# Performance Study of ETX Metric in Flight Ad-Hoc Networks

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**Abstract.** Flying Ad-hoc networks (FANETs) are wireless networks that allow unmanned aerial vehicles (UAVs) to interact with one another without a permanent infrastructure. For effective data transfer in FANETs, routing protocols like Ad hoc On-Demand Distance Vector (AODV) are crucial. While several studies have investigated the use of ETX (Expected Transmission Count) in specialized networks such as Vehicular Ad-hoc Networks (VANETs) and mesh networks, there is a lack of comprehensive study across routing protocols under FANETs. This research gap shows how important it is to have a structured way to check how well ETX metrics work in FANETs, taking into account network structure, mobility patterns, and environmental circumstances. The research examined the efficacy of ETX and hop count routing metrics utilizing the NS-3 network simulator. In this work, simulations of Ad hoc On-Demand Distance Vector (AODV) routing protocol were conducted in two scenarios: one employing the ETX metric (AODV-ETX) and the other utilizing the conventional hop count metric (original AODV). Various performance metrics, including average throughput, average end-to-end delay, packet delivery ratio (PDR), and useful traffic ratio (UTR), are evaluated.

The results show that in varying density of network environments, the ETX metric leads to higher delays but improves packet delivery ratios, throughput, and UTR. However, in scenarios with varying speeds of UAVs, it leads to a high end-to-end delay, a lower packet delivery ratio, lower throughput, and a lower UTR, compared with the hop-count metric. It is observed as well that the ETX metric performed better than the hop count metric in terms of end-to-end delay, packet delivery ratio, throughput, and UTR when the network load changes.

**Keywords:** ETX, FANETs, NS-3.

## 1 Introduction.

In recent years, wireless networks have gained appeal in modern communications, especially in mobile contexts like FANETs, MANETs, and VANETs [1]. The numerous applications of UAVs (Unmanned Air Vehicles) have garnered significant attention. Current advancements in electronics, sensors, and communication have enabled the creation of tiny UAVs for military, commer-

cial, and civilian uses. However, one tiny UAV is insufficient. Multiple UAVs can create a system that exceeds the capabilities of a single tiny UAV. A flying ad hoc network (FANET) is a network of tiny UAVs connected and working together to achieve high-level goals.
The fundamental characteristics of FANETs include mobility, ease of installation, and a relatively low cost of operation, versatility, the absence of central control, the ability to self-organize, and the ad hoc nature of relationships between UAVs, these features can help to extend the communication range in areas that lack infrastructure [2].
Furthermore, even if bad weather disconnects some UAVs from the network during operation, the remaining UAVs can still connect to the network, in addition, these networks may overcome issues like short range, network failure, and restricted guidance that occur in a single UAV system. The design of FANETs ensures that all UAVs interact with each other and the base station at the same time, even in the absence of a pre-established fixed infrastructure. This allows for immediate delivery of aggregated data to the base station as well as sharing among linked UAVs. Despite this, there is a need to surmount several formidable obstacles to enhance networking and communications [1]. The FANET nodes, have unique mobility, capable of reaching speeds between 30 and 460 km/h [2] in three-dimensional space. Consequently, the communication pathways among UAVs demonstrate considerable variability and are exceedingly unpredictable. Moreover, frequent alterations in topologies lead to an elevated incidence of packet loss, increased routing expenses, and communication delays. The interplay of elevated velocity, considerable distance between airborne nodes, erratic weather conditions, and possible node failures may result in network disruptions.

**Fig. 1.** Flight ad-hoc Network.

In such cases, the creation of a new routing path becomes critical. Subsequent events, like mission updates, may also cause modifications in topology. Additionally, several military and emergency rescue applications require the prioritization of low latency, high dependability, and resilience. The dynamic characteristics and frequent operations of a FANET present considerable hurdles for the formulation of efficient routing protocols. Routing is a formidable challenge in FANETs. An effective routing system must be rapidly adaptive to alterations in topology and wireless connection conditions, which are prevalent in FANETs [3]. Many routing protocols employ different methods to improve network performance, decrease packet losses, and adapt to changing settings and situations. Additionally, because of their commonalities, researchers have looked at the idea of implementing the routing algorithms employed in MANETs into FANETs [4]. Some researchers have categorized this into primary groups like Proactive protocols, Reactive protocols and Geographic routing protocols [5], while others [6] have classified this into Swarm-based routing, Position-based routing, Topology- based routing, Hierarchical- based routing, DTN-based routing, and Learning algorithm.

The most widely used routing protocols generally consider hop-count as routing metric, however it may not perfectly determine the optimal path between source and destination nodes.

Many common routing protocols employ hop-count as a default metric, although it may not determine the optimal path between source nodes and destination nodes. This issue is particularly prevalent in FANET networks. As route reliability varies over time, link brakes grow, leading to large packet losses. The Expected Transmission Count (ETX) metric was suggested in [8] to address hop-count metric issues, particularly in throughput and PDR, however FANETs have not fully explored both of them. The main objective of this study is to derive the relative merits of this metric. The motivation of this research is that having a good understanding of the relative merits will help to serve as a base for developing more effective routing metric for routing protocols in FANETs networks.

This article is organized based on the following; related work as discussed in section II, and the simulation environment used to include network topology, traffic patterns and simulation parameters as stated in section III. Section IV presents the results and discussion of the study, and Section V concludes the paper.

## 2 RELATED WORK

Despite its initial introduction in 1999 [7], AODV remains one of the most extensively used communication protocols. Recent studies have examined the AODV protocol in several MANETs, such as [9]. Further research indicates that wireless sensor networks and FANETs (i.e UAVs) may employ the AODV protocol.

