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Comparative Performance Analysis of Reactive vs. Proactive Routing Protocols in High-Mobility Flying Ad Hoc Networks

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Abstract

Flying Ad Hoc Networks (FANETs) are emerging as critical components in a wide range of applications, including surveillance, disaster response, and remote sensing. FANETs (Flying Ad Hoc Networks) represent specialized extension of VANETs (Vehicular Ad-Hoc Networks), which in turn are a subset of Mobile Ad-hoc network. However, the dynamic nature of UAV mobility in 3-D dimension, frequent topology changes, and limited communication range present significant challenges to efficient routing, further FANETs lack a dedicated routing protocol to efficiently manage communication between UAVs. This study investigates the performance of two reactive routing protocols On-Demand Distance Vector (AODV) and AODV with Expected Transmission Count (AODV-ETX) and one proactive protocol— Optimized Link State Routing (OLSR) under varying UAV mobility speeds, network densities, and traffic source densities. The performance was evaluated using key metrics such as end-to-end delay, Packet Delivery Ratio (PDR), useful traffic ratio (UTR), and throughput. The results reveal that OLSR consistently achieves superior performance across all scenarios. At high UAV speeds (60 m/s), OLSR maintains the lowest end-to-end delay (159 ms–179 ms) and highest PDR (68%), while AODV-ETX shows the highest delay (up to 260 ms) due to link-quality monitoring overhead. In dense networks with 200 UAVs, OLSR sustains a PDR of up to 67% and throughput of 1330 bps, compared to AODV’s significant decline to 40% PDR and 829 bps throughput. Similarly, under increasing

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traffic loads, OLSR maintains the highest UTR (rising from 5.1% to 8.4%) and stable throughput, whereas AODV and AODV-ETX exhibit notable performance degradation. These findings underscore OLSR's robustness and scalability, making it more suitable for high-density and high-mobility FANET environments.

Keywords:AODV-ETX, OLSR, AODV, FANETs, NS-3.

تحليل الأداء المقارن بين بروتوكولات التوجيه التفاعلية والاستباقية في شبكات FANET ذات الحركية العالية

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الملخص

تُعد شبكات الطيران الموجهة ذاتياً (FANETs) من التقنيات الحديثة التي تكتسب أهمية متزايدة في العديد من التطبيقات مثل المراقبة، والاستجابة للكوارث، والاستشعار عن بُعد. وتُعد FANETs امتداداً متقدماً لشبكات المركبات (VANETs)، وهي بدورها جزء من شبكات الأجهزة المحمولة الموجهة ذاتياً (MANETs). ومع ذلك، فإن الخصائص الفريدة لحركة الطائرات بدون طيار (UAVs) في الفضاء ثلاثي الأبعاد، والتغير المستمر في هيكلية الشبكة، والمدى المحدود للتواصل اللاسلكي، تفرض تحديات كبيرة أمام تصميم بروتوكولات توجيه فعالة وموثوقة. كما أن FANETs لا تمتلك حتى الآن بروتوكول توجيه مخصص يتلاءم مع طبيعة هذه البيئة الديناميكية. تهدف هذه الدراسة إلى تحليل أداء ثلاثة بروتوكولات توجيه في بيئة FANET وهي: بروتوكول AODV (تفاعلي)، ونسخته المحسّنة AODV–ETX التي تعتمد على مؤشر عدد النقل المتوقع (ETX) لقياس جودة الروابط، بالإضافة إلى بروتوكول OLSR (استباقي) الذي يعتمد على تحديثات دورية لحالة الروابط. وقد تم تقييم الأداء استناداً إلى مؤشرات أساسية تشمل متوسط التأخير من طرف إلى طرف، ونسبة تسليم الحزم (PDR)، ونسبة الحركة المفيدة

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(UTR)، ومعدل الإنتاجية (Throughput). أظهرت النتائج أن بروتوكول OLSR يتفوق على نظيريه في جميع السيناريوهات. فعند سرعات عالية للطائرات بدون طيار (60 م/ث)، حقق OLSR أقل تأخير (من 159 إلى 179 مللي ثانية) وأعلى نسبة تسليم حزم (68%)، في حين سجل AODV-ETX أعلى تأخير (يصل إلى 260 مللي ثانية) بسبب عبء مراقبة جودة الروابط. وفي الشبكات الكثيفة التي تضم 200 طائرة بدون طيار، حافظ OLSR على نسبة تسليم حزم تصل إلى 67% ومعدل نقل قدره 1330 بت/ث، مقارنة بانخفاض حاد في أداء AODV الذي بلغ 40% PDR و829 بت/ث فقط. أما عند زيادة حجم الحركة داخل الشبكة، فقد أظهر OLSR قدرة على الحفاظ على أعلى نسبة للحركة المفيدة (من 5.1% إلى 8.4%) وأداء ثابت، في حين تدهور أداء كل من AODV وAODV-ETX بشكل ملحوظ. توضح هذه النتائج أن بروتوكول OLSR يتمتع بقدرة عالية على التكيف مع بيئات FANET ذات الكثافة العالية والحركية المرتفعة، مما يجعله الخيار الأكثر ملاءمة كحل توجيه فعّال وقابل للتوسع في مثل هذه الشبكات.وبالمثل، في ظل الأحمال المرورية المتزايدة، حافظ OLSR على أعلى نسبة حركة مفيدة (من 5.1% إلى 8.4%) وإنتاجية مستقرة، في حين أظهرت بروتوكولات AODV وAODV-ETXتدهوراً واضحاً في الأداء. وتؤكد هذه النتائج متانة OLSR وقدرته العالية على التوسع، مما يجعله الخيار الأمثل لبيئات FANET التي تتميز بالكثافة العالية والحركية الكبيرة.

