Implementation of RWP and Gauss Markov Mobility Model for Multi-UAV Networks in Search and Rescue Environment

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Abstract—Future generations of wireless networks are expected to heavily rely on unmanned aerial vehicles (UAVs). UAV networks have extraordinary features like high mobility, frequent topology change, tolerance to link failure, and extending the coverage area by adding external UAVs. UAV network provides several advantages for civilian, commercial, search and rescue applications. A realistic mobility model must be used to assess the dependability and effectiveness of UAV protocols and algorithms. In this research paper, the performance of the Gauss Markov (GM) and Random Waypoint (RWP) mobility models in multi-UAV networks for a search and rescue scenario is analyzed and evaluated. Additionally, the two mobility models GM and RWP are described in depth, together with the movement patterns they are related with. Furthermore, two-simulation scenarios conduct with help of an NS-3 simulator. The first scenario investigates the effect of UAV Speed by varying it from 10 to 50 m/s. the second scenario investigates the effect of the size of the transmitting packet by varying it from 64 to 1024 bytes. The performance of GM and RWP was compared based on packet delivery ratio (PDR), goodput, and latency metrics. Results indicate that the GM model provides the highest PDR and lowest latency in such high mobility environments.

Keywords—UAV, UAV network, emergency scenario, GM, RWP

1 Introduction

Future UAV technology is viewed as a revolution in civil infrastructure because of its low cost, reduced risks, and quick deployment. UAVs are algorithm-controlled, non-human flying nodes that do not need human interaction to move. Because of the integrating features of many electronics devices, UAVs are appropriate for mission-critical applications requiring reliable communication [1]. As seen in Figure 1, UAV networks come in two different forms. The UAV is connected to a satellite or a grounded base station through a single-UAV network. A multi-UAV network links several UAVs as well as a satellite or terrestrial base station. The UAVs in a multi-UAV network can be flexibly arranged in different topologies at any time. The connection between both the UAV and the ground base station is known as the UAV/BS link, whereas the connection between the UAV is known as the UAV/UAV link. [2].