Researchers have suggested a ZigBee AODV (Z-AODV) to adapt the AODV protocol to wireless sensor networks [10], and have modified the AODV to enhance VANET QoS in [11], [12], next section will give a brief information about AODV routing protocol

A flocking-based routing protocol for unmanned aerial vehicles (UAVs) called BR-AODV was suggested in [13]. In order to compute routes on demand, the protocol makes use of a popular ad hoc routing protocol. In addition, it makes use of the Boids

of Reynolds mechanism in order to preserve connectivity and routes while transferring data.
The ETX metric [8] has been proposed and included to the route cost to enhance the multi-hop routing protocol's route discovery and maintenance over the hop-count. The number of transmitted and received probe packets determines it.
The authors of [14] suggest three new ETX-based metrics to make the ETX metric better in VANET networks. These are light ETX (L-ETX), light reverse ETX (LR-ETX), and power light reverse ETX (PLR-ETX). The aim is to reduce the routing overhead in dynamic ad hoc networks. In [15], the authors have used Network Simulator 3 (NS3) to compare how well Ad hoc On Demand Distance Vector (AODV), AODV-ETX, and Modified AODV-ETX work in vehicular ad hoc networks (VANET).
In [16], the Expected Transmission Count (ETX) metric has combined with the Received Signal Strength Indicator (RSSI) and battery voltage in order to make judgments on routing.
In [17] it presents EEMGR, a routing protocol for Wireless Multimedia Sensor Networks (WMSNs) that integrates Energy-Aware and ETX (Expected Transmission Count) metrics for routing decision-making.
Link State-Aware Geographic Opportunistic (LSGO) [18], utilizes both ETX and geographic location.
The VETX metric combines two metrics, least hop-count, and ETX, in Low-Power and Lossy Networks (LLNs) [19]. The purpose of this work aims to select optimum route in high density network, the implementation of VETX is evaluated using the Cooja simulator.
Collision-aware routing (SCAOR) is described as an opportunistic routing protocol in [20]. This routing protocol uses a routing metric that is based on node density, ETX-based connection quality, and packet advancement.
A software-defined framework called SD-TDQL has introduced in [21] that use ETX to measure network quality. The forwarding ratio of each node serves as the probability of successful transmission, representing the trustworthiness probability. Each node assesses the trust value of its neighbors based on the reliability of packet forwarding.

**a.** Overview on AODV , “Ad hoc on –demand distance vector (AODV)

The key characteristic of AODV is its on-demand behavior, which initiates routing activities only when the data packets require a route. If there is no existing route from the UAV source to the UAV destination, such that a route discovery process is based on query and reply cycles. One feature of AODV relies on route tables and sequence numbers to prevent routing loops and determine which routes are fresh. Many details of this protocol are available at [6].

**b.** Overview on Expected transmission count (ETX)

The expected transmissions and retransmissions (ETX) for a link are the expected data transmissions and retransmissions that are necessary to deliver a successful packet. ETX is a routing metric that has been intended to locate high throughput routes in a multi-hop wireless network. The ETX metric considers the effects of link loss ratios,

asymmetry in both directions of each link, and interference among the consecutive links in a path. All of these factors are taken into consideration.
A link's ETX is determined from its forward and reverse delivery ratios. Forward delivery ratio (df) is the probability that a data packet gets to the receiver; reverse delivery ratio (dr) is the probability that the ACK packet arrives. The chance of a transmission being received and acknowledged is df x dr. Each packet transmission is a Bernoulli trial, resulting in an expected number of transmissions as follows in equation 1:

$$ETX=\frac{1}{dfxdr} \tag{1}$$

The chosen route has the lowest ETX number compared to other routes from the same source to the same destination [8].

**Table 1.** simulation parameters used in this simulation

| Parameter | Value |
|---|---|
| Application Type | Constant bit rate (CBR). |
| Number of UAV sources that transmit packets. | 20 |
| Routing Protocols | AODV-ETX,AODV-hop count |
| Simulation time | 110 seconds. |
| Packet Size | 64 bytes. |
| Data rate | 2048bps. |
| Simulation area | 2000m × 2000m ×900m. |
| Transmission power | 20dbm. |
| Physical data rate | 6Mbps. |
| Modulation type | OFDM and 10 MHz bandwidth. |
| MobilityModel | GaussMarkovMobilityModel[22]. |
| Speed Mobilty | [0-60]m/s. |
| Mobility model. | Random way point. |
| MAC layer. | 802.11p |
| Antenna model. | Omni Antenna. |
| Propagation model. | TwoRayGroundPropagationLoss Model. |

# 3 Simulation Results and Analysis

## 3.1 Simulation parameters and Topology

The research examined the behavior of ETX and hop count routing metrics through the network simulator NS-3.33. The academic community extensively uses NS-3 due to its simulator core, which facilitates parallel execution, encompasses a diverse array of communication protocols, and offers relative ease of extension for specific needs. Consequently, the NS-3 simulator is selected for the assessment of this research.

This research incorporates the AODV routing protocol with ETX metric and simulate AODV in both case one in case of using ETX with AODV (AODV-ETX) and other in case of use AODV with hop count (original AODV). Table 1 provides all simulation parameters used in this simulation environment, while Figure 2 illustrates the simulation topology.

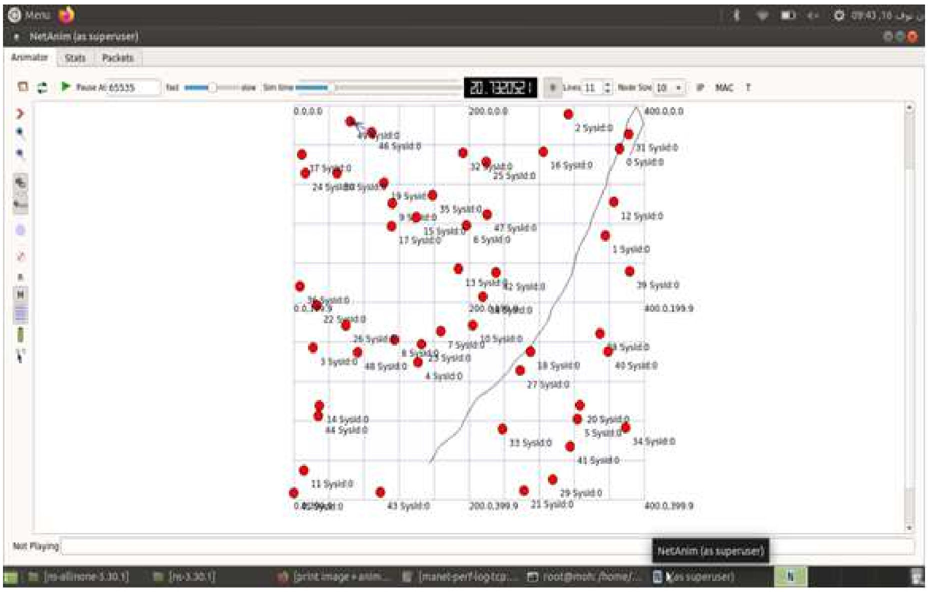

**Fig. 2.** Simulation Topology.

### 3.2 Performance metrics

This section introduces the metrics to evaluate the performance of the ETX and hop count metrics described in this work:

