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A Mini-Review of Flying Ad Hoc Networks Mobility Model for Disaster Areas

Intan Nabina Azmi[1], **Yusnani Mohd Yussoff**[1*], **Murizah Kassim**[1], **Nooritawati Md Tahir**[1,2]

[1] *School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA, MALAYSIA.*

[2] *Institute for Big Data Analytics and Artificial Intelligence (IBDAAI), Universiti Teknologi MARA, MALAYSIA.*

**Corresponding Author (Email: yusna233@uitm.edu.my).*

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Abstract

This paper presents a mini-review of Flying Ad Hoc Networks' (FANETs) mobility model. FANETs are groups of small UAVs connected in an ad hoc manner to achieve specific goals. Drones are becoming one of the reliable and trusted technologies in military, delivery, and surveying tasks. Drones are also beneficial in difficult-to-access areas, especially during disasters. Considering the large scales of the disaster areas that lack network coverage and limitations of ad hoc networks, an effective mobility model is needed to scan the area and transmit data to the base station effectively. Therefore, this study investigates related works on the mobility model of drones, the network technology used, and the performance of the FANETs in terms of throughput. The main objective is to identify the most efficient mobility model for search and rescue. Approximately 90% of the research deploys many drones with different types of mobility with high-covered areas. Moreover, the 5th generation mobile technology has performed high throughput compared to the 802.11 protocols based on the review. FANETs are also found to be stable regardless of the number of drones usage. The outcome from this review will guide the following research area, specifically efficient drone mobility models in search and rescue.

Disciplinary: Drone Applications, Disaster & Sustainability Management, Communication Systems and Networks.

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1 Introduction

Unmanned Aerial Vehicles (UAVs) or drones are technology designed to monitor environments that are difficult to reach due to their challenging conditions and riskiness. Recently, drones are widely used in many search and rescue (SAR) in remote and disaster areas (Chowdhury *et al.*, 2017; Shrit *et al.*, 2017; Almeida *et al.*, 2019; Dering *et al.*, 2019; Jahir *et al.*, 2019). Among the limitations of drones are battery life, central processing unit (CPU), memory, poor communication environment, and flight path to cover a large area within an endurance period. Locating the victims rapidly in disaster areas is the biggest challenge for rescue teams. Wireless multi-hop of end devices was proven to function during a post-disaster event, for instance, the Great East Japan Earthquake in Higashi-Matsushima City. Drone technology has also led to a more practical search in significant areas and accelerated searches. Thus, wireless connectivity and other factors, such as flying hours, continue to be explored as essential research scope for research related to drones (Iqbal, 2018; Alani *et al.*, 2019; Avezum *et al.*, 2019). Additionally, the primary problems in drone-related applications are out-of-range situations due to the extensive disaster area coverage and low-quality signals. Therefore, Wireless Flying Ad-hoc Networks (FANETs) are the potential solution to enhance wireless connectivity. Another interesting aspect of FANETs is their ability to react to any malfunction during actual implementation. This is vital since it can lead to failure in the response system during stressful environments like the disaster area. Further, Wireless Sensor Networks (WSNs) were introduced as a fault injection to validate any failure systems known as AVR-INJECT. The AVR-INJECT is used for injecting codes into the AVR microcontrollers, which are commonly used in WSN nodes specifically at three locations, namely the data memory, the code memory, and the internal processor registers via SoftWare Implemented Fault Injection (SWIFI) technique. AVR-INJECT was applied in 800 experiments, with 726 fault injections done in three hours, to ensure that the proposed method was effective in WSNs (Cinque *et al.*, 2009).

Conversely, the Wireless Ad Hoc Network is a network between two end devices in ensuring wireless communication without reliance on the router or base station. Further, Mobile Ad-hoc Network (MANET) (Alam, 2017) can be divided into two sub-classes, namely Vehicle Ad-hoc Network (VANET) (Báguena *et al.*, 2013) and Flying (FANET) (Mahmud and CHO, 2019). MANET can be established instantly between end devices with Wi-Fi connections. A chaotic situation, however, often occurs without power, making it impossible to communicate with emergency services. A 4G and Long Range Radio (LoRa) technology were used in the ad hoc networks to assist the rescue team in obtaining a good quality video stream to provide accurate analysis and a precise action plan before the mission (Bertoldo *et al.*, 2018).