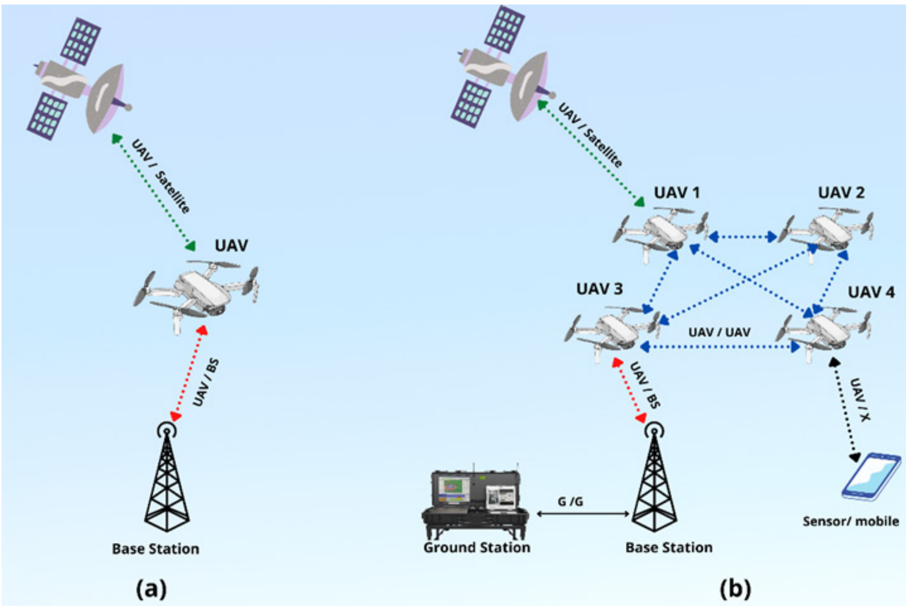

Fig. 1. (a) Single-UAV network (b) Multi-UAV network

New military and civilian applications including battel filed, surveillance, infrastructure inspection, remote sensing ,smart farming, traffic monitoring, and search rescue and missions have been made possible by these innovative flying UAVs [3][4][5]. Furthermore, UAVs are capable of providing temporary communication links in crises, disasters, inaccessible places, and areas with poor satellite signal coverage [6]. For instance, UAV communication may be used in search and rescue operations when normal communication infrastructure is broken and it is challenging to establish infrastructure in a short amount of time. This is because they are easily adaptable and configured with ad-hoc UAV networks [7][8]. Although UAV enable new applications through their ad hoc networks and flying features, several challenges must be overcome, including routing protocols, infrastructure design, and mobility models[9]. There has been an increase in the quantity of literature on routing protocols, mobility models, and communication standards in recent years. Mobility patterns are crucial in the design of UAVs due to dynamic topological change, fast flight speeds, and often disrupted or disconnected links [10].

Although mobility models play a significant role in the functioning of the UAV network, most research has used 2-D mobility models. For simulating node mobility in 3D, only a few simulator tools are available. As a result, this paper presents an evaluation and performance analysis of Multi-UAV networks using 2D and 3D mobility models. In particular, GM and RWP mobility models are being evaluated for use with UAVs in search and rescue situations. The NS-3.32 simulator was used to mimic the performance of UAVs under real-world conditions in search and rescue scenarios.

The rest of the article is structured as follows: Section two describes UAV Mobility Models. Section three, Methodology and Simulation Setup, discusses the simulation platform, settings, scenarios, and performance metrics utilized in the research study. Section four of the Result Analysis provided simulation results in the format of tables and graphs. Finally, in section five, the conclusion and future work were drawn.

2 Mobility models for UAVs

A mobility model is a set of guidelines that control how a mobile node moves. Additionally, it controls how a node's location, acceleration, and speed change over time. In order to simulate the development of new routing or communications algorithm and procedures, these mobility models are necessary. Although several UAV mobility models have been proposed thus far, their movements are motivated by particular applications and circumstances [11].

2.1 Gauss Markov (GM)

Liang and Haas were the ones who initially proposed the Gauss-Markov (GM) Mobility Model. [12]. The requirement for a more realistic model, where a node, for instance, may progressively accelerate, slow down, or turn, is what motivated GM model. Gaussian equations, which incorporate Gaussian random noise and average speed and direction, are used to relate a UAV's current speed and direction to its previous movement. [13]. The following formulae can be used to determine the direction and speed of a UAV.

$$S_t = \alpha S_{t-1} + (1-\alpha)S' + \sqrt{(1-\alpha^2)}Sx_{t-1} \quad (1)$$

$$D_t = \alpha D_{t-1} + (1-\alpha)D' + \sqrt{(1-\alpha^2)}Dx_{t-1} \quad (2)$$

Where, S_t and D_t are the speed and direction at time instant t, S' and D' are the mean speed and mean direction, while α is a memory level parameter with value between $0 < \alpha < 1$.

The amount of dependence on previous speed and direction is controlled by α parameter. The model is deemed to exhibit time dependency as a result. The speed and direction of a specific UAV is estimated at a predetermined moment t. After the UAV flying within this direction and at that speed for a fixed amount of time T, the speed and direction are once more calculated. The direction of movement of the UAV is compelled to reverse 180 degrees once it leaves the simulation field's boundaries. It prevents the UAVs from flying close to the edge of the simulation area. Figure 2 is an example of a UAV trajectory using the GM model.

