Performance Analysis of Routing Protocols in UAV Ad Hoc Networks

Huanfeng Hu*
School of Software, Nanchang Hangkong University, China
2310804076@qq.com

Jian Shu
School of Software, Nanchang Hangkong University, China
shujian@nchu.edu.cn

Linlan Liu
School of Information Engineering, Nanchang Hangkong University, China
liulinlan@nchu.edu.cn

ABSTRACT

In recent years, the Unmanned Aerial Vehicle Ad Hoc Network (UANET) is getting great attention due to its wide applications in natural disasters, military strikes, daily life and so on. The notable characteristics of UANET, such as nodes' high mobility and rapid changes of network topology, bring challenges to apply suitable routing protocols in UANET. This paper summarizes various routing protocols in UANET, and divides them into two categories: proactive routing protocol and reactive routing protocol. In addition, a routing protocol named AODV-iETX (Ad Hoc On-demand Distance Vector - improved Expected Transmission Count) is proposed by improving AODV-ETX. We simulate UANET in NS-3 and analyze the performance of these routing protocols. Experimental results demonstrate that the performance of reactive routing protocols is generally better than proactive routing protocols in packet delivery ratio and average throughput. Besides, the results show that in most cases, AODV and AODV-EE-Hello are more effective than other routing protocols. Moreover, the proposed routing protocol AODV-iETX is slightly better than AODV-ETX.

CCS CONCEPTS

• Networks; **• Network types**; **• Ad hoc networks**; **• Mobile ad hoc networks**; **• Network protocols**; **• Network layer protocols**; **• Routing protocols**;

KEYWORDS

Unmanned aerial vehicle, Ad hoc network, Routing protocol, Performance analysis

ACM Reference Format:
Huanfeng Hu*, Jian Shu, and Linlan Liu. 2021. Performance Analysis of Routing Protocols in UAV Ad Hoc Networks. In *2021 International Conference on Mechanical, Aerospace and Automotive Engineering (CMAAE 2021), December 03–05, 2021, Changsha, China.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3518781.3519205

CMAAE 2021, December 03–05, 2021, Changsha, China

ACM ISBN 978-1-4503-8520-6/21/12…$15.00
https://doi.org/10.1145/3518781.3519205

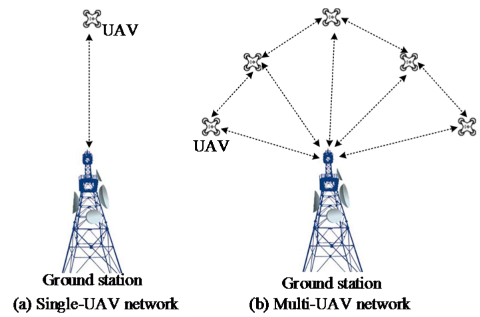

Figure 1: UAV Network: (a)Single-UAV Network, (b)Multi-UAV Network.

1 INTRODUCTION

Unmanned aerial vehicle (UAV) is a kind of flying device that can transmit commands through the network to complete a remote control. Due to its low cost, great mobility, operation ease and no risk of casualties, it has been widely considered in civil and military fields [1]. In recent years, with the expansion of UAV applications in various fields, in some complex situations, the UAV system has developed from a single-UAV system to a multi-UAV cooperative system [2], as shown in Figure 1

In the single-UAV system, UAV communicates with designated ground station [3]. Although the number of UAVs is increasing, only a single-UAV communication is established between UAV and the infrastructure. However, due to the dynamic environment and the mobility of node, UAV may not be able to maintain its communication link forever. Therefore, designing an efficient network communication architecture has become an important problem to be solved.

To solve this problem, the multi-UAV system is developed. Multiple UAVs can communicate not only with the ground stations, but also with other UAV. Moreover, to realize the cooperative work, the UAV Ad Hoc Network (UANET) [4] was formed by establishing wireless communication routing between UAVs.

The main contributions of this paper comprise the following aspects.

•We explain the differences between UANET, Mobile Ad Hoc Network (MANET) and Vehicular Ad Hoc Network (VANET).

•The AODV-iETX (Ad Hoc On-demand Distance Vector - improved Expected Transmission Count) routing protocol is proposed in this paper on the basis of AODV-ETX (Ad Hoc On-demand Distance Vector - Expected Transmission Count) [5] routing protocol. Experiments show that in terms of the performance of the packet

Table 1: The comparison of UANET, MANET and VANET

	UANET	MANET	VANET
Node mobility	Very high	Low	High
Node density	Very low	Low	High
Topology change	Very fast	Slow	Fast
Computational power	High	Low	High
Mobility mode	Combination of regular and random	Random	Regular
Power consumption	Depend on the type of UAVs	Low	No need

delivery ratio, average throughput and network overhead, AODV-iETX routing protocol is slightly better than AODV-ETX routing protocol.