Disrupted power supplies and damaged communication infrastructure are also foremost challenges in disaster management. In 2012, the Department of Irrigation and Drainage utilized a short message service (SMS) to alert residents to floods. Most rural mobile phone users utilized this method (Akanmu and Rabi'u, 2012). Communication and network technologies, such as long-term evolution (LTE/4G) (Qazi *et al.*, 2015a), fifth-generation (5G) (Sung *et al.*, 2019), ad hoc (Qazi *et al.*, 2015), and LoRa (Chen *et al.*, 2018; Rahmadhani *et al.*, 2019; Hoang *et al.*, 2020) are available to consider for drone communications.

Additionally, mobility models for surveillance should be examined. A systematic path for drones could avoid flying at similar spots and collisions, thus improving communication (Nawaz et al., 2019). The five categories of flying patterns are random-based, time-based, path-based, group-based, and topology-based (Oubbati et al., 2019). Hence, this study aims to identify the most optimum wireless communication technology for the ad hoc network and flying pattern covering large areas.

2 Drone Implementations

2.1 Drone Deployment at Disaster Area

Whether the disaster is natural or man-made, disaster management agencies should consider high-end technology, such as drones, to reduce their harmful effects. In 2020 only, the world has experienced several disasters such as Beirut Explosion (Ben and Maria, 2020), California Wildfires (Boynton, 2020), and the Philippine Volcano eruption (Martin, 2020). Drones have been widely used to view the affected areas. Nonetheless, the drone still faces several challenges and needs to improve.

2.2 Drone Applications

Drones are intelligent inventions that could ease manpower's daily tasks. It can deploy and monitor industrial areas (Potter *et al.*, 2019), farms (Peter *et al.*, 2020; Ammar and Koubaa, 2020), and platforms for human communication (Tropea and Fazio, 2019). Drones are designed with several embedded devices, such as transceivers, flight controllers, power circuits, global positioning systems, and sensors, which make them powerful. Various sizes, types, and prices are available. Usually, the mini version was used for search and rescue mission study (Korneev *et al.*, 2018; Leonov and Litvinov, 2018; Leonov and Ryabchevsky, 2018; Litvinov *et al.*, 2018). Alternatively, the higher performance was used for professional tasks such as forensic purposes (Yousef et al., 2020), post-disaster volcanic eruption mapping (Rokhmana and Andaru, 2016), searching for flood survivors (Ravichandran *et al.*, 2019), and flood surveillance (Sumalan et al., 2016).

2.3 Network for Drone in Disaster Areas

A real-time survey will be more efficient for rescue teams to locate hazards and victims, along with Wi-Fi-connected controllers are best for streaming live videos. Among the IEEE 802.11 models, 802.11n offers the most extended transmission range of 250m and supports a 600Mbps data rate (Abdelrahman et al., 2015). The use of appropriate flight patterns can optimize battery usage as drone batteries are limited (Yuansen *et al.*, 2018).

3 Mobility Model for Drones

This section discusses the drone mobility model and network performance, focusing on the technical specification and the coverage of drones for victim identification in disaster areas. The research gaps were identified and further explored.

There are four different kinds of Random-based mobility models, including Random Walk Mobility (RWM), Random Waypoint Mobility (RWPM), and Manhattan Grid Mobility (MGM). RWM allows the drones to move at a constant time with varying distances, speeds, and directions. An

RWPM is similar to an RWM but requires waiting before the drones change directions. Finally, MGM is a mobility model based on the road grid topology of urban cities.

Sharma and Kim (2019) designed a random 3D model based on an RWPM and uniform model. Two drones were used to achieve the highest coverage area, 78.75% in 0.0016km² 2D area.

Next, to ensure good network connectivity and efficient energy consumption, (Leonov et al., 2018) developed an autonomous drone distribution model that allows the drones to communicate with each other for the area being surveyed. The study applied three different models, namely random, topology, and forces. For random based, five to thirty drones were used in a 16km² which covered 1.27% of the area. This study enhanced MGM by introducing a new method of measuring mobile node speed. AODV, DSDV, and DSR were used to validate the performance of this technique (Kour and Ubhi, 2019). Flying around a 19.8km² area, this model can cover 56.3% of the area. In contrast, an RWPM model was used to investigate the reachability using AODV and OLSR routing protocols in FANET by deploying ten to a hundred drones. Throughout 4.32km² areas, seven drones achieved 28.63% coverage (Leonov *et al.*, 2018).