الكلمات المفتاحية: شبكات الطيران الموجهة ذاتياً ، برنامج محاكاة الشبكات-3 ، AODV-ETX, OLSR, AODV

I. Introduction

Flying Ad Hoc Network (FANET) is a type of Ad hoc network that facilitates communication among particularly unmanned aerial vehicles (UAVs). Unlike traditional networks, FANETs operate by allowing UAVs to communicate with each other and enabling the exchange of data dynamically without relying on fixed infrastructure. The concept of UAVs involves multiple nodes communicating with each other to perform tasks efficiently.

FANETs differ from traditional ad-hoc networks such as mobile ad-hoc networks mobile ad-hoc networks (MANETs), and vehicular ad-hoc networks (VANETs) [1]. As illustrated in Figure 1, UAVs in FANET move in three-dimensional (3D) space at high seed

http://www.doi.org/10.62341/mmaa2707

whereas MANETs and VANETs move in two-dimensional. Also, the topology is different where the UAVs in FANET involve frequent topology changes due to UAV movement which requires adaptive routing protocols. In FANETs, the communication range is also different from MANETs and VANETs since UAVs communicate over larger distances often using BS or high-frequency links. Figure1 show the MANETs, VANETs and FANETs topologies. The summarization of characteristics of MANETs, VANETs and FANETs are tabulated in Table1.

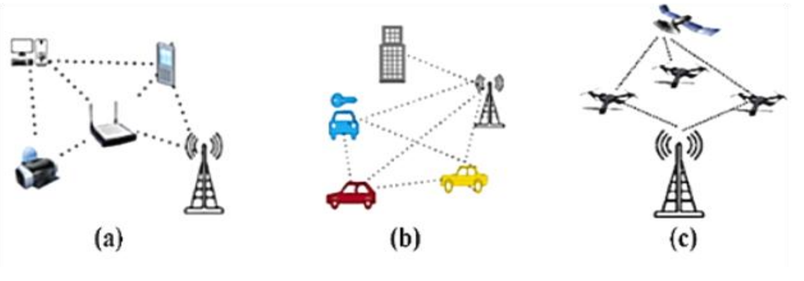

Fig 1: Network Topologies of (a) MANETs, (b) VANETs, and (c) FANETs [2].

Table1.MANETs, VANETs and FANETs Categorization

Characteristics	VANETs	FANETs	MANETs
Node Type	Vehicles	UAV or Drones	Sensors, Wireless routers and smart phones or computers
Mobility	2D	3D	2D
Wireless Technology	IEEE802.11p	IEEE802.11 a/b/g/n/p	IEEE802.15.4- IEEE802.11 a/b/g
Node Density	High	Low-medium	Low-Medium- high
Node Speed	Medium-high	Medium-high	Static-Medium-high

These unique characteristics of FANETs pose significant challenges for routing protocols, as frequent disconnections, dynamic UAVs counts, and energy constraints demand mechanisms capable of ensuring reliable and efficient communication under harsh conditions.

Therefore, the communication paths between UAVs exhibit significant changeability and are very unreliable. Furthermore, frequent topology changes result in a high number of packet losses, routing costs, and communication delays. High velocity, significant separation between airborne nodes, unpredictable climatic conditions, and potential node failures can combine to disrupt links.

http://www.doi.org/10.62341/mmaa2707

Furthermore, many military and emergency rescue applications need the consideration of low latency, high dependability, and resilience. In conclusion, a FANET's dynamic nature and frequent operations make the development of effective routing protocols some-what demanding [1] [2].