1. Average Throughput: The number of data packets in bits that received at destination during exchange of data packets between UAVs.

$$\text{Average Throughput [b/s]} = \frac{\boldsymbol{P_r * 8}}{\boldsymbol{T_r - T_s}} \tag{2}$$

where, $\mathbf{T_r}$ the time at which last packet is received by receiver and $\mathbf{T_s}$ is the time when the first packet is sent by sender, where Pr is the total number of packets received successfully in bytes.

**2.** Average End to End Delay (AEED): The total time taken by all data packets from source to destination over total number of successful received data packets.

$$\text{AEED=End\_to\_End\_delay} \times 1000\text{(ms)}. \tag{3}$$

Where

$$\text{End\_to\_End\_delay} = \frac{\boldsymbol{TDT}}{\sum_{i=1}^{N} \boldsymbol{P_r}} \quad (4)$$

$$\text{TDT=TDT+}\sum_{i=0}^{N} delay\ [i] \quad (5)$$

$$\text{delay[i]=}T_r[i] - T_s[i]. \quad (6)$$

Where $P_r$ represents a total number of successful received data packet, delay[i] is delay of flow i.

3. Packet delivery ratio (PDR): PDR is the ratio between the number of received data packets by destinations UAVs to total number of data packets sent by UAVs senders.

$$\text{PDR} = \frac{\boldsymbol{Totalnumberofrecieveddatapackets}}{\boldsymbol{totalnumberofsentdatapackets}} \text{x100} \quad (7)$$

4. Useful traffic ratio (UTR): The ratio between total number of received data packets in bytes to total number of control packets sent and data packets sent.

$$\text{UTR=}\frac{\boldsymbol{Totalnumberofrecieveddatapackets}}{\boldsymbol{totalnumberofsentpackets}} \text{ X 100} \quad (8)$$

Where total number of sent packets =total number of data packet sent (in bytes) + total number of control packets in all layers (in bytes)

# 4 Results and Discussion

The researchers conducted simulation experiments with different scenarios. The simulation results of the AODV-ETX were compared with the simulation results of the original AODV. Using a simulation model described in previous sections, end-to-end delay, throughput, packet delivery ratio, and useful traffic ratio have been determined and plotted. The performance metrics are obtained by averaging results over 100 simulation runs. Each data point represents an average of at least 10 runs with identical traffic models but randomly generated with different mobility scenarios. Identical mobility and traffic scenarios are used throughout this work.
The following three experiments were conducted to evaluate the performance of the ETX metric with hop-count metric:

1. Varying speed of UAVs: In this scenario, the effect of movement of UAVs has been studied by varying the maximum speed of the UAVs from 10m/s to 60 m/s, with increments of 10m/s. The results are shown in figures3,4,5 and 6.

It is clear from figure 3, the ETX metric has higher delay than the hop count in all cases of speed values. This is due to the fact that discovery of new route with ETX metric takes more time than hop-count.

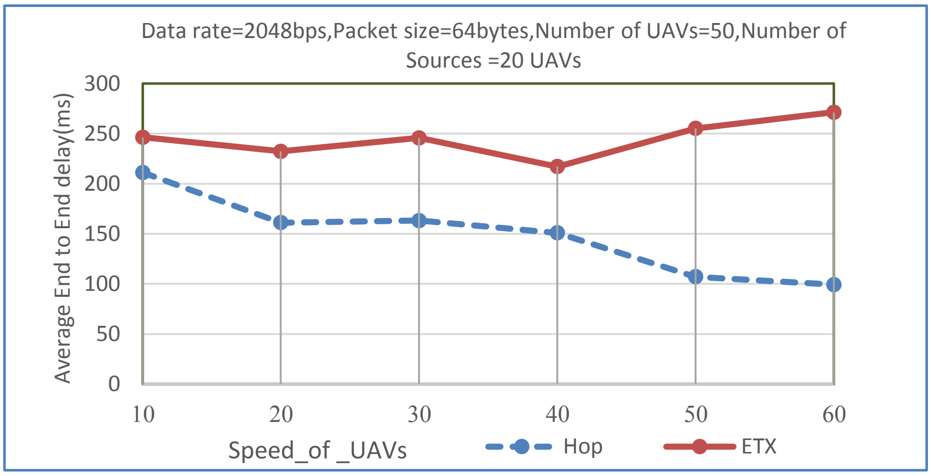


**Fig. 3.** Speed of UAVs versus Average End to End Delay.

Fig. 4. illustrates the performance of packet delivery ratio changes with the UAVs maximum speed. Compared against the ETX metric, the hop count metric performed better. This is because ETX responds slowly to the rapidly changing network topology, which leads to unnecessary routing discovery process and results in data loss.

