Hindawi
Wireless Communications and Mobile Computing
Volume 2022, Article ID 5428280, 12 pages
https://doi.org/10.1155/2022/5428280

Research Article

UAV Routing Protocol Based on Link Stability and Selectivity of Neighbor Nodes in ETX Metrics

Jinze Huang,[1] Fengbiao Zan ,[2] Xin Liu,[2] and Da Chen[1]

[1]*School of Physics and Electronic Information Engineering, Qinghai Nationalities University, Xining 810007, China*
[2]*School of Computer Science, Qinghai Nationalities University, Xining 810007, China*

Correspondence should be addressed to Fengbiao Zan; zanfb@163.com

Received 9 February 2022; Accepted 28 March 2022; Published 14 May 2022

Academic Editor: Mingqian Liu

With the extensive application of UAVs in various fields, it becomes more important to design a routing protocol that ensures stable transmit between UAV groups. This is because UAV groups are densely packed, move fast, and communication links are fragile. Aiming at the intensive and highly maneuverable UAV group, the AODV-NLS-ETX—a routing protocol based on the link stability of neighbor nodes—is proposed on the basis of the ETX metric based AODV protocol. The protocol is simulated and compared with other protocols. The simulation results show that AODV-NLS-ETX is superior to other protocols in packet delivery rate and throughput under high shift speed, dense nodes, and high routing overhead. It can effectively reduce the high delay brought by the ETX mechanism. The delay is the most stable and is not easy to cause network congestion. It can be better applied to dense and highly mobile unmanned aerial vehicles.

1. Introduction

Nowadays, the advancement of science and technology has greatly promoted the wide use of UAVs. From the structural point of view, UAVs mainly include four types: fixed wing, rotating flapping wing, hybrid wing, and gas envelope [1], and it plays a huge role in high-altitude pesticide spraying, agricultural, forestry spectral monitoring, vertical take-off landing military monitoring, transportation of rescue materials, obstacle sensing, and satellite cooperative communication [2–7].

Generally, UAVs work collaboratively in the form of clusters, so relevant researches tend to replace UAVs with network nodes. The Manhattan model, random waypoint model, and random street model [8] are the major three simulation models that are suitable for UAVs, among which the random waypoint model is selected in this research. In the UAV ad hoc network, nodes move faster in a relatively limited area. When there is a long communication distance between the destination node and source node, the UAV ad hoc network, by virtue of its high dynamics, enables the two nodes to forward data packets at high-speed through relay nodes. In the real scenario, the internal data transmission between UAVs is completed via the dynamic variability of ad hoc network. Figure 1 shows the communication structure of UAV ad hoc network. The base station transmits the signal to UAV A, where the UAV A is equivalent to the source node in the network simulation scenario, while UAV B is the relay node, and UAV C is the destination node. When the communication distance between A and is C within the maximum communication range, then A will directly send data to C. Otherwise, A will firstly send data to B, and then B will forward to C so as to complete the communication.

Since UAV ad hoc network is featured by high intensity and dynamic, especially in the cluster operation, the problems of signal noise interference and communication system identification performance are particularly prominent [9, 10]. So it becomes a hotspot to improve the communication quality between UAVs, thereby making it significant to choose an appropriate ad hoc network routing protocol. Compared with other ad hoc network routing protocols,

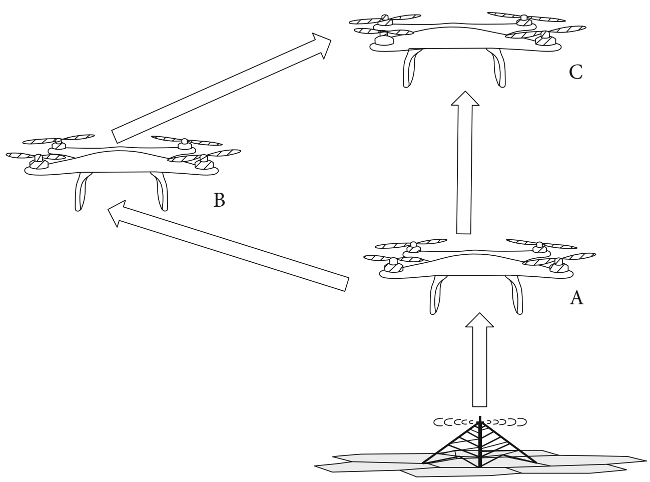

Figure 1: Communication structure of UAV ad hoc network.

AODV is widely used in UAV ad hoc network as it is convenient and efficient performance [11]. In contrast, the traditional AODV protocol is often faced with broken communication links and insufficient data information transmission in the UAV ad hoc network that is intensive, highly dynamic, and drastically changing. Designing a more efficient and stable routing protocol becomes quite important.

In response to such problems, many scholars proposed various stable and efficient protocols based on AODV. Bahloul et al. [12] designed a cluster-based UAV routing protocol (BR-AODV), which calculates in accordance with the on-demand routing mechanism of AODV and achieves routing maintenance as well as data transmission by introducing the base station discovery mechanism and Boids mechanism; Ramesh et al. [13] put forward a congestion adaptive routing protocol (CA-AODV) with a mechanism for monitoring node congestion, in which a warning will be issued between nodes once congestion occurs in the routing path so as to avoid node congestion; Wu et al. [14] mentioned an optimized protocol based on node residual energy and relative movement speed (EV-AODV), which considered the power of node receiving signal, the number of link hops and the node residual energy, normalized relative movement speed, as well as strengthened the node link mechanism; Tan et al. [15] presented an efficient digital signature algorithm based on elliptic curve cryptosystem and applied it to the AODV protocol; Chen et al. [16] proposed a greedy perimeter stateless routing protocol (TQNGPSR), which implemented flow balancing and evaluated the quality of wireless links by taking advantage of the neighboring congestion packets. In addition to above, there are still many other studies achieved good results in various indicators [17–22].

The ETX metric mechanism of AODV is suitable for slow-topologically stable networks. However, in the highly dynamic UAV ad hoc network, the ETX metric mechanism performs worse than the hop count metric mechanism of AODV. It is easy to cause network congestion and high delay, and the two mechanisms will generate much routing overhead in the large-scale mobility UAV ad hoc network, which affects the network performance. The current common research is how to reduce the routing overhead and improve its performance. For example, PAODV is mentioned in [23], which improves network performance by reducing routing overhead. Reference [24] proposed ND-AODV based on PAODV, further reducing the routing overhead and improving its performance. Reference [25] proposed three ETX mechanisms to reduce the routing overhead because of the high routing overhead of the ETX metric mechanism. But none of them consider enhancing their network performance in the case of high routing overhead.