Simulations in 2D and 3D produced similar results as reported in (Sharma and Kim, 2019) and (Lin *et al.*, 2019). Comparing the 3D and 2D models, the 3D model performed better. The smooth random walk model combined several models, including paparazzi (path-based), particle swarm (group-based), and smooth turn (time-based). The study found that twenty to hundred and forty drones could cover 52.8% of the four km² areas. Furthermore, the three models were analyzed related to the performance of mobile ad hoc tactile networks with two different types of network protocols (Arshad *et al.*, 2019). The models investigated were RWM, Reference Point Group Mobility (RPGM), and MGM. The coverage achieved with eight, nine, and twelves drones was 62.8%, 43.6%, and 26.0%, respectively.

There are also four types of path-based mobility models: semi-random circular movement (SRCM), paparazzi (PPRZ), and flight plan (FP). SRCM is a model where the drones fly around fixed points in an area with variously sized circles. PPRZ uses a similar concept with SRCM, though it flies differently and generally applies in actual implementation. The topology is also time-dependent, the paths being marked before launch.

The algorithms developed to determine whether small drone deployment can provide a secure and dependable communication system during a disaster were explored (Ali *et al.*, 2019). Furthermore, there were two allocation methods for drones utilizing sixteen drones and four per row and column. The result showed that the covered area was 73.6% and 70.4% for the four km² areas. Note that RPGM is a group-based model where the drones move together with a leader drone as a reference. Two models were used (Arshad *et al.*, 2019), involving an RPGM of nine mobile nodes that covers 43.6% of one km² area. The RWM proved to have the highest covered area while using the fewest mobile nodes compared to the RPGM and the MGM models.

Conversely, the Self-Deployable Point Coverage (SDPC) is one of the topology-based models. An SDPC model was designed to achieve maximum coverage of each drone and ground connection;

thus, the drones will move together at a similar distance or stay at a specific point. Self-deployable drones capable of providing flexible communication services to victims during the post-disaster period have been explored (Sanchez-Garcia *et al.*, 2015). Several different Jaccard threshold values of 0.2, 0.5, and 0.8 were used in the model. Results showed that the drones' position has the most excellent coverage with 80.93% based on one km^2 area at 0.8 thresholds.

Further, there were another three models (Messous *et al.*, 2016), and the second model was known as the alpha-based model. This model allowed the drones to preserve a substantial distance between them and remain connected. Overall, the deployment of drones to cover a 16km^2 area with a coverage area of 28.91% were between five to thirty drones. Again, the covered area percentage was the smallest, but the dimension area is the second largest with the highest number of drones.

Next, the development of a drone's network for effectively communicating with users in a particular coverage area was investigated (Tropea and Fazio, 2019). Nine drones flew squarely with three in each row and column using the static mobility model. The coverage area of this formation is 98.3% from 0.73km^2 with 100 maximum mobile users. Due to the high number of drones needed, this method is not suitable for SAR. A forces-based mobility model uses repulsion and attraction to move the drone around the area. According to Messous et al. (2016), the third model used similar numbers and dimensions of drones, with five to thirty drones deployed in 16km^2 and achieved 22.8% of the covered area. Compared to forces-based and random models, the alpha model has contributed to the most covered area. Table 1 tabulated previous research related to the drone mobility model, including the broadest coverage area based on each mobility model.

Table 1: List of mobility models with the number of drones and dimensions.

Network	**Ref**	**Mobility Model**	**Number of Drones**	**Proposed Area (km^2)**	**Covered Area (km^2)**	**Covered Area (%)**
802.11p	Lin *et al.* (2019)	RWM	20-140	4	2.1134	52.84
802.11b	Arshad *et al.* (2019)	RWM	8	1	0.6277	62.77
		RPGM	9	1	0.4359	43.59
		MGM	12	1	0.2601	26.01
802.11g	Leonov et al. (2018)	RWPMM	10-100	4.32	1.2368	28.63
802.11	Messous et al. (2016)	Random	5, 10, 15, 20, 30	16	0.2031	1.27
		Forced	5, 10, 15, 20, 30	16	3.6495	22.81
		Alpha-based	5, 10, 15, 20, 30	16	4.625	28.91
	Sanchez-Garcia *et al.* (2015)	Jaccard W = 0.2	5	1	0.4295	42.95
		Jaccard W = 0.5	5	1	0.6067	60.67
		Jaccard W = 0.8	5	1	0.8093	80.93
	Kour & Ubhi (2019)	EMGM	10, 50, 100	19.8	11.1524	56.33
	Tropea and Fazio (2019)	Static	9	0.73	0.7166	98.26
	Sharma and Kim (2019)	RWPMM & Uniform	2	1.6	1.262	78.75
	Ali *et al.* (2019)	Matching algorithm-based UE	16	4	2.9459	73.65
		Minimal distance allocation	16	4	2.8155	70.39

Previous research has developed a mobility model for drones that suggested using more drones and contributed to a higher cost of drone maintenance. Few studies have analyzed the packet delivery ratio (PDR) and drones' throughput, which should be further investigated. The analysis of PDR and throughput using a minimal number of drones is crucial in any disaster area. Additionally, identifying the optimal drone flight pattern can help reduce energy consumption. These are the future research areas to be explored.

