Routing in a Fleet of Micro Aerial Vehicles: First Experimental Insights

Mahdi Asadpour[1], Simon Egli[1], Karin Anna Hummel[1], Domenico Giustiniano[2]
[1]ETH Zurich, Zurich, Switzerland
[2]IMDEA Networks Institute, Madrid, Spain
{mahdi.asadpour,simon.egli,karin.hummel}@tik.ee.ethz.ch, domenico.giustiniano@imdea.org

ABSTRACT

Micro aerial vehicles (MAVs) have the potential to support civilian applications in large areas by providing an ad-hoc multi-hop wireless network. Yet, available network routing protocols have not been designed for the micro aerial use case and it is unclear how well they can cope in practice with the wireless link and topology dynamics posed by MAVs. To answer this question, we provide a first assessment of major ad-hoc routing protocols in a lab study. Further, we present measurement results for B.A.T.M.A.N. and greedy geographical routing in a small IEEE 802.11n MAV testbed and discuss potential directions for future research.

1. INTRODUCTION

The miniaturization of unmanned aerial vehicles is driving their deployment in civilian applications, such as search and rescue [1], farmland monitoring, product delivery, and many more. These micro aerial vehicles (MAVs) feature a weight of a few kilograms or less, embedded computing and communication facilities, and small cameras and other sensors, such as a Global Positioning System (GPS) unit. By leveraging wireless networks, data gathered with the on-board sensors can be transmitted from the MAVs to the ground. In case a large area has to be covered, a fleet of MAVs may form an ad-hoc multi-hop network. Despite the fact that traditional routing protocols for mobile ad-hoc networks (MANETs) have been designed to handle topology changes, it is unclear how well they can cope with the highly dynamic setting imposed by MAVs, including obstructions of the signal that are caused by the MAVs' own frame and antenna properties [2]. We approach this open question by conducting experimental studies on MANET routing protocols.

2. EXPERIMENTAL EVALUATION

We investigate major routing algorithms in aerial multi-hop IEEE 802.11n networks in lab and field experiments by analyzing both the impact of the routing decisions on transmission performance and the efficiency of route maintenance.

Performance of transmission: We measure the end-to-end UDP *throughput* (in bit/s). Therefore, we use the 'iperf' tool for generating traffic load and measuring the (multi-hop) throughput from a source to a destination. In our lab pre-study, we further measure the end-to-end *delay* (in seconds) and the *packet loss* (in %) of a transmission. In the field study, we introduce a metric to describe the "quality of a route" in terms of the *success ratio of UDP throughput measurements*. A measurement is considered to be successful if the throughput is greater than zero, otherwise it is assumed to fail.

Performance of route maintenance: To analyze the efficiency of the routing protocol, we use the *route convergence time* (in seconds), i.e., the delay between a topology change and the reaction of the routing protocol, and the *route overhead* in terms of number of routing control packets transmitted per second.

Figure 1: Left: Arducopter platform with on-board wireless package and two external circular antennas. Right: Test scenario of two quadrocopters moving between two waypoints: distance of MAV$_2$ to the ground station varies from $40-450$ m; distance of MAV$_1$ to the ground station varies from $20-260$ m.

Table 1: Results of routing protocols in lab tests (2-hop case).

	B.A.T.M.A.N.	OLSR	AODV
Throughput (Mbit/s)	9.72	9.55	7.49
Delay (ms)	163	170	183
Packet loss (%)	5	6	74
Route convergence time (s)	11	23	2
Routing overhead (#/s)	∼15	∼2	∼5

2.1 Lab experiment

To get first insights into MANET routing protocols, we perform a lab experiment with notebooks connected via IEEE 802.11n and emulated connectivity. We investigate the major MANET routing protocols Advanced On-demand Distance Vector (AODV), Optimized Link State Routing (OLSR), and Better Approach To Mobile Adhoc Networking (B.A.T.M.A.N.). We perform multiple experiments (details can be found in [5]); Table 1 summarizes the results for the 2-hop scenarios. We find that B.A.T.M.A.N. outperforms

AIRBORNE'14, August 11, 2014, Philadelphia, PA, USA.
ACM 978-1-4503-2985-9/14/08.
http://dx.doi.org/10.1145/2636582.2636832.

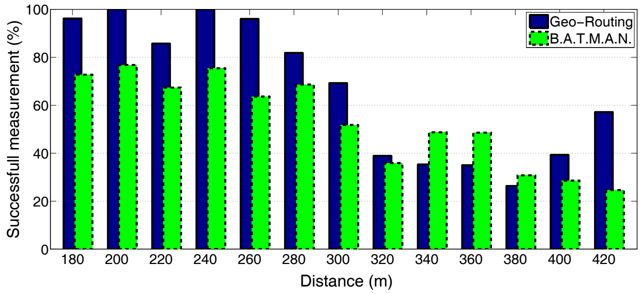

Figure 2: Success ratio of UDP throughput measurements over selected distances of MAV_2 to the ground station.

