Comparative study of entity and group mobility models in MANETs based on underlying reactive, proactive and hybrid routing schemes

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Abstract—**Unpredictable mobility is a distinguishing feature of self-configuring MANeTs. Such erratic mobility makes the network topology highly dynamic and results in larger link breakages and link establishments between the nodes. Routing protocols must dynamically recalculate the routing paths in order to cater such link changes. Each mobility model influences network performance in a different way and have a special influence on the performance of routing protocols. Many academic papers have evaluated the influence of mobility models of MANeTs on network performance assuming similar routing and network conditions. In this paper, we do not cater the influence of mobility models in a standalone position rather we have varied mobility and analyzed the effect of several entity and group mobility patterns under proactive, reactive and hybrid routing schemes based on several performance metrics. We have analyzed that proactive schemes and group mobility models outclass their counter parts.**

Keywords- MANeTs; mobility models; routing protocols; performance evaluation; simulation

I. Introduction

MANET is an autonomous collection of mobile users that communicate over relatively bandwidth constrained wireless links. Since the nodes are mobile, the network topology may change rapidly and unpredictably over time. The network is decentralized, where all network activity including discovering the topology and delivering messages must be executed by the nodes themselves, i.e., routing functionality will be incorporated into mobile nodes. Several adhoc networks are used in practice such as Vehicular AdHoc Networks (VANETs) are used for communication among vehicles, and between vehicles and roadside equipment. Intelligent vehicular ad hoc networks (InVANETs) are a kind of artificial intelligence that help vehicles to behave in intelligent manners during vehicle-to-vehicle collisions, accidents etc. Internet Based Mobile Ad hoc Networks (iMANET) link mobile nodes and fixed Internet-gateway nodes. In such type of networks normal ad hoc routing algorithms don't apply directly.

There are many works related to the performance evaluation of mobility models and routing protocols such as [1-9]. Gowrishankar et al. [1] carried out a simulation based comparative study of various group mobility models such as community model, GFMM, RPGM, Manhattan and RWP-SS by using Adhoc On-Demand Distance Vector (AODV) as underlying routing scheme. They computed packet delivery ratio, average network delay, throughput, routing overhead and average hop count under varying mobility conditions. Simulation results concluded that community mobility model had overall performance advantage over other group mobility models. Mbarushimana et al. [2] accomplished the comparative study of reactive and proactive routing protocols under similar network conditions. Their simulation results show the superiority of proactive over reactive protocols such as traffic delivery at the cost of a higher routing load but this comparison does not take into consideration the underlying dynamic mobility and change in network state. Similarly Madhusudan et al. [3] simulated DSR, AODV and Zone Routing Protocol (ZRP) against Random Walk and Random Waypoint mobility models, and evaluated the effect of transmission range and pause time on data delivery ratio. Results depicted that there exists direct relationship between delivery ratio and both these parameters. VinodKumar et al. [4] is another classical example of such work; they evaluated AODV, Dynamic Source Routing (DSR), ZRP, Fish Eye State Routing (FSR) by varying mobility and calculated throughput, number of received packets, jitter and end-to-end delay. Results concluded that table-driven schemes performed well in high mobility scenarios than on-demand schemes.

We have extended the idea of [1] by adding other mobility models and routing schemes. Our study is unique in the sense it provides a comparison between major mobility patterns (entity and group) by varying mobility and underlying routing methodologies (proactive, reactive, hybrid) in a single paper. This combination of routing schemes and mobility models has not been evaluated before.

Rest of the paper is categorized as follows. Section II and Section III present an overview of routing protocols and mobility models respectively, that have been used in this study. Section IV provides detailed information on performance evaluation parameters that we have opted for comparison. Section V presents proposed model. Section VI supplies simulation related information; Section VII provides performance review of mobility models whereas Section VIII concludes the paper.

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II. ROUTING PROTOCOLS

Different types of routing protocols are available for mobile ad hoc networks, that is proactive, reactive and hybrid protocols. Reactive routing protocols are also called "on-demand" routing protocols. In reactive routing, paths are searched only when needed; a route discovery operation invokes a route determination procedure which terminates when either a route has been found or no route is available after examination for all route permutations. In proactive routing, routing paths are pre-established. Routing tables are maintained at all the nodes of the network which are updated in both ways; after a predefined amount of time and in case of occurrence of an event like a node coming or a node leaving the network. Compared to the proactive routing, reactive routing protocols have less control overhead but more average latency due to route calculation on demand. Hybrid schemes use the best features of both: the reactive scheme and the proactive scheme. Hybrid routing uses distance-vectors for more accurate metrics to determine the best paths to destination networks, and report routing information only when there is a change in the topology of the network. Hybrid routing provides rapid convergence but requires less processing power and memory as compared to pro-active routing.

AODV and DSR from reactive schemes, Optimized Link State Routing (OLSR) and FSR from pro-active schemes, and ZRP from hybrid schemes have been selected for carrying out simulation.