•We sort out and analyze various routing protocols that can be used in UANET, and find the most suitable routing protocol. Experiments show that the reactive routing protocols are more suitable than the proactive routing protocols in UANET, especially the AODV (Ad Hoc On-demand Distance Vector) [6] and AODV-EE-Hello (Ad Hoc On-demand Distance Vector - Energy Efficient - Hello) [7] routing protocol.

The remainder of this paper is organized as follows. Section 2 introduces the basic concepts of UANET, and summarizes the differences between UANET, MANET and VANET. Section 3 describes the research of routing protocols in UANET. In Section 4, the routing protocols in UANET are compared and analyzed through experiments. Section 5 summarizes the whole paper. Section 6 is the prospect of future work.

2 UANET

In recent years, due to the advantages of fast and flexible networking, UANET has been used to send information intelligently and quickly in some situations such as battlefields and earthquake-stricken areas. It has a wide range of application prospects [4].

UANET is a kind of mobile ad hoc network, which is considered as the combination of MANET and VANET [8]. However, there are some differences between UANET, MANET and VANET [9]. Nodes in MANET are walking on the ground and nodes in VANET are driving on the road, while nodes in UANET are flying in the air. Therefore, nodes in UANET have higher mobility than nodes in MANET and VANET. Moreover, the network topology of UANET changes more frequently than that of MANET or VANET. The comparison of UANET, MANET and VANET is shown in Table 1

UANET includes communication between UAVs at the same or different levels, UAVs and the base stations, base stations and satellites, satellites and UAVs, and the base stations and users. The combination of these communication modes constitutes the communication in UANET, as shown in Figure 2. In UANET, each node acts as a transceiver and router, and the cooperation among multiple UAVs is realized through multi-hop routing. The multi-hop routing is the key of network communication in UANET. A great routing protocol can establish an effective communication link between source node and target node, so that the UAV nodes can complete the tasks better.

However, in UANET, there are many characteristics, such as high mobility of nodes, frequent changes of network topology and

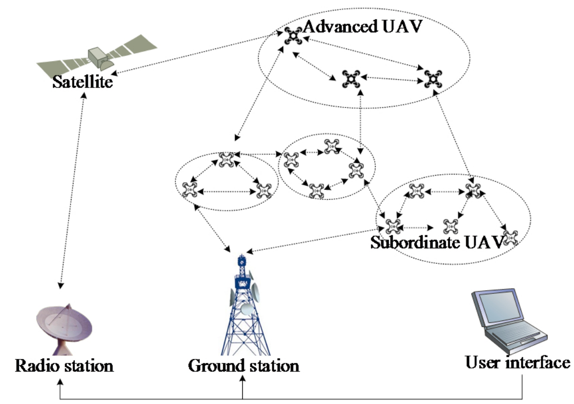

Figure 2: UAV Ad Hoc Network, UANET.

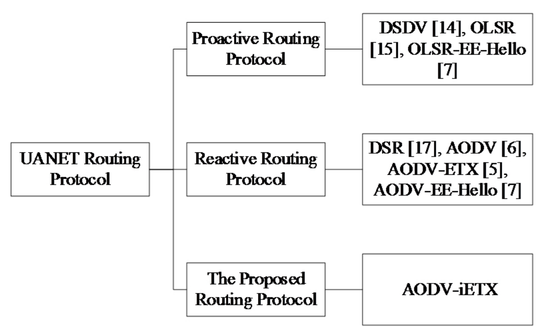

Figure 3: UANET Routing Protocols.

so on [10]. These factors will make the communication between UAV nodes more complicated [11]. Furthermore, UANET has dynamic real-time tasks, and it has higher requirements for end-to-end transmission delay and other indicators. Therefore, it is a very challenging task to design a suitable routing protocol for UANET.

3 UANET ROUTING PROTOCOLS

In recent years, many routing protocols have been proposed in UANET. Figure 3 shows the routing protocols which are used for performance analysis, including the proactive routing protocols, the reactive routing protocols [12] and the proposed AODV-iETX routing protocol.

3.1 Proactive Routing

Proactive routing uses a routing table to store all the routing information in the network [13]. Nodes exchange routing information periodically, perform routing discovery actively, and maintain the routing tables to all nodes in the network.

