FANET Application Scenarios and Mobility Models

Armir Bujari
University of Padua
Padua, Italy
abujari@math.unipd.it

Claudio E. Palazzi
University of Padua
Padua, Italy
cpalazzi@math.unipd.it

Daniele Ronzani
University of Padua
Padua, Italy
dronzani@math.unipd.it

ABSTRACT

FANETs are a promising solution for application scenarios involving UAVs. There are many mobility models that can be used to reproduce the behavior of the mobile nodes in an ad-hoc network, but some of these cannot simulate the realistic motion of UAVs. In this paper we list the available mobility models and try to understand which ones should be adopted for different FANET application scenarios, discussing their pros and cons.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless communication, Network Topology; H.1 [**Models and Principles**]: Miscellaneous

Keywords

FANETs; UAVs; Mobility models; Wireless networks

1. INTRODUCTION

Recently, the deployment of a swarm of UAVs to pursue a task is enjoying increasing success, since a group of UAVs instead of one single UAV leads to many advantages; for example the possibility to extend the mission coverage, to guarantee a reliable ad-hoc network, or to enhance the operation performance [1].

The possibility to use a swarm of UAVs, which may collaborate with each other to offer a cooperative task, defines a new type of ad-hoc network called Flying Ad-hoc NETwork (FANET). Such a network introduces important communication issues, like routing, which is one of the most critical aspects in this context [2].

To face these problems, many researches have been proposed innovative communication protocols, which employ simulations as validation tools in order to analyze their performance metrics. When flying objects are considered, a mobility model specifically designed for UAVs' movement is needed. In fact, the particular mobility of mobile nodes can significantly affect the performance of a simulated aspect of the network. Such aspects are not yet well explored and the current mobility models cannot reproduce entirely a realistic behavior of UAVs, severely misleading the simulation outcome.

In this paper we categorize and describe real possible FANET application scenarios (Section 2) and describe available mobility models for simulators, illustrating strengths and weaknesses (Section 3). We then associate the most feasible mobility models to every scenario, providing a guidelines to researchers developing FANET-related models and simulations (Section 4). Finally, conclusions are drawn (Section 5).

2. APPLICATION SCENARIOS OF FANETS

We can divide the applications into three main classes, which identify the specific purposes of the FANET.

- **Surveillance/monitoring.** This class contains applications that involve UAVs as flying cameras. The tasks typically involve capturing real-time images, video or audio from flying devices, in order to process them and catch sensitive information. For example, in search and rescue missions UAVs are looking/sensing for a target, typically on the ground [3]. Traffic and urban monitoring is another scenario, which could involve a FANET as observational infrastructure [4, 5]. Also in military context, aerial reconnaissance missions range from information collection on battlefields to law enforcement activities [6]. Agricultural management [7, 8, 9] is another application context.

- **Environmental sensing.** In this class, UAVs act as sensors that detect environmental information on a specified area [10, 11]. In this context, applications might need several sensor data to evaluate some environmental conditions. A sensor network arranges sensors in proximity or within the phenomenon to be observed. Temperature, humidity, pressure, light intensity, pollution level are typical physical quantities that a sensor network can analyze.

- **Relaying network.** FANETs can deploy connectivity in areas that need a certain kind of communication. Autonomously operated UAVs are being used as airborne communication relays to efficiently and securely transmit information collected by ground sensors to distant control centers, and for increasing the communication range of relaying ground nodes.

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3. MOBILITY MODELS

We can categorize the mobility models into five classes:

- **Randomized mobility models**. Randomized mobility models are the simple models for network research. They represent multiple mobile nodes whose actions are completely independent of each other and past actions. Examples are Random Walk (RW) [12], Random Way-Point (RWP) [13] and Random Direction (RD) [14]. In these mobility models, each node randomly chooses a direction (or a way-point) and speed to move for a certain period. Another randomized mobility model is Manhattan Grid (MG) [15], which uses a grid road topology that constraints the node to move in horizontal or vertical direction on an urban map.

- **Time/space dependent mobility models**.
This category of mobility models tries to avoid sharp speed and sharp direction changes. The smooth change of motion can be performed using different mathematical equation. Examples are Boundless Simulation Area (BSA) [16] and Gauss-Markov (GM) [17], which use a relationship between the previous direction and speed and the current ones to update the new values at each step. Smooth Turn (ST) mobility model [18] allows the mobile nodes to move in curved trajectories, choosing a point in the space and then circling around it until the UAV selects another turning point.