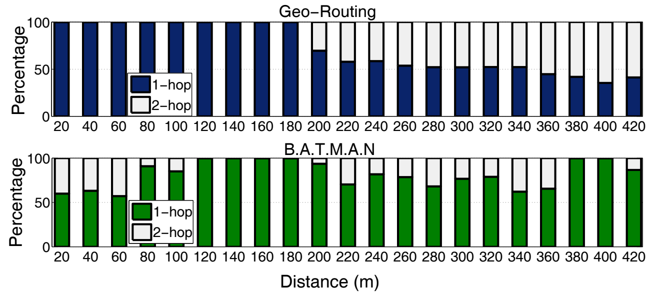

Figure 3: Ratio of 1-hop and 2-hop routes over the distance of MAV_2 to the ground station.

OLSR and AODV in terms of throughput and packet loss. However, B.A.T.M.A.N. generates significant routing overhead and shows a relatively long route convergence time.

2.2 Inflight experiment

We now compare B.A.T.M.A.N. (the best performing routing protocol in our lab test) with greedy geographical routing (geo-routing). Greedy geo-routing leverages the knowledge about the locations of MAVs and forwards packets to the neighboring MAV that is closest to the destination [4]. In our implementation of geo-routing, links of a distance longer than 200 m are considered to be too weak for transmission and alternative links are preferred, if available. Tests are conducted in the field by making use of a small MAV testbed consisting of two moving quadrocopters (cf., Figure 1, on the left) and a stationary ground station, all equipped with WLAN IEEE 802.11n and XBee-Pro (for sending GPS data).

As depicted in Figure 1 (on the right), MAV_1 and MAV_2 are flying between two waypoints, at an altitude of 30 m. They are always in 802.11n communication range of the ground station and one another. MAV_2 is constantly generating UDP traffic that is transmitted through the 802.11n network to the ground station. Data may be routed directly to the ground station (1-hop) or via MAV_1 (2-hop), depending on the routing decision. In case the destination is temporarily not reachable, packets are dropped. The experiment lasted for approximately eight minutes for each routing scheme.

Performance of transmission: Figure 2 details the quality of a route in terms of the success of UDP throughput measurements. It can be observed that the ratio of successful measurements decreases significantly with increasing distance, where more often no reliable end-to-end route can be provided. For the vast majority of distances, geo-routing achieves a better success ratio. Yet, at some distances, from 320 m to 380 m, B.A.T.M.A.N. outperforms geo-routing. This result indicates that geographical closeness is not in all cases the best criterion and there is room for optimization.

The achieved throughput of both routing protocols varies heavily with the distance of MAV_2 to the ground station, the routing decision, and the respective distances of the wireless links (2-hop case). For a sample distance of 200 m between MAV_2 and the ground station where both 1-hop and 2-hop transmissions are observed, we measure a median throughput of 5.95 Mbit/s for B.A.T.M.A.N. and 7.55 Mbit/s for geo-routing. These results are only indicative, as the dispersion is high in this dynamic setting.

Performance of route maintenance: Next, we investigate how well both routing algorithms react to topology changes by studying the use of 1-hop and 2-hop transmissions in our scenario (cf. Figure 3). It can be observed that geo-routing uses the 1-hop link from MAV_2 to the ground station when the distance between them is below 200 m (this is also the link distance threshold used by our geo-routing implementation). With increasing distance, geo-routing increases the ratio of 2-hop transmissions. As the routing table is updated on average every second with new location information, the route convergence time is about one second for geo-routing. B.A.T.M.A.N. does not show a similarly consistent behavior. At shorter distances in the range of $20 - 100$ m, we observe that the algorithm often does not choose direct, 1-hop, transmission, which is clearly better in our simple scenario, but chooses 2-hop transmission. A potential cause for this behavior is B.A.T.M.A.N.'s long convergence time of $\sim$ 28 s and high routing overhead of $\sim$ 10 messages per second, whereas geo-routing requires 2 messages per second (the numbers are average values).

3. DISCUSSION

We found that major routing protocols feature a long convergence time and high routing overhead, which does not make them sensitive enough to adapt to the dynamics of aerial networks in a timely manner. By making use of specific characteristics of MAV networks [2,3] such as the availability of GPS data, geographical routing is a promising paradigm to follow. Still, geographical routing needs to be fine-tuned to fully unleash its potential, and compared to other routing algorithms with optimized parameter settings to draw final conclusions. The field tests further showed that the end-to-end path is often unreliable, which calls for the use of delay tolerant networking approaches.

Acknowledgments

This research has been partially funded by the SNSF Sinergia project SWARMIX, project number CRSI22_133059.

4. REFERENCES

[1] SWARMIX project. `http://www.swarmix.org/`.

[2] M. Asadpour, B. V. den Bergh, D. Giustiniano, K. A. Hummel, S. Pollin, and B. Plattner. Micro aerial vehicle networks: An experimental analysis of challenges and opportunities. *IEEE Comm. Mag., Ad-hoc and Sensor Networks series*, July 2014.

[3] M. Asadpour, D. Giustiniano, K. A. Hummel, S. Heimlicher, and S. Egli. Now or later? - Delaying data transfer in time-critical aerial communication. In *9th CoNEXT*, pages 127–132. ACM, 2013.

[4] B. Karp and H.-T. Kung. GPSR: Greedy perimeter stateless routing for wireless networks. In *6th MobiCom*, pages 243–254. ACM, 2000.

[5] M. Liechti. Semester thesis: Real-world evaluation of ad hoc routing algorithms. ETH Zurich, ftp://ftp.tik.ee.ethz.ch/pub/students/2012-HS/SA-2012-35.pdf, April 2013.