A. AODV

AODV, a reactive scheme, creates routes on demand [10]. Whenever a node needs to send a packet to some destination, it broadcasts a route request RREQ packet. Packet is re-broadcasted by the neighboring nodes till it reaches the final destination or to the node that has latest path to the destination. Each node, re-broadcasting the packet, maintains a record of the nodes that sent the first copy of the request packet so that reverse path can be maintained for route reply RREP delivery. AODV significantly reduces the flooding overhead at the cost of average latency.

B. DSR

DSR is another reactive scheme that is based on source routing [11]. Unlike other reactive schemes, it does not send hello messages to its neighbors, thus reduces periodic update overhead. It involves two phases of route construction and route management. Route Request RREQ and Route Reply RREP mechanism of DSR is same as for AODV with two exceptions: DSR maintains multiple routes per destination, DSR adds complete path to destination in the data packet.

C. OLSR

OLSR, a proactive scheme, uses hello and topology control messages to discover and broadcast link state information to other nodes of the network [12]. Through hello messages, each node finds its 2-hop neighbors and selects another node as MPR if each of its 2-hops neighbors can be reached via that selected MPR. MPRs are responsible for broadcasting messages during flooding, and generating link state information.

D. FSR

FSR is another proactive routing scheme that is based on the concept of multi-level fisheye scope [13]. Here nodes do not broadcast link state information rather they only send information to the neighboring nodes in order to reduce routing update overhead. Routing update occurs at a frequency that depends upon distance to destination. Link state entries are then used to create topology map of the network and calculate optimal route.

E. ZRP

ZRP, having reactive as well as proactive touch, is the oldest amongst hybrid routing schemes [14]. ZRP was designed to counter the control overhead of table-driven schemes and latency of on-demand schemes. ZRP maintains a zone around each node that consists of all nodes within 'k' hops away from that node. Proactive routing is used within the zone whereas reactive routing is used amongst zones. For data delivery, it is checked whether the destination node exists within the zone or not. If yes, data is sent immediately otherwise RREQ packet is sent to border nodes. Border nodes check within their own zones for destinations. If found, border node sends RREP on reverse path otherwise it adds its own address to the packet and forwards to its own border nodes. Process continues until packet reaches to the destination itself or to a node having destination within its zone. Path in the RREP packet is used for sending data to destinations.

III. MOBILITY MODELS

A Mobility Model (MM) mimics the behavior of real Mobile Nodes (MNs). Two major classifications of mobility models are entity and group mobility models. Entity mobility models map the movement behavior of individual MNs whereas group mobility models mimic the movement behavior of MNs, moving in groups. Random Walk, Restricted Random Walk and Random Direction mobility models have been selected from the category of entity models whereas Pursue and Column mobility models are representatives of group mobility models.

A. Random Walk

Random Walk (RW) mobility model mimics the natural erratic movement of human beings. Here, a MN moves from its present location to a new location by randomly choosing a speed and direction in which to travel. The new speed and direction are chosen from pre-defined ranges of [min-speed, max-speed] and [0, 2*pi] respectively. Each node either moves for a constant time't' or covers a constant distance 'd' before choosing new direction and speed. MN does not pause before changing direction and speed.

B. Restricted Random Walk

Restricted Random Walk (RRW) mobility model, a tailored version of Random Walk, imposes restrictions on the speed and direction of MNs. In this model, after a mobile node finishes a movement, it chooses a speed uniformly between [s-k,s+k] where 's' is the last speed and 'k' is a constant, and the direction angle between [α+Π/4, α-Π/4] where α is the previous angle which is either incremented or decremented by Π/4.

C. Random Direction

Random Direction (RD) mobility model was designed to solve the convergence problem of RW. In RW, MNs appear to converge, disperse, and converge again because of huge probability of selecting center point of simulation as destination, or moving through the center in heading towards destination whereas in RD, a MN travels to the border of the simulation area in a specified direction. Once the simulation boundary is reached, MN pauses for a specified time, chooses another angular direction and continues the process.

D. Column Mobility Model

Column (COL) mobility model includes a group of MNs that move in a straight and fixed direction. It resembles the natural movement of people moving in a straight line. This mobility model also impersonates the movement of military robots for destruction of mines.

E. Pursue Mobility Model

In Pursue (PR) mobility model, a group of mobile nodes chase a given target node. Pursuing nodes move according to pursue mobility model. Target node may move according to any mobility model however Random Way Point is the most preferred choice for target node. This mobility pattern is extensively used in target tracking and law enforcement. Velocity vector, calculated using position of the target node, is added to the previous position of seeker nodes so that they can intercept the target node.

IV. PERFORMANCE EVALUATION PARAMETERS

Selection of appropriate performance evaluation parameters plays a pivotal role in accomplishing meaningful study. Among dozens of performance evaluation parameters, we have chosen Control Packet Throughput, Data packet Throughput, Average Latency and Average Hops.