DSDV (Destination Sequence Distance Vector) [14] routing protocol is widely used in mobile ad hoc networks. It is based on the traditional Bellman-Ford routing mechanism. In DSDV, every node maintains a routing table to other nodes, and each route has a sequence number to avoid network loops. The route with the larger sequence number is the preferred route. When two or more routes have the same sequence number, the route with fewer hops will be the preferred route.

OLSR (Optimized Link State Routing) [15] is a classic proactive routing protocol based on the link state. The core idea of OLSR is the multi-point retransmission (MPR). During the flooding process, all the link state information is generated from the nodes selected by MPR. Only the selected nodes can forward the information in network and make routing decisions by using the link state information. OLSR can reduce the overhead of information forwarding and network control. It is especially suitable for the large-scale networks.

OLSR-EE-Hello (Optimized Link State Routing - Energy Efficient - Hello) [7] determines the hello message interval based on the task-related information, such as the number of UAV nodes and UAVs' transmission range, thus reducing unnecessary hello messages. Experiments show that OLSR-EE-Hello can meet network performance requirements with minimum energy consumption and ensure the throughput of the flying ad hoc network.

3.2 Reactive Routing

In contrast to the proactive routing, the reactive routing protocol aims to reduce the routing overhead caused by the maintenance of the routing table. It starts routing discovery only when the source node needs it. The routing table of the node is built on demand, which only represents a part of the whole network topology [16].

DSR (Dynamic Source Routing) [17] [18] is a typical reactive routing protocol. It performs routing discovery on demand, and can find multiple routes to the destination node. In addition, its routing maintenance mechanism is used to maintain all path failures. In DSR, each data packet must contain the addresses of all the relay nodes, which makes it unsuitable for networks with highly dynamic topology.

AODV (Ad Hoc On-demand Distance Vector) [6] [19] routing protocol is a widely used reactive routing protocol in ad hoc networks. During the routing discovery process, each routing request has a sequence number, which is used by nodes to prevent them from repeating routing requests. In addition, AODV broadcasts hello messages periodically to maintain the route. Once a link is found to be broken, the node will send a routing error packet message to inform the source node about the link failure, so that the source node can restart the routing discovery. This routing protocol can adapt to the dynamically changing link conditions, and reduce control overhead.

AODV-ETX (Ad Hoc On-demand Distance Vector - Expected Transmission Count) routing protocol [5] uses link quality ETX to improve the AODV routing protocol. The ETX value of the link represents the expected number required for the UAV node to make a successful transmission on the link. It is the product of the reciprocal of the forward and reverse successful transmission probabilities on the link. AODV-ETX accumulates the ETX value of each link on a route, and selects the route with the smallest sum of ETX value as the final transmission route. Experiments show that AODV-ETX is better than AODV in terms of end-to-end delay and packet loss ratio.

AODV-EE-Hello (Ad Hoc On-demand Distance Vector - Energy Efficient - Hello) routing protocol [7] and OLSR-EE-Hello are proposed at the same time. Compared with AODV, AODV-EE-Hello may be more balanced and reduce the energy consumption of UAV nodes.

3.3 Proposed Routing

In recent years, reactive routing protocol has attracted the attention of scholars at home and abroad because of its low routing overhead and no need to maintain the whole network information. In addition, in UANET, there may be some unfavorable factors, such as noise interference, channel competition and signal attenuation, which will lead to unidirectional links and link disconnection. Therefore, judging the link quality between nodes can select the better next hop.

In this paper, we use the improved ETX (Expected Transmission Count) to improve the AODV routing protocol, and then propose the AODV-iETX routing protocol. The ETX value can be used to measure the link quality between the current node and its neighbors. It can be calculated based on the success probabilities of forward and reverse transmission on the link [5]. If the forward transmission success probability is $s_1(t)$ and the reverse transmission success probability is $s_2(t)$, the link quality ETX_{IJ} between node I and J can be expressed as Equation (1).

$$ETX_{IJ} = \frac{1}{s_1(t) \times s_2(t)} \quad (1)$$

Considering the unidirectional link that may exist in the UANET, we improve ETX by calculating the probability of unidirectional successful transmission on the link, so as to obtain the value of iETX (improved Expected Transmission Count). If the success probability of unidirectional transmission between nodes is $s(t)$, the link quality $iETX_{IJ}$ between node I and J can be expressed as Equation (2).

$$iETX_{IJ} = \frac{1}{s(t)} \quad (2)$$

The smaller the value of iETX is, the better the link quality between nodes in network. We use the iETX to improve the AODV routing protocol, thus proposing the AODV-iETX routing protocol. This routing protocol selects the route with the smallest sum of iETX value as the data transmission route. Moreover, when there are two or more routes with the same iETX value in the network, the route with a smaller number of hops will be selected as the final data transmission route.