Aiming at this problem, this paper proposes an ETX metric protocol AODV-NLS-ETX based on neighbor node link stability. This protocol reduces the retransmission information by using the neighbor node information and the HELLO packet setting information. Meanwhile, the node link stability is strengthened through taking ETX metric as the unit of AODV instead of hop count. In the case of high routing overhead, its network performance is further enhanced, making the ETX mechanism suitable for highly dynamic and dense UAV ad hoc networks.

To verify its performance, we compare and analyze the AODV-NLS-ETX protocol with the AODV protocol, the AODV-ETX protocol, the ND-AODV-ETX protocol and the ND-AODV protocol. The ND-AODV-ETX protocol is designed by combining the ND-AODV protocol with the ETX metric.

2. ND-AODV Protocol Principle

As a classic routing protocol, the AODV protocol will not be introduced here. The principle of ND-AODV protocol and ND-AODV-ETX is the same, except that the hop number mechanism is changed to the ETX mechanism, so we only introduce the ND-AODV protocol. The ND-AODV protocol is improved based on PAODV. PAODV sets two probability parameters $p1$ and $p2$ according to the node density. Choose $p1$ when the node density is small, and choose $p2$ when the node density is high. In order to judge whether the network density is sparse or dense, a threshold Avg is introduced, and its calculation formula is as follows:

$$Avg = \sum_{i=1}^{n} NBi/n. \tag{1}$$

The threshold can judge the density of the network. However, the probabilities $p1$ and $p2$ do not specify the optimal probability value in the reference [23], so the threshold is also difficult to calculate. In order to solve this problem, the reference [24] proposed the ND-AODV protocol.

The ND-AODV protocol introduces a new parameter pi; its calculation formula is as follows:

$$pi = \min\left(1, k/NBi\right). \tag{2}$$

According to the number of neighborhood node density, pi can be easily calculated, which solves the problem that $p1$

and $p2$ and the threshold in PAODV are difficult to calculate. However k as a constant value, it is necessary to judge its optimal value. In reference [24], $k = 11$ is optimal. k taking a high value will result in a high routing overhead. The range $10 \leq k \leq 15$ protocol has both high overhead and good performance. The range $k < 10$ reduce performance and low overhead. Since this paper studies how to improve the performance of the UAV ad hoc network under high routing overhead, but we also need a low-overhead comparison. Therefore, after careful consideration, the k value in ND-AODV and ND-AODV-ETX is chosen to be one without considering the optimal value.

3. Working Principle of Node Link

In this research, the proposed protocol includes two aspects: one is the selection of ETX node link and the other is the sending state and sending selection mechanism algorithm of HELLO packet in neighbor node. The protocol is designed to reduce retransmissions and strengthen link stability. Its working principle is introduced as follows.

3.1. Selection of ETX Node Link. As can be learned from the introduction in [26], the ETX metric mechanism monitors the expected number of transmissions on a link by installing a probe in each data packet. The traditional hop number mechanism in the AODV protocol will be replaced by the ETX metric in order to find out the propagation link with the smallest propagation value. If the node communication link is re-established, then the ETXr in a node link can be obtained by calculating the probability of successful forward transmission as well as reverse retransmission of the link. The ETXr is calculated as follows:

$$ETXr = \frac{1}{fr \times fd}. \quad (3)$$

f_r is the probability of successful link forward transmission, and f_d is the probability of successful link reverse transmission, indicating the ACK packet received from the destination node to the source node. Both of which can be calculated through data probe monitoring. The probability of successful link forward transmission cannot be directly calculated, but the f_r can be obtained according to the data probe detection in the period T during communication from the source node to the destination node. The reverse retransmission probability f_d is obtained by data probe packet transmission within w seconds, and the formula [26] is as follows:

$$fd = \frac{count(t - w, t)}{w/T}. \quad (4)$$

In Formula (4), the numerator represents the data probe packet actually received during the window w when the data packet is transmitted on the link, and the denominator represents the data probe packet that shall be received theoretically. Where we set the denominator to one and directly calculate the probability through the numerator.The ETX of the overall network link can be calculated by calculating the ETX through a single link.

$$ETX = \sum_{i=1}^{r} ETXr. \quad (5)$$

Assuming that there are r links in the network environment, then the overall ETX is the overall addition of a single link, as shown in Formula (5) [26]. In order to select a more stable ETX link, a threshold value of chain stability is set up. Since the probabilities of successful link forward transmission and reverse retransmission are fr and fd, respectively, then the probability of successful node link is f:

$$f = fr \times fd. \quad (6)$$

The probability of failed data transmission on a single node link can be calculated through f, which is the probability of node link breakage fl. In this research, fl is set as the threshold, and the probabilities of failed reverse retransmission are fld. When the threshold $fl<fld$ or $fl = fld$, the link will be discarded so as to select a more stable ETX link. In the transmission process of the ETX link, the probability of reverse retransmission is generally very small. However, the probability of retransmission will greatly increase in a highly dynamic UAV ad hoc network, which can be effectively reduced by setting the constraint condition of $fl<fld$. When in reverse transmission, set $fld = fl$, which indicates that the ETX transmission can be reduced when the probability of successful reverse transmission is almost equal to the successful transmission of the entire link $f \approx fd$, thereby selecting a more stable link. fl, fld, and the constraints are

$$fl = 1 - f, \quad (7)$$

$$fld = 1 - fd, \quad (8)$$

$$ETX = \begin{cases} \sum_{i=1}^{r} ETXr, fl < fld \| fl = fld \\ 0 \end{cases}. \quad (9)$$

ETX will be accumulated link by link within the constraints, while the unreliable links will be discarded outside the constraints; 0 in Formula (9) means that ETX is not calculated. In this case, the ETX metric becomes more stable, the retransmissions of data probe packets are reduced in the selected node link, and the reliability and stability of node link are improved, which contributes to a stable transmission of data probe packets and higher successful rate of data transmission.