A. Control Packet Throughput

Control Packet Throughput is the percentage ratio of total control packets received and sent by the network.

$$ControlPacketThroughput = \frac{\sum_{i=1}^{n} ControlPacketsReceivedByNode'i'}{\sum_{i=1}^{n} ControlPacketsSentByNode'i'} \times 100$$

B. Data Packet Throughput

Data Packet Throughput is the percentage ratio of total data packets received and sent by the network. change formula as above.

$$DataPacketThroughput = \frac{\sum_{i=1}^{n} DataPacketsReceivedByNode'i'}{\sum_{i=1}^{n} DataPacketsSentByNode'i'}$$

C. Average Latency

Average Latency elaborates that on average how much delay the packets suffer in transmission from source to destination node. Average latency covers delay, experienced by data packets only.

$$AverageLatency = \frac{\sum_{i=1}^{n}\sum_{j=1}^{k}(ReceivingTimeOfPacket'j' - SendingTimeOfPacket'j')}{\sum_{i=1}^{n} PacketsReceivedByNode'i'}$$

D. Average Hops

Average Hops depicts that on average how many hops a packet has to cover before reaching destination. It is basically the average number of hops between source and destination nodes.

$$AverageHops = \frac{\sum_{i=1}^{n}\sum_{j=1}^{k} HopsCoveredByPacketNumber'j'}{\sum_{i=1}^{n} PacketsReceivedByNode'i'}$$

$i=1,\ldots,n$ depict total nodes in the network whereas $j=1,\ldots,k$ represent number of packets received or sent by single node 'i'.

V. PROPOSED MODEL

We developed a software using OMNeT++ that creates given number of mobile nodes, having built-in OSI layer system. In Figure, two such mobile nodes are shown communicating with each other through the simulated physical layer. Each node communicates with the nodes in its vicinity in the same way.

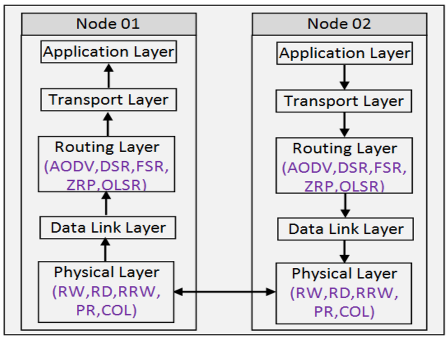

Figure 1. Two Nodes of the Proposed Model for Simulation

Software supports configurable routing and mobility pattern for given network. We implemented mobility models on physical layer and routing protocols on network layer. Implementation of all the mobility models was based on [15] and only intra-group communication was allowed between nodes of group mobility models. Similarly, implementation of routing protocols was based on RFC 3561[10], RFC 4728[11] and RFC 3626[12] for AODV, DSR and OLSR protocols respectively, however FSR and ZRP were based on internet draft version 03 [13] and 04 [14] of their respective series.

VI. SIMULATIONS

Several simulation scenarios have been furnished to compare the mobility models. Software supports adjustable number of nodes, mobility pattern and routing method. Table I represents adjustable parameters of the system.

Simulations were conducted for each unique combination of routing protocol and mobility model. All the adjustable parameters were kept fix except number of nodes, which were varied from a minimum of ten to a maximum of fifty.

Total simulation scenarios = 5(mobility model) x 5(routing protocol) x 41 (number of nodes varying from 10-50)

= 1025

TABLE I. ADJUSTABLE SIMULATION PARAMETERS

Simulation Parameter	Value (Range of Values)
Number of nodes	**10-49**
Number of entity MMs	**3 (RW, RRW, RD)**
Number of group MMs	**2 (Pursue, Column)**
Length of Column(Column MM)	**7 nodes**
Number of reactive protocols	**2 (AODV, DSR)**
Number of proactive protocols	**2 (OLSR, FSR)**
Number of hybrid protocols	**1 (ZRP)**
Data packet size	**256 bytes**
Channel capacity	**2 Mbps**
Software	**OMNeT++**
Simulation area	**500m x 500m**
Simulation time	**1500 sec**
Pause time	**5 sec**

Each simulation was run for 1500 seconds. We have assumed that each host participating in the network should also be willing to forward packets for other hosts in the network. Second assumption was that hosts within the MANeT may move at any time without prior notice.