Despite the increasing use of UAVs across various applications, FANETs still lack routing protocols specifically designed to address their unique operational requirements. Existing protocols originally developed for MANETs and VANETs such as OLSR, AODV, and its enhanced variant AODV-ETX are frequently applied in ad hoc environments. However, these protocols are not inherently optimized for the high mobility, rapid topology changes, and three-dimensional movement characteristic of UAV networks. As a result, they often suffer from significant limitations, including increased latency, reduced packet delivery ratios, and inefficient use of network resources. These shortcomings underscore the need for a thorough evaluation of existing routing protocols under FANET-specific conditions to better understand their performance constraints and guide the development of more suitable, adaptive solutions.

In this study, the performance of three prominent routing protocols—OLSR, AODV, and AODV-ETX—is thoroughly evaluated within the context of FANETs. The manuscript offers the following key contributions:

- **Comprehensive Performance Evaluation of FANET Routing Protocols:** A detailed comparative analysis is conducted to assess the behavior of OLSR, AODV, and AODV-ETX under varying network conditions. Metrics such as end-to-end delay, throughput, PDR, and UTR are measured to understand each protocol's efficiency and reliability in FANET environments.
- **Assessment of Protocol Behavior under Varying FANET Conditions:** The protocols are tested across multiple simulation scenarios involving changes in UAV speed, network density, and traffic load. These scenarios reflect real-world FANET dynamics and help identify how each protocol adapts to increasing mobility, congestion, and scalability challenges.

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II. Literature Review

Routing protocols are designed to facilitate and ensure an efficient communication between UAV nodes. The protocols help manage dynamic topology, high mobility and intermittent connectivity in FANETs. These protocols contain the process and steps for UAV nodes to find the routes from the source to base destination nodes or to multi-UAVs [2][3]. Routing protocols are mainly classified as proactive, reactive and hybrid each with distinct mechanism for route discovery and maintenance as illustrated in figure 2.

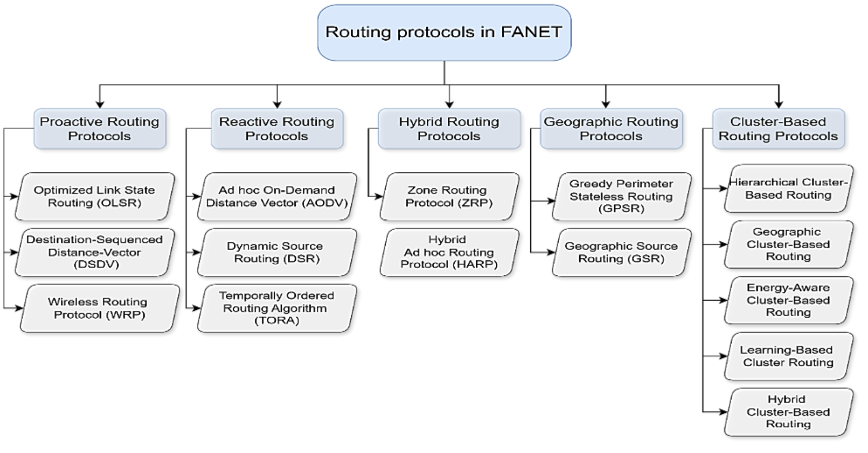

Fig2: Classification of Routing Protocols.

Prior research has analyzed the performance of individual routing protocols in Mobile Ad-hoc Networks (MANETs) and Vehicular Ad-hoc Networks. However, a comprehensive comparative analysis considering both proactive and reactive protocols using NS-3 is limited in FANETs. Proactive protocols, such as OLSR [4], work on the basis of a routing table, where it contains all routing information. The table is periodically updated and shared among all nodes in the network based on changing in network topology, while in reactive routing protocols like AODV, the route is established only on demand. Variants like AODV-ETX enhance reactive routing by incorporating link-quality metrics, potentially addressing unreliable wireless links [5][6].

Several studies have done of routing protocol in FANET, further there is a lack of details in mobility model that used in their research, their foundational study highlights the necessity for advanced simulators and 3D mobility models to effectively address FANETs'

http://www.doi.org/10.62341/mmaa2707

dynamic challenges. Table 2 presents a comparative summary of key related works on routing protocol evaluation in FANETs. It highlights the simulation tools, evaluated protocols, experimental scenarios, performance metrics, key findings, and limitations of each study.