Table 2 summarizes the advantages and disadvantages of the routing protocols described in this section.

4 SIMULATIONS AND ANALYSIS

In this section, the performance of the proposed routing AODV-iETX, the proactive routing protocols DSDV [14], OLSR [15], OLSR-EE-Hello [7] and the reactive routing protocols DSR [17], AODV [6],

Table 2: Summary of routing protocols in UANET

Routing protocols		Advantages	Disadvantages
Proactive routing	DSDV	Avoids routing loops	Increases delay
	OLSR	Reduces overhead	High routing loops
	OLSR-EEHello	Reduces the energy consumption	High routing loops
Reactive routing	DSR	Finds all path to destination	Scaling problem
	AODV	High delivery ratio	High delay
	AODV-ETX	Considers the link quality	Increases overhead
	AODV-EE-Hello	More balance	High delay
Proposed routing	AODV-iETX	Considers the unidirectional link	Increases overhead

Table 3: Simulation parameters

Parameters	Value
Mobility model	Gauss-Markov [21]
Number of UAV nodes	20, 25, 30, 35, 40, 45, 50
Moving speed (m/s)	20~30, 40, 50, 60, 70, 80, 90
Delay model	Constant speed propagation delay model
Propagation loss model	Range propagation loss model
PHY/MAC protocol	802.11b
Antenna	Omnidirectional
Data flow	CBR
Data transmission rate (Kbps)	2
Packet size (bytes)	500
Simulation time (s)	300

AODV-ETX [5] and AODV-EE-Hello [7] are compared by changing the maximum speed of nodes and the network density in UANET.

4.1 Simulation Environment

The simulation environment is Ubuntu 18.04 and Network Simulator 3 (NS-3) [20]. The simulation scenario is a network composed of UAVs, and the size of this scenario is a rectangular area of 1500m * 1500m. To fully reflect the performance of the routing protocols, the simulation environment is set as an ideal environment without interference and occlusion. The UAV nodes considered in the network are fixed-wing UAVs with minimum and maximum airspeed constraints, which have the same wireless transceiver equipment and enough energy. The transmission radius of UAV node is 300m, and the UAV can fly within the mission area of 1500m * 1500m * 300m. In each experimental scenario, the simulation results are the average of 10 simulations.

The setting of simulation parameters is shown in Table 3

4.2 Performance Metrics

In the above scenarios, the following four indicators are used to evaluate the performance of routing protocols.

4.2.1 Packet Delivery Ratio. The packet delivery ratio reflects the transmission quality of current network. It represents the ratio of the total number of packets received by the destination node to the total number of packets sent by the source node during the simulation time. It is defined as Equation (3).

$$PDR = \frac{PR_{SUM}}{PS_{SUM}} \quad (3)$$

where PR_{SUM} is the number of data packets successfully reaching the destination node, and PS_{SUM} is the total number of data packets sent by the source node.

4.2.2 Average End-to-End Delay. The average end-to-end delay reflects the current congestion situation of the network. It is the average value of the difference between the receiving time and the sending time of all data packets successfully received by the destination node. It is defined as Equation (4).

$$Avdelay = \frac{1}{N}\sum_{i=0}^{N}(Rece(i) - Send(i)) \quad (4)$$

where N is the total number of the data packets that are transmitted successfully, $Rece(i)$ is the time when the $i-th$ data packet reaches the destination node, and $Send(i)$ is the time when the $i-th$ data packet is sent.

4.2.3 Average Throughput. Average throughput is the amount of effective data that can be transmitted by each node in a unit time. It is the ratio of the sum of valid data bytes in the successfully transmitted data packets to the total transmission time and the number of nodes, which reflects the average traffic rate received by each node. It is defined as Equation (5).

$$Th = \frac{1}{NUM_{node} \times (TR_E - TR_S)}\sum_{i=0}^{N} RB(i) \quad (5)$$

where NUM_{node} is the number of nodes in network, N is the total number of the successfully transmitted data packets, and $RB(i)$ is the number of bits in the $i-th$ data packet that successfully reached the destination. TR_E is the time when the data packet ends receiving in the network, and TR_S is the time when the data packet starts to be received in the network.