TABLE II. CONTROL AND DATA PACKET THROUGHPUT FOR DIFFERENT COMBINATIONS OF ROUTING PROTOCOLS AND MOBILITY MODELS

Mobility Models		Control Packet Throughput						Data Packet Throughput					
		Pro-active RP		*Reactive RP*		*Hybrid RP*	*Average for MM*	*Pro-active RP*		*Reactive RP*		*Hybrid RP*	*Average for MM*
		OLSR	*FSR*	*AODV*	*DSR*	*ZRP*		*OLSR*	*FSR*	*AODV*	*DSR*	*ZRP*	
Entity MM	***Random Walk***	52.63	60.49	38.07	41.76	49.02	**48.39**	48.41	52.9	58.91	67.41	38.93	**53.31**
	R. Random Walk	59.86	64.88	48.71	44.54	55.23	**54.64**	51.76	50.07	70.34	75.66	40.66	**57.70**
	Random Direction	46.73	49.02	28.01	28.07	38.07	**37.98**	43.39	44.68	59.84	51.68	36.00	**47.12**
Group MM	***Pursue***	74.09	77.93	59.88	62.22	70.10	**68.84**	59.39	66.85	82.27	80.95	34.05	**64.70**
	Column	77.62	72.61	61.05	68.34	70.61	**70.05**	57.88	60.15	74.07	71.83	45.00	**61.79**
Average for individual RPs		**62.19**	**64.99**	**47.14**	**48.99**	**56.61**		**52.17**	**54.93**	**69.09**	**69.51**	**38.93**	

TABLE III. AVERAGE DELAY AND AVERAGE HOP COUNT FOR DIFFERENT COMBINATIONS OF ROUTING PROTOCOLS AND MOBILITY MODELS

Mobility Models		Average Delay						Average Hop Count					
		Pro-active RP		*Reactive RP*		*Hybrid RP*	*Average for MM*	*Pro-active RP*		*Reactive RP*		*Hybrid RP*	*Average for MM*
		OLSR	*FSR*	*AODV*	*DSR*	*ZRP*		*OLSR*	*FSR*	*AODV*	*DSR*	*ZRP*	
Entity MM	***Random Walk***	0.03	0.04	0.30	0.20	0.08	**0.13**	1.09	1.10	3.14	3.43	2.80	**2.31**
	R. Random Walk	0.01	0.04	0.15	0.17	0.11	**0.10**	1.02	1.04	2.78	2.95	1.09	**1.78**
	Random Direction	0.13	0.13	0.25	0.30	0.20	**0.20**	2.57	2.42	3.12	3.29	2.87	**2.85**
Group MM	***Pursue***	0.01	0.02	0.07	0.07	0.03	**0.04**	1.01	1.05	1.09	2.04	2.06	**1.45**
	Column	0.03	0.02	0.09	0.11	0.07	**0.06**	1.02	1.01	2.29	2.40	2.08	**1.76**
Average for individual RPs		**0.04**	**0.05**	**0.17**	**0.17**	**0.10**		**1.34**	**1.32**	**2.48**	**2.82**	**2.18**	

VII. PERFORMANCE EVALUATION

In this section, we analyze how different combinations of mobility models and routing protocols react when subjected to topology changes. The performance of five routing protocols and five mobility models is measured based on throughput (control and data), average end-to-end delay and average hops. Table-II and Table-III provide a comprehensive overview of the performance. Red entries represent average value of performance measures for individual mobility models, blue entries represent average values of performance parameters for individual routing protocols, whereas black entries illustrate performance measures for their different combinations. Following performance comparison, discussion and conclusions are based on results of Table II and Table III.

A. Performance Comparison of Mobility Models

While analyzing performance of mobility models in Table II and Table III, we see that group mobility models outclass entity mobility models in all respects. Group mobility models exhibit higher average values of throughput, and lower average values of hop count and latency. There are solid reasons behind this phenomenon. Firstly, nodes in group mobility models move in a group and links are always maintained amongst them when they chase target so control information is transferred more reliably that results in higher control packet throughput. Secondly, group nodes share similar aim and links seldom break in a group, so data is sent more reliably on connected and active links that results in higher data packet throughput. Thirdly, group models result in least average hops because group nodes are mostly first hop or second hop neighbors so data packets and control packets need to cover fewer hops. Finally, average latency is also good for group mobility models because mostly, communication takes place amongst group nodes which are very close to each other so packets suffer minimum end-to-end delay.

B. Performance Comparison of Entity Mobility Models

Performance of different entity mobility models varies drastically as can be viewed in Table II and Table III. Restricted Random Walk has least average hops and average latency because nodes, being moving in a constrained area, are fewer hops away from each other so data transmission takes lesser time, and covers fewer links whereas Random Direction mobility model has worst average latency and average hops because nodes are allowed to move to the border of simulation area. Hop counts between the sender and receiver are much higher and transient network partitions are more likely to be expected in random direction. Also, in random direction, larger link breakages and inaccurate route information between unconstrained nodes increases average latency. Performance of Random walk falls between these two extremes because nodes, although not constrained, are more likely to choose center of simulation area as destination.

In case of data and control packet throughput, Restricted Random Walk, once again outclasses others because of same reasons. In Restricted Random Walk, most often nodes move in the vicinity of neighbors so links seldom break between nodes and hence routing information does not get stale whereas in Random Walk, nodes are free to move so links may break. Situation becomes more severe in random directions where links break very often.