Table 2: A Comparative of Existing Studies on FANET Routing Protocol Performance

Study	Protocols Evaluated	Simulation tools	Scenario Considered	Metrics Used	Limitations	Strengths / Contributions
Alrayes, M. M., & Elwaer, A., (2025), [6].	AODV-ETX, AODV.	NS-3	Mobility, node density	PDR, Delay, Throughput.	Limited ETX-specific focus, lacks hybrid analysis	ETX effects on FANETs under varying conditions
Salma Badaw et al [7](2021)	AODV, DSR, OLSR, ZRP	NetSim	Disaster management	PDR, Delay, Throughput ,packet Overhead	Consider 2D simulation area.	Evaluation under emergency scenario
Garcia-Santiago et al., (2018) [8].	AODV, DSDV	NS-2	Robotic FANETs	PDR, Delay	No real-world scalability test	Further results for robotic applications
Leonov, A. V., & Litvinov, G. A., (2018) [9].	AODV, OLSR	NS-2	SAR & monitoring missions	Delay, Throughput	Limited to static mission profile	Mini-UAV applicability in practical settings
Rani, A., & Bhardwaj, V., (2024). [10]	AODV, DSR, ZRP	NS-3	General mobility	PDR, Throughput.	lack of details in mobility model that used in their research	Evaluates three protocols under similar settings
K. Singh al.(2015) [11]	AODV-DSDV-OLSR	NS-2.	General mobility	Delay, Throughput.	Limited results, Consider 2D simulation area	Evaluates three protocols under similar settings
Zayed Khalifa al(2024)[12]	AODV-ETX, AODV.	NS-3	3D simulation area.	delay, throughput, packet delivery ratio, and useful traffic ratio	Not study hybrid routing algorithm	ETX effects on FANETs under varying conditions

http://www.doi.org/10.62341/mmaa2707

III. Simulation Results and Analysis

1. Methodology and Evaluation Framework

To evaluate the performance of the selected routing protocols in FANETs, this section outlines the simulation environment, including the network topology, mobility models, traffic patterns, and key simulation parameters. The setup is implemented using the NS-3Version 33[13] simulator to replicate realistic UAV network conditions. Additionally, a set of standardized performance metrics such as end-to-end delay, throughput, packet delivery ratio, and useful traffic ratio are defined to assess the effectiveness and efficiency of each protocol under varying network scenarios. Table 1, provides simulation parameters used in simulation environment, while Figure 3 shows the simulation topology.

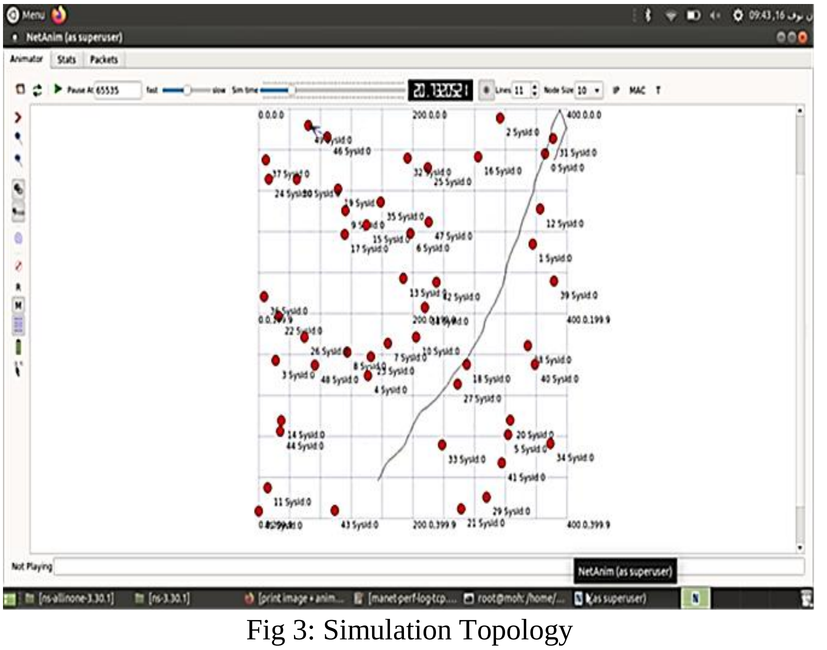

Fig 3: Simulation Topology

Table3: Simulation parameters

Parameter	Value
Application Type	Constant bit rate (CBR).
Number of UAV sources that transmit packets.	20

http://www.doi.org/10.62341/mmaa2707

Routing Protocols	AODV-ETX,AODV-hop count ,OLSR
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[14].
Speed Mobilty	[0-60]m/s.
Mobility model.	Random way point.
MAC layer.	802.11p
Antenna model.	Omni Antenna.
Propagation model.	TwoRayGroundPropagationLoss Model.

2. Performance metrics

This section outlines the key performance metrics employed to evaluate the routing protocols under study, following the approach presented in [18]:

- **Average Throughput**: This metric quantifies the successful data delivery rate, measured in bits per second (bps), representing the total number of bits received at the destination UAVs during communication.

$$Average\ Throughput\ [b/s] = \frac{P_r * 8}{T_r - T_s} \quad (1)$$

Where P_r is the total number of successfully received packets in bytes, T_s is the time when the first packet is transmitted, and T_r is the time when the last packet is received.

http://www.doi.org/10.62341/mmaa2707

- **Average End-to-End Delay (AEED):** This represents the average time taken for data packets to travel from the source to the destination UAVs, expressed in milliseconds (ms).

$$AEED = End\_to\_End\_delay \times 1000(ms) \quad (2)$$

Where:

$$End\_to\_End\_delay = \frac{TDT}{\sum_{i=1}^{N} P_r} \quad (3)$$

$$TDT = \sum_{i=0}^{N} delay\,[i] \quad (4)$$

$$delay[i] = T_r[i] - T_s[i] \quad (5)$$

Here, delay[i] is the delay for the i^{th} flow, and N is the total number of successfully received packets.