3.2. Selection Sending Mechanism Algorithm of HELLO Packet in Neighbor Node. During the transmission, the ETX in the data probe packet of AODV protocol is constantly accumulated to select the routing path with the best quality. In the selection process, the sending of ETX is in line with the transmission mechanism of the HELLO packet, which will not affect the HELLO packet itself. At the same time, HELLO packet is used to detect active routes, and the neighbor nodes determine the existence of active routes accordingly. However, in a highly dynamic UAV ad hoc network, the node link is so fragile that the HELLO packets are bound to be sent excessively in order to detect a new active route, which is likely to cause network congestion. In the case of network congestion, the ETX metric mechanism of AODV is useless as it may lead to higher delay. Therefore, in response to this situation, an algorithm for selecting the sending mechanism of HELLO packet between the neighbor nodes is proposed.

Figure 2 shows the process of selecting neighbor nodes in this algorithm. First, assume that node A is the source node and node D is the destination node, between which the established of communication link needs to be forwarded by a relay node. This algorithm restricts the node area within a circle. On this basis, when the distance d between two nodes is less than the radius R inside the circle, both nodes are defaulted as neighbor nodes, and then an effective link will be established between the nodes. Otherwise, no effective link will be established between the nodes. According to Figure 2, there are two approaches to establish a link between node A and node D: A-C-D and A-B-D. However, since the distance d between A and B is greater than the circle radius R, no effective path is established between nodes A and B. The dashed arrow in Figure 2 represents an invalid link while the solid arrow indicates a valid link. Similarly, for node B-D and node C-D, no effective link can be established because the distance d between node B and node D is greater than R. Thus, the final path is A-C-D, and stable link is established since neighbor nodes are selected.

After the node link is established, the node will provide connection information by broadcasting a HELLO packet so as to find the active path. At this moment, the data probe packet will be sent to establish a valid link. For the sake of preventing from sending too many HELLO packets, the link stability (LS) is set in this research.

$$LS = \frac{f}{\pi R^2 \times T}. \tag{10}$$

f is the probability of successfully sending data in node link, πR^2 is the area of the algorithm limited circle, and T is the sending period. In experimental simulation, the period T is set to 1 s to effectively reduce the synchronous sending effect caused by the data probe packet. By Formula (10), the probability of successfully sending data packets is dispersed to the link established by neighbor nodes inside the circle, the link stability threshold is established, and then the effective range of a link threshold is determined via algorithm simulation. On the condition of within this rang, the node will broadcast a HELLO packet to search for an active path, and the node will establish an ETX metric link. LS is set to unsigned 32 bits and the threshold range is set to $0x0000 < LS < 0x1111$, within which node congestion can be effectively controlled. The overall algorithm flow is shown in Figure 3.

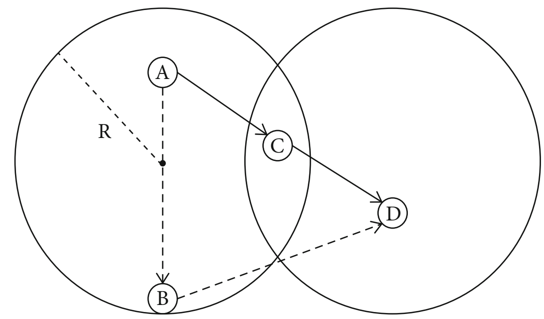

Figure 2: Neighbor node selection mechanism.

4. Working Mechanism of AODV-NLS-ETX

4.1. Route Request and Route Reply Process. The AODV-NLS-ETX protocol is improved based on AODV-ETX protocol [27]. The packet format of RREQ and RREP is the same as that of AODV-ETX, so its route request and route reply process are in accordance with ETX metric [26]. The packet format is as follows.

According to Table 1 and Table 2, the ETX metric mechanism is added to the packet formats of both RREQ and RRE P so that the corresponding routing table will be updated once a node sends such a packet. Figure 4 shows the process of AODV-NLS-ETX routing request and reply.

In Figure 4, node A is the source node, and node E is the destination node. Theoretically, there are three ways to establish a link from node A to node E: A-B-C-E, A-B-D-E, and A-B-C-D-E. First, node A sends an RREQ packet to node B. At this moment, the initial value of ETX is set to 0, and node D and node C separately receive the RREQ packet from node B so that the ETX value is calculated. In addition to receiving the RREQ packet from node B, node D also receives RREQ packet from node C. Different from the AODV protocol that discards the RREQ information from node D immediately, AODV-NLS-ETX protocol calculates the ETX value carried by node B and node D and discards the RREQ packet with larger ETX so as to select the link with the smallest ETX value. Similarly, the destination node E also selects the link with the smallest ETX value while receiving the RREQ packet from nodes D and C. As shown in Figure 4, the actual link finally selects A-B-C-E possibly because that the A-B-C-E link has the smallest ETX value and the lowest energy loss compared with the other two links. Then, the destination node E receives the RREQ packet, generates a RREP packet, replies to node A, and continuously updates the overall routing table.

4.2. Routing Maintenance Process. This protocol modifies the format of HELLO packet by adding the node link stability (LS). The modified format is shown in Table 3.

The modification of HELLO packet format not only enables protocol to reduce the number of RREQ packet requests in highly dynamic and intensive network topology, but also improves the reliability of data transmission and lowers the delay caused by link disconnection. The routing maintenance process of AODV-NLS-ETX is shown in Figure 5.

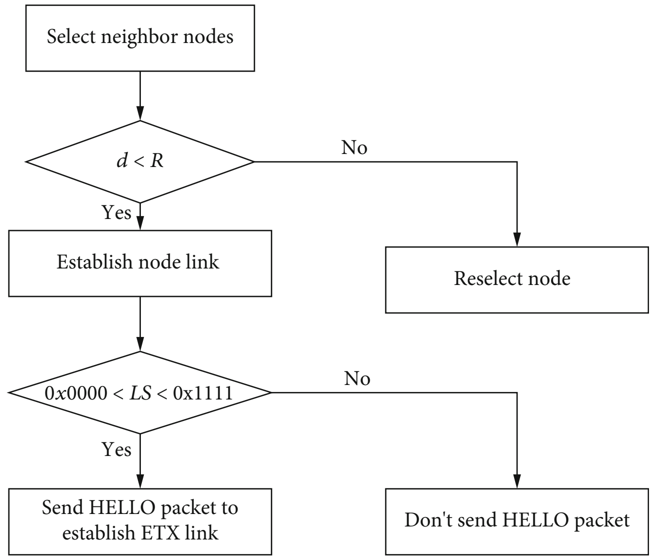

Figure 3: Algorithm flow of selecting and sending mechanism of the HELLO packet in neighbor node.