C. Performance Comparison of Group Mobility Models

It is also interesting to analyze the performance variance amongst group mobility models. The average hop count of Pursue mobility model is less than for Column model. This was expected because each group node in Pursue model is more or less one hop away from other nodes of the group, so nodes are lesser hops away from each other. On the other hand, in column model, number of hops depends on the length of column because as the length increases, hop count between side nodes increases. Similarly, average latency of pursue model is less because of the same reason.

Data packet and control packet throughput is more or less similar for both the mobility models because no matter how many hops exist between nodes, they are tightly bound to each other in both the mobility scenarios and data reliably reaches the destination node.

D. Performance Comparison of Routing Methodologies

Talking about performance of routing protocols, control packet throughput is maximum for pro-active schemes, moderate for hybrid schemes and least for reactive schemes. Proactive routing protocols send packets with link state information to their neighbors so these packets are somehow reliably transferred. On the other hand route requests packets of reactive schemes are flooded in the network with no guarantee of delivery to the destination node. Similarly, Reactive schemes are best in terms of Data packet throughput whereas hybrid schemes are worst. Proactive schemes show somehow intermediate behavior. Reactive schemes calculate route when needed so they have more recent route information on which data is reliably transferred, proactive and hybrid schemes may have stale cache routes that result in packet loss.

In case of average latency, proactive schemes perform much better than hybrid and reactive schemes. In, proactive schemes, routes are already established, so it takes lesser time to transmit packets from source to destination whereas in case of reactive schemes, routes are calculated on-demand so it takes more time to deliver single packet because of additional route calculation time. Hybrid schemes show moderate average latency because they have partial routes established and route calculation takes more time than reactive ones and lesser time than proactive ones.

Paths, calculated in proactive schemes are much smaller in length as compared to the paths created in reactive schemes. Proactive schemes have built-in ability to create optimized paths e.g. MPRS have been purposely created in OLSR to create optimized and shortest paths whereas reactive and hybrid schemes do not have such innate characteristics.

E. Performance Comparison of AODV and DSR

Amongst reactive routing schemes, DSR has more average latency as compared to AODV because in DSR, when a route request is sent, destination replies to all RREQ, making it slower to determine the least congested path, whereas AODV replies to first RREQ. Result is converse in case of average hops; number of hops is much smaller for DSR as compared to AODV. Possible reason is that DSR uses source routing, so packet destined to a node covers only those hopes mentioned in packet header whereas in case of AODV, hops are determined on each forwarding node and in case of link breakages, these hops may be much higher.DSR also has higher data throughput initially because of its aggressive routing mechanism that decays as the time passes whereas converse is true for AODV. Control packet throughput is almost similar for both the algorithms as they share almost similar route discovery mechanism.

F. Performance Comparison of OLSR and FSR

Amongst proactive routing schemes, OLSR and FSR both have almost equal average latency because they both maintain full topology map at each node, and are able to immediately provide routes information when needed. Average hops, although increase both for OLSR and FSR with the increased mobility, are larger for OSLR than FSR because route in FSR becomes more accurate as packet moves towards destination whereas in OLSR stale routes may cause data delivery failures and may increase average number of hops.Control packet throughput and data packet throughput both are initially high for OLSR but degrade with increased number of nodes that result in increased routing overhead. However, FSR maintains a steady throughput level irrespective of the size of mobility. In FSR, packets are routed correctly because the route information becomes more accurate as the packet moves closer to destination. Individual simulation results are presented in Fig. 1, 2, 3 and 4, e.g., Fig. 1 (a), (b), (c), (d) and (e) depict the control packet throughput of different mobility models under varying mobility for AODV, DSR, OLSR, FSR and ZRP protocols respectively. X-axis represents number of nodes which are varied from 10 to 49, whereas y-axis represents resultant control packet throughput for different mobility models.

