless mobile nodes that dynamically form a temporary network among themselves without the use of any existing network infrastructure or centralized administration. In an ad-hoc network, each node is a host as well as a router, routing packets between other nodes that are not in direct wireless range of each other. All the nodes employ an ad-hoc routing protocol in order to achieve the purpose of routing packets among themselves. We show from our results in the paper that Mobility Models have a considerable effect on the performance of these ad-hoc routing protocols. We also notice that some routing protocols perform better with some Mobility Models than with others. In Section.II we review some of the related work in performance measurement of routing protocols. Section.III summarizes the Mobility Models that we use in the study while Section.IV explains the experiment methodology. Section.V explains the results and Section.VI presents the conclusions.

II. RELATED WORK

A. Broch et al

Broch et al [4] made a performance comparison of the routing protocols DSR, DSDV, AODV and TORA for an ad-hoc network. They extended ns-2 [7] to include node mobility, a realistic physical layer, radio network interfaces and the IEEE 802.11 MAC protocol using Distributed Coordination Function (DCF) for their simulation purposes. Also, the protocols DSDV and AODV used were modified versions of the original specifications that were found to have better performance than the original protocols themselves. While the metrics used were packet delivery ratio, routing overhead and path optimality, only one mobility model namely Random Waypoint model [9] was used in their experiments. All metrics were plotted with variation of pause time of nodes in the Random Waypoint model and are hence not directly comparable to our graphs wherein the metrics have been plotted against node speed. However, we make limited comparisons of their results with ours in section 5.

B. Johansson et al

Johansson et al [5] introduced a new metric to measure performance of routing protocols in ad-hoc networks called 'mobility' which is a function of the relative motion of the nodes taking part in a scenario. They conducted simulations on AODV, DSDV and DSR using delay, throughput and routing overhead as the metrics and plotting their variation with varying 'mobility'. Although the 'mobility' is varied by varying the speed of the nodes, there is no direct correspondence between the 'mobility' and speed of the node. They also come up with scenarios with different 'mobility' and measure the metrics mentioned earlier for those scenarios. Based on their conversion of the mobility metric to actual speed of the node, we make limited comparisons of their results to ours.

C. Hong et al

Hong et al [6] introduced a new mobility model called the Mobility Vector Model and compared the performance of the routing protocols DSR, AODV and FSR using their mobility model along with other mobility models like Random Walk, RPGM and the Random Waypoint Model. The simulations were done using the GloMoSim [8] library. The metrics measured were Link Up/Down Rate (changes /link/second) and Packet Delivery Ratio with variation of average speed and transmission range respectively. Because of their use of non-traditional metrics, their results cannot be directly compared to our results.

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III. MOBILITY MODELS

In order to test the performance of the routing protocols with the mobility models, we added code to the NS-2 (Version 2.26) [7] network simulator implementing the following mobility models whose details are explained below:

A. Column Model

The Column Model is movement of all nodes in a group in single file behind one another. One of the nodes in the group is the leader and the rest of the nodes follow in a column behind the leader node. All nodes have a varying speed that is a slight variation from the AVERAGE_SPEED where AVERAGE_SPEED is a value of speed in m/s. All the nodes need to be close to AVERAGE_SPEED in order to maintain the formation as they travel. The direction of motion of the leader node and by effect the rest of the nodes in a group are chosen as follows. The leader node initially chooses a random destination to begin with. After reaching the destination, each new destination is chosen using the parameters (r, $\Delta\theta$) where r is the distance to the new destination and $\Delta\theta$ is the change in the direction of movement from the previous movement direction. For ease of description, let's call this motion of the leader node the SMOOTH_VARIATION motion. In our experiments, we choose $\Delta\theta$ as a random value between 0 and 10 degrees and an r-value of 10 m. All other nodes move by just following the leader's path. Column Model motion can be best described by the motion of a train wherein each of the nodes may be represented by trailer cars and the leader node in the front may be represented by the train engine.

B. Pursue Model

The Pursue Model is basically designed to mimic the pursuit of a single node by a group of nodes. The direction of motion of the runaway node follows the SMOOTH_VARIATION motion as described earlier. The value of r was 1m and $\Delta\theta$ was a random value between 0 and 10 degrees for this model. In our model, all nodes have a randomly varying speed between zero and MAX_SPEED where MAX_SPEED is a value of speed in m/s. The nodes in pursuit of the runaway node have a direction that at any instant will be in a straight line towards the runaway node.

