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Analysis of Mobility Models and Routing Schemes for Flying Ad-Hoc Networks (FANETS)

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Abstract

This paper addresses the challenges of high mobility and frequent topology changes in Flying Ad-hoc Networks (FANETs) by presenting the first of its kind comprehensive analysis of mobility models. They govern the movement pattern of UAVs and the variation in speed and direction that occur over time. Therefore, the simulation study of effective routing strategies depends on suitable mobility models. In this paper, we have performed experimental performance evaluation of available mobility models that can generate realistic scenarios for FANET applications. Both reactive (AODV and DSR) and proactive (OLSR) routing protocols are compared for Reference Point Group Mobility model, Gauss Markov mobility model, Random Waypoint mobility model and Manhattan Grid Mobility model. Packet Delivery Ratio (PDR), Average End-to-End Delay, and routing overhead were used as performance metrics for examining maximum reliability and minimal latency requirements of FANETs. Results show that Dynamic Source Routing (DSR) outperforms Ad-hoc On Demand Distance Vector (AODV) and Optimized Link State Routing (OLSR) in terms of PDR, latency and routing overhead for all mobility models.

Keywords: UAVs, mobility models, routing, latency, reliability, FANETs.

INTRODUCTION

Ad-hoc network can be established between UAVs to attain an economical solution along with increased range. The establishment of multi-hop, wireless, inter-UAV communication network is termed as a Flying Ad-hoc Network (FANET).

UAVs moving at a typical speed of 30-460 km/hr experience link failures due to frequent topology changes [1]. Such problems cannot be tolerated for highly sensitive applications that require real time and reliable data transmission. Thus, researchers have tried to develop customized routing protocols for FANETs that may address these challenges.

Efficient routing in FANETs is also dependent on mobility models that capture trails and speed deviations of the UAVs. Since the destination, speed and direction of nodes is not solely random hence mobility model of

MANETs such as Random Waypoint (RWP) cannot be wholly used for predicting the behaviour of routing protocols in a FANET scenario. However, semi random movement may arise as a result of environment changes leading to redefining path plans. Therefore, random-based mobility models are also used to model FANETs. Temporal-based models which generate correlated movement of nodes can be used for critical flight missions where the movement of UAVs should be systematic. Mobility models with spatial dependency can be used to generate group movements as of swarm of UAVs, which move in collaboration with each other for dedicated missions. Another class of mobility models is geographic restriction based mobility models in which movement of nodes is subjected to the environment. This type of mobility pattern can be used to generate predefined pathways for UAVs.

In this paper, we have evaluated four available mobility models which include Reference Point Group Mobility model, Gauss Markov mobility model, Random Waypoint mobility model and Manhattan Grid mobility model selected from families of spatial dependent, temporal dependent, random based and geographic restriction based mobility models respectively. The unique presentation of this paper involves categorization of suitable mobility models for different applications in UAV domain. The effect of dynamic FANET environment, characterized by high mobility and generated by these models, is evaluated for different routing protocols i.e. DSR, AODV and OLSR.

The rest of the paper is organized as follows: Section 2 summarizes related work, section 3 gives basic overview of mobility models used in the simulation. The simulation methodology is presented in section 4 and results and analysis are shown in section 5.

RELATED WORK

Some studies have used existing MANET mobility models while others have proposed specific models for UAV ad-hoc networks. Smooth turn mobility model [3] has been proposed for Air Borne (AN) networks. The model accounts for spatial and temporal dependency of airborne vehicles in highly random AN networks. The trajectory of vehicles is predicted by using the correlated information of speed and acceleration which is straight and smooth at turns.