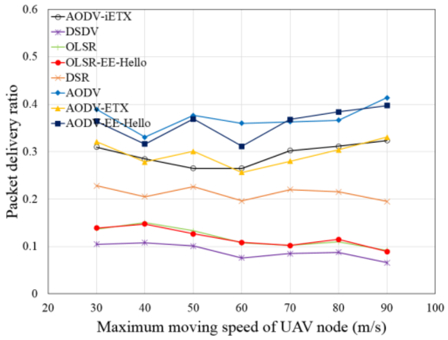

Figure 4: Packet Delivery Ratio Performance under Different Maximum Speeds.

4.2.4 Overhead. Overhead basically reflects the ratio of control packets used to build and maintain routes. It is the ratio between the number of control packets and data packets sent in the network. It is defined as Equation (6).

$$Overhead = \frac{P_{control}}{P_{data}} \quad (6)$$

where $P_{control}$ is the number of control packets sent in the network, P_{data} is the number of data packets successfully sent in the network.

4.3 Experiment Results and Analysis

In this section, we have conducted two sets of simulation experiments: analysing the impact of the node maximum speed on routing, and analysing the impact of network density on routing.

4.3.1 The Impact of Node Maximum Speed. This paper analyses the performance of the routing protocols by changing the maximum speed of UAV nodes in UANET. In this part, the node minimum speed is kept at 20m/s, and the maximum speed ranges from 30m/s to 90m/s, such as 30, 40, 50, 60, 70, 80 and 90. The number of nodes in the network is taken as 35.

Figure 4 shows how the performance of packet delivery ratio changes with the node maximum speed. Compared with the proactive routing protocols, the reactive routing protocols have better performance. In the reactive routing protocols, AODV and AODV-EE-Hello always perform best. This is because DSR reacts slowly to the rapidly changing network topology, which leads to unnecessary routing discovery process and data loss. AODV-ETX and AODV-iETX perform network transmission by comparing the link quality between nodes. They are unsuitable for UANET where the nodes move rapidly and the links are frequently broken. Moreover, AODV-iETX is better than AODV-ETX, this is because AODV-iETX considers the unidirectional links between nodes.

Figure 5 shows how the performance of average end-to-end delay changes with the node maximum speed. With the increase of node maximum speed, the proactive routing protocols always perform better than the reactive routing protocols. This is because the reactive routing protocols start routing discovery and build the routing tables of nodes when nodes need it, which leads to high delay. AODV-iETX is slightly worse than AODV-ETX. This is because AODV-iETX considers both unidirectional links and normal links, which leads to a certain delay. Moreover, the performance

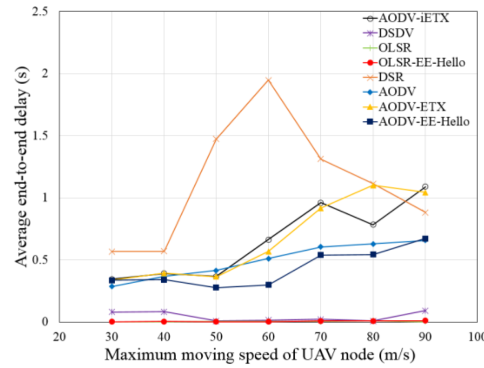

Figure 5: Average End-to-end Delay Performance under Different Maximum Speeds.

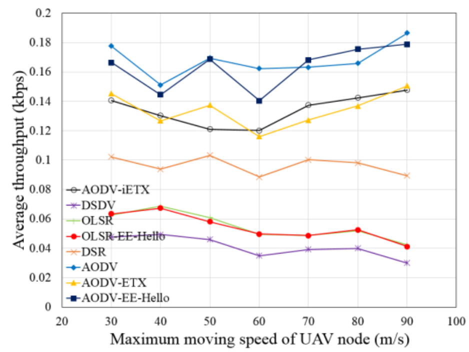

Figure 6: Average Throughput Performance under Different Maximum Speeds.

of DSR is the worst, because the changes of the network topology can cause path interference, which will lead to the fluctuation of routing performance.

Figure 6 shows how the performance of average throughput changes with the node maximum speed. The performance of the reactive routing protocols is better than the proactive routing protocols. This is because the reactive routing protocols have a higher performance of the packet delivery ratio, so their average throughput performance is better. AODV-iETX is slightly better than AODV-ETX. This reason is that AODV-iETX may communicate through unidirectional links, and nodes can forward more data, so its average throughput performance is better.