Table 1: RREQ packet format.

Type	J	R	G	D	U	Reserved	Hop count
RREQ ID							
Destination IP address							
Destination sequence number							
Originator IP address							
Originator sequence number							
ETX							

Table 2: RREP packet format.

Type	R	A	Reserved	Prefix Sz	Hop Count
Destination IP address					
Destination sequence number					
Originator IP address					
Life time					
ETX					

As indicated in Figure 5, it is assumed that there are two links between the source node A and the destination node E: A-B-C-E and A-B-D-E. When node B is ready to transmit HELLO packet to node C and node D during a certain period of time, first, node B and node C will check the link stability. When confirming within the specified range, node B will transmit HELLO packet to node C, or if the link has been disconnected, then node B will receive the RERR packet within specified time to repair the route or choose a new path. If the node link stability between node B and node D exceeds the threshold, then the HELLO packet will not be transmitted (the dotted line in the figure represents the unsuccessful transmission). As a result, the corresponding RREQ packet will not be sent, thereby reducing the number of requests and decreasing the sending of HELLO packet. Through this mechanism, the selected ETX metric link is more stable and firm so that the data transmission success rate is improved.

5. Analysis of Simulated Results

5.1. Performance Index. The indicator of routing overhead has been mentioned earlier in this article. Next, we will combine PDR, average end-to-end delay, and throughput to test the performance of five protocols in the UAV ad hoc network. The introduction of the four indicators is as follows.

PDR is the ratio of the data packet received by the destination node to that sent by the source node, which manifests the protocol reliability. The higher the ratio, the more reliable the protocol data transmission will be:

$$PDR = \frac{receivedpackets}{sentpackets}. \tag{11}$$

The average end-to-end delay is the ratio of the time the destination node receives the data packet minus the time the source node sends the data packet to the overall network receives the data packet. The smaller the delay, the better the network quality will be:

$$Delay = \frac{\sum_{i=1}^{packets}(endtime - starttime)}{packetsum}. \tag{12}$$

Throughput is the ratio of the total bytes received by the destination node to the network transmission time, which reflects the amount of network transmission information. The greater the ratio, the greater the amount of information, and the higher the protocol transmission efficiency will be:

$$Throughput = \frac{8 * ryBetes}{Tranmissiontime}. \tag{13}$$

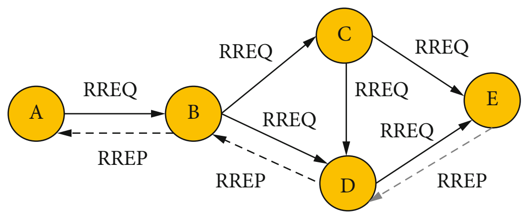

Figure 4: AODV-NLS-ETX routing request and reply process.

Table 3: HELLO packet format.

Type	Reserved
Destination IP address	
Destination sequence number	
Hop count	
Life time	
ETX	
Link stability	

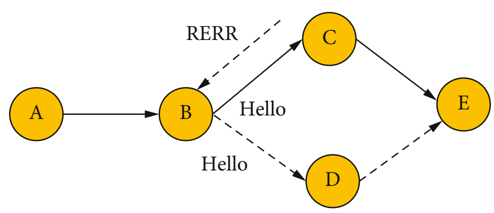

Figure 5: AODV-NLS-ETX routing maintenance process

Routing overhead is the ratio of the routing control packet sent by the network to the data packet received. The smaller the routing overhead, the fewer the additional control packets will be:

$$Overhead = \frac{\text{routing control packets}}{receivedpackets}. \quad (14)$$

5.2. Experimental Environment. In this research, the open source software NS3 is applied to simulate the UAV ad hoc network under the 4000 m × 4000 m rectangular ideal environment. For each simulation, the period is 300 s, the data packet size are 64 bytes, the transmission rate is 2048 bps, the MAC layer protocol is IEEE802.11b, and the maximum communication distance of the node is 1000 m. In the simulation environment, we selected two environments. One is to increase the moving speed to simulate a high mobility network, and the other is to increase the number of nodes to simulate a dense network. Change the random seed 10 times and take the average. Table 4 and Table 5 show the simulation scenarios.

5.3. Experimental Results. Figure 6 shows the change of PDR of five protocols with the number of nodes. As can be seen from the figure, the PDR of the AODV-NLS-ETX protocol is better than other protocols. The AODV-NLS-ETX protocol establishes links and sets constraints according to the neighbor node selection mechanism, enhancing the ETX link stability and improving the reliability of data transmission. The overall PDR of AODV-NLS-ETX is about 11% higher than that of AODV-ETX and about 11% higher than ND-AODV-ETX. Due to maintaining a fixed node moving speed, the transmission of the ETX measurement mechanism is better than the hop transmission mechanism. The PDR of AODV-ETX and ND-AODV-ETX is better than AODV and ND-AODV.

Figure 7 shows how the throughput of the five protocols changes with the number of nodes. The throughput of the AODV-NLS-ETX protocol is also better than that of other protocols. In the early stage, with the node density increase, AODV-NLS-ETX needs to establish a stable ETX link through the probe packet, so the throughput decreases. With the establishment of the link, the data can be transmitted stably, so the throughput gradually increases. The throughput of the AODV-NLS-ETX protocol is about 12% higher than that of AODV-ETX and about 12% higher than that of the ND-AODV-ETX protocol.

Figure 8 shows the change in the delay of the five protocols with the number of nodes. Compared with AODV-ETX and ND-AODV-ETX protocols, the delay of the AODV-NLS-ETX protocol is significantly reduced, and the delay is not different from that of AODV and ND-AODV protocols, and it is very stable. This is because the AODV-NLS-ETX protocol reduces the detection of reverse data probe packets and retransmission to a certain extent. In addition, because a more stable link is selected, it is not easy to generate network

Table 4: Simulation scenario under different number of nodes.

