Simulation-Based Comparison of AODV, OLSR and HWMP Protocols for Flying Ad Hoc Networks

Danil S. Vasiliev, Daniil S. Meitis, and Albert Abilov

Izhevsk State Technical University,
Department of Communication Networks and Systems,
ul. Studencheskaya, 7, 426069 Izhevsk, Russia
{danil.s.vasilyev,daniil.meitis,albert.abilov}@istu.ru
http://www.istu.ru/

Abstract. In this paper, we analyze Quality of Service (QoS) metrics for AODV, OLSR and HWMP routing protocols in Flying Ad Hoc Networks (FANETs) with the help of an NS-3 simulation tool. We compare proactive, reactive, and hybrid approaches to search and maintain paths in FANET based on hop count, PDR (Packet Delivery Ratio), and overheads metrics in source-destination transmission through the swarm of UAVs (Unmanned Aerial Vehicles). In the article, swarms of 10, 15 and 20 nodes were considered. The Gauss-Markov Mobility Model is used to simulate the UAV behavior in a swarm. The size of a simulated area is variable and changes from 250 to 750 meters. Average metrics were calculated in all cases. In addition, we calculate the Goodput metric and compare it with correspondent overheads. Results show that using HWMP in the considered mobile scenario grants higher PDR in trade-off, increased overheads.

Keywords: Mobile Ad Hoc Networks, Unmanned Aerial Vehicles, Quality of Service, Routing protocols, Computer simulation.

1 Introduction

Unmanned Aerial Vehicles (UAVs or drones) have become more functional since the last decade. They found new applications in search operations, pollution monitoring, wildfire management, border surveillance, etc. Drones communicate with each other in UAV systems during these operations, e.g., they transmit live video or sensor data.

Swarms of small drones are a cheap and fast way to provide a wide selection of services in a disaster area. UAVs maintain ad hoc connections in the swarm to deliver data safe and sound. Therefore, they could be considered as a set of nodes in a Flying Ad Hoc Network (FANET) [1], [2].

UAV-node velocities cause many challenges for MANET (Mobile Ad Hoc Networks) deployment. Mobility factors have an influence on QoS (Quality of Service) parameters in the network. Constant movement of nodes leads to frequent

S. Balandin et al. (Eds.): NEW2AN/ruSMART 2014, LNCS 8638, pp. 245–252, 2014.

link outages and packet loss. Thus, FANETs need special approaches for data delivery and routing [3], [4], [5], [6], [7]. Routing protocols are critical for live streaming from on-board cameras in the swarm.

Intraswarm communications impose new challenges for researchers. New simulation models and tools have been proposed to investigate routing and data delivery in FANETs [8], [9]. NS-3 provides routing protocols [10], signal propagation and mobility models [11]. Therefore, this simulation environment allows comparing ad hoc routing protocols in a FANET mobile scenario. In this paper, we analyze QoS metrics for AODV, OLSR and HWMP protocols in the case of source-destination transmission through a swarm of drones.

The remainder of this paper is organized as follows: Section 2, overview of routing protocols for FANET; Section 3, description of chosen simulation scenario; Section 4, QoS metrics used; Section 5, results; Section 6, conclusion.

2 Routing Protocols for FANET

FANET needs an efficient way to organize a swarm of nodes. Internode communication requires a routing mechanism to deliver information from one node to another through complicated mesh topology. Routing protocols for mesh networks use reactive, proactive, or hybrid approaches. In this paper, AODV, OLSR and HWMP protocols were considered. Each protocol presents a unique way to provide routing.

AODV (Ad hoc On-demand Distance Vector) protocol uses a reactive approach. This protocol constructs new routes as a user need them to transmit data through ad hoc network and maintains them until they exist.

OLSR (Optimized Link State Routing) is a proactive protocol, and, therefore, it tracks the network topology. Every OLSR node sends HELLO messages with regular intervals for its 1-hop neighbors. MPR (Multipoint Relays) reduce OLSR control overhead.

HWMP (Hybrid Wireless Mesh Protocol) is described in 802.11s draft and allows using reactive and proactive approaches within one network. In this protocol, AODV-like reactive routing competes with the root-centric proactive mode in a search for the best path through the ad hoc network with help of PREQ (Path Request) messages. In the NS-3 802.11s model, the node knows the root path but also tries to find new reactive paths to provide the best route based on an ALM (Air Time Link) metric following the hybrid nature of the protocol [8].

AODV and OLSR depend upon L3 and IP-addresses but HWMP is an L2.5 protocol and uses MACs to route data. Each of the protocols constructs routing tables (with MACs in HWMP case) on each node.