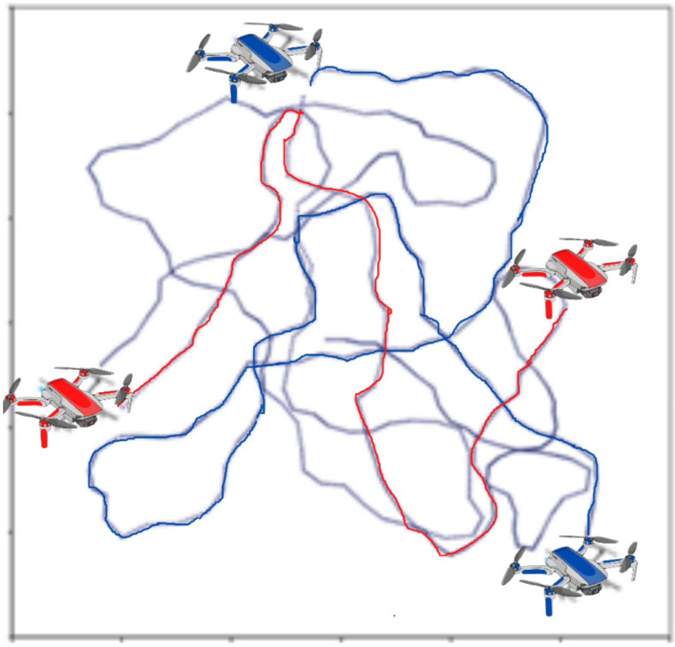

Fig. 2. Example of UAV trajectory in GM model

GM model have adopted for several UAVs application. A 3D geometry model for air-to-ground channels is proposed. Meanwhile, to construct dynamic trajectories, the GM mobile model is used [14]. A mobile edge-computing network with an UAV placed on it investigated, where each TU's mobility is controlled by a GM random model, and the UAV conducts computing tasks that have been allocated from mobile terminal users (TUs). [15].

2.2 Random way point (RWP)

The Random Waypoint Mobility (RWP) is memory less model had come up first by Johnson and Maltz [16]. The first deployment of UAVs in this model's simulation region is random, and each UAV is autonomous. The RWP model operates as follows: Initially, a UAV chooses a destination and starts to flying in that direction in a straight trajectory with a fixed randomized velocities from [0, Vmax]. When a UAV reaches the designated target, it pauses for a period of time known as the pause time T_{pause}. The UAV starts to proceed to a new destination with a real self-direction and speed after the pause period is over. [17]. The two crucial parameters that control the mobility behavior of UAVs in the RWP model are T_{pause} and V_{max}. Figure 3 shows the UAV trajectory using RWP model [18].

Several application of UAV have used RWP model. To explore how UAV mobility affects communication systems and physical layer security, it is believed that UAV will adhere to the RWP model. [19]. In a decode-and-forward (DaF) wireless system scenario, an intelligent reflecting surface (IRS) would be used to facilitate communication between a UAV and a ground station (GS). In particularly, the UAV operates in a dynamic urban environment at low altitudes in accordance with RWP. [20].

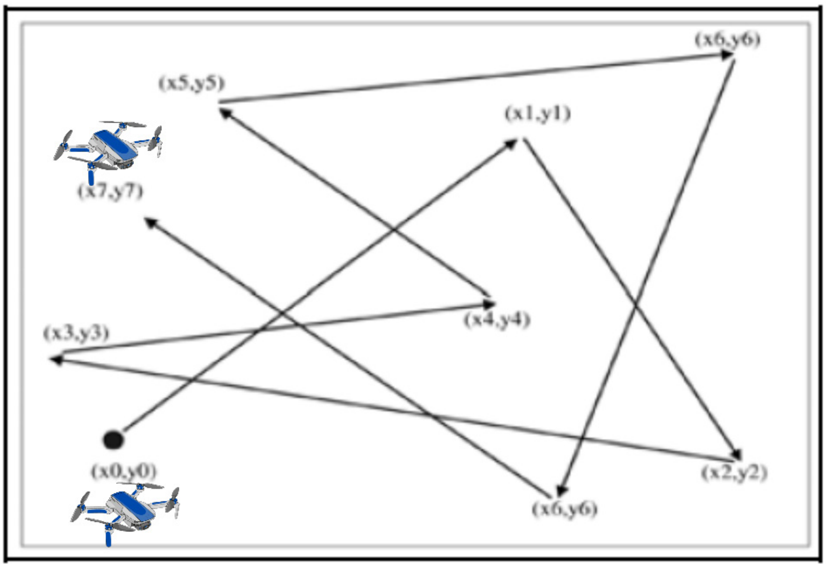

Fig. 3. Example of UAV trajectory in RWP model

2.3 Mobility models and UAVs application

Table 1 present a summary of feasible mobility models for UAV application scenario. Obviously, each UAV scenario required different type of Mobility models [18].