In [4] have provided two mobility models for group surveying scenario of UAVs. The first model is based on memoryless movement of UAVs whereas the second model uses the idea of pheromones to provide dependent and coordinated movement among UAVs. The random model provides left, right and straight movements according to fixed probabilities. The study reveals that the models provide a trade-off between maximum coverage and maximum connectivity. Paparazzi Mobility Model [5] (PPRZM) based on Paparazzi system for the UAVs. The model supports five movements: Stay-At, Way-Point, Eight, Oval and Scan. Results show that PPRZM gives more realistic results in terms of End-to-End delay as compared to Random Way Point (RWP) Mobility model. Semi-Random Circular Movement (SRCM) mobility model has been proposed for UAV MANETs [6]. The UAV movement is around a fixed point with a random radius.

Gauss Markov mobility model [7] has been used along with the proposed Geographic Position Mobility Oriented Routing (GPMOR). It has utilized the best next hop discovery property of Gauss Markov Mobility model to make their routing protocol more robust towards route failures. Similarly, an optimized 3-D version of Gauss Markov mobility model has been used in [10] for highly dynamic air-borne networks. In Directional Optimized Link State Routing (DOLSR) [8] protocol has been proposed for UAVs in which simulations have been performed using Random Way Point mobility model.

MOBILITY MODELS

This section briefly discusses the mobility models and presents movement traces of nodes for FANET scenarios as used in the simulations.

Reference point group mobility (RPGM) model

Group mobility models can be used to simulate group of UAVs in performing autonomous military operations without centralized control. Reference Point Group Mobility model falls in the category of mobility models exhibiting spatial dependency. Nodes are divided into groups and the movement of nodes within one group is dependent on each other. Every group has a group center that moves on a predefined path and defines the movement trend of the entire group. The direction and speed of every node in the group depends on its own reference point and a random deviating vector from group center [2].

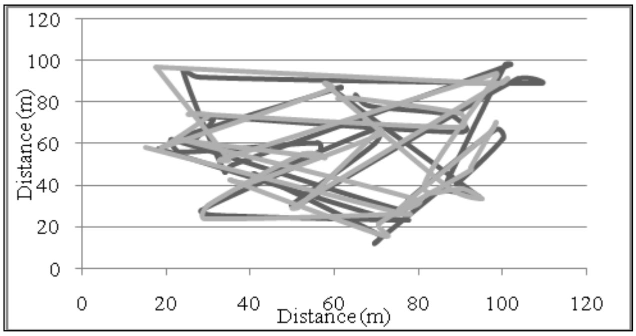

Figure 1. Movement trace of two nodes under RPGM mobility model in 130 x 130 m area.

Gauss Markov (GM) mobility model

In Gauss Markov mobility model, at the start, a specific speed and direction is defined for each node. This is a memory based model with speed and direction of a node at time instant T depending on speed and direction at time instant T-1. The values are updated after constant time intervals. Hence, Gauss Markov mobility model exhibits temporal dependency. The degree of randomness in the movement can be obtained through a parameter alpha (0 < alpha < 1). For a memoryless, Gauss Markov mobility model alpha = 0 and for full memory based model alpha = 1^2.

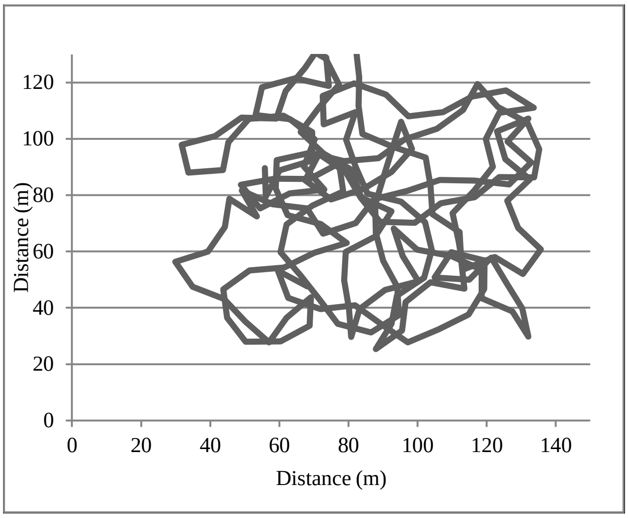

Figure 2. Movement trace of single node under GM mobility model in 130 x 130 m area.