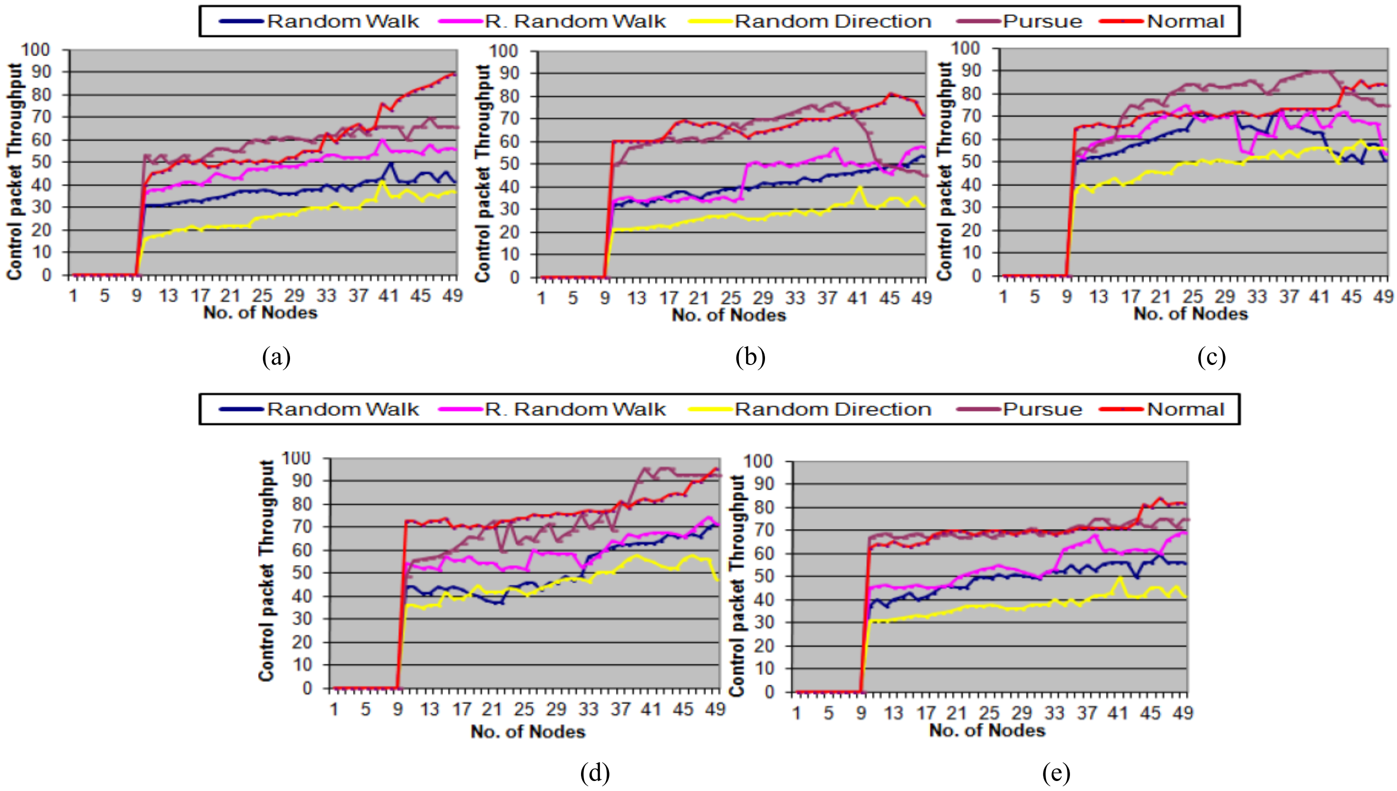

Figure 2. Effect of varying mobility on Control Packet Throughput under (a) AODV, (b) DSR, (c) FSR, (d) OLSR, and (5) ZRP routing scheme