4 Related Case Evaluation

This section elaborates on the communication performance based on throughput, mobility model, communication technology, and the number of drones. Throughput evaluation is essential for a small network or a limited number of network points since it can analyze the total number of successfully delivered data packets over the full time taken for the data packet to travel as

$$Throughput = \frac{\sum P_{Received}}{T_{Received} - T_{Transmission}} \quad (1),$$

where: $\sum P_{Received}$ = total number of packets transmitted from drone to the base station,

$T_{Received}$ = time when the packets arrive at the base station,

$T_{Transmission}$ = the time when the drone transmits.

Table 2 shows that 12321 km² is the largest simulation area investigated using single drone deployments, and the Random Waypoint Model (RWPM) gained the highest throughput (Xia *et al.*, 2019). Two experiments using different size antennas and the Long-Term Evolution (LTE) network achieved 1Gbps and 100Mbps throughput. Most of the models applied were between 1km². For 25km² the models utilized were random-based, specifically RWPM, RWM, MGM, while for path-based the models used were Semi-Circular Random Movement (SCRM), Pursue (PRS) Mobility Model, and Spiral Line Mobility Model (SLMM), and PPRZ, along with group-based. Even with the most drone deployments, the highest throughput is occasional. Next, sixty drones were used, contributing to 0.2 and 0.3Mbps (Zhou *et al.*, 2004) compared to findings from (Tang *et al.*, 2019) which gained the highest throughput of 40Mbps using twenty drones. In contrast, path-based flight patterns attained a higher throughput than random patterns, with path-based obtaining 9 to 9.2Mbps versus random-based at 5.1-8.6Mbps (Alkhatieb et al., 2020). Conversely, simulation and numerical analysis were performed for the area below 25km², which yielded 0.514Gbps from three drones (Park *et al.*, 2019). This work is ranked among the highest throughput with fewer drone use. However, the simulation area is considered negligible because of only 0.0625km² area. Despite a similar number of drones, network, and model classes, the throughput gain in (He et al., 2020) was better than in (Thounhom and Amornkul, 2016). Using ten drones for the group mobility model led to a higher throughput rate for the group with ten drones than for the two groups using five drones each (Misra and Agarwal, 2012). Also, the study showed that the second largest experiment area has the lowest throughput (Tan *et al.*, 2020). The RWP model with 40 drones resulted in greater throughput than similar models, but with fewer drones. Meanwhile, another study applied RWM with more drones in a smaller area size (Fan *et al.*, 2018) compared with (Tan *et al.*, 2020), resulting in a gain of 0.00148Mbps as reported in Tan *et al.* (2020).

Table 2: Comparison of previous work based on throughput, mobility model, communication technology, and the number of drones utilized.

Ref	Area Size (km^2)	Number of Drones	Network Type	Mobility model	Throughput (Mbps)
Xia *et al.* (2019)	12321	1	5G with antenna = 16 by 4	RWPM	1,000
			5G with antenna = 64 by 16		1,000
			LTE		100
Tan *et al.* (2020)	25	20	802.11b	RWPM	0.00160
		40			0.00350
Fan *et al.* (2018)	12	50	802.11p	RWM	0.00148
Zhou *et al.* (2004)	6.16	60	802.11	RWPM	0.3
				VTM	0.2
Tang *et al.* (2019)	4	4 cloudlets 16 UAVs		Distance-based	40
Alkhatieb et al. (2020)	3	15		RWPM	8.61425
				MGM	5.14299
				SCRM	9.05163
				PRS	9.18919
Misra and Agarwal (2012)	2.25	1 group (10nodes)		BFBIGM	0.014
		2 group (5nodes)			0.012
He et al. (2020)	1	20		SLMM	0.43
Thounhom and Amornkul (2016)				Paparazzi	0.39
Erim and Wright (2017)	0.25	3		MGM	1.875
				RWPM	1.385
				RPGM	0.71
				GMMM	0.69
Park et al. (2019)	0.0625		5G	An algorithm based on K-mean	514
Koushik *et al.* (2019)	0.01	4	802.11	DQN (spiral shape)	0.5
Park *et al.* (2018)	0.0004	20		Static	0.8
		15			0.7
Qazi et al. (2015b)	N/A	30	LTE	GMMM	0.6
Kuschnig and Bettstetter (2013)	N/A	1	802.11a	Time-based	12