Random waypoint (RWP) mobility model

Random Waypoint is a commonly used model of MANETs. Initially, there is random deployment of nodes in the simulation area. The nodes remain stationary for a certain time termed as pause time and then start moving towards randomly chosen destinations. The chosen speed is uniformly distributed between Vmin and Vmax [2]. In some applications like patrolling UAVs may be allowed to adopt flexible trajectories. Such scenarios can be modelled using Random Waypoint mobility model. Unlike MANETs, UAVs cannot make sharp turns that occur in RWP. So, this random based model cannot provide realistic results for FANETs.

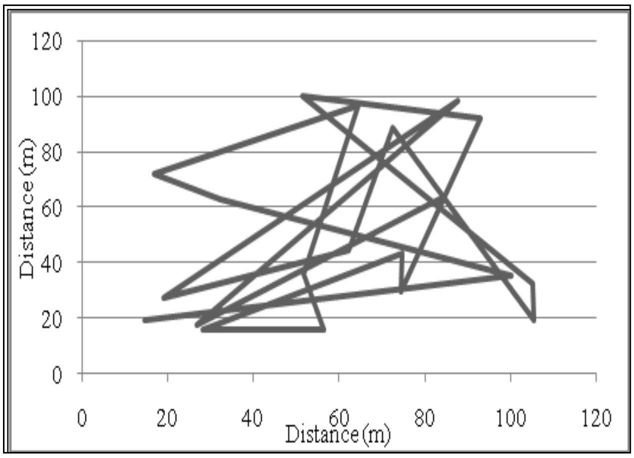

Figure 3. Movement trace of single node under RWP mobility model in 130 x 130 m area.

Manhattan grid mobility (MGM) model

Manhattan Grid mobility model can be used to emulate map based approach in which the movement of UAVs takes into account geographic restrictions. The nodes move on pre-defined horizontal and vertical grids. The nodes are allowed to move in north, south, east or west direction. Straight movement of nodes on the defined grids occurs with probability 0.5 and the nodes take turns on corners with probability 0.25. The speed of a node in a lane at a certain time interval is dependent not only on the previous time interval, but also on the nodes moving in the same lane.

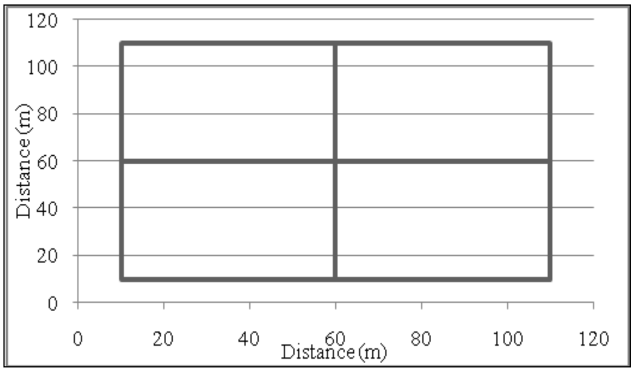

Figure 4. Movement trace of single node under MGM mobility model in 130 x 130 m area.

Based on comprehensive study of FANET applications, mobility models have been categorized for various scenarios in Table-1.

Table 1: Mobility models feasibility for FANET application scenarios.

Mobility Model	**Proposed Application Scenario**
Manhattan Grid Mobility (MGM) model	Complex Urban Environments [11]
Random Waypoint (RWP) mobility model	Patrol systems [12]
Reference Point Group Mobility (RPGM) model	Disaster management, Search and destroy operations [13, 9]
Gauss Markov	Multi-tier Airborne MANETs [10]