C. RPGM-RW Model

This Model that we implemented is based on the RPGM Model (Reference Point Group Mobility Model) [10] and we call it the RPGM-RW (Random Waypoint) Model. Our implementation consists of a leader node moving using SMOOTH_VARIATION motion. The value of r was 1m and $\Delta\theta$ was a random value between 0 and 10 for this model. The rest of the nodes in the group move using the Random Waypoint Model, but with the restriction that their movement is limited to within a certain radius R around the leader node. In our experiments, we chose that all the nodes in a group move within a radius of 100 m from the leader node. All nodes other than the leader have a randomly varying speed between 0 and MAX_SPEED where MAX_SPEED is a value of speed in m/s.

IV. EXPERIMENTS

A. Methodology

All our experiments for each mobility model had 5 groups of nodes with 10 nodes in each group. Each group independently modeled each of the mobility models that were being tested. Our experiments also include the Random Waypoint Model along with the mobility models described above for comparison purposes.

The simulation parameters are shown in Table.IV. Each simulation had 20 connections running simultaneously. The connections were evenly divided between nodes within the same group and nodes in different groups. In order to have a fair comparison of performance of all protocols, we subjected all the protocols to identical workloads and environment conditions. Each run of the simulator accepts a scenario file that describes the exact motion of each node, together with the exact time at which each change in motion is to occur. For the Pursue Mobility Model, the RPGM-RW Model and the Random Waypoint Model [9], we had scenario files wherein the speeds of the nodes varied randomly between 0 and MAX_SPEED. The levels of MAX_SPEED used were 1, 5, 10, 15 and 20. For the Column Mobility Model, the speeds of the nodes were close to AVERAGE_SPEED with a little variation about it. The levels of AVERAGE_SPEED used were 1, 5, 10, 15 and 20. We had 10 scenario files for each level of speed for each mobility model.

TABLE I. CONSTANTS USED IN THE DSDV SIMULATION

Periodic route update interval	15 s
Periodic updates missed before link declared broken	3
Initial triggered update weighed settling time	6 s
Weighed settling time weighing factor	7/8
Route advertisement aggregation time	1s
Maximum packets buffered per node per destination	5

TABLE II. CONSTANTS USED IN THE DSR SIMULATION

Time between retransmitted ROUTE REQUESTs (exponentially backed off)	500 ms
Size of source route header carrying n addresses	4n + 4 bytes
Timeout for non-propagating search	30 ms
Time to hold packets awaiting routes	30s
Max rate for sending gratuitous REPLYs for a route	1/s

TABLE III. CONSTANTS USED IN THE AODV SIMULATION

Time for which a route is considered active	10 s
Lifetime on a ROUTE REPLY sent by destination node	10 s
Number of times a ROUTE REQUEST is retried	3
Time before a ROUTE REQUEST is retried	1 s
Time for which the broadcast id for a forwarded ROUTE REQUEST is kept	6 s
Time for which reverse route information for a ROUTE REPLY is kept	6 s
Time before broken link is deleted from routing table	3 s
MAC layer link breakage detection	Yes

TABLE IV. SIMULATION PARAMETER VALUES

Transmitter Range	250 m
Bandwidth	2 Mbps
Simulation Time	900 s
Number of Nodes	50
Environment Size	1500 x 300 m
Traffic type	Constant Bit Rate
Packet Rate	4 packets/s
Packet Size	64 byte
Number of flows	20

This means that we made 10 repetitions for each speed for a total of 50 simulations (10 repetitions * 5 speeds) for each mobility model. The metrics used to measure the performance of the routing protocols are:

Packet delivery ratio: The ratio of the number of packets originated by the application layer CBR sources to the number of packets successfully delivered to their CBR sink at the final destination.

Packet 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.

Throughput: The data transferred by all connections in bits/second as an average throughout the entire length of the simulation

Path Optimality: The difference between the number of hops a packet took to reach its destination and the length of the shortest path that physically existed through the network when the packet was originated.

V. RESULTS

A. Packet Delivery Ratio

In Tables V-VIII, we tabulate the Packet Delivery Ratio as a function of speed for the four mobility models. All data points are an average of 10 repetitions. We notice that that the best performance with respect to packet delivery ratio is from DSR, followed by DSDV and then AODV. We also notice that there is more variation of the packet delivery ratio with speed for the Column and the RPGM-RW model than the Pursue and the Random Waypoint model. This is because the groups of nodes in Column and RPGM-RW models are usually more compactly packed together resulting in less homogenous spacing of nodes in the given topology. This makes the functionality of routing highly dependent on the individual formations of nodes in each simulation. This in-turn results in the highly erratic variation of the Packet Delivery Ratio. Since the distribution of nodes is more homogeneous in the Pursue and Random Waypoint Model, there is less variation in the Packet Delivery Ratio.