Table 1. A summary of application for UAV and the required mobility models

Application	Mobility models	characterization
Search and Rescue mission	GM RWP	UAV search Randomly on specific area of mission
Urban and Traffic monitoring	MG	UAV make a surveillance in the streets of city
Agriculture Management	PPRZM	UAV operations in agricultural sectors
Sensing Environment	Static	UAVs function as base stations with sensing.
Patrolling	DPR	Mission in real-time with understanding of crucial regions

3 Methodology and simulation set up

3.1 Search and rescue environment

When a rectangular search zone is clearly defined, search and rescue operations frequently follow a simple scan plan created from GM Model. Whenever a randomized search method is necessary, GM model may duplicate a search operation in a clearly specified area regardless of the absence of collision awareness. [21]. When a UAV enters the region, GM has a realistic teleportation feature with 3D mobility. When the UAV leaves the region, each UAV must wait a certain amount of time before re-entering. We want assured delivery and the highest delay tolerance in emergency search situations. In our simulation, we assumed that all UAVs remained inside the mission area.

3.2 Simulation setup

The simulation step was completed with the help of the well-known NS-3.35 simulator [22]. A UAV node participating in a data packet transport might act as the end destination or as a multi-hop routing. Table 2 has more information on configuring the simulation settings.

Table 2. Simulation setup

No	Parameter	Value
1	Network Simulator	Ns-3.32
2	Simulation Area	3600*2400 meter
3	Simulation time	600 sec
4	MAC Protocol	IEEE802.11b
5	Mobility model	GM, EGM, RWP
6	UAV Altitude	100 meter
7	UAV Speed	10-20 m/s
8	UAV Density	50 UAV
9	UAV transmission range	300 meter
10	Routing protocol	AODV

3.3 Simulation scenario

This study conduct two simulated scenarios to evaluate the behavior of the GM and RWP models in multi-UAV networks with search and rescue environments. The following scenarios were simulated:

1. The first scenario investigates the effect of mobility by varying UAV velocity from (10, 20, 30, 40, 50) m/s over GM and RWP models.
2. The second scenario investigate the effect of data packet by varying UAV transmitted packet size (64, 128, 256, 512, 1024) bytes over GM and RWP models.

3.4 Performance metrics

We measured performance metrics to compare effectiveness of mobility model in this mobile and data packet scenarios.

The Packet Delivery Ratio (PDR) displays the proportion between both the number of data packets broadcast by the source and those that are received at the destination. The following equation serves as the basis for measuring this metric.

$$PDR = \frac{R_{pkt}}{T_{pkt}} \tag{3}$$

Where R_{pkt} the total data packet received by destination UAV. T_{pkt} the data packet transmitted by source UAV.

Goodput is the total number of data packet received by destination UAV during simulation divide by the simulation time. Goodput is measured by bit/sec and can be express by the following equation.

$$Goodput = \frac{\sum R_{pkt}}{T_{sim}} \tag{4}$$

Where, T_{sim} is the simulation time.

Latency is the total time taken be data packet to transmit from source to destination UAV. Latency is measured by second; the mobility model with minimum latency is required for real-time application. This metrics can be calculated using the following equation.

$$Latency = T_{des} - T_{src} \tag{5}$$

Where T_{des} is the time of reach the data packet destination UAV, T_{src} is the time of transmit the packet from source UAV.

4 Result analysis

4.1 Effect of UAV speed on the behavior of mobility models

Figure 4 show the PDR performance of M-UAV network under RWP and GM mobility models. By varying the speed of UAVs from 10 to 50 m/s it is possible to see the degradation in the performance. For example, GM model has PDR of 98% with UAVs speed 10m/s, while it has PDR of 95% at speed of 50m/s. the same trend can be observed for RWP. This is due to high mobility of UAV, which leads to change network topology rapidly and fails links to deliver packets. Both models only have the same PDR rating of 98% at a UAV speed of 20 m/s. According to the graph in Figure 4, the performance of the GM model is better than the RWP model.