Figure 7 shows how the performance of overhead changes with the node maximum speed. With the increase of node maximum speed, OLSR, OLSR-EE-Hello, AODV and AODV-EE-Hello always have the best performance. In addition, due to the multi-point retransmission mechanism of OLSR and OLSR-EE-Hello, AODV and AODV-EE-Hello are slightly worse than OLSR and OLSR-EE-Hello. However, compared with other performance improvements, it is still acceptable. Besides, AODV-iETX is slightly better than AODV-ETX in most cases. This is because AODV-iETX considers the unidirectional links between nodes, which is more suitable for the UANET with frequent network topology changes, thus reducing the number of routing updates and the overhead.

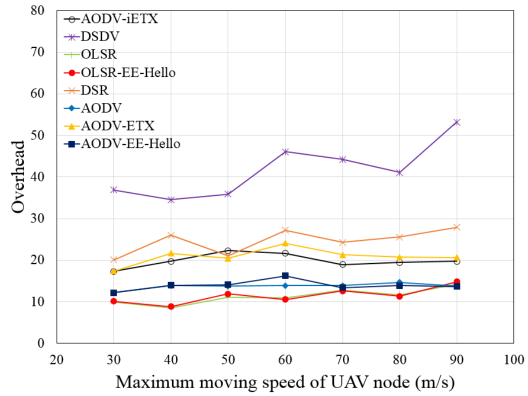

Figure 7: Overhead Performance under Different Maximum Speeds.

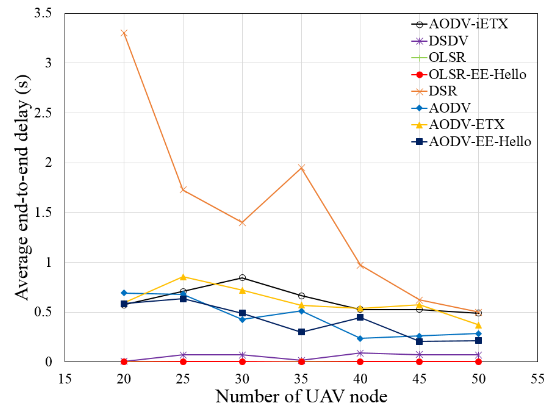

Figure 9: Average End-to-end Delay Performance under Different Network Densities.

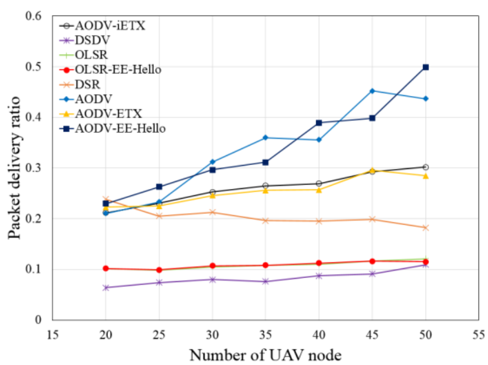

Figure 8: Packet Delivery Ratio Performance under Different Network Densities.

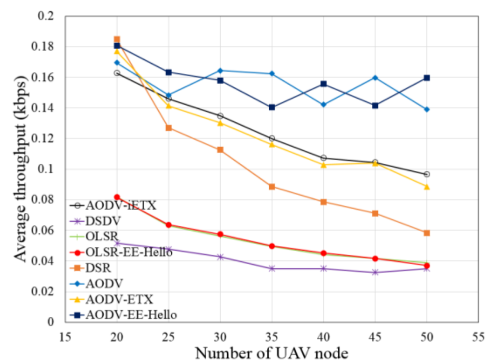

Figure 10: Average Throughput Performance under Different Network Densities.

4.3.2 The Impact of Network Density. We analyse the performance of the routing protocols by changing the network density. In this part, the number of nodes ranges from 20 to 50, such as 20, 25, 30, 35, 40, 45 and 50. The speed of nodes in the network ranges from 20m/s to 60m/s.

Figure 8 shows how the performance of the packet delivery ratio changes with the network density. With the increase of the number of nodes, the performance of all routing protocols is improving. In most cases, the performance of the proactive routing protocols is the worst, while AODV and AODV-EE-Hello are generally the best. This is because with the increase of the number of nodes in the network, AODV and AODV-EE-Hello can effectively find the routes and get better performance of packet delivery ratio through their broadcast mechanism. However, AODV-iETX, AODV-ETX and DSR are still unsuitable for networks with frequent topology changes and frequent disconnection of communication links.