3 Simulation Scenario

Highly mobile nodes propose many challenges to researches. We have used the Gauss-Markov Mobility Model implemented in NS-3 to analyze routing in the swarm. Node position is always dictated by its previous position due to high moving speed [9]. The path of a drone is determined by the memory of the model.

We simulated FANET with AODV, OLSR and HWMP routing protocols in NS-3 environment. Fig. 1 illustrates a simulated network that consists of two ground stations and a variable number of nodes in the swarm between them. The area of simulation is constrained by the imaginary square box with variable side A (Fig. 1). Source and destination nodes are stationary and located in top-right and bottom-left corners of the box, correspondingly. The remaining nodes represent drones: they move following the Gauss-Markov Mobility Model and form the swarm. Swarm nodes have velocities from 25 to 30 meters per second. They are bound by the box and reflect from its borders without any speed reduction.

Swarms of 10, 15, and 20 nodes were simulated. Nodes used 802.11n on 5 GHz and 54 Mbps bandwidth. Signals were simulated with the Friis Signal Propagation Model, and transmission range of each node was about 250 meters. During the simulation, the source node transmitted 1406 bytes UDP datagrams (real-time video streaming) to the destination with a speed of 1 Mbps. Swarm nodes tried to deliver these datagrams to the destination through paths selected by AODV, OLSR or HWMP routing protocols.

Value A (Fig. 1) defined a box side. It was variable and changed from 250 to 750 meters with 50 m step. Therefore, the node density gradually dropped down and nodes were forced to find new paths in the swarm with help of routing protocols.

Stations and swarm nodes used one of the above mentioned routing protocols. The most important control messages for each protocol (HELLO or PREQ) were transmitted with 0,5 sec intervals.

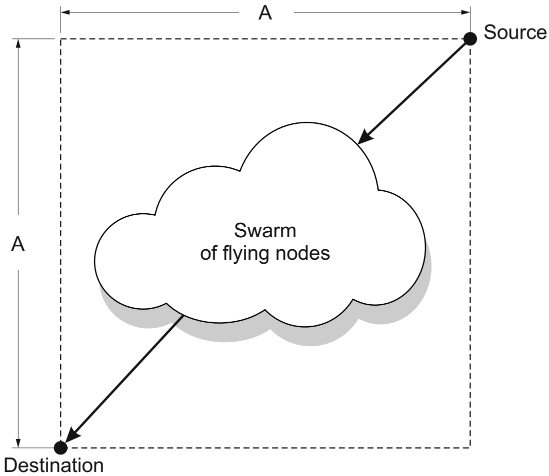


Fig. 1. Simulated network. Value A defines square box side

4 Quality of Service Metrics

We measured QoS metrics to compare effectiveness of protocols in this mobile scenario.

Average Packet Delivery Ratio (PDR_{ave}) shows a ratio between the number of datagrams received by the destination and the number of datagrams transmitted by the source. This metric is measured based on application layer sequence numbers added in the simulated UDP datagrams:

$$PDR_{ave} = \frac{Rx}{Tx} \ , \tag{1}$$

where Rx – number of datagrams received by the destination, Tx – number of datagrams transmitted by the source.

Average Goodput is all UDP payload received by the destination during the simulation divided by the simulation time:

$$Goodput_{ave} = \frac{\sum_{i=1}^{n} S_i}{T} \ , \tag{2}$$

where S_i – each received datagram payload size in kbits, n – number of received datagrams, T – simulation time in seconds.

Average Hop Count was found based on Time-to-Live field in the IP-header (for AODV and OLSR) or Mesh-header (for HWMP) in the datagrams received by the destination, summarized and divided by the number of received datagrams:

$$Hopcount_{ave} = \frac{\sum_{i=1}^{n} H_i}{n} \ , \tag{3}$$

where H_i – each received datagram hop-count metric, n – number of received datagrams.

Overheads were measured as all control messages of each routing protocol in bytes divided by the simulation time:

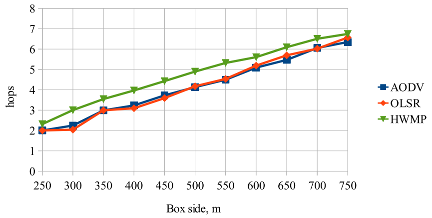
$$Overheads_{ave} = \frac{\sum_{i=1}^{n} OH_i}{T} \ , \tag{4}$$

where OH_i – protocol control message size in kbits, n – number of control messages in the simulation, T – simulation time in seconds.