AODV: While there is no consistent variation with speed, we do notice that AODV doesn't perform as well for the column model as for the other models. Considering the fact that this is coupled with lower routing overhead for AODV with the column model indicates that there is no efficient routing information being exchanged between the nodes in the case of long routes formed in the Column Model leading to adverse performance.

DSDV: The models arranged in order of performance for DSDV is Pursue, RPGM-RW, Random Waypoint and then Column.

DSR: DSR is more suited for the Pursue and the Random Waypoint models than the column and the RPGM-RW models. This is because less homogeneity in the column and RPGM-RW model results in less route formations between nodes in different groups. The packet delivery ratio in the Column model is the least because of the longer route formations in addition to the less homogeneity. It is noteworthy that the packet delivery ratio doesn't seem to vary drastically with speed for any of the mobility models.

B. Packet Routing Overhead

In Fig.1 we plot the Packet routing overhead. All the points in the graphs are plotted as an average of ten repetitions of the experiment. We notice that DSR has the least routing overhead, followed by DSDV and then AODV.

AODV: We notice that AODV is highly sensitive to the homogeneity of the distribution of nodes. We see that for the Column model which has the least homogeneity, the routing overhead is low, and the routing overhead for the RPGM-RW model that has higher homogeneity than the Column model, the routing overhead is almost twice as much. As the homogeneity increases, we also see the routing overhead increase correspondingly in the Pursue and Random Waypoint model. This lower overhead for less homogeneity can be explained by the fact that in models with less homogeneity, all the routes within a group are usually preserved because the nodes are in very close vicinity of each other. Hence, these routes are preserved in the routing tables for a long time and there don't have to be repeated route discoveries for communication within groups. Also the path maintenance for routes within a group doesn't cause much overhead because the routes are often valid for a long time. The local connectivity management in AODV using *Hello* messages between neighbors is more effective within the groups of nodes because of their relative proximity to each other and their relative immobility to each other. The steady decrease in the routing overhead in the Pursue model is explained by the fact that there is less homogeneity at

TABLE V. PACKET DELIVERY RATIO VARIATION WITH AVERAGE SPEED OF NODE FOR THE COLUMN MODEL

	1 m/s	*5 m/s*	*10 m/s*	*15 m/s*	*20 m/s*
AODV	0.393	0.402	0.394	0.414	0.387
DSDV	0.619	0.636	0.584	0.607	0.551
DSR	0.669	0.718	0.662	0.689	0.638

TABLE VI. PACKET DELIVERY RATIO VARIATION WITH MAXIMUM SPEED OF NODE FOR THE PURSUE MODEL

	1 m/s	*5 m/s*	*10 m/s*	*15 m/s*	*20 m/s*
AODV	0.488	0.494	0.467	0.508	0.47
DSDV	0.767	0.779	0.767	0.734	0.722
DSR	0.995	0.984	0.974	0.935	0.945

TABLE VII. PACKET DELIVERY RATIO VARIATION WITH MAXIMUM SPEED OF NODE FOR THE RPGM-RW MODEL

	1 m/s	*5 m/s*	*10 m/s*	*15 m/s*	*20 m/s*
AODV	0.421	0.479	0.531	0.45	0.51
DSDV	0.72	0.708	0.715	0.632	0.737
DSR	0.802	0.852	0.797	0.749	0.861

TABLE VIII. PACKET DELIVERY RATIO VARIATION WITH MAXIMUM SPEED OF NODE FOR THE RANDOM WAYPOINT MODEL

	1 m/s	*5 m/s*	*10 m/s*	*15 m/s*	*20 m/s*
AODV	0.539	0.44	0.442	0.421	0.432
DSDV	0.758	0.703	0.661	0.653	0.623
DSR	0.999	0.99	0.986	0.981	0.978

speeds with passing time in the Pursue model because the pursuing nodes seem to catch up faster with the runaway nodes resulting in a closer formation of the pursuing nodes around the runaway node. Another contributing factor is the fact that at lower speeds, there is more flooding by AODV in the network by route discovery packets for routes that take longer to be established between far away nodes, while at higher speeds there is higher possibility of faraway nodes coming closer and hence a route being established between them with the passage of time which reduces the flooding of route request packets into the network. Higher flooding of route request packets also explains the initial spike of routing overhead at the low speed of 1 m/s with the Random Waypoint model.