METHODOLOGY

We have carried out this research to analyse the behaviour of routing protocols for different mobility models in FANETs. The simulations were performed on NS2 which is a discrete network simulator. To generate movement of nodes for different mobility models, BonnMotion utility was used which creates, analyses and exports mobility scenarios to different network simulators [14]. Figure-5 shows the network topology used in our simulations. The network topology consists of 5 nodes where center node acts as a sink and a relaying node and it assigns timeslots, such that two nodes contend for the medium in that duration and transmit their data to node 0 while the remaining two are in sleep mode. The effect of collision has been introduced for acquiring more comprehensive results. The nodes move with average speeds ranging from 10m/s to 500m/s. The pause time was set to 10s to generate highly dynamic scenario with frequent topology changes. CBR traffic model was used with packet size of 100 bytes transmitted at a constant rate of 50kbps. In FANETs, a line of sight is maintained between UAVs [1]. Hence, the radio propagation model used is free space model as it works on the assumption of a single clear line of sight between transmitter and receiver. The simulation parameters have been selected in reference [7, 8].

BonnMotion generates node movement patterns according to the mobility models specified by taking certain parameters as input such as maximum minimum speed, number of nodes, speed standard deviations, group change probabilities, pause time and simulation area and duration. The traces of node movements generated for different mobility models have been presented in the previous section.

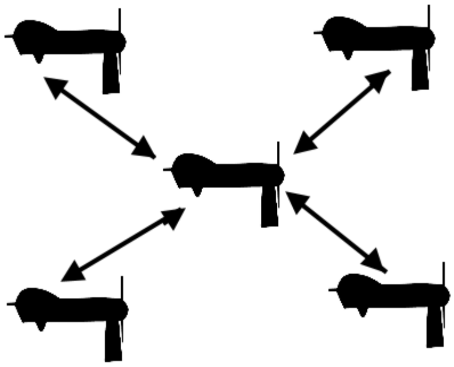

Figure 5. Network topology.

Table 2. Simulation parameters.

Parameter	Value
Simulation tool	NS-2.35
Simulation time	200
MAC Protocol	802.11
Simulation Area	200 x 200
Propagation model	Free space
Routing Protocol	AODV, DSR, OLSR
Traffic	CBR
Number of nodes	5
Transmission Range	75m
CBR data rate	50 kbps
Packet size	100 bytes
Speed	10,50,100,200,300,400,500 (m/s)
Channel capacity	11 Mbps
Mobility models	Reference Point Group Mobility Model (RPGM) Gauss Markov mobility model (GM) Random Waypoint mobility model (RWP) Manhattan Grid Mobility model (MGM)

The performance evaluation parameters used for FANET topology are described below:

Packet delivery ratio (PDR)

It gives the ratio of data packets received at the destination successfully to the data packets generated by the source. This parameter is used to determine network reliability.

$$\text{Packet delivery ratio} = P_{destination} / P_{source} \quad (1)$$

where $P_{destination}$ = data packets received at the destination and P_{source} = data packets generated by the source.

Average end to end (E2E) delay

This metric tells about the average time it takes for data packets to reach the destinations successfully.

$$\text{Average End-to-End Delay} = T_{trans}+T_{ret}+T_{buff}+T_{process} \quad (2)$$

where T_{rans} = transmission time, T_{ret} = retransmission time, T_{buff} = buffering time and $T_{process}$ = processing time.

Routing overhead

Routing overhead determines the total number of routing packets that took part in the transmission.

RESULTS AND DISCUSSION

Figures-6-9 depict the performance of different mobility models in terms of PDR for AODV, DSR and DSDV. It can be observed that for all scenarios, DSR maintains high PDR. The use of data link acknowledgements makes DSR robust to link failures. Moreover, since routing information is overheard by intermediate nodes, they learn multiple routes to a certain destination and include them in their caches. In case one link does not work from the cache, the alternate route can be used. AODV and OLSR show a decreasing trend in delivery ratio with the increase in speed. Since OLSR is table driven protocol, the routes in the table become outdated very quickly and the rediscovery of the broken ink takes time. AODV due to its on-demand nature reacts more rapidly towards route failures.