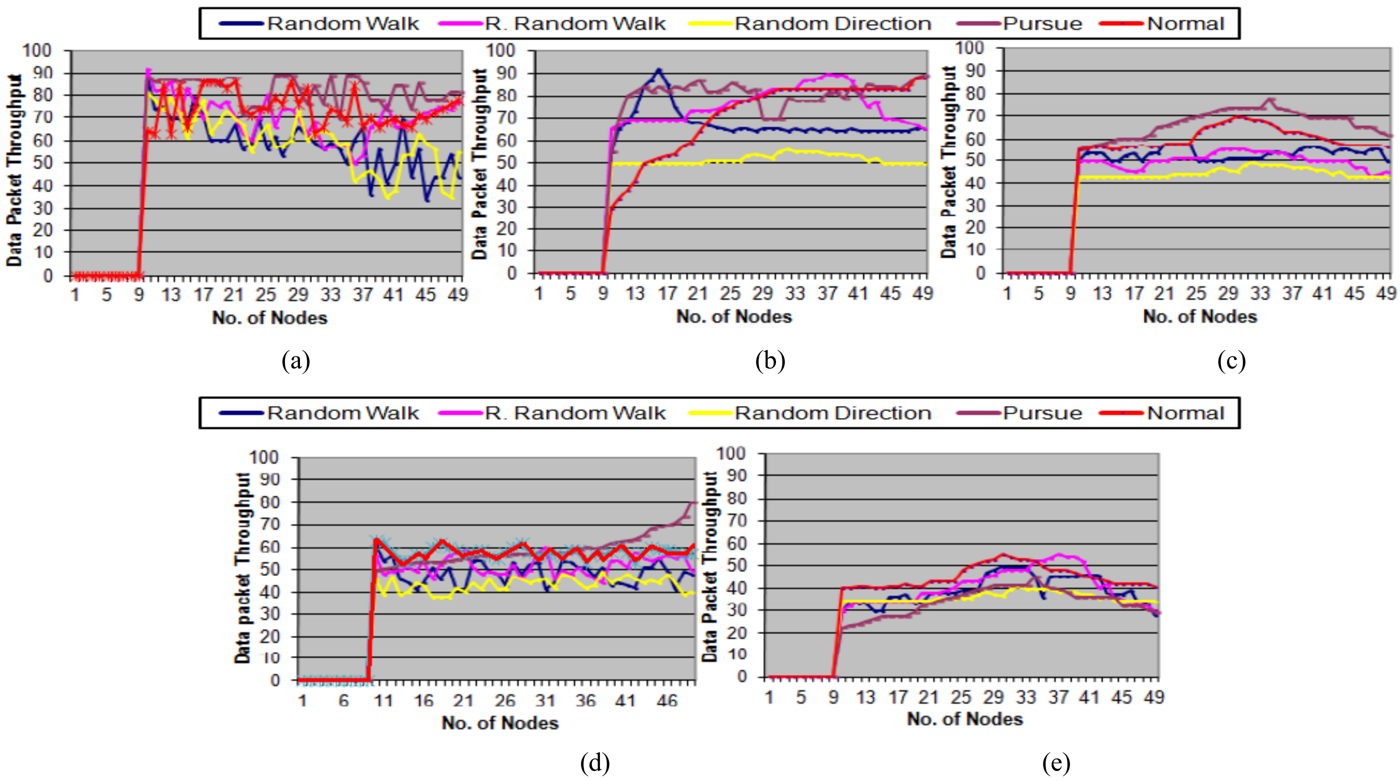

Figure 3. Effect of varying mobility on Data Packet Throughput under (a) AODV, (b) DSR, (c) FSR, (d) OLSR, and (5) ZRP routing scheme

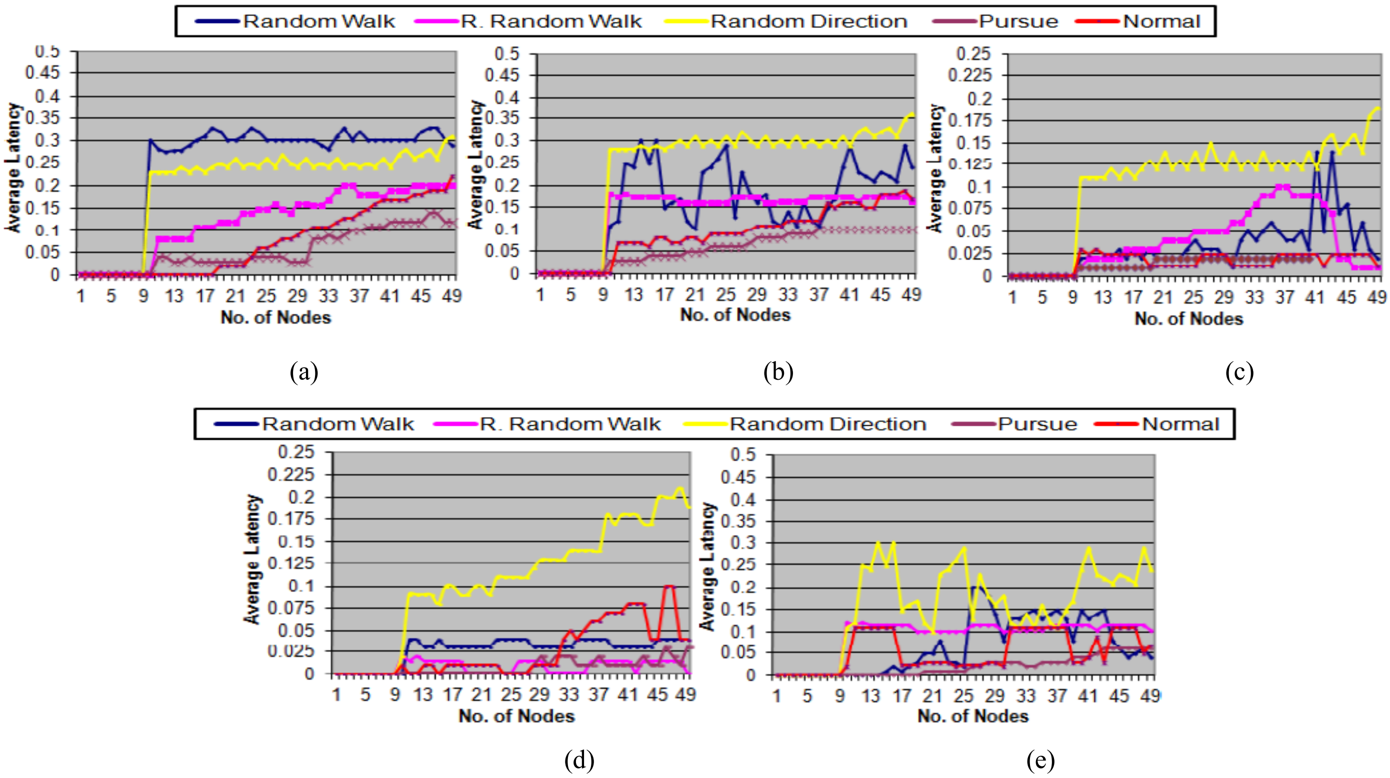

Figure 4. Effect of varying mobility on Average Delay under (a) AODV, (b) DSR, (c) FSR, (d) OLSR, and (5) ZRP routing scheme