Figure 9 shows how the average end-to-end delay changes with the network density. Compared with the reactive routing protocols, the proactive routing protocols can effectively reduce the average end-to-end delay of data transmission in network. This is because proactive routing always maintains the routes to all nodes in the network, and has a low delay in network transmission.

Figure 10 shows how the average throughput performance changes with the network density. In most cases, the reactive routing protocols have better performance. This is because the reactive routing protocols only start routing discovery when a UAV node wants to establish a communication. This will reduce the competition and conflict between nodes, so as to ensure the average throughput.

Figure 11 shows how the overhead changes with the network density. With the increase of the number of nodes, the overhead of all routing protocols is increasing. OLSR, OLSR-EE-Hello, AODV and AODV-EE-Hello always perform best. In most cases, AODV-iETX is slightly better than AODV-ETX. This is because AODV-iETX considers both unidirectional links and normal links between nodes, so the transmission routes between nodes are more stable, the number of route updates is less and the routing overhead is lower.

5 CONCLUSION

This paper introduced the basic concepts of UANET, and concluded the differences between UANET, MANET and VANET. Furthermore, we summarized some routing protocols that had been used in UANET in recent years, and proposed the AODV-iETX routing

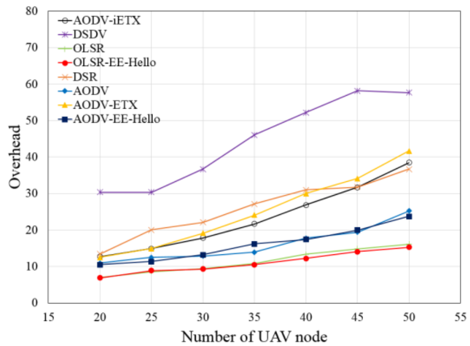

Figure 11: Overhead Performance under Different Maximum Speeds.

protocol. Finally, we simulated UANET with NS-3, and analyzed the performance of these routing protocols by changing the maximum speed of nodes and network density.

Experimental results show that the performance of the reactive routing protocols is generally better than the proactive routing protocols in terms of packet delivery ratio and average throughput. For the average end-to-end delay, the proactive routing protocols perform slightly better than the reactive routing protocols. For the network overhead, OLSR, OLSR-EE-Hello, AODV and AODV-EE-Hello always perform best. In general, AODV and the improved AODV have the best performance, thus they can be good choices to optimize the performance of UANET. Moreover, the performance of the proposed routing protocol AODV-iETX is slightly better than AODV-ETX routing protocol.

6 FUTURE WORK

In this paper, we verified the reactive routing protocol AODV has better performance in UANET. Moreover, the proposed routing protocol AODV-iETX is better than AODV-ETX, because it considers the link quality of unidirectional links between nodes. However, due to the high mobility of UAV nodes in UANET, links between nodes are frequently disconnected, which leads to the performance of AODV-iETX not reaching the optimal.

The above routing protocols make routing decisions based on the current network state, which lags behind the real-time topology changes in UANET. Considering the high mobility, positioning capabilities and computing capabilities of UAV nodes, we can predict the changes of network topology by predicting the position of UAV nodes. At the same time, we can calculate the link quality between nodes on the basis of node position prediction. By considering the link quality between nodes, the next hop with better communication link will be selected, which can make the routing more stable. Therefore, in the future work, we will improve the AODV routing protocol by combining the position prediction of UAV nodes and the link quality between nodes, and make it more suitable for UANET.

ACKNOWLEDGMENTS

This work was supported in part by the National Natural Science Foundation of China under Grant 61762065, Grant 62062050 and Grant 61962037, in part by the Natural Science Foundation of Jiangxi Province under Grant 20202BABL202039 and Grant 20181BAB202015, and in part by the Innovation Foundation for Postgraduate Student of Jiangxi Province under Grant YC2019091.