Simulation parameter	Parameter setting
Simulation area	4000 m × 4000 m
Simulation model	Random waypoint
Communication link	10
Business source	CBR
MAC layer protocol	IEEE802.11b
Number of nodes	50, 55, 60, 65, and 70
Node movement speed	40 m/s
Max. Communication distance	1000 m

Table 5: Simulation scenario under different node movement speed.

Simulation parameter	Parameter setting
Simulation area	4000 m × 4000 m
Simulation model	Random waypoint
Communication link	10
Business source	CBR
MAC layer protocol	IEEE802.11b
Number of nodes	40
Node movement speed	20,25,30,35,and 40 (m/s)
Max. Communication distance	1000 m

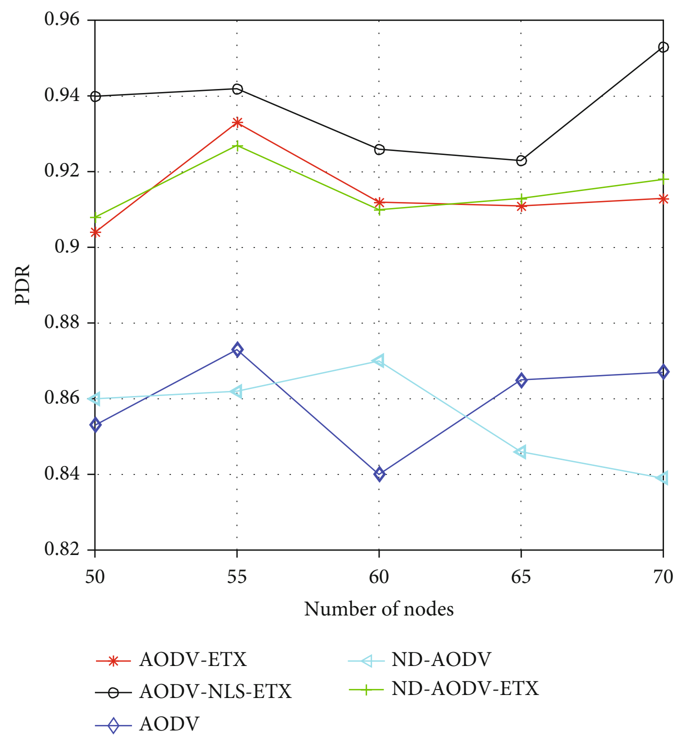

Figure 6: PDR under different number of nodes.

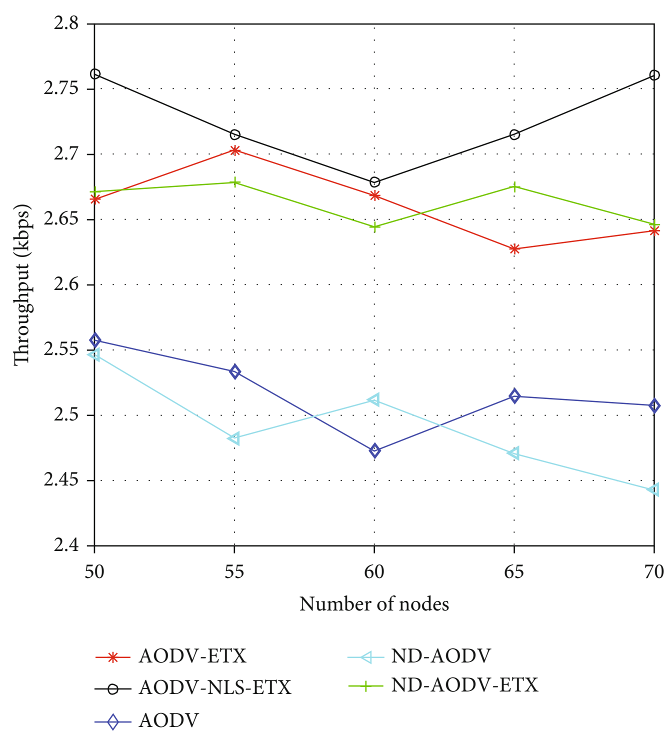

Figure 7: Throughput with different number of nodes.

congestion, so the delay is very stable. The reverse retransmission of AODV-ETX and ND-AODV-ETX will bring a high delay, and the performance is even inferior to the hop number mechanism of AODV and ND-AODV protocols.

Figure 9 shows the change in the overhead of the five protocols with the number of nodes. Compared with other protocols, the overhead of AODV-NLS-ETX is significantly higher than that of different protocols. This is because

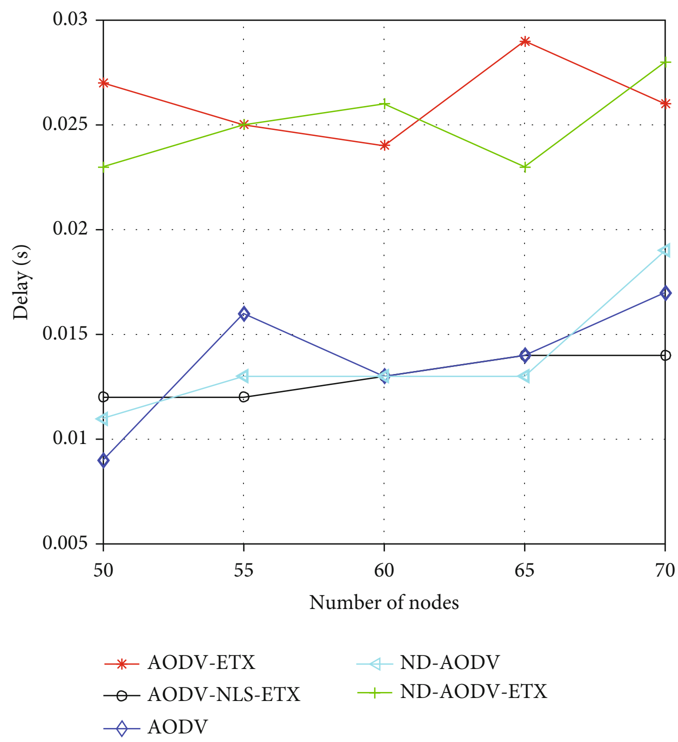

Figure 8: Delay with different number of nodes.