- **Packet Delivery Ratio (PDR)**: This metric evaluates the reliability of the routing protocol by calculating the ratio of the number of data packets successfully received by the destination UAVs to the total number of packets transmitted by the source UAVs.

$$PDR = \frac{Totalnumberofrecieveddatapackets}{totalnumberofsentdatapackets} \times 100 \quad (6)$$

- **Useful Traffic Ratio (UTR)**: UTR assesses bandwidth efficiency by measuring the proportion of received data packets relative to the total transmitted packets (including both data and control packets).

$$UTR = \frac{Total\ number\ of\ recieved\ data\ packets}{total\ number\ of\ sent\ packets} \times 100 \quad (7)$$

The total sent packets include both application-layer data and control overhead across all layers.

IV. Results and Discussions

The simulation experiments results are discussed under various scenarios; the OLSR protocol has juxtaposed simulation

http://www.doi.org/10.62341/mmaa2707

results with the original AODV and AODV-ETX protocols. Further, the simulation model that has been discussed in the previous section was used to assess and demonstrate the end-to-end delay, throughput, packet delivery ratio, and effective traffic ratio. Each data point signifies an average from a minimum of 10 iterations using identical traffic models, albeit with randomly generated mobility scenarios. This work employs uniform mobility and traffic scenarios.

The following three experiments were conducted to evaluate the performance of AODV, AODV-ETX and OLSR:-

- Varying speed of UAVs.
- Varying number of UAVs.
- Varying number of Traffic Sources.

1. Varying speed of UAVs

In this scenario, the effect of the movement of UAVs has been studied by varying the speed of the UAVs from 10 m/s to 60 m/s, with increments of 10 m/s, within a network comprising 50 UAVs, of which 20 are designated as sources of traffic, that send at a data rate of 2048 bps and a packet size of 64 bytes.

Figure 4 clarifies the average end-to-end delay for AODV, AODV-ETX, and OLSR protocols. The results indicate that each protocol has its performance characteristics. For example, the AODV used the hop count metric; the delay decreased as the UAV speed increased, going from 211 ms at 10 m/s to 99 ms at 60 m/s. This study indicates that AODV adapts to higher mobility by consistently choosing more efficient routes. AODV-ETX illustrates the greatest delay, with values between 230 and 260 ms. The AODV-ETX gives priority to link quality rather than the shortest path, which frequently leads to longer routes and increased end-to-end delay. In contrast, OLSR is a proactive protocol that sustains a topology map via regular updates, thereby ensuring route availability as required. OLSR exhibits the lowest and most consistent end-to-end delay values across varying UAV velocities (i.e. is ranging from 159 to 179 ms).

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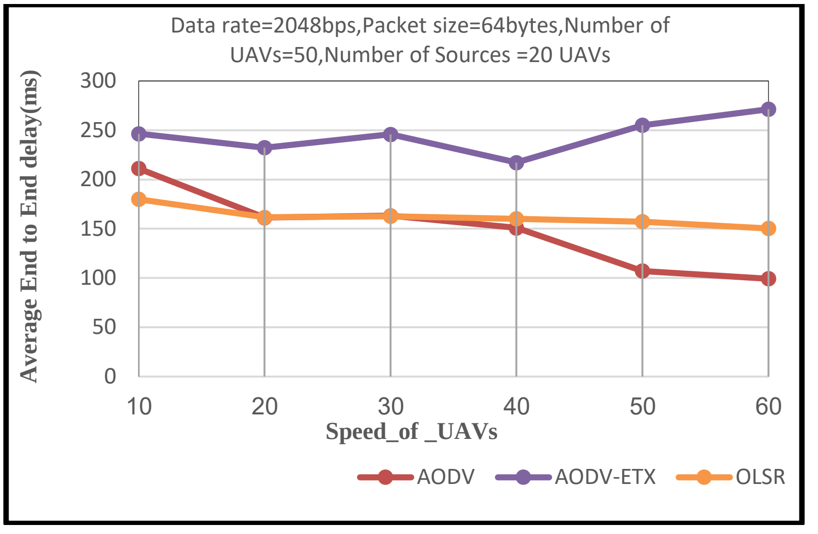

Fig1: Speed of UAVs versus Average End to End Delay

Figure 5 illustrates the performance of packet delivery ratio for AODV, AODV-ETX, and OLSR as a function of UAV speed.