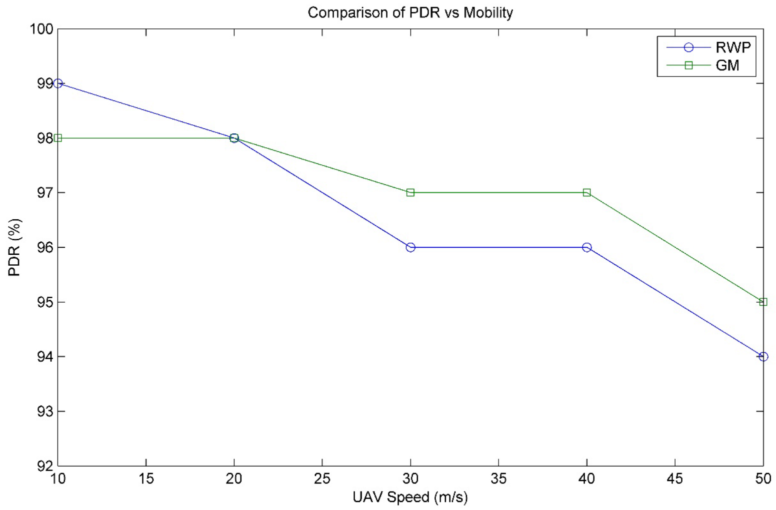

Fig. 4. PDR vs UAV speed

The goodput performance of M-UAV network under the GM and RWP models is illustrates in Figure 5. Similar to PDR performance, when the UAV speed increases the goodput performance dropped. This is due the increase in the number of dropped packet. We can notice that GM models provide better goodput performance as compared to RWP model. GM model archive maximum goodput at UAV speed of 10m/s. on the other hand, RWP model present slightly better goodput than GM model at UAV speed 30 m/s.

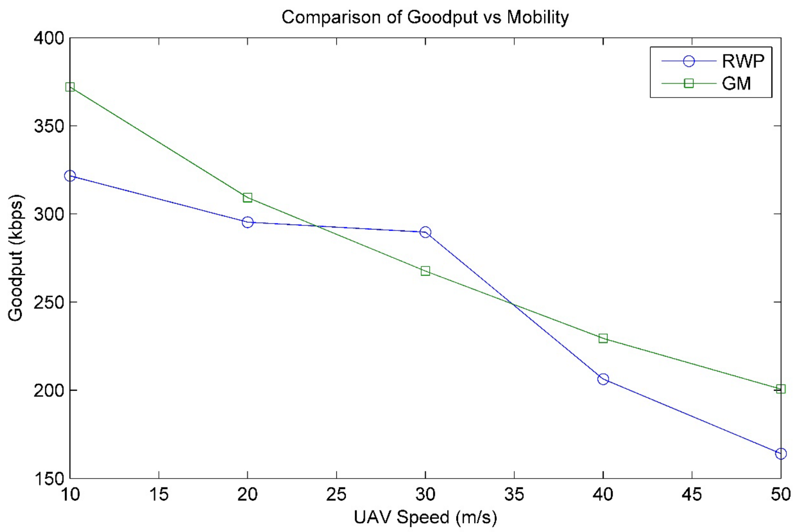

Fig. 5. Goodput vs UAV speed

Figure 6 display the Latency performance of M-UAV network under GM and RWP Mobility models. As the UAV speed increase from 10 to 50 m/s the latency increase in M-UAV network because the high speed of UAVs leads to breakage the link between UAVs and route discovery. Form graph in Figure 6 it can be seen that performance of RWP model is slightly outperform GM model at 40 and 50 m/s UAV speed respectively. While GM model achieve the minimum latency at 20 m/s UAV speed. Real time application like search and rescue operation require minimum latency.