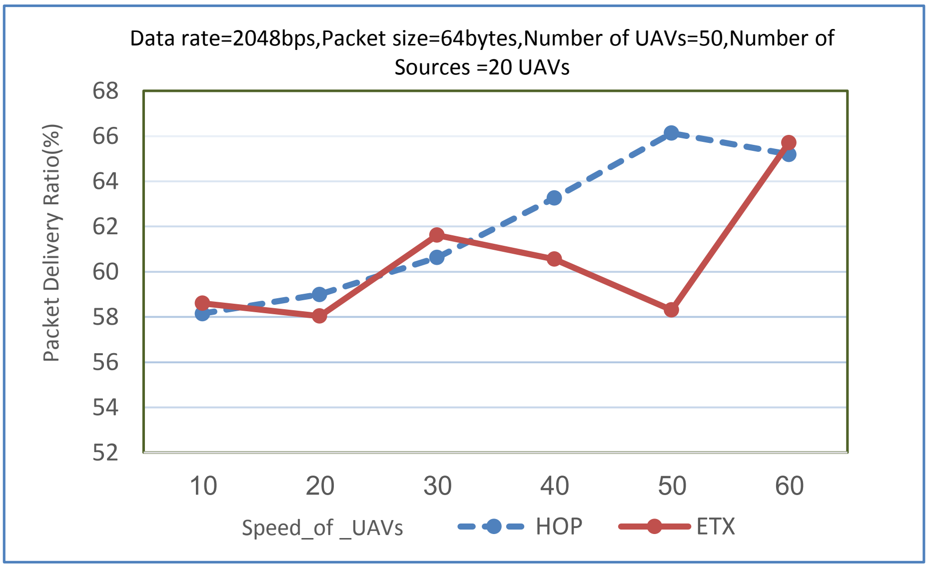


**Fig. 4.** Speed of UAVs versus Packet Delivery Ratio.

It can be seen from figure 5, hop count shows better performance at moderate speeds but declines at higher speeds in most cases. The hop count has a higher useful traffic ratio than the ETX metric; hence, the hop count uses less control overhead compared with the ETX metric for routing establishment.

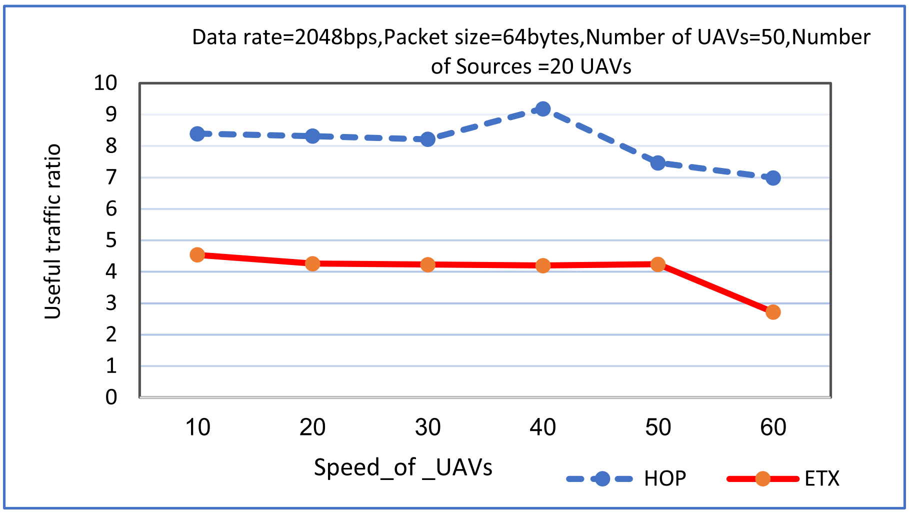


**Fig. 5.** Speed of UAVs versus Useful Traffic Ratio

Figure 6 shows how the performance of average throughput changes with the UAV maximum speed. The hop count metric has better performance than the ETX metric. This is due to the hop count metric having a higher performance of the packet delivery ratio, which provides a better average throughput performance.

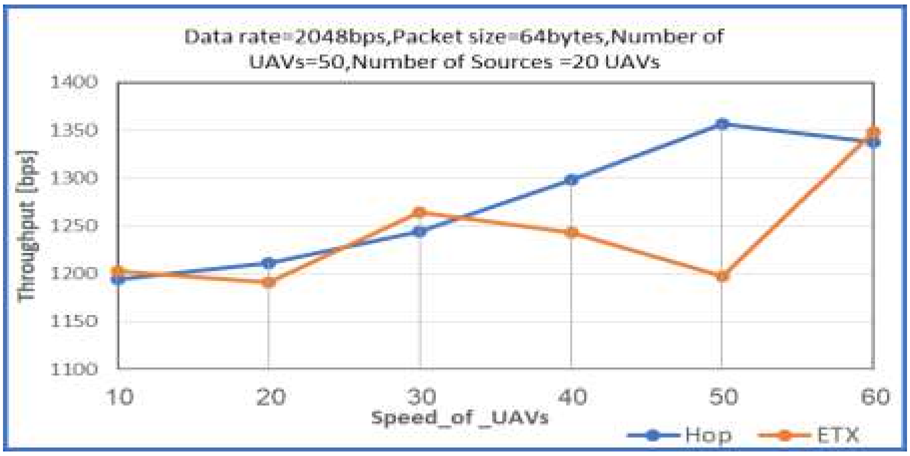


**Fig. 6.** Speed of UAVs versus Throughput.

2. Varying number of UAVs: This research studied the impact of network density on network performance by varying the number of UAVs in term of average end to end delay. From figures 7, it is observed that as the number of UAVs increases, both end-to-end delay increases for both the ETX metric and the hop count metric. It is evident that the delay in ETX metric is larger than the hop count metric. This is due to the fact that the ETX metric takes time to calculate the link quality for each link from source to destination, hence the route establishment takes more time than hop count metric. Furthermore, the path length of the ETX metric might be is longer than the path with hop count metric.

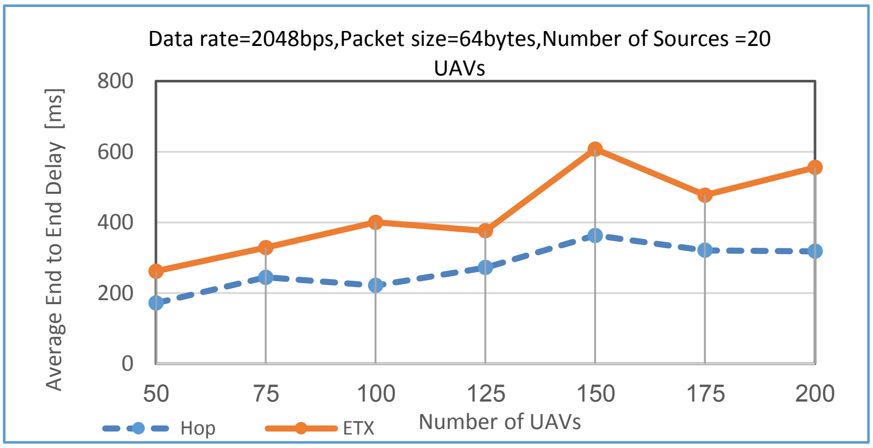


**Fig. 7.** Average End to End Delay Versus Number of UAVs.

In Figure 8, PDR (packet delivery ratio) are inversely proportional with an increase in the number of UAVs. This is the result of the number of packets that are received at destinations decreases as the number of UAVs increases. It can observe that the ETX metric consistently performs better than the hop count metric across various numbers of UAVs, which helps in sustaining better throughput and packet delivery ratio in dynamic and dense network environments.