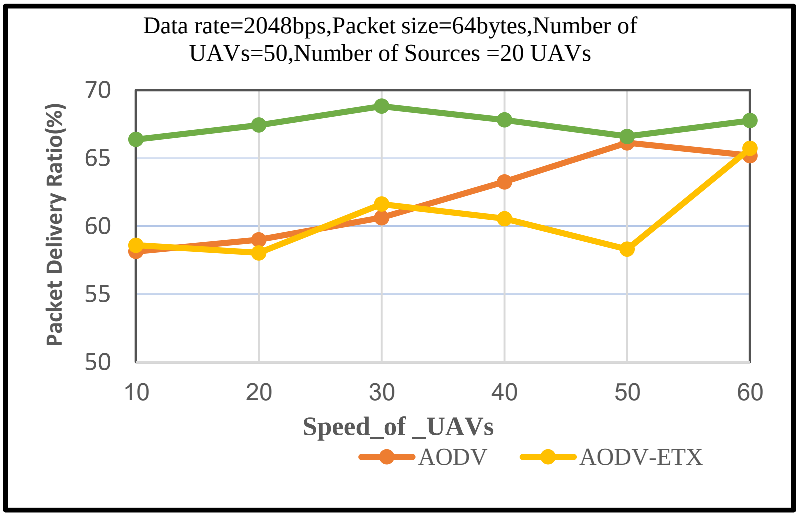

Fig5. Speed of UAVs versus Packet Delivery Ratio.

OLSR consistently has the best packet delivery ratio (PDR), which is between 66% and 68% at all speeds, because it's proactive in nature, which sustain a current topology map via regular updates, it shows the least amount of change, which lowers the chance of packet loss due to old or unavailable routes.

http://www.doi.org/10.62341/mmaa2707

AODV-ETX shows the greatest variability in packet delivery ratio (PDR), fluctuating between 58% and 65%. The AODV-ETX seeks to enhance dependability by choosing routes with best link quality, particularly noticeable at speeds between 20 and 60. AODV retains a reasonable packet delivery ratio (PDR) between 58% and 65%, such that route discovery delays can lead to packet loss within a mobile context.

In AODV, the PDR, on the other hand, rises to 65% at speed 60, which shows that AODV can react to changes in the topology, because it rediscovers routes more often at higher speeds.

It can be seen from figure 6, OLSR consistently exhibits the highest useful traffic ratio across all speeds, peaking at 9 and declining to 8.5 at the maximum speed. Nonetheless, being a proactive protocol, OLSR incurs a considerable number of control overhead packets due to regular topology changes (e.g., Hello and topology Control messages). The amount of overhead from control packets increases with an increase in UAV speed, as the topology undergoes more frequent changes requiring periodic updates; the useful traffic ratio declines incrementally, illustrating increased control overhead and a decrease in data traffic ratio. It starts with a slightly lower useful traffic ratio than OLSR (9.0), and as speed goes up, it drops significantly, achieving 8.5 at speed 60 m/s. AODV, as a reactive protocol, produces control packet overhead only during the route discovery phase. At lower velocities, the topology exhibits greater stability, necessitating fewer route discoveries, hence having a relatively low control overhead. As UAV speed increases, the topology changes more often, requiring further route discoveries and increasing the control overhead. This leads to a decreased usable traffic ratio at higher speeds, as a greater percentage of the traffic comprises control messages. AODV-ETX consistently demonstrates the lowest effective traffic ratio, commencing at 4.0 and down to 2.5 at maximum velocity. The AODV-ETX metric needs supplementary control overhead to assess link quality. This overhead exceeds that of AODV, as it entails continual monitoring of link quality to identify feasible paths. When the speed of UAVs increases, the topology of the network changes frequently, which forces AODV-ETX to recalculate routes and update link quality metrics; hence, control packet overhead becomes more noticeable, and the control messages consume a higher amount of traffic than data, so the usable traffic ratio drops significantly.