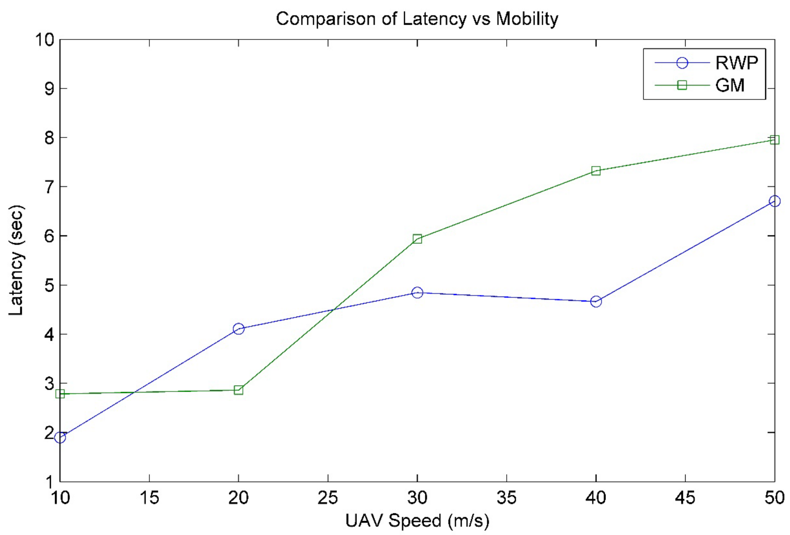

Fig. 6. Latency vs UAV speed

4.2 Effect of UAV packet size on the behavior of mobility models

The discussion on the impact of packet size starts with Figure 7, which depicts PDR for an M-UAV network. Consider the small packet size at value of 64 byte both GM and RWP have the high PDR around 98%. As the packet size increase, we can notice that GM present better performance as compared to RWP model. Further, the GM model show smooth behavior with little change in PDR due to smooth change in UAV trajectory. In addition, it is evident from Figure 7 that the performance of M-UAV network influence by the varying of Packet size.

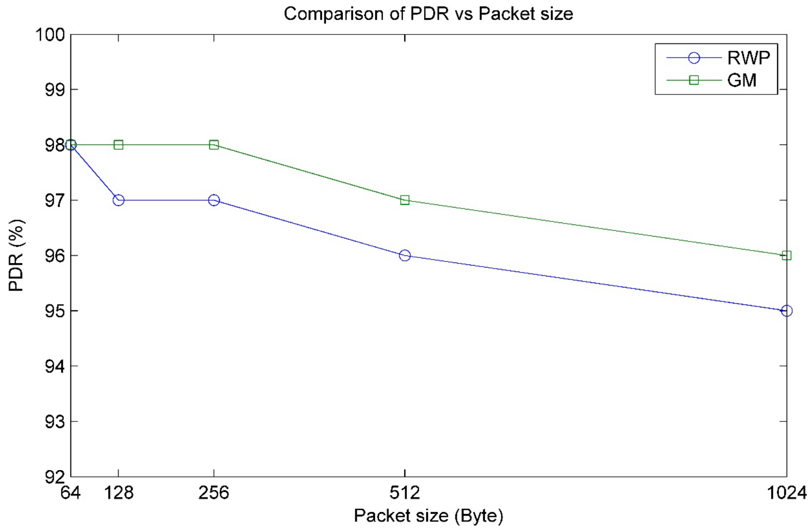

Fig. 7. PDR vs UAV packet size

Figure 8 display the goodput performance of M-UAV network under GM and RWP models. Form Figure 8 it notice that the good put of M-UAV network increase as the size of UAV packet increases from 64 to 1024 byte. GM model present a higher goodput value and a clear superiority in performance as compared to RWP model. On the other hand, RW model show poor behavior due to sudden change in mobility pattern. Further, GM models achieve maximum goodput with value of 376 kbps at UAV packet size 1024byte.