DSDV: The increase in routing overhead with speed in the column model, the RPGM-RW model and the Random Waypoint model is because increased speed causes increased rate of change of metrics among the routes in the routing tables of the nodes along with a higher rate of change of sequence numbers resulting in more frequent transmission of incremental updates and 'full dump' packets. The decreasing overhead with speed in the pursue model can be attributed to the decrease in homogeneity of nodes along with increasing speed resulting in overhead similar to the Column and RPGM-RW models that are characterized by less homogeneity. As previously noted, models with reduced homogeneity have less overhead because route establishment and maintenance of routes within the groups cost less since they are fairly stable.

DSR: DSR seems to show a uniform rise in most cases with increasing speed. This is because, with higher speeds there are more route changes resulting in more route discovery and route maintenance packets being sent. We also note that DSR isn't as affected as the other protocols with change in the homogeneity of nodes in the topology. We attribute this to the efficient caching strategy of DSR wherein multiple routes are cached for each destination by promiscuously listening to the packets that are being transmitted which results in fewer route discoveries even when the nodes are more evenly dispersed (more homogeneity).

Table.IX-XI provide a limited comparison of our results to those from [4] and [5]. Table.X contains the comparison of the routing protocols from [4] using Random Waypoint Model with a speed of 20 m/s and with zero pause time, while Table.XI contains the similar data from [5] for Random Waypoint with speed of 20 m/s (mobility = 3.5) and pause time of 1 m/s (they don't do zero pause time). AODV has greater packet routing overhead than any of the other protocols. Also, DSDV outperforms DSR in our experiments in the Column and the RPGM-RW model while still confirming to the numbers in [4] and [5] for the Random Waypoint Model. This means that DSDV is a better protocol than DSR in terms of packet overhead for mobility models with less homogeneity.

C. Throughput and Optimality

Our results show that the protocols in order of performance are DSR, DSDV and AODV in terms of both throughput and optimality. DSR throughput is better when there's less aggregation of nodes. The Column model has the best optimality followed by the RPGM-RW model, Pursue model and then Random Waypoint model.

VI. CONCLUSIONS

Speed is an Illusion: The effect of speed of nodes in an ad-hoc network on the performance of the routing protocols is over-rated. This is evident from the plots of the various metrics against speed. We reason that the rate of change of connectivity which directly effects routing protocol performance depends more on a factor depending jointly on the transmission range and the size of the field used in which the nodes are placed. The packet size also plays an important role in routing protocol performance based on our initial experiments.

TABLE IX. COMPARISON OF PACKET ROUTING OVERHEAD FOR MOBILITY MODELS

	*AODV/DSR*100*	*DSDV/DSR*100*	*AODV/DSDV*100*
Column	261.62-422.69	24.4-30.27	1056.2-1426.57
Pursue	2466.98-19104.72	65.91-480.25	3428-3978.09
RPGM-RW	535.38-1141.19	21.73-51.22	2219.52-2463.57
Random Waypoint	1081.36-2888.6	28.57-148.28	1139.95-3833.85

TABLE X. COMPARISON OF PACKET ROUTING OVERHEAD FROM BROCH ET AL [4]

	AODV/DSR*100	DSDV/DSR*100	AODV/DSDV*100
Random Waypoint	534.78	195.65	273.33

TABLE XI. COMPARISON OF PACKET ROUTING OVERHEAD FROM JOHANSSON ET AL [5]