- **Path-planned mobility models**. These mobility models provide a path scheme with a predefined shape. UAVs follow a specific pattern until they arrive at the end of it, and randomly change to another pattern or repeat the same one. Semi-Random Circular Movement (SRCM) [19] is an example of a mobility model designed for the curved movement scenarios of UAVs and suitable for simulating UAVs turning around a specific position. Paparazzi mobility model (PPRZM) [20] is an example of stochastic mobility model that is based on a state machine containing six movement pattern states: Stay-At, Eight, Oval, Scan and Way-Point. Each UAV chooses one of these patterns and a random speed.

- **Group mobility models**. These models include a spatial constraint among all the mobile nodes. The Reference Point Group mobility (RPGM) [21] model simulates a random motion of mobile nodes around a reference point that moves on the area with a simple RWP model. Special cases of RPGM are defined in [12]: in Column (CLMN) each mobile node moves around a reference point placed on a given line, which is moving in a forward direction; Nomadic Community (NC) randomly moves mobile node around a given point that, in turn, moves randomly; Pursue (PRS) is similar to Nomadic, but the mobile nodes attempt to follow a particular target, without a simple random movement around it.

- **Topology-control based mobility models**.
When certain network or mission constraints have to be continuously satisfied, the mobility model needs a real-time control of mobile nodes topology. A classic example is the Distributed Pheromone Repel (DPR) mobility model [6] for reconnaissance and search missions. In this model, each mobile node maintains an own pheromone map. The Self-Deploy Point Coverage (SDPC) mobility model is proposed in [22] for disaster scenarios. It deploys a set of UAVs on a disaster area in order to create a communication infrastructure that the victims of the disaster event can use. The aim of each UAV is to cover the maximum number of people on the ground maintaining a connection with the other UAVs.

4. APPLICATION SCENARIOS AND MOBILITY MODELS

In Table 1, a summary of application scenarios and feasible mobility models associations is shown. RW, RWP and RD do not reflect any particular kind of movement to reach any task. Hence, these three models are not taken into consideration.

4.1 Search and rescue

A typical pattern for search and rescue operations is a simple scan scheme derived from PPRZM, when a rectangular search area is well defined. However, PPRZM does not have any connectivity or collision control. Also SRCM can restricts UAVs to circle around a fixed target as a potential search target location.

When a randomized search scheme is required, BSA, GM or ST can reproduce a search task in a well defined area, even here with a lack of connectivity and collision awareness. BSA has the unrealistic teleportation feature when an UAV gets out from the area. To tackle this problem, when the UAV goes out the area, each UAV needs to delay the time to re-enter. In emergency search scenarios, we need a guaranteed delivery and maximum delay tolerance; in this case, randomized mobility models are not adequate.

A more robust mobility model for search and rescue scenarios is the DPR mobility model, in which the movements depend on visited areas by UAVs. In this case, in order to guarantee a certain coordination, UAVs need a strong connectivity. SDPC is the most useful mobility model specifically designed for disaster scenarios, because it allows the UAVs to reach the victims taking into consideration their connectivity.

4.2 Traffic and urban monitoring

For a surveillance infrastructure on crossroads, UAVs can be positioned stationary as fixed cameras on each crossroads to monitor some events.

If we need mobile UAVs to turn around the urban area, an MG mobility model could be adapted for this purpose, but with the disadvantage of lack of connectivity guarantee.

Another scenario can present particular events, like a car accident. A group of UAVs may reach the area before help arrives, in order to check the victims state and possible danger situations. SRCM may be suitable for this type of scenario.

4.3 Reconnaissance and patrolling

When UAVs have to patrol periodically around a specific target (bases, buildings, people or ground vehicles), a SRCM may be used. When these targets also move, a group mobility model (CLMN, NC or PRS depend on the target behavior) can satisfy such a context.

Table 1: Mobility models feasibility for FANET application scenarios

Application	Mobility Model	Description
Search and Rescue Operations	BSA, GM, ST	Random search on a specified target area.
	PPRZM	Each UAV selects the scan pattern in random position.
	SRCM	Scanning in a circular area.
	DPR	Scanning an area through repeated checks.
	SDPC	Reaching victims on a disaster area.
Traffic and Urban Monitoring	Static	UAVs as fixed cameras at crossroads.
	MG	Surveillance of city streets.
	SRCM	Patrolling of a crash event before the rescue team arrives.
Reconnaissance and Patrolling	Static	Static first line of defense and patrol.
	SRCM	Surveillance of a target.
	BSA, GM	Missions without path prediction by adversaries.
	DPR	Real-time missions with awareness of critical areas.
Agricultural Management	CLMN	Field condition checking
	PPRZM	UAV actions (e.g., irrigation) on cultivated fields.
Environmental Sensing	Static	UAVs as stationary sensor nodes.
Relaying Network	Static	Static UAV communication infrastructure.
	MG	V2V connectivity among urban vehicles.