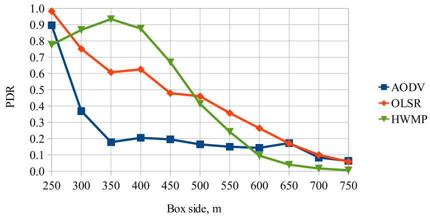
5 Results

QoS metrics were calculated based on information in pcap-files collected during the simulations. Figures show average values of the 10 simulation runs. Each run was 5 minutes long.

Results for hop-count metric and PDR_{ave} are illustrated in Fig. 2 for the swarm of 20 nodes in the box with variable sides. Hop count metric (Fig. 2a) increases linearly as box size grows. HWMP demonstrated longer paths due to

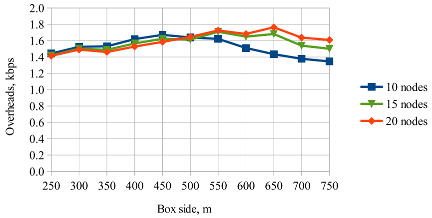


(a) Average hop count for each routing protocol

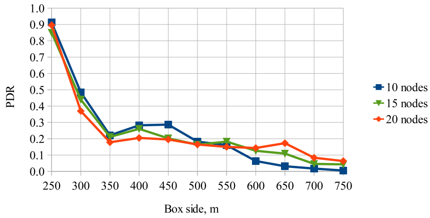


(b) Average packet delivery ratio for each routing protocol

Fig. 2. Measurement results for the swarm of 20 nodes

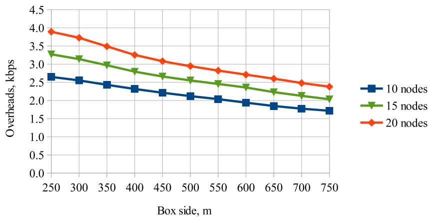


(a) Average overhead bandwidth for each swarm size

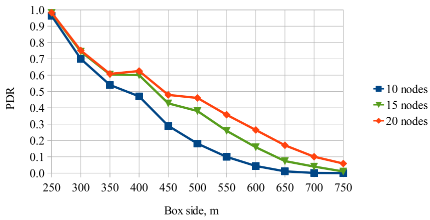


(b) Average packet delivery ratio for each swarm size

Fig. 3. Measurement results for AODV routing protocol

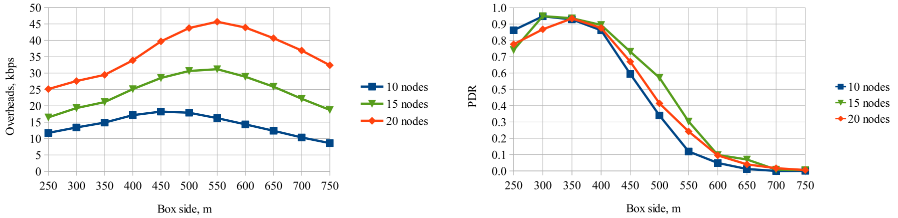


(a) Average overhead bandwidth for each swarm size



(b) Average packet delivery ratio for each swarm size

Fig. 4. Measurement results for OLSR routing protocol



(a) Average overhead bandwidth for each swarm size (b) Average packet delivery ratio for each swarm size

Fig. 5. Measurement results for HWMP routing protocol

using the ALM routing metric. While, AODV and OLSR use a hop-count metric to find new paths.

The plot (Fig. 2b) for PDR_{ave} presents an advantage of HWMP for box sizes from 300 to 500 meters. After this value, all protocols perform PDR lower than 0.5. PDR_{ave} for OLSR decreases linearly as paths lengthen and demonstrates the second result for a packet delivery metric. PDR_{ave} for AODV rapidly drops down and a path could not be established for the highly mobile scenario.

Figs. 3a, 4a and 5a show overheads for each protocol and box size. Reactive AODV protocol has minimal overheads for all swarm sizes. As we showed in Fig. 2, bigger box size causes more hop counts for the path between the source and the destination. Overheads of AODV do not depend on hop count in the chosen path. Proactive OLSR overheads are bigger for larger swarms, but slightly decrease as node density lowers. HWMP has an extremum for each swarm size and fully correlates to box size. This behavior could be explained by frequent error message generation during recovery of lost paths. This process is intensive in the middle part of the simulation.

Better results for PDR_{ave} metric for HWMP could be explained by higher overheads. But an overhead metric is dependent on the maximum number of control message retransmissions (PREQs). In the NS-3 model of HWMP, one additional retransmission is allowed. Thus, this feature of HWMP routing algorithm gives it an advantage over AODV and OLSR in PDR_{ave} metric and a disadvantage in overheads.