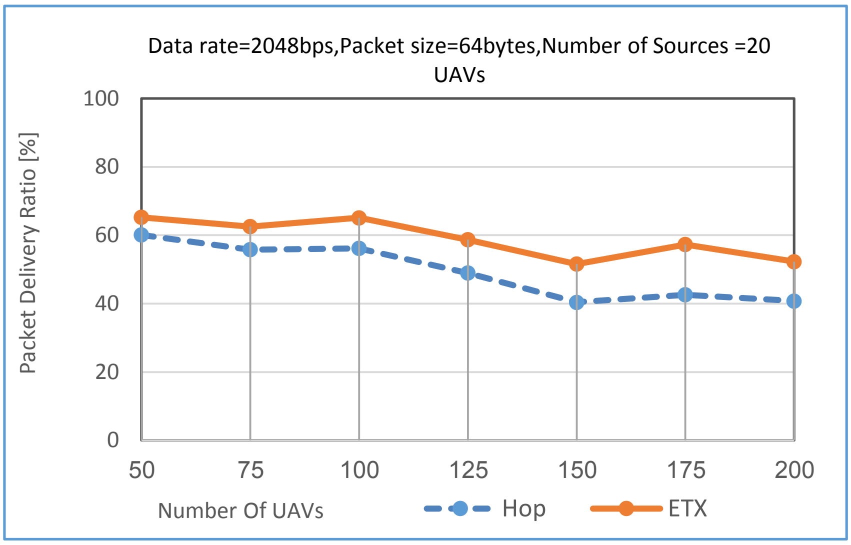


**Fig. 8.** Packet Delivery Ratio versus Number of UAVs.

From Figure 9, it can be observed that regardless of whether ETX or hop count is used, routing protocols present a Useful Traffic ratio (UTR) that decreases with an increase in the number of UAVs. Where in a small number of UAVs, the ETX metric has a lesser UTR than hop count, while in a high number of UAVs, the hop count metric has a lesser UTR than ETX metric. From these results, it can be concluded that the hop count is unable to bear efficiency in large networks, while the ETX has better performance in large networks.

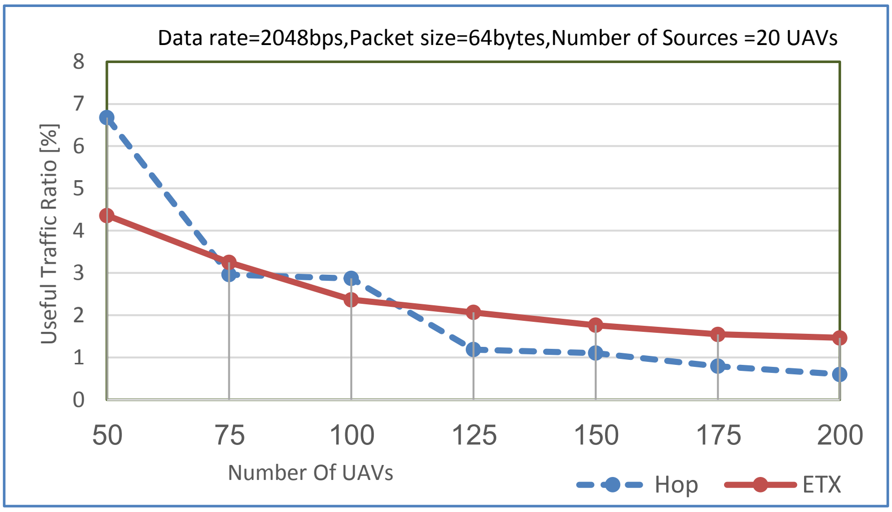


**Fig. 9.** UTR versus Number of UAVs

It can be seen from figure 10. The throughput shows a slight decrease as the number of UAVs increases. Despite the decrease, the ETX metric has better throughput than hop-count `drops in large networks.

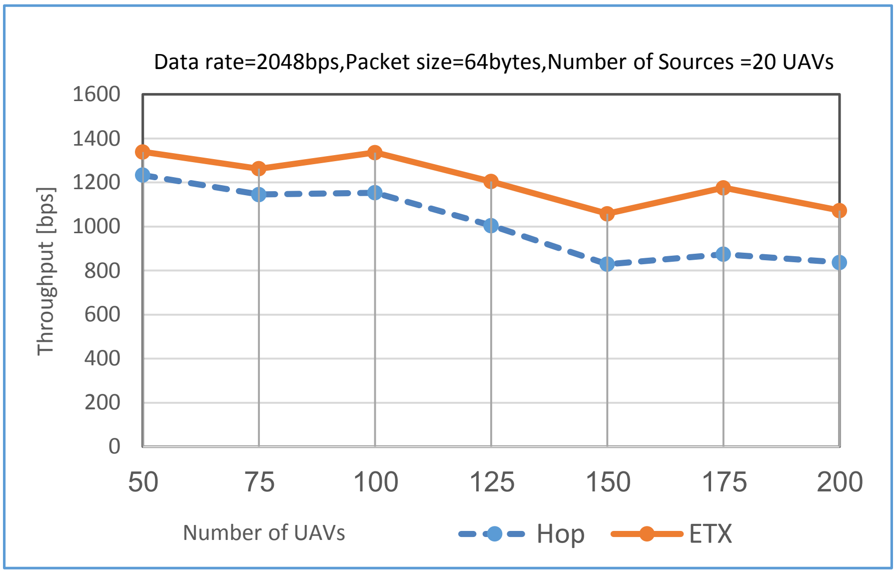


**Fig. 10.** Throughput. versus. Number of UAVs

3. Varying number of Sources: The performance of ETX metric is evaluated with the number of sources (i.e., flows), varying from 10 to 50 in the number of sources. The purpose of this study is to analyze the capacity of the wireless network. As shown in Figure 11, end-to-end delay varies with the number of sources (i.e., traffic flows). It is observed that, at lower traffic loads, the end-to-end delay is low and increase relatively with traffic load. The contention time and retransmission time at the MAC layer also increased and ETX has a higher delay than hop count.