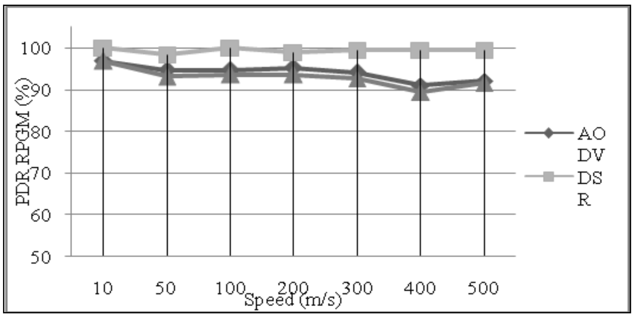

Figure 6. PDR versus speed for RPGM.

It can be observed from Figure-6 that RPGM provides higher PDR for all routing protocols. This is because the movement of all nodes in RPGM is governed by defining a maximum distance from group center. Thus, the network is in a fully connected state most of the time. Also, as the speed increases, PDR does not drop below 90% because when UAVs are moving as a swarm and are in the radio range of each other, the effect of high mobility nullifies whereas in other mobility models the increase in node mobility causes decrease in PDR because of the uncoordinated node movements. Routing protocols play an important role by finding alternate valid routes. Thus, suitable mobility models along with appropriate routing protocol can address the issue of link breakages due to high mobility and can help in maintaining an acceptable PDR depending on the application for which FANET nodes are deployed.

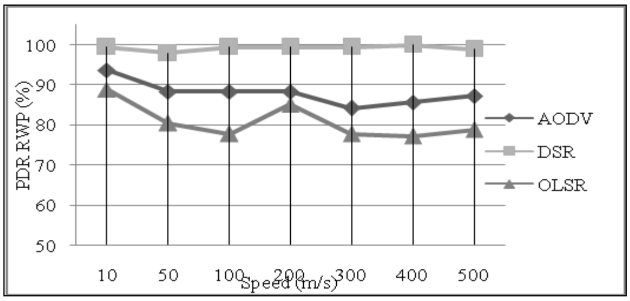

Figure 7. PDR versus speed for RWP.

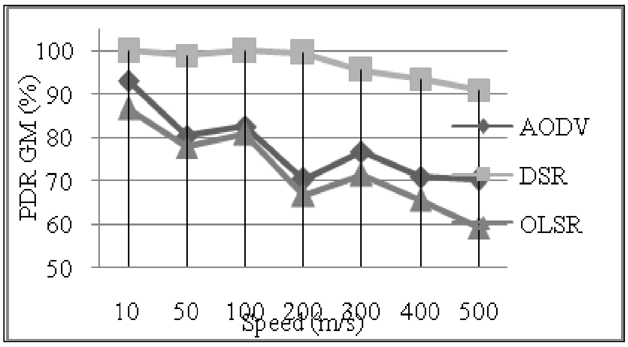

Figure 8. PDR versus speed for GM.

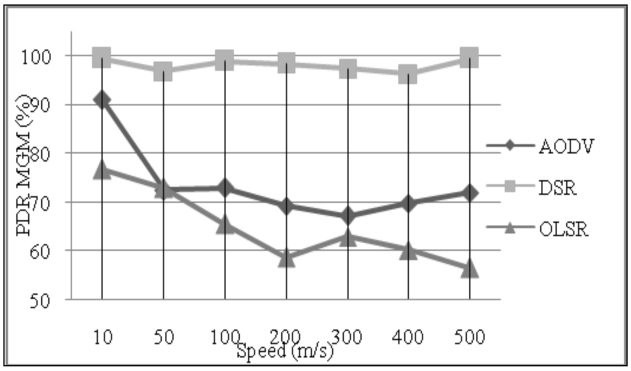

Figure 9. PDR versus speed for MGM.

Figures-10-13 show average end to end delay of AODV, DSR and OLSR for mobility models. It must be noted that the delays are effective delays of data packets that successfully arrive at the destination. As shown, DSR exhibits higher delays followed by AODV and OLSR. The route caching mechanism of DSR increases the end to end delay of the network. Due to high mobility, the cache contains more percentage of stale routes. If the mobile source node fails to find route to the destination, it starts discovery for new route. The entire process increases the packet reception time. AODV on the other hand omits route cache discovery process and shows less average delay. OLSR has routes available all the time and can provide them when required. Due to low PDR of OLSR, fewer data packets are able to reach intended destinations within the simulation time and give low average end-to-end delay of data packets.