Average Goodput metric mimics PDR_{ave} curves. This metric helps comparing payload and overheads. AODV and OLSR protocols Goodput metrics were much higher than correspondent overheads in all cases; e.g., the worst case for both protocols was the Goodput of 60.54 Kbps against 2.38 Kbps overheads (with OLSR in the swarm of 20 nodes and 750 meters box size). HWMP demonstrated overheads higher than the Goodput for the boxes with 700 and 750 meters sides.

Figs. 3b, 4b, and 5b allow comparing AODV, OLSR and HWMP by PDR_{ave} metric. AODV does not show any dependence on swarm size; e.g., 10 nodes or 20 nodes. OLSR slightly increases for bigger swarms and, therefore, it gets benefits from higher node density. HWMP tries to hold PDR_{ave} high (around

0.8–0.9) but after 400 meters, it falls exponentially. PDR_{ave} curves for HWMP demonstrate similar behavior for all swarm sizes.

6 Conclusions

In this paper, we have examined AODV, OLSR and HWMP routing protocols in order to choose the best of them for live streaming through a highly mobile ad hoc network of UAVs. We compared effectiveness of protocols based on hop count, PDR, and overheads metrics. HWMP showed the highest PDR and the highest overheads in source-destination transmission through the swarm of drones. OLSR earned the second place and AODV was unpredictable in such mobile environments due to its pure reactive nature. PDR metric for AODV and HWMP protocols does not depend on swarm size. This behavior is defined by the reactive component of both protocols. Simulation results show that a hybrid approach and HWMP can significantly improve the QoS for the video transmission in mobile ad hoc networks of flying robots.

In the simulated scenario, overheads for OLSR are lower than for HWMP, but we could manage time intervals between control messages in order to improve PDR for OLSR. Nevertheless, control overhead reduction needs additional research due to special conditions for transmission in a wireless medium.

Node movement and link outage affect on QoS metrics in any case. Mobility prediction algorithms, opportunistic data delivery techniques, and new coding schemes are needed to organize live video streaming in such networks. Moreover, further improvement of routing protocols are vital to provide high quality communication in FANETs.

References

1. Bekmezci, I., Sahingoz, O.K., Temel, S.: Flying Ad-Hoc Networks (FANETs): A survey. Ad Hoc Networks 11(3), 1254–1270 (2013)
2. Bok, P.-B., Tuchelmann, Y.: Context-Aware QoS Control for Wireless Mesh Networks of UAVs. In: 2011 Proceedings of 20th International Conference on Computer Communications and Networks (ICCCN), pp. 1–6 (2011)
3. Beard, R., McLain, T., Nelson, D., Kingston, D., Johanson, D.: Decentralized Cooperative Aerial Surveillance Using Fixed-Wing Miniature UAVs. Proceedings of the IEEE 94(7), 1306–1324 (2006)
4. Robinson, W., Lauf, A.: Resilient and efficient MANET aerial communications for search and rescue applications. In: 2013 International Conference Computing, Networking and Communications (ICNC), pp. 845–849 (2013)
5. Rosati, S., Kruzelecki, K., Traynard, L.F., Rimoldi, B.: Speed-Aware Routing for UAV Ad-Hoc Networks. Report, GLOBECOM 2013, Atlanta, GA, USA (2013)
6. Guo, Y., Li, X., Yousefi'zadeh, H., Jafarkhani, H.: UAV-aided cross-layer routing for MANETs. In: Proceedings of Wireless Communications and Networking Conference (WCNC), pp. 2928–2933 (2012)
7. Li, Y., Shirani, R., St-Hilaire, M., Kunz, T.: Improving routing in networks of Unmanned Aerial Vehicles: Reactive-Greedy-Reactive. Wireless Communications and Mobile Computing 12(18), 1608–1619 (2012)

8. Wei, Y., Blake, M.B., Madey, G.R.: An Operation-time Simulation Framework for UAV Swarm Configuration and Mission Planning. In: 2013 International Conference Computational Science (ICCS), pp. 1949–1959 (2013)
9. Ho, D., Grotli, E.I., Shimamoto, S., Jahansen, T.A.: Optimal Relay Path Selection and Cooperatice Communication Protocol for a Swarm of UAVs. In: The 3rd International Workshop on Wireless Networking & Control for Unmanned Autonomous Vehicles: Architectures, Protocols and Applications, pp. 1585–1590 (2012)
10. Andreev, K., Boyko, P.: IEEE 802.11s Mesh Networking NS-3 Model. Report, Workshop on NS-3, Malaga, Spain (2010)
11. Broyles, D., Jabbar, A., Sterbenz, J.: Design and Analysis of a 3-D Gauss-Markov Mobility Model for Highly Dynamic Airborne Networks. In: Proceedings of the International Telemetering Conference 2010, San Diego, CA (2010)