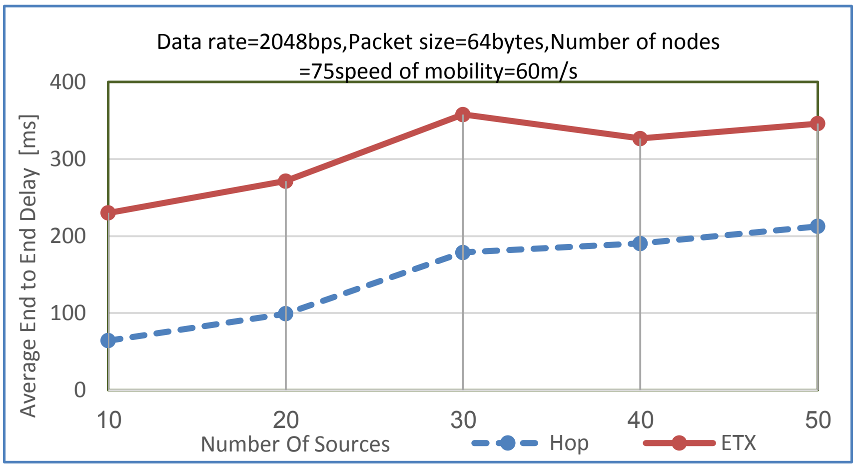


**Fig. 11.** Average end to end delay versus Number of sources.

Based on Figure 12, the research noted that the packet delivery ratio is reaching a maximum value at lower traffic flow, and decrementing with an increment in traffic flow. This is caused by a high level of network congestion and multiple access interferences at certain regions of the FANET network. The introduction of the ETX metric leads to identifying high-quality routes and therefore significantly increases the PDR.

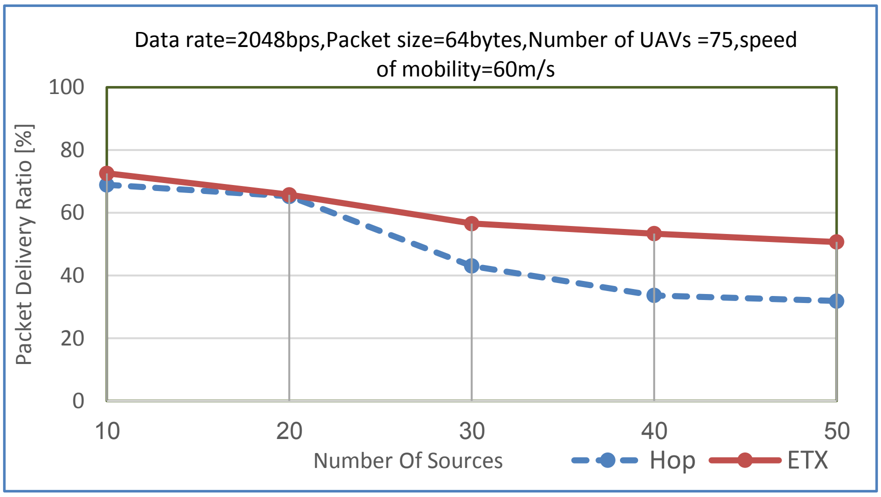


**Fig. 12.** Packet Deliver ratio versus Number of sources.

As illustrated in Figure 13, there is a 7% traffic ratio measured when there are 10 sources. When the sources increase, both metrics show a decrease in useful traffic ratio. The hop count metric has a sharper decline, indicating that the efficiency of hop-count decreases more significantly with more sources. On the other hand, the useful traffic ratio decreases more slowly, showing that it can handle an increase in number of sources better than the hop count. The network becomes more congested, leading to a lower useful traffic ratio.

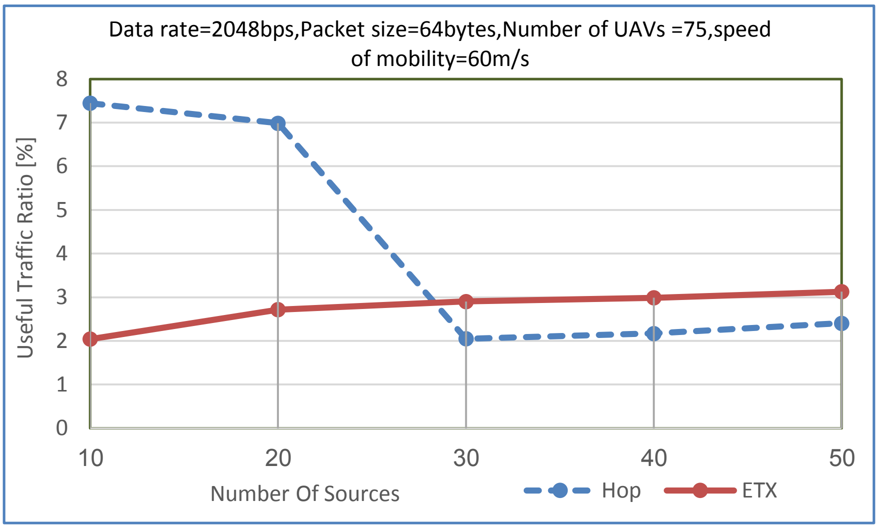


**Fig. 13.** Useful traffic ratio versus Number of sources.

Figure 14 depicts that throughput of both metrics decreases as the number of sources increases. The ETX metric shows a higher throughput compared to hop count across all number of source cases; the maximum number of throughputs reached 1500 bps when ETX was applied, while hop count reached about 1400 bps when the number of sources was 10. With hop count, the minimum number of throughputs reached about 1205 bps and 610 bps when the number of sources reached 50. This means as the number of sources increases, the congestion in the network will increase, and both metrics will introduce large overhead packets to find out high-quality routes, which has an effect on network throughput.