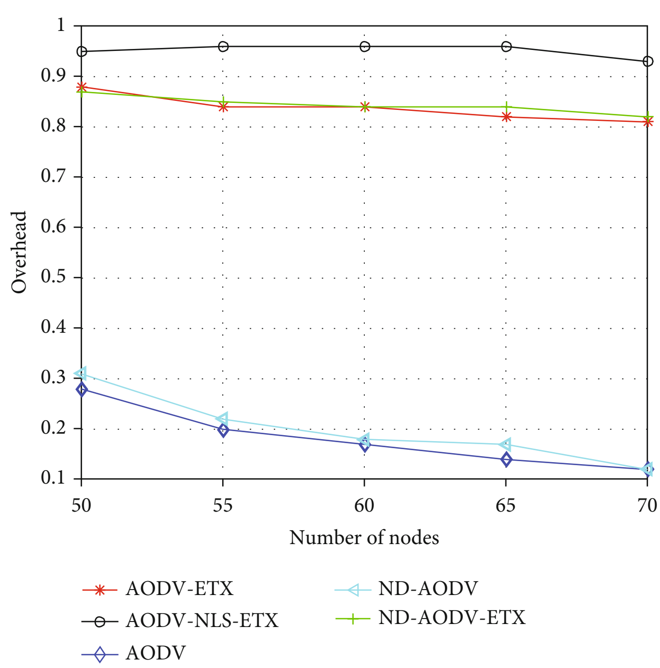

Figure 9: Overhead under different number of nodes.

AODV-NLS-ETX needs to broadcast more RREQ packets than AODV-ETX and ND-AODV-ETX to establish a stable link to generate a lot of overhead. The ETX mechanism itself occupies many bytes in the routing control packet, which will also produce a high routing overhead. Therefore, the overhead of the three protocols will be higher than that of AODV and ND-AODV.

Figure 10 describes the changes of PDR of the five protocols with the node speed. It can be seen that the PDR of ND-AODV-ETX and AODV-NLS-ETX shows a downward

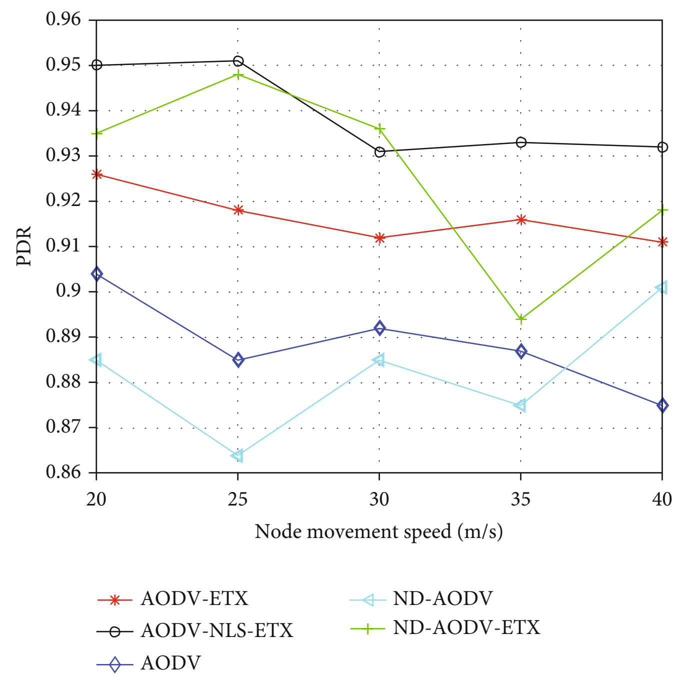

Figure 10: PDR at different node speeds.

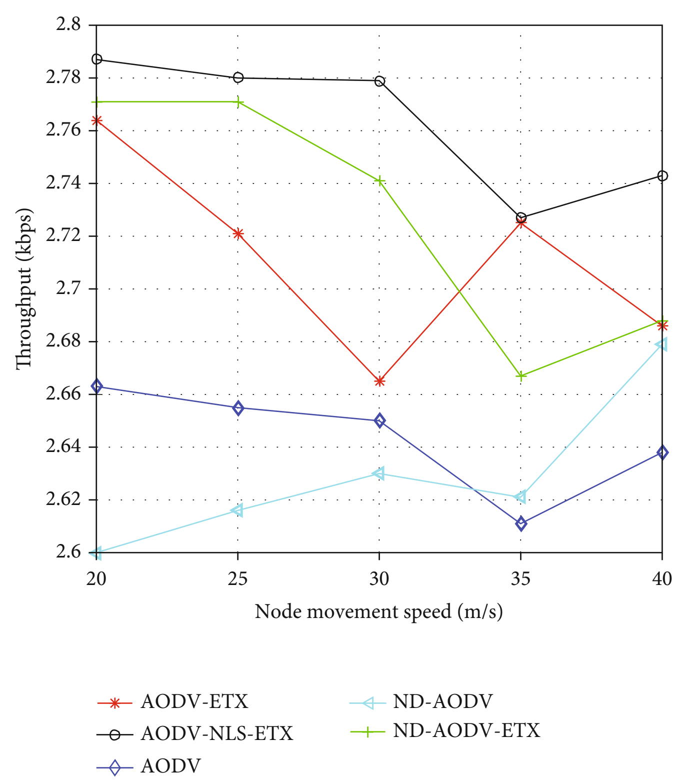

Figure 11: Throughput at different node speeds.

trend between 25 and 30 speeds. This is because the ETX link of the two protocols is broken in this speed range and the ETX link needs to be re-established to transmit data. However, because the link established by the ND-AODV-ETX protocol is not as stable as that of the AODV-NLS-ETX protocol, PDR shows a downward trend in an extended speed shift period overall performance is not superior to that of AODV-NLS-ETX. The PDR of AODV-NLS-ETX is about 11% higher than that of AODV-ETX and about 7% higher than that of ND-AODV-ETX.