Table 2 shows four studies that deployed 3-20 drones in an area with less than 1km2 area. Erim and Wright (2017) evaluated four mobility models with three drones and four scenarios were used for the same network. The MGM and RWPM models achieved throughputs of 1.4-1.9Mbps compared to the RPGM and Gauss Markov Model Mobility (GMMM) models with 0.7Mbps each. Then, a static model was applied using fifteen and twenty drones in a 0.0004km^2 area utilizing a similar network (Koushik *et al.*, 2019). The drones gained 0.7Mbps on fifteen and 0.8Mbps on twenty. Moreover, the Deep Q-learning network was developed using a path-based model. This pattern obtained 0.5 Mbps throughput using four drones within 0.01km² (Koushik *et al.*, 2019). Qazi et al. (2015b) evaluated the GMMM in a real scenario with thirty drones that gained 0.6Mbps after using the same network (Xia *et al.*, 2019). The throughput by Qazi et al. (2015b) was lower than Xia *et al.* (2019) due to real-life obstacles that interrupted the signals, but the network was suitable for real-life scenarios. Kuschnig and Bettstetter (2013) examined real-world scenarios by extending the antenna size to increase the 802.11 communication range. By using a single drone, the proposed method achieved throughput as targeted for 300m with 12Mbps.

The results obtained in Tables 1 and 2 are analyzed based on the drones' weight, wind, and flight altitude. A bigger drone attached to a bigger battery can fly longer (Biczyski *et al.*, 2020). A drone flight path will be affected in the presence of wind (Wang *et al.*, 2019). Additionally, based on a numerical study conducted, higher drone altitude will provide a more comprehensive view but, the drone will only capture low-quality RGB images (Seifert *et al.*, 2019). Thus, these aspects should be considered for optimal operation.

5 Conclusion

This study conducted a mini-review on the mobility model of flying ad hoc networks for SAR activity in the disaster area. Most studies have used small coverage simulation areas with more than ten drones, while for the 25km² areas, more than twenty drones were used. Utilizing more drones is not an option in an actual disaster situation, leading to high costs and reduced drone stability. The wind produced by the group of drones may cause the drones to consume more energy during flying. It was found that the Jaccard model managed to cover more than 50% of the one km² area using only five drones. Also, the 5G network showed good performance under conditions of large disaster areas. Hence, these will be the criteria and aspects to be considered for the stage of research.

6 Availability of Data And Material

Data can be made available by contacting the corresponding author.

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Intan Nabina Azmi received a Diploma and a B. Eng. (Hons) in Electrical Engineering (Electronics) from Universiti Teknologi MARA (UiTM), Malaysia. She pursues her Master of Science at the College of Engineering, UiTM, Shah Alam, Malaysia. Her research interests are Information Delivery to Wireless Networks, Mobile Drone Models, and Drone Applications in Disaster Areas.

Dr.Yusnani Mohd Yussoff is an Associate Professor at the College of Engineering, UiTM, Shah Alam Malaysia. Her research area focusses on Wireless Sensor Network, Trusted Authentication, Embedded Security and Internet of Thing. She is Head of Information, Security and Trusted Infrastructure Laboratory or InSTIL Research Group (RG). She is a member of IEEE, IAENG and Board of Engineer Malaysia.

Dr.Murizah Kassim is an Associate Professor at the College of Engineering, UiTM, Shah Alam, Selangor. She received her PhD in Engineering from Universiti Kebangsaan Malaysia (UKM). Her research areas are Computer Network, IoT, Web and Mobile Development Applications. She is also Head of Enabling Internet of Things Technologies (ElIoTT) RG UiTM and a member of MBOT, IEEE, IET, IAENG and IACSIT.

Dr.Nooritawati Md Tahir is a Lecturer at the College of Engineering, UiTM, Shah Alam, Malaysia. Her research interest is in the field of Image Processing, Pattern Recognition and Computational Intelligence. She is also a Chartered Engineer (CEng) registered with the Engineering Council UK and Senior Member of IEEE.