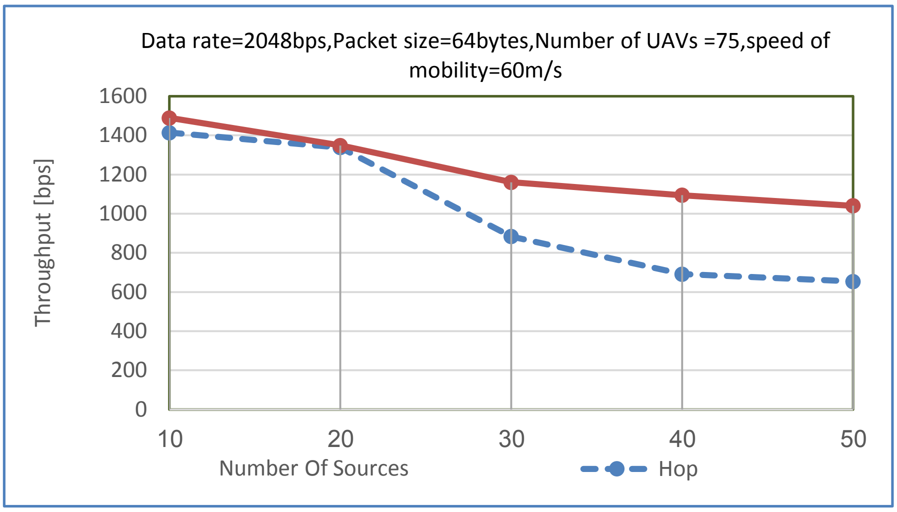


**Fig. 14.** Throughput versus Number of sources.

## 5 Conclusion

Flying Ad Hoc Networks, also known as FANETs, are networks of unmanned aerial vehicles, or UAVs, that are capable of self-organization and communication. They are not dependent on any external network infrastructure. The highly dynamic nature of UAVs in FANETs causes abrupt changes in the network topology and hence makes routing among the UAVs a crucial task for a wide range of uses, including monitoring the environment, dealing with emergencies, and surveillance. The main challenge to designing routing protocols that are suitable for all scenarios and conditions is still under research. Routing metrics are crucial in determining the optimal quality path. This research looked at how well ETX and hop count routing metrics worked in the NS-3 network simulator and compared them. This shows how important it is to choose the right metrics to improve network performance in flying Ad hoc Networks (FANETs).

This research tested the Ad hoc On-Demand Distance Vector (AODV) routing protocol in two scenarios: one using the ETX metric (AODV-ETX) and the other using the classic hop count metric (original AODV). The results show that the ETX metrics cause longer delays in different types of network densities while improving packet delivery rates, throughput, and UTR. In cases with different UAV speeds, this results in significant end-to-end delay, a lower packet delivery ratio, lower throughput, and a lower UTR, in contrast to the hop-count metrics. The ETX metric outperforms the hop count metric for end-to-end delay, packet delivery ratio, throughput, and UTR under varying network loads. These research findings highlight the importance of properly selecting routing metrics to guarantee resilient and effective communication in FANETs. Subsequent research can expand upon these findings to enhance and optimize routing strategies that utilize the advantages of ETX for superior network performance.

## References


1. Khan, Muhammad Asghar, Alamgir Safi, Ijaz Mansoor Qureshi, and Inam Ullah Khan. "Flying ad-hoc networks (FANETs): A review of communication architectures, and routing protocols." In 2017 First international conference on latest trends in electrical engineering and computing technologies (INTELLECT), pp. 1-9. IEEE, 2017.
2. Lakew, Demeke Shumeye, et al. "Routing in flying ad hoc networks: A comprehensive survey." IEEE Communications Surveys & Tutorials 22.2 (2020): 1071-1120.
3. Jevtic, Nenad J., and Marija Z. Malnar. "Novel ETX-based metrics for overhead reduction in dynamic ad hoc networks." IEEE Access 7: 116490-116504, (2019).
4. Oubbati, Omar Sami, Mohammed Atiquzzaman, Pascal Lorenz, Md Hasan Tareque, and Md Shohrab Hossain. "Routing in flying ad hoc networks: Survey, constraints, and future challenge perspectives." IEEE Access 7 (2019): 81057-81105.
5. Malhotra, Atul, and Sanmeet Kaur. "A comprehensive review on recent advancements in routing protocols for flying ad hoc networks." Transactions on Emerging Telecommunications Technologies 33, no. 3 (2022): e3688.
6. Almansor, M.J., Din, N.M., Baharuddin, M.Z., Ma, M., Alsayednoor, H.M., Al-Shareeda, M.A. and Al-asadi, A.J., 2024. Routing protocols strategies for flying Ad-Hoc network (FANET): Review, taxonomy, and open research issues. Alexandria Engineering Journal, 109, pp.553-577.
7. C.Perkins, “Ad hoc on –demand distance vector (AODV) routing”, RFC 3561, July 2003.
8. D.S J De Couto, D.Aguayo, J.Bicket, and R.Morris, A High- Throughput Path Metric for Multi-Hop Wireless routing, in ACM Mobicom, 2003.
9. OKSahingoz. “Routing ptocols in flying Ad-hoc networks (FANETs): Concepts and challenges”. Journal of Intelligent & Robotic Systems, pp. 513-27. April 2014.
10. T. de Almeida Oliveira and E. P. Godoy, ZigBee wireless dynamic sensor networks: Feasibility analysis and implementation guide, IEEE Sensors J., vol. 16, no. 11, pp. 46144621, Jun. 2016.
11. F. S. Mubarek, S. A. Aliesawi, K. M. A. Alheeti, and N. M. Alfahad, Urban-AODV: An improved AODV protocol for vehicular ad-hoc net works in urban environment, Int. J. Eng. Technol., vol. 7, no. 4, pp. 30303036, 2018. Accessed: Aug. 21, 2019. [Online].Available: https://www.sciencepubco.com/index.php/ijet/article/view/21535.
12. S. Goyal, An improvement of AODV routing protocol for vehicular adhoc networks (VANETs), Int. J. Adv. Res. Comput. Eng. Technol., vol. 4, no. 6, pp. 25332538, Jun. 2015. [Online]. Available:http://ijarcet.org/wp-content/uploads/IJARCET-VOL-4-ISSUE-6-2533-2538.pdf.
13. El Houda Bahloul N., Boudjit S., Abdennebi M., and Boubiche D. E., A flocking-based on demand routing protocol for unmanned aerial vehicles, Journal of Computer Science and Technology. (2018) 33, no. 2, 263–276, https://doi.org/10.1007/s11390-018-1818-3, 2-s2.0-85044446491.
14. Jevtic, Nenad J., and Marija Z. Malnar. "Novel ETX-based metrics for overhead reduction in dynamic ad hoc networks." IEEE Access 7: 116490-116504,(2019).
15. Ardianto, Bayu, Hery Sapto Dwi Nurcahyo, Hasan Muftić, Ruki Harwahyu, and Riri Fitri Sari. "Performance Comparison of AODV, AODV-ETX and Modified AODV-ETX in VANET using NS3." In 2022 IEEE International Conference on Cybernetics and Computational Intelligence (CyberneticsCom), pp. 156-161. IEEE, 2022.
16. Ye, R., Boukerche, A., Wang, H. et al. E3TX: an energy-efficient expected transmission count routing decision strategy for wireless sensor networks. Wireless Netw 24, 2483–2496 (2018). https://doi.org/10.1007/s11276-017-1483-4.