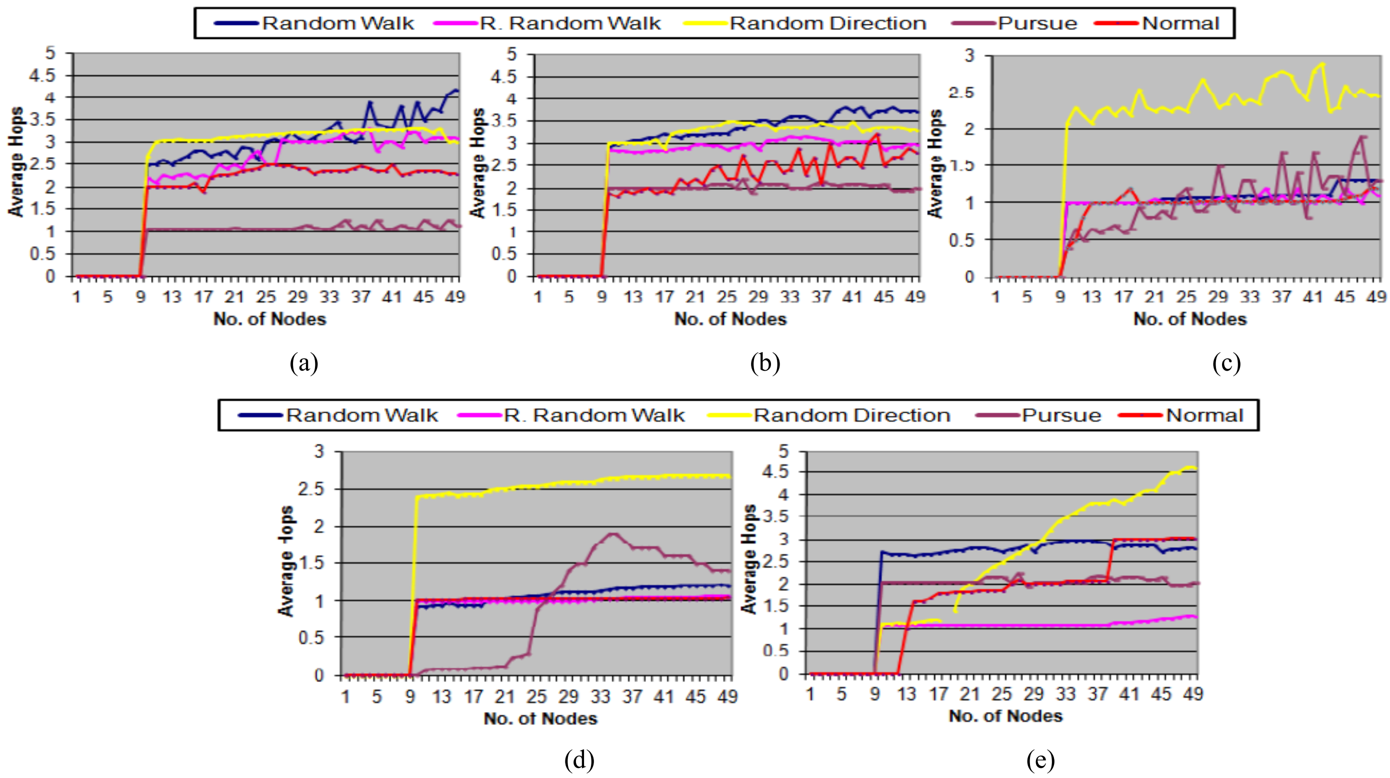

Figure 5. Effect of varying mobility on Average Hops under (a) AODV, (b) DSR, (c) FSR, (d) OLSR, and (5) ZRP routing scheme

VIII. CONCLUSION

In this paper we have accomplished a comprehensive analysis of the performance of mobility models of MANeTs under reactive, proactive and hybrid routing schemes by varying mobility. The simulation experiments were carried out for a minimum of 10 nodes to a maximum of 50 nodes. The results gained during the simulation experiments were quite informative. From results, we can conclude that proactive schemes outclass reactive and hybrid schemes in several ways. Similarly, group mobility models outshine entity mobility models in almost all aspects. Individually speaking, restricted random walk and pursue mobility models had overall performance advantage over other entity and group mobility models respectively. Since different combinations of routing protocols and mobility models vary in performance level, so their combination should be very carefully selected depending upon the application scenario.

FUTURE WORK

Though our preliminary investigation is much promising, there is a lot more to be done. This research can further be extended into two directions. First, adding more routing protocols and mobility models to this study may provide a clearer view. Second, incorporating other performance evaluation parameters can potentially provide better comparative study.

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