	AODV/DSR*100	DSDV/DSR*100	AODV/DSDV*100
Random Waypoint	287.5	156.25	184

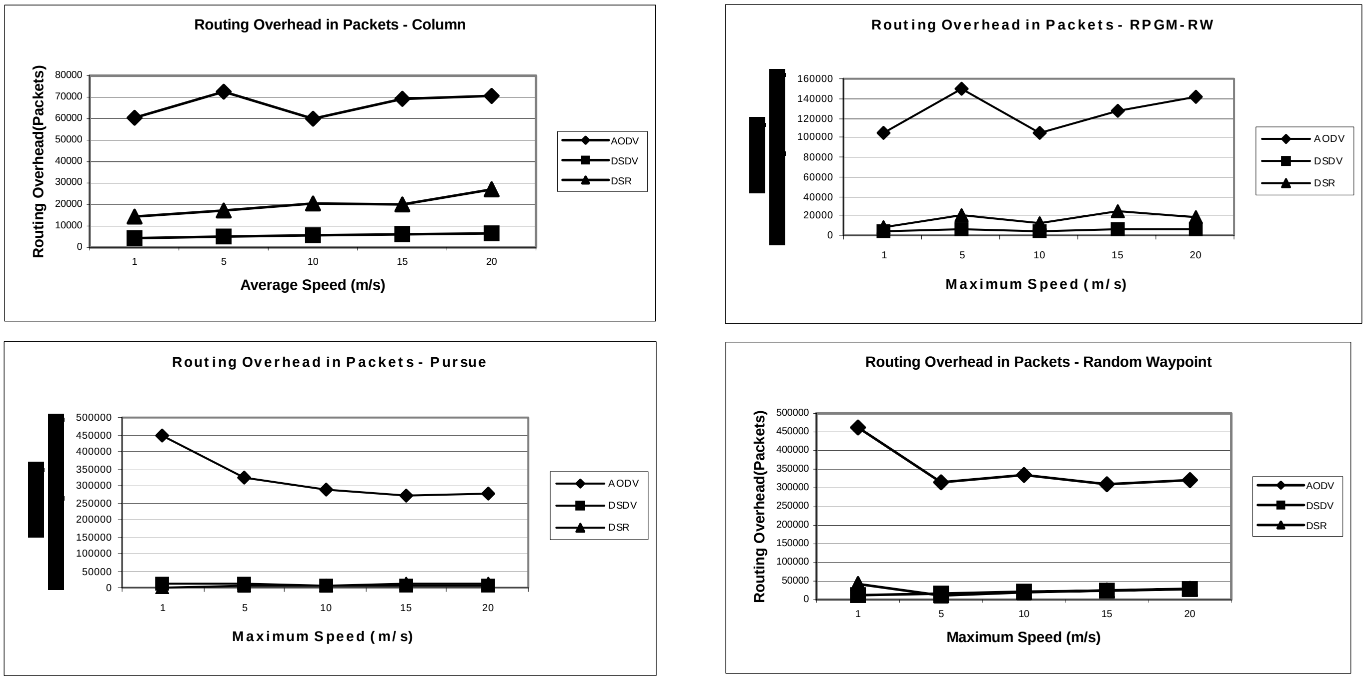

Figure 1. Packet Routing Overhead of the Mobility

DSR outperforms the other protocols: This is because DSR has many optimizations like packet salvaging, automatic route shortening, and caching of multiple routes. Many DSR optimizations are also facilitated by using the nodes in promiscuous mode to get routing information from overheard packets.

DSDV performs better than AODV: We notice that DSDV, in spite of not being an On-Demand protocol performs surprisingly better than AODV.

AODV High Routing Overhead: AODV seems to have really high routing overhead because of the flooding of route requests throughout the network whenever a node needs a route to a destination. DSR cleverly avoids flooding of route discovery packets to some extent by sending the initial route discovery packet with a TTL of 1 so that only the adjacent nodes get the request. If this fails, only then does it resort to flooding the route discovery packets. Another important reason for the high routing overhead of AODV is that AODV doesn't cache multiple routes to a destination like DSR does and has to resort to route discovery more often.

Similarity of Column model and RPGM-RW model: This is attributed to the fact that there is more compact grouping of nodes within a group in these models resulting in less homogeneous dispersion of nodes in the topology provided.

Similarity of Pursue model and Random Waypoint model: This is due to the fact that there is relatively less compact grouping of nodes within a group resulting in a more homogenous dispersion of nodes in the topology.

AODV performs better with Column and RPGM-RW models: AODV has much lower routing overhead for the Column and RPGM-RW models.

AODV Routing Overhead for the Pursue Model: AODV routing overhead decreases with increase in speed for the pursue model. We attribute this to the fact that AODV performs relatively better in models with higher aggregation of nodes. Since in the Pursue Model, there is a gradual increase in aggregation of nodes with passing time, which happens faster for higher node speeds, we see that the routing overhead decreases with increasing node speed.

DSR fares better with Pursue Model and Random Waypoint: This is because less homogeneity in the column and RPGM-RW model results in less route formations between nodes in different groups than in the Pursue and Random Waypoint Model.

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