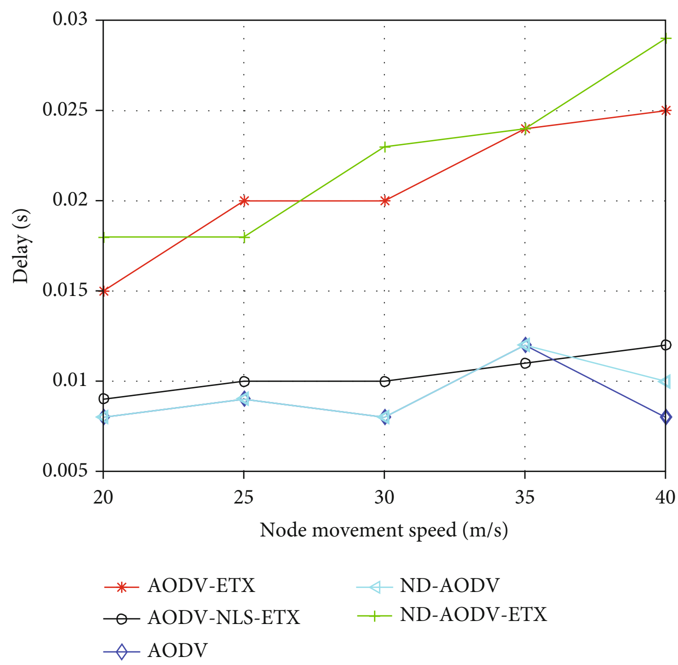

Figure 12: Delay at different node speeds.

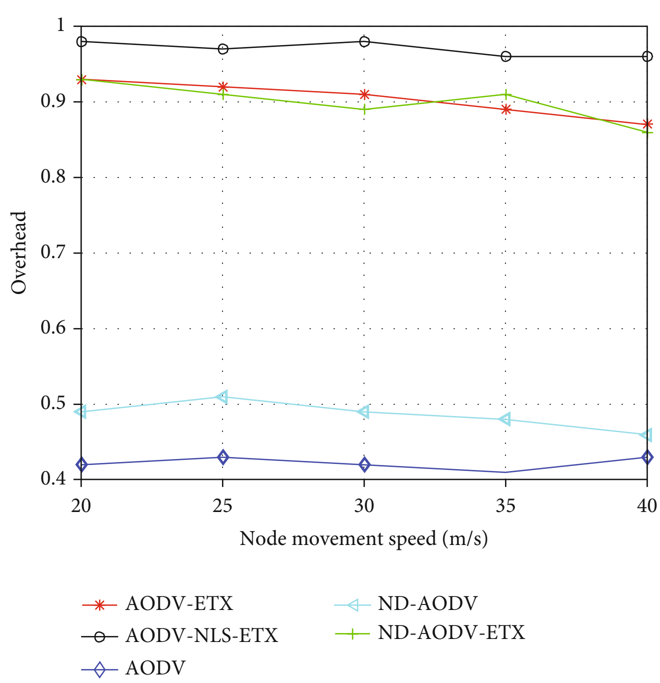

Figure 13: Overhead at different node speeds.

Figure 11 depicts the change of throughput with node moving speed. With the increase in node moving speed, the throughput of the AODV-NLS-ETX protocol is better than that of other protocols. Because the transmission link of the AODV-NLS-ETX protocol is relatively stable, the throughput will also show corresponding advantages. The throughput of the AODV-ETX protocol increases suddenly when the speed is shifted to 35 m/s. It may be that the throughput of AODV-ETX increases due to the relative rise of PDR and the increase of transmitted data. After that, the throughput decreases gradually and tends to be flat because the information remains effectively transmitted. The throughput of AODV-NLS-ETX is about 11% higher than that of AODV-ETX and about 5% higher than that of ND-AODV-ETX.

Figure 12 shows the change of average end-to-end delay with node moving speed. It can be seen that the delay of AODV-ETX and ND-AODV-ETX is always higher than that of the AODV-NLS-ETX protocol. Because the ETX mechanism is easy to break the node-link in the high-speed scenario, and the reverse link data monitoring will also bring many retransmissions, the delay of these two protocols is very high. In the early speed change, the delay of ND-AODV and AODV is almost the same. This is because when the node density is relatively sparse, ND-AODV has little advantage over AODV, so the delay performance is the same. Due to network congestion, when the node speed is 35 m/s, the delay of both protocols suddenly increases. Although AODV-NLS-ETX has a slightly higher delay than the hop number mechanism protocols, its delay change is the most stable due to a stable link. It is not easy to cause network congestion, so it can be determined that AODV-NLS-ETX has more advantages in a high-speed environment.

Figure 13 shows how the routing overhead changes with the node speed. With the increase of the node speed, the routing overhead of each protocol is relatively high. Because AODV-NLS-ETX broadcasts more RREQ request packets and ETX itself adds larger routing control packets, the overhead is the highest. The routing overhead of the AODV-ETX protocol is almost the same as that of the ND-AODV-ETX protocol. The overhead of ND-AODV is significantly higher than that of AODV. This is because in the case of relatively sparse nodes, the increase of node moving speed causes an increase in routing request packets.

6. Conclusion

This paper proposes an ETX metric UAV routing protocol (AODV-NLS-ETX) based on the link stability of neighbor nodes. Compared with the other four protocols, the AODV-NLS-ETX protocol has higher overhead, but has good performance. It is superior to other protocols in packet delivery rate and throughput. In terms of delay, this protocol reduces the high delay brought by the ETX mechanism. Although the delay is slightly increased compared with AODV and ND-AODV, it is the most stable and is not easy to cause network congestion. Especially in the high-speed and intensive UAV ad hoc network scenario, this protocol has stronger stability and reliability, is suitable for high-speed large-scale drone scenarios, and can also meet more network requirements.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Acknowledgments

This work was supported by the Tianjin University-Qinghai Nationalities University Independent Innovation Fund Project “Huangshui River Ecological Environment Monitoring and Governance,” the Qinghai Provincial Network Comprehensive Key Laboratory Project, and the Qinghai Nationalities University Graduate Student Innovation Project (10M2021005). In addition, thanks are due to two scholars, Jevtic and Malnar, for their work on Github.

References

[1] C. Lee, S. Kim, and B. Chu, “A survey: flight mechanism and mechanical structure of the UAV,” *International Journal of Precision Engineering and Manufacturing*, vol. 22, no. 4, pp. 719–743, 2021.

[2] M. F. F. Rahman, S. Fan, Y. Zhang, and L. Chen, “A comparative study on application of unmanned aerial vehicle systems in agriculture,” *Agriculture*, vol. 11, no. 1, p. 22, 2021.