17. S. Aswale and V. R. Ghorpade, "EEMGR: Energy and ETX aware Multipath Geographic Routing in WMSN," 2018 3rd International Conference On Internet of Things: Smart Innovation and Usages (IoT-SIU), Bhimtal, India, 2018, pp. 1-6, doi: 10.1109/IoT-SIU.2018.8519870.
18. X. Cai, Y. He, C. Zhao, L. Zhu, and C. Li, LSGO: Link state aware geographic opportunistic routing protocol for VANETs, EURASIP J. Wireless Commun. Netw., vol. 2014, no. 1, Dec. 2014, Art. no. 96. Accessed: Aug. 8, 2019. doi: 10.1186/1687-1499-2014-96.
19. Subramani, B. "Enhanced Objective Function ETX Metric in Routing Protocol for Low-Power and Lossy Networks (RPL)." , International Journal of Computer Networks and Applications (IJCNA), Volume 9, Issue 4, July – August (2022).
20. V. Sadatpour, F. Zargari, and M. Ghanbari, A collision aware opportunis tic routing protocol for VANETs in highways, Wireless Pers. Commun., pp. 114,. doi: 10.1007/s11277-019 06557-x,May 2019. Accessed: Aug. 6, 2019.
21. Zhang, Dajun, et al. "Software-defined vehicular networks with trust management: A deep reinforcement learning approach." IEEE Transactions on Intelligent Transportation Systems 23.2 (2020): 1400-141406557-x,May 2019. Accessed: Aug. 6, 2019
22. Sahingoz, Ozgur Koray. "Networking models in flying ad-hoc networks (FANETs): Concepts and challenges." Journal of Intelligent & Robotic Systems 74 (2014): 513-527.

# دراسة أداء مقياس عدد الإرسال المتوقع في الشبكات الجوية المؤقتة

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**الملخص:** الشبكات الجوية المؤقتة (FANETs) هي شبكات لاسلكية تسمح للطائرات بدون طيار (UAVs) بالتواصل مع بعضها البعض دون بنية تحتية دائمة. ولنقل البيانات بشكل فعال في شبكات FANET، فإن بروتوكولات التوجيه مثل Ad hoc On-Demand Distance Vector (AODV) تكون ضرورية الاستخدام ، على الرغم من أن العديد من الدراسات تناولت استخدام ETX (عدد الإرسال المتوقع) في الشبكات المتخصصة مثل شبكات السيارات المخصصة (VANETs). والشبكات المتشابكة، إلا ان هذه الدراسات لم تتناول استخدامها في FANETs. في هذا البحث تمت دراسة فعالية مقاييس التوجيه ETX وعدد القفزات باستخدام محاكي الشبكة NS-3 ، وقد تم إجراء محاكاة لبروتوكول التوجيه عند الطلب (AODV) في سيناريوهين: أحدهما يستخدم مقياس ETX (AODV-ETX) والآخر يستخدم مقياس عدد القفزات التقليدي (AODV) الأصلي وقد. تم التقييم بالعديد من مقاييس الأداء، بما في ذلك متوسط الإنتاجية، ومتوسط التأخير من طرف إلى طرف، ونسبة تسليم الحزم (PDR) ، ونسبة المرور المفيد (UTR). وقد أظهرت النتائج أنه في السناريوهات التي تتغير فيها عدد المركبات الجوية، معدل التأخير مقياس ETX للحزم اكثر من مقياس عدد القفزات ولكنه في المقابل فان مقياس ETX افضل في نسب تسليم الحزم، والإنتاجية، وUTR. اما في حالة السيناريوهات ذات السرعات المتغيرة للطائرات بدون طيار، فان مقياس ETX يسبب في تأخير عالي من طرف إلى طرف للحزم، ونسبة تسليم حزم أقل، وإنتاجية أقل، و UTR أقل مقارنة بمقياس عدد القفزات. كما لوحظ أن مقياس ETX أدى بشكل أفضل من مقياس عدد القفزات من حيث اقل زمن التأخير من طرف إلى طرف، وافضل نسبة تسليم الحزم، والإنتاجية، و UTR في حالة سيناريوهات تغير حمل الشبكة.

**الكلمات المفتاحية :** محاكي الشبكات Ns-3 , شبكات الجوية المؤقتة, مقياس عدد الارسال المتوقع.