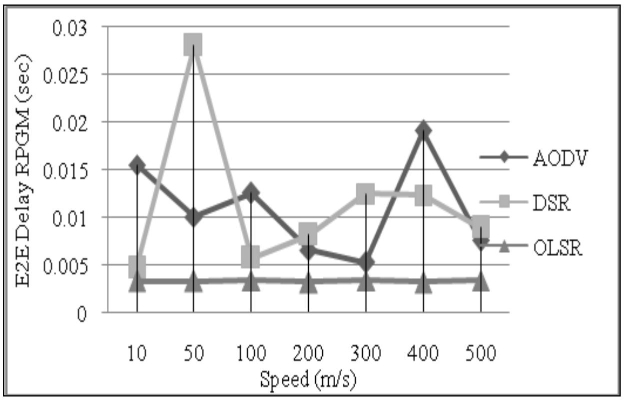

Figure 10. Average E2E delay versus speed for RPGM.

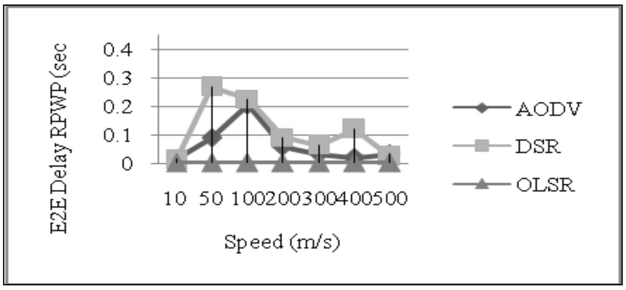

Figure 11. Average E2E delay versus speed for RWP.

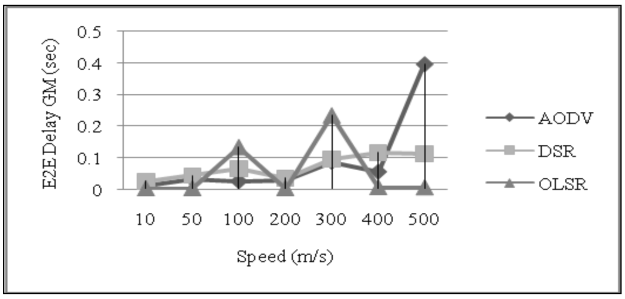

Figure 12. Average E2E delay versus speed for GM.

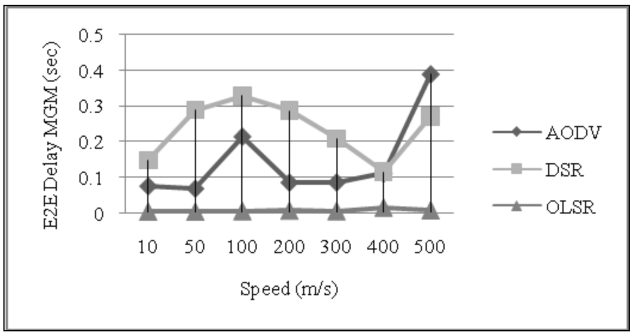

Figure 13. Average E2E delay versus speed for MGM.

Figures-14-17 shows control or routing overhead for AODV, DSR and OLSR. DSR demonstrates lowest routing overhead than AODV and OLSR. Since DSR also takes advantage of source route caches hence the number of route request packets generated is less than that of AODV. However, with the increase in speed, routing overhead of DSR also increase because frequent link failures make route cache mechanism less effective. OLSR depicts extremely large routing overhead due to the transmission of periodic HELLO and Topology Control (TC) messages. Unlike our topology, dense and large networks can make the most of OLSR due to multi point relay selection mechanism which guarantees improved scalability in the sharing of topology information.