REFERENCES

[1] Q. Zhang, M. Jiang, Z. Feng, *et al.* "IoT Enabled UAV: Network Architecture and Routing Algorithm," IEEE Internet of Things Journal, vol. 6, no. 2, pp. 3727-3742, 2019.
[2] I. Bekmezci, O. K. Sahingoz, S. Temel. "Flying Ad-Hoc Networks (FANETs): A survey," Ad Hoc Networks, vol. 11, no. 3, pp. 1254-1270, 2013.
[3] M. F. Khan, K. L. A. Yau, R. M. Noor, *et al.* "Routing schemes in FANETs: A survey," Sensors, vol. 20, no. 1, pp. 38, 2020.
[4] O. S. Oubbati, M. Atiquzzaman, P. Lorenz, M. H. Tareque and M. S. Hossain. "Routing in Flying Ad Hoc Networks: Survey, Constraints, and Future Challenge Perspectives," IEEE Access, vol. 7, pp. 81057-81105, 2019.
[5] J. Nenad, M. Marija. "Implementation of ETX metric within the AODV protocol in the NS-3 simulator," Telfor Journal, vol. 10, no. 1, pp. 20-25, 2018.
[6] C. E. Perkins, E. M. Belding-Royer. "Ad-hoc On-Demand Distance Vector Routing," in Proc. IEEE 2nd Workshop on Mobile Computing Systems and Applications. IEEE, 1999, pp. 90-100.
[7] I. Mahmud, Y. Z. Cho. "Adaptive hello interval in FANET routing protocols for green UAVs," IEEE Access, vol. 7, pp. 63004-63015, 2019.
[8] A. AlKhatieb, E. Felemban, A. Naseer. "Performance Evaluation of Ad-Hoc Routing Protocols in (FANETs)," in Proc. 2020 IEEE Wireless Communications and Networking Conference Workshops (WCNCW). IEEE, 2020, pp. 1-6.
[9] A. Nayyar. "Flying ad hoc network (FANETs): simulation based performance comparison of routing protocols: AODV, DSDV, DSR, OLSR, AOMDV and HWMP," in Proc. 2018 International Conference on Advances in Big Data, Computing and Data Communication Systems (icABCD). IEEE, 2018, pp. 1-9.
[10] Y. Wang, T. Sun, G. Rao, *et al.* "Formation tracking in sparse airborne networks," IEEE Journal on Selected Areas in Communications, vol. 36, no. 9, pp. 2000-2014, 2018.
[11] M. Y. Arafat and S. Moh. "Routing Protocols for Unmanned Aerial Vehicle Networks: A Survey," IEEE Access, vol. 7, pp. 99694-99720, 2019.
[12] L. Gupta, R. Jain, G. Vaszkun. "Survey of important issues in UAV communication networks," IEEE Communications Surveys & Tutorials, vol. 18, no. 2, pp. 1123-1152, 2015.
[13] G. S. Vasilyev, D. I. Surzhik, O. R. Kuzichkin, *et al.* "Algorithms for Adapting Communication Protocols of Fanet Networks," JSW, vol. 15, no. 4, pp. 114-122, 2020.
[14] A. Garcia-Santiago, J. Castaneda-Camacho, J. F. Guerrero-Castellanos, *et al.* "Evaluation of AODV and DSDV routing protocols for a FANET: Further results towards robotic vehicle networks," in Proc. 2018 IEEE 9th Latin American Symposium on Circuits & Systems (LASCAS). IEEE, 2018, pp. 1-4.
[15] K. Singh, A. K. Verma. "Applying OLSR routing in FANETs," in Proc. 2014 IEEE International Conference on Advanced Communications, Control and Computing Technologies. IEEE, 2014, pp. 1212-1215.
[16] E. M. Royer, C. K. Toh. "A Review of Current Routing Protocols for Ad-Hoc Mobile Wireless Networks," IEEE Personal Communications, vol. 6, no. 2, pp. 46-55, 1999.
[17] D. Johnson, Y. Hu, and D. Maltz, "The Dynamic Source Routing Protocol (DSR) for Mobile Ad Hoc Networks for IPv4", document RFC 4728, 2007.
[18] N. Megha, B. C. Mallikarjun. "Performance Evaluation of Routing Protocol for FANET Using Ns2," International Journal of Engineering Research & Technology (IJERT), vol. 9, no. 7, pp. 1128-1132, 2020.
[19] K. Singh, A. K. Verma. "Experimental analysis of AODV, DSDV and OLSR routing protocol for flying ad hoc networks (FANETs)," in Proc. 2015 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT). IEEE, 2015, pp. 1-4.
[20] G. F. Riley, T. R. Henderson. "The ns-3 network simulator," Modeling and tools for network simulation. Springer, Berlin, Heidelberg, pp. 15-34, 2010.
[21] D. S. Lakew, U. Sa'ad, N. N. Dao, *et al.* "Routing in Flying Ad Hoc Networks: A Comprehensive Survey," IEEE Communications Surveys & Tutorials, vol. 22, no. 2, pp. 1071-1120, 2020.