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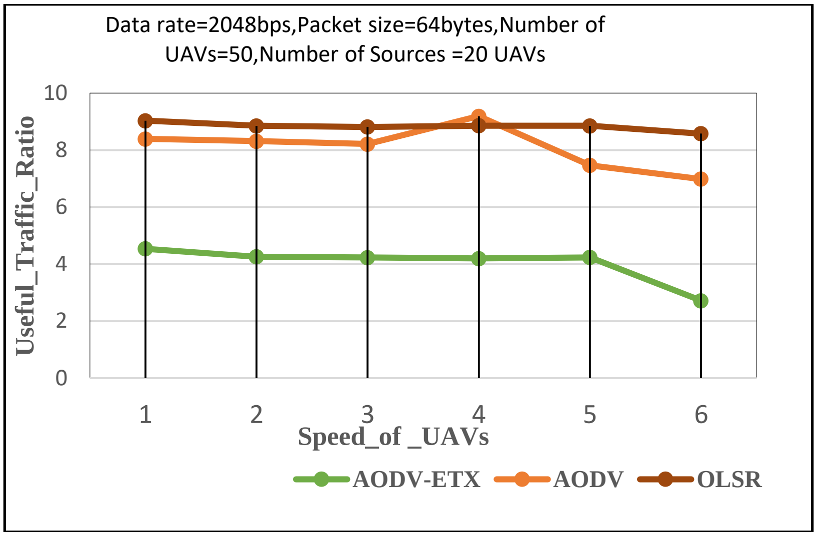

Fig6. Speed of UAVs versus Useful Traffic Ratio

Figure 7 shows how the performance of average throughput changes with the UAV maximum speed. It is clear that OLSR regularly gets the highest throughput (1362–1410 bps), which shows how well it sends data. AODV shows a moderate throughput, ranging from 1193 to 1357 bps. As a reactive protocol, AODV-ETX exhibits the most variability in throughput, ranging from 1191 to 1348 bps.

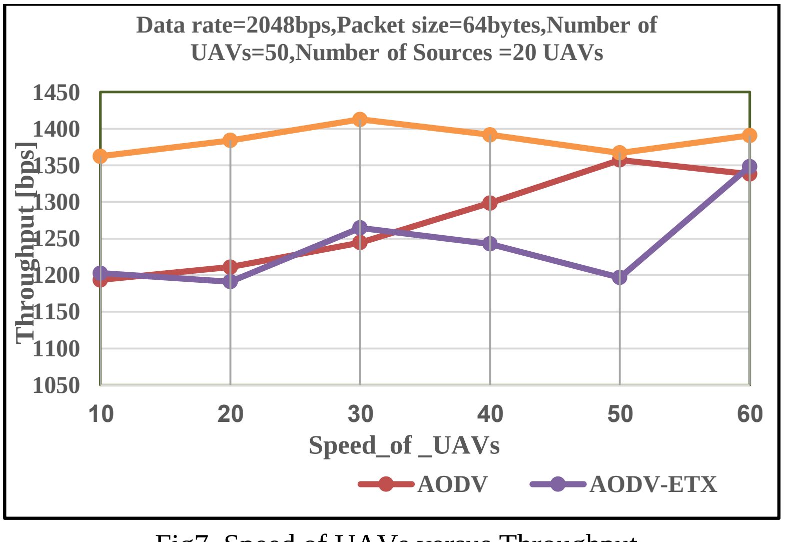

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Fig7. Speed of UAVs versus Throughput.

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2. Varying Number of UAVs

In this scenario, the effect of the movement of UAVs has been studied by varying the speed of the UAVs from 50 to 200, with increments of 25, where the speed of each UAV is 5 m/s and the number of UAVs that send traffic is 20, with a data rate of 2048 bps and a packet size of 64 bytes.

From figure8, the observation shows that the AODV has moderate increase in delay as the network scales, likely due to increased congestion , at 50 UAVs, the delay starts around 171 ms and then slightly increases to about 363 ms. The delay remains relatively stable, hovering around 250–360 ms, while beyond 150 UAVs, it increases slightly, reaching around 350 ms.

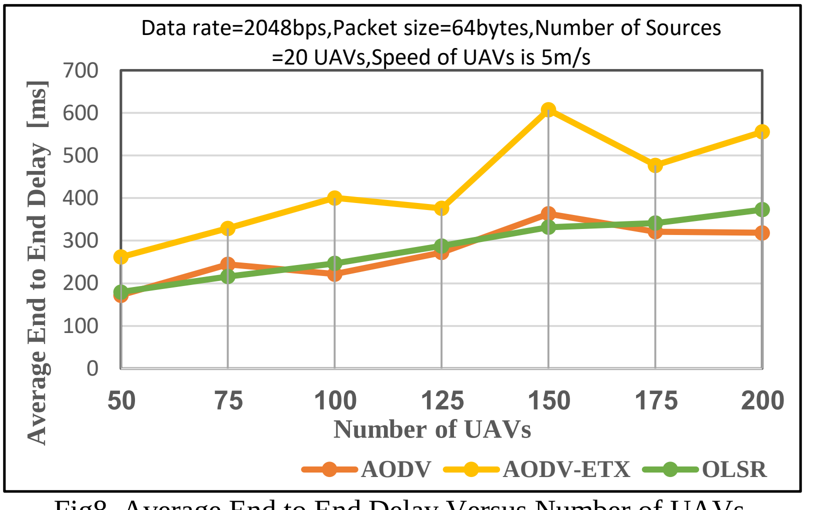

Fig8. Average End to End Delay Versus Number of UAVs.