In fight-flight principles, each UAV travels to the involved area and then gets out returning to the base station. BSA or GM are good mobility models for this application, since they produce random paths not predictable by enemies.

For missions in which a certain cooperation among UAVs is needed, the DPR mobility model includes a map of attraction points that can represent sensible areas (people concentration, lively areas, areas at risks, etc.).

4.4 Agricultural management

Typically, agricultural scenarios require a one-time movement. For actuator UAVs (performing irrigation or pest control tasks) PPRZM (scan pattern) can be adequate, since the rectangular nature of the operation areas like cultivated fields. A CLMN mobility model can be appropriate to check the field area conditions.

4.5 Environmental sensing

UAVs as sensor nodes are placed stationary on the area to be sensed, sending periodically environmental information to the base station. Applications for sensor networks are typically performed by DTNs, which do not need a real-time communication or a continue network connectivity [23, 24]. A single UAV can move with a predefined path scheme in which each way point is a static UAV sensor; the moving UAVs catch the data from each UAV sensor (via a wireless connection) and then return to the base station.

4.6 Relaying Network

The need of a communication infrastructure where there is no connectivity can be performed by statically deploying a set of UAVs, which act as a relay chain among UAVs, or even in a heterogeneous scenario involving UAVs, vehicles, pedestrians, etc. [25, 26].

In urban scenarios, UAVs can be used as routers for V2V connectivity, allowing vehicles on the streets to communicate with each other; a simple MG can represent such scenario.

5. CONCLUSION

In this paper we have explored several mobility models, discussing their characteristics in terms of motion realism, randomization, network connectivity and collision avoidance. For each application scenario we have considered the most fitting mobility model so as to provide guidelines to researchers creating simulation experiments about FANETs.

In the future, further research on mobility models can of course be done. For example, a research branch can be devoted to a deeper examination of flying devices' motion in the real world to generate more accurate mobility models.

Finally, we woud also like to investigate how different mobility models and routing strategies may affect the QoS of the considered applications [27].

6. REFERENCES

[1] I. Bekmezci, O. K. Sahingoz, and a. Temel, "Flying Ad-Hoc Networks (FANETs): A survey," *Elsevier Ad Hoc Networks*, vol. 11, no. 3, pp. 1254–1270, 2013.

[2] C. E. Palazzi, A. Bujari, G. Marfia, and M. Roccetti, "An overview of opportunistic ad hoc communication in urban scenarios," in *2014 13th Annual Mediterranean Ad Hoc Networking Workshop (MED-HOC-NET)*, pp. 146–149, June 2014.

[3] J. Scherer, S. Yahyanejad, S. Hayat, E. Yanmaz, V. Vukadinovic, T. Andre, C. Bettstetter, B. Rinner, A. Khan, and H. Hellwagner, "An autonomous multi-UAV system for search and rescue," *DroNet 2015*, pp. 33–38, 2015.

[4] T. Samad, J. S. Bay, and D. Godbole, "Network-centric systems for military operations in urban terrain: The role of UAVs," *Proceedings of the IEEE*, vol. 95, no. 1, pp. 92–107, 2007.

[5] R. Reshma, T. Ramesh, and P. Sathishkumar, "Security situational aware intelligent road traffic monitoring using UAVs," in *2016 International Conference on VLSI Systems, Architectures, Technology and Applications (VLSI-SATA)*, pp. 1–6, IEEE, jan 2016.

[6] E. Kuiper and S. Nadjm-Tehrani, "Mobility models for UAV group reconnaissance applications," *Second International Conference on Wireless and Mobile Communications, ICWMC 2006*, 2006.

[7] H. Chao, M. Baumann, A. Jensen, Y. Chen, Y. Cao, W. Ren, and M. McKee, “Band-reconfigurable Multi-UAV-based Cooperative Remote Sensing for Real-time Water Management and Distributed Irrigation Control,” *IFAC Proceedings Volumes*, vol. 41, no. 2, pp. 11744–11749, 2008.

[8] J. Torres-Sánchez, F. López-Granados, A. I. De Castro, J. M. Peña-Barragán, and M. Jurado-Expósito, “Configuration and Specifications of an Unmanned Aerial Vehicle (UAV) for Early Site Specific Weed Management,” *PLoS ONE*, vol. 8, p. e58210, mar 2013.

[9] X. Li, Y. Zhao, J. Zhang, and Y. Dong, “A Hybrid PSO Algorithm Based Flight Path Optimization for Multiple Agricultural UAVs,” in *2016 IEEE 28th International Conference on Tools with Artificial Intelligence (ICTAI)*, pp. 691–697, IEEE, nov 2016.