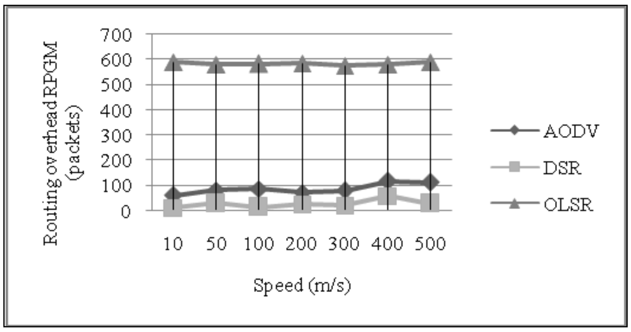

Figure 14. Routing overhead versus speed for RPGM.

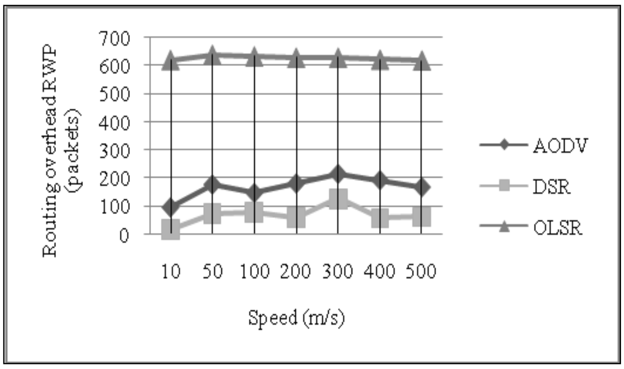

Figure 15. Routing overhead versus speed for RWP.

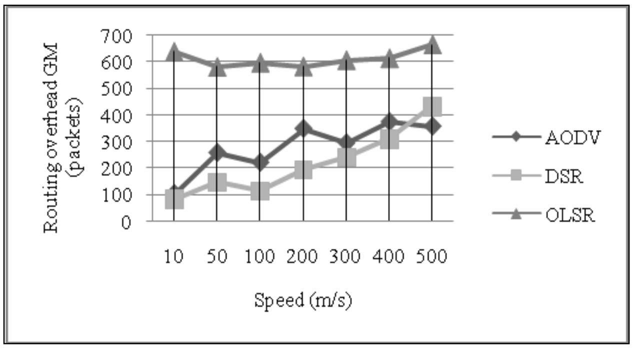

Figure 16. Routing overhead versus speed for GM.

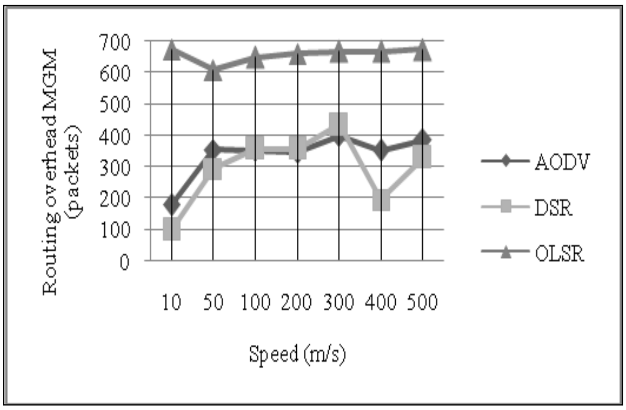

Figure 17. Routing overhead versus speed for MGM.

CONCLUSION

FANETs are used for critical and sensitive applications such as reconnaissance and patrolling and hence simulation analysis needs to be performed under realistic environments. Accurate mobility models are essential to foretell communication problems during protocols evaluation that may arise in real-world scenarios.

There is not a standard method to validate or select a mobility model for FANETs because different applications may require different movement patterns. Therefore, we have suggested different mobility models for various applications and have evaluated DSR, AODV and OLSR routing protocols using these models. DSR gave better results for highly dynamic environments generated by Reference Point Group Mobility, Gauss Markov, Random Waypoint and Manhattan Grid mobility models.

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