While in OLSR, the performance remains stable, demonstrating a gradual increase in delay as network density size expands. The delay with 50 UAVs is roughly 200 ms, comparable to the AODV; the delay increases as the number of UAVs increases, with UAVs settling at around 350 ms between 150 and 200 UAVs.In contrast, AODV-ETX, the selection routes based on the expected number of transmissions needed to successfully deliver a packet, we notice that it struggles with scalability, showing a significant spike in delay (up to 600 ms) at 150 UAVs, where at 50 UAVs, the delay is around 250 ms, slightly higher than the AODV, and starts to increase as the number of UAVs grows, peaking at around 600 ms when the number of UAVs reaches 150; after 150 UAVs, the delay decreases to around 477 ms at 175 UAVs and slowly starts to increase again at 550ms when the number of UAVs is 200; the AODV-ETX has the highest delay among protocols.

As shown in figure 9, in all protocols, the packet delivery ratio (PDR) decreases as the number of UAVs increases, specifically, the network density increases, leading to a higher probability of collision as the number of UAVs increases from 50 to 200

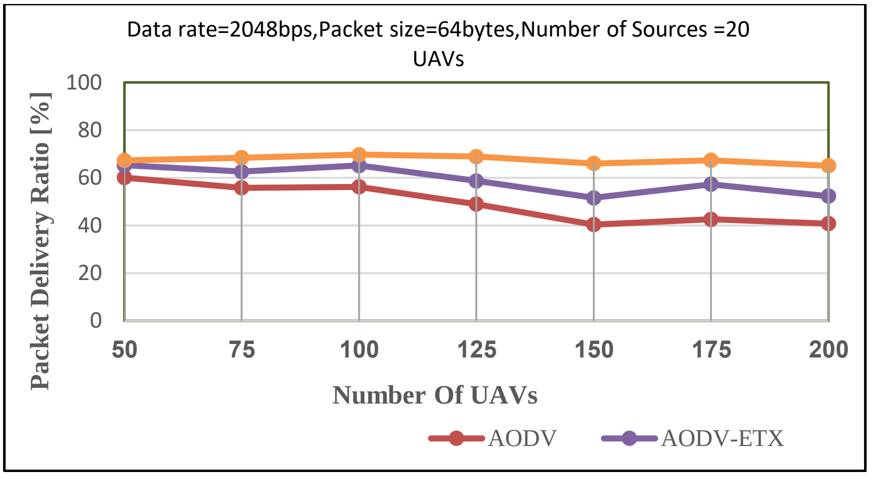

Fig9. Packet Delivery Ratio versus Number of UAVs.

. In AODV, PDR starts at about 60% for 50 UAVs and drops to 40-45% for 200 UAVs, struggling in larger networks. And stays around 55% for up to 125 UAVs. It grows slightly to 45% at 175 UAVs but then falls back to 40% at 200 UAVs, this shows that AODV has difficulty getting reliable in denser networks. This is probably because it doesn't take quality of link into account, which causes more packet losses due to congestion. While in the AODV-ETX protocol emphasizes link quality by estimating the expected transmission count; it starts with a PDR of about 65% at 50 UAVs, which remains consistent up to 100 UAVs, then declines to 58% at 125 UAVs, drops to 50% at 150 UAVs, experiences a slight recovery to 57% at 175 UAVs, and ends at 52% at 200 UAVs. The observed pattern suggests that AODV-ETX initially performs well, but it encounters difficulties in a large network. The reliance on outdated link quality estimates under dynamic conditions may account for this. The OLSR protocol, using proactive routing, offers

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the greatest and most reliable PDR; it starts at 67% at 50 UAVs and remains at this level up to 125 UAVs, then slightly decreases to 65% at 150 UAVs and fluctuates between 65% and 65%-67% up to 200 UAVs. This consistency ensures that OLSR effectively adjusts to increases in network size.

In figure 10, AODV shows a moderate useful traffic ratio, ranging from 6.6% to 0.6%. At 50 UAVs, AODV's useful traffic ratio begins at around 6.6%, declining to 2.9% at 75 UAVs, 2.8% at 100 UAVs, 1.18% at 125 UAVs, 1.1% at 150 UAVs, 0.79% at 175 UAVs and 0.6% at 200 UAVs. The reactive nature leads to reduced control overhead in smaller networks due to infrequent route discoveries. But as the network size gets expanded, the increased frequency of route discoveries, caused by a denser and more dynamic topology, and increased link breakages result in a lower useful traffic ratio. AODV’s performance lies between OLSR and AODV-ETX, more efficient than AODV-ETX but less efficient than OLSR’s effectiveness.