[10] Peng Wei, Quanquan Gu, and Dengfeng Sun, “Wireless sensor network data collection by connected cooperative UAVs,” in *2013 American Control Conference*, pp. 5911–5916, IEEE, jun 2013.

[11] O. Alvear, C. T. Calafate, E. Hernández, J.-C. Cano, and P. Manzoni, “Mobile Pollution Data Sensing Using UAVs,” *The 13th International Conference on Advances in Mobile Computing and Multimedia*, pp. 393–397, 2015.

[12] M. Sánchez and P. Manzoni, “ANEJOS: A Java based simulator for ad hoc networks,” *Future Generation Computer Systems*, vol. 17, no. 5, pp. 573–583, 2001.

[13] D. B. Johnson and D. A. Maltz, “Dynamic Source Routing in Ad Hoc Wireless Networks,” *Mobile Computing*, vol. 353, pp. 153–181, 1996.

[14] E. Royer, P. Melliar-Smith, and L. Moser, “An analysis of the optimum node density for ad hoc mobile networks,” *ICC 2001. IEEE International Conference on Communications. Conference Record (Cat. No.01CH37240)*, vol. 3, pp. 857–861, 2001.

[15] F. Bai, N. Sadagopan, and A. Helmy, “The IMPORTANT framework for analyzing the impact of mobility on performance of RouTing protocols for Adhoc NeTworks,” *Ad Hoc Networks*, vol. 1, no. 4, pp. 383–403, 2003.

[16] Z. J. Haas, “A New Routing Protocol for the Reconfigurable Wireless Network,” *Proceedings of the 1997 IEEE 6th International Conference on Universal Personal Communications, ICUPC’97*, vol. 2, pp. 562–566, 1997.

[17] V. Tolety, “Load Reduction in Ad Hoc Networks Using Mobile Servers,” *Master Thesis, Colorado School ofMines*, 1999.

[18] Y. Wan, K. Namuduri, Y. Zhou, and S. Fu, “A smooth-turn mobility model for airborne networks,” *IEEE Transactions on Vehicular Technology*, vol. 62, no. 7, pp. 3359–3370, 2013.

[19] W. Wang, X. Guan, B. Wang, and Y. Wang, “A novel mobility model based on semi-random circular movement in mobile ad hoc networks,” *Information Sciences*, vol. 180, no. 3, pp. 399–413, 2010.

[20] O. Bouachir, A. Abrassart, F. Garcia, and N. Larrieu, “A mobility model for UAV ad hoc network,” *Unmanned Aircraft Systems (ICUAS), 2014 International Conference on*, pp. 383–388, 2014.

[21] X. Hong, M. Gerla, G. Pei, and C.-C. Chiang, “A group mobility model for ad hoc wireless networks,” *Proceedings of the 2nd ACM international workshop on Modeling, analysis and simulation of wireless and mobile systems - MSWiM ’99*, pp. 53–60, 1999.

[22] J. Sanchez-Garcia, J. M. Garcia-Campos, S. L. Toral, D. G. Reina, and F. Barrero, “A Self Organising Aerial Ad Hoc Network Mobility Model for Disaster Scenarios,” *Proceedings - 2015 International Conference on Developments in eSystems Engineering, DeSE 2015*, pp. 35–40, 2016.

[23] A. Bujari, C. E. Palazzi, D. Maggiorini, C. Quadri, and G. P. Rossi, “A solution for mobile dtn in a real urban scenario,” in *2012 IEEE Wireless Communications and Networking Conference Workshops (WCNCW)*, pp. 344–349, April 2012.

[24] S. CC, V. Raychoudhury, G. Marfia, and A. Singla, “A survey of routing and data dissemination in delay tolerant networks,” *J. Netw. Comput. Appl.*, vol. 67, pp. 128–146, May 2016.

[25] M. Fazio, C. E. Palazzi, S. Das, and M. Gerla, “Automatic ip address configuration in vanets,” in *Proceedings of the 3rd International Workshop on Vehicular Ad Hoc Networks*, VANET ’06, (New York, NY, USA), pp. 100–101, ACM, 2006.

[26] A. Hamidian, C. E. Palazzi, T. Y. Chong, J. M. Navarro, U. Korner, and M. Gerla, “Deployment and evaluation of a wireless mesh network,” in *2009 Second International Conference on Advances in Mesh Networks*, pp. 66–72, June 2009.

[27] L. Donatiello and M. Furini, “Ad hoc networks: a protocol for supporting qos applications,” in *Proceedings International Parallel and Distributed Processing Symposium*, pp. 8 pp.–, April 2003.