[3] T. Adão, J. Hruška, L. Pádua et al., “Hyperspectral imaging: a review on UAV-based sensors, data processing and applications for agriculture and forestry,” *Remote Sensing*, vol. 9, no. 11, p. 1110, 2017.

[4] S. Yu, J. Heo, S. Jeong, and Y. Kwon, “Technical analysis of VTOL UAV,” *Journal of Computer and Communications*, vol. 4, no. 15, pp. 92–97, 2016.

[5] D. Jo and Y. Kwon, “Development of rescue material transport UAV (unmanned aerial vehicle),” *World Journal of Engineering and Technology*, vol. 5, no. 4, pp. 720–729, 2017.

[6] N. Aswini, E. Krishna Kumar, and S. V. Uma, “UAV and obstacle sensing techniques – a perspective,” *International Journal of Intelligent Unmanned Systems*, vol. 6, no. 1, pp. 32–46, 2018.

[7] M. Liu, Z. Liu, W. Lu, Y. Chen, X. Gao, and N. Zhao, “Distributed few-shot learning for intelligent recognition of communication jamming,” *IEEE Journal of Selected Topics in Signal Processing*, 2021.

[8] L. Gupta, R. Jain, and G. Vaszkun, “Survey of important issues in UAV communication networks,” *IEEE Communications Surveys & Tutorials*, vol. 18, no. 2, pp. 1123–1152, 2016.

[9] M. Liu, C. Liu, M. Li, Y. Chen, S. Zheng, and N. Zhao, “Intelligent passive detection of aerial target in space-air-ground integrated networks,” *China Communications*, vol. 19, no. 1, p. 52, 2022.

[10] M. Liu, J. Wang, N. Zhao, Y. Chen, H. Song, and R. Yu, “Radio frequency fingerprint collaborative intelligent identification using incremental learning,” *IEEE Transactions on Network Science and Engineering*, 2021.

[11] J. Maxa, G. Roudierem, and N. Larrieu, “Emulation-based performance evaluation of routing protocols for UAANETs,” in *International Workshop on Communication Technologies for Vehicles: Nets4Cars/Nets4Trains/Nets4Aircraft 2015: Communication Technologies for Vehicles*, Lecture Notes in Computer Science, pp. 227–240, Springer, Cham, 2015.

[12] N. El Houda Bahloul, S. Boudjit, M. Abdennebi, and D. E. Boubiche, “A flocking-based on demand routing protocol for unmanned aerial vehicles,” *Journal of Computer Science and Technology*, vol. 33, no. 2, pp. 263–276, 2018.

[13] B. Ramesh and D. Manjula, “CA-AODV: congestion adaptive AODV routing protocol for streaming video in Mobile ad hoc networks,” *International Journal of Communications, Network and System Sciences*, vol. 1, no. 4, pp. 322–328, 2008.

[14] J. Wu, S. Shi, Z. Liu, and X. Gu, “Optimization of AODV routing protocol in UAV ad hoc network,” in *Proceedings International Conference on ArtificialIntelligence for Communications*

and Networks (AICON), LNICST 286, pp. 472–478, Cham, 2019.

[15] X. Tan, Z. Zuo, S. Su, X. Guo, and X. Sun, "Research of security routing protocol for UAV communication network based on AODV," *Electronics*, vol. 9, no. 8, p. 1185, 2020.

[16] Y. Chen, N. Lyu, G. Song, B. W. Yang, and X. H. Jiang, "A traffic-aware Q-network enhanced routing protocol based on GPSR for unmanned aerial vehicle ad-hoc networks," *Frontiers of Information Technology & Electronic Engineering*, vol. 21, no. 9, pp. 1308–1320, 2020.

[17] M. F. Bedasa, A. S. Bedada, and W. B. Mulatu, "Adaptation of smart antenna with AODV routing protocol for ad hoc wireless networks," *Open Access Library Journal*, vol. 7, no. 7, pp. 1–21, 2020.

[18] A. Touzene and I. al-Yahyai, "Performance analysis of grid based AODV routing algorithm for AD hoc wireless networks," *International Journal of Communications, Network and System Sciences*, vol. 8, no. 13, pp. 523–532, 2015.

[19] D. K. Sharma, A. N. Patra, and C. Kumar, "P-AODV: a priority based route maintenance process in mobile ad hoc networks," *Wireless Personal Communications*, vol. 95, no. 4, pp. 4381–4402, 2017.

[20] O. Usman, O. Chughtai, N. Nawaz, Z. Kaleem, K. A. Khaliq, and L. D. Nguyen, "A reliable link-adaptive position-based routing protocol for flying ad hoc network," *Mobile Networks and Applications*, vol. 26, no. 4, p. 18201, 2021.

[21] S. Jobaer, Y. Zhang, M. A. Iqbal Hussain, and F. Ahmed, "UAV-assisted hybrid scheme for urban road safety based on VANETs," *Electronics*, vol. 9, no. 9, p. 1499, 2020.

[22] S. Priya and N. Kannan, "Refined trust energy-ad hoc on demand distance vector (ReTE-AODV) routing algorithm for secured routing in MANET," *Wireless Networks*, vol. 23, no. 7, pp. 2227–2237, 2017.

[23] N. Nabil, N. Najib, and J. Najib, "A review and a new approach to reduce routing overhead in MANETs," *Wireless Networks*, vol. 21, no. 4, pp. 1119–1139, 2014.

[24] M. Malnar and N. Jevtic, "An improvement of AODV protocol for the overhead reduction in scalable dynamic wireless ad hoc networks," *Wireless Networks*, vol. 28, no. 3, pp. 1039–1051, 2022.

[25] N. J. Jevtic and M. Z. Malnar, "Novel ETX-based metrics for overhead reduction in dynamic ad hoc networks," *IEEE Access*, vol. 7, pp. 116490–116504, 2019.

[26] N. J. Jevtic and M. Z. Malnar, "Implementation of ETX metric within the AODV protocol in the NS-3 simulator," *Telfor Journal*, vol. 10, no. 1, pp. 20–25, 2018.

[27] N. J. Jevtic and M. Z. Malnar, "The NS-3 simulatorimplementation of ETX metric within AODV protocol," in *2017 25th Telecommunication Forum (TELFOR)*, pp. 1–4, Belgrade, Serbia, 2017.