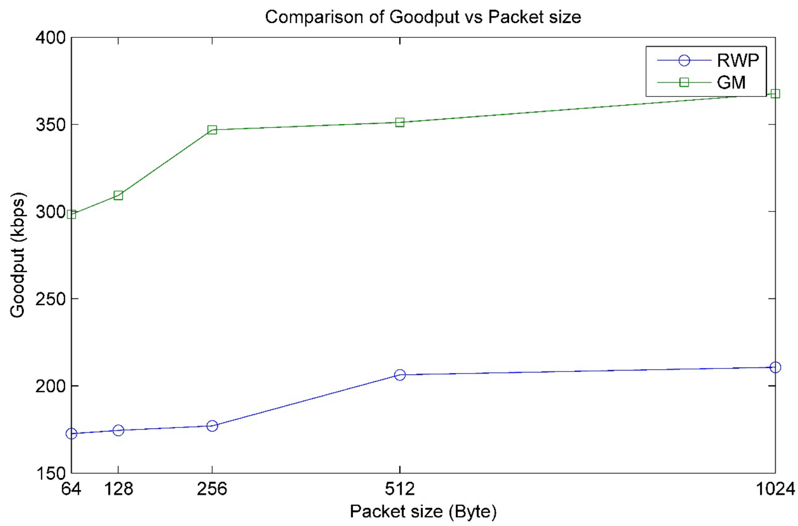

Fig. 8. Goodput vs UAV packet size

Figure 9 present the Latency performance of M-UAV network under GM and RWP Mobility models. As the UAV packet size increase from 64 to 1024 byte the latency increase in M-UAV network because if the UAV cannot transmit the data packet it will be enter queue and this leads to increase latency. Form graph in Figure 9 it can be seen that performance of GM model is slightly outperform RWP model at UAV packet size of 512 and 1024 byte respectively. Only at 256 byte RWP model has less latency than GM model. Therefore, GM model is suitable for emergency application of UAV Network.

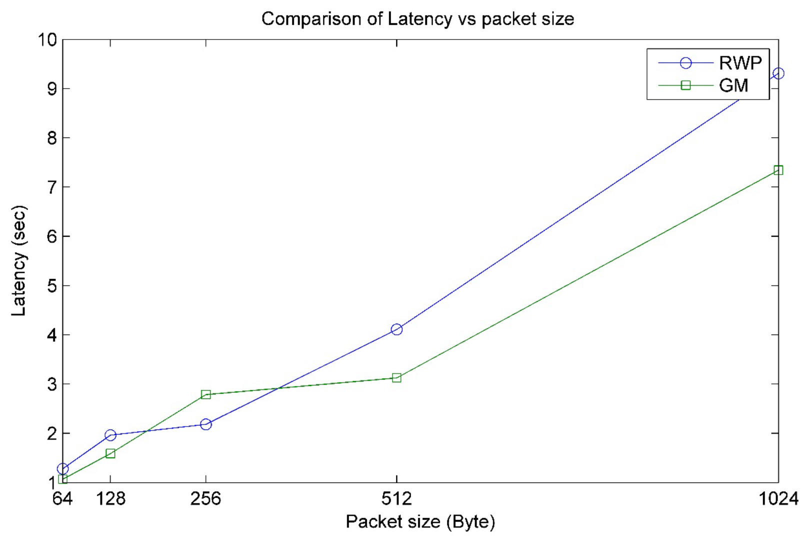

Fig. 9. Latency vs UAV packet size

5 Conclusion

In this paper, we have examined GM and RWP Mobility models in order to choose the best of them for search and rescue mission through a Multi-UAV network. We compared effectiveness of mobility models based on PDR, goodput, and latency metrics. In addition, two simulation scenarios conduct by varying the UAV speed and size of Transmission packet. GM showed the highest PDR and the highest goodput as compared to RWP in the two scenarios through the Multi-UAV network. Further, GM provide the lowest latency with varying packet size. On the other hand, RWP present poor behavior in such high mobility environments due to its random nature and sudden change in direction and speed of UAVs. Latency metrics for GM and RWP mobility models effected by UAV speed due to the time dependent and random component of both models. Results indicate that a GM models can significantly improve the performance for the search and rescue mission in Multi-UAV network. In future work, modified GM mobility models can be considered in smart city environment.

Further, the UAV communication protocols effect on mobility models need to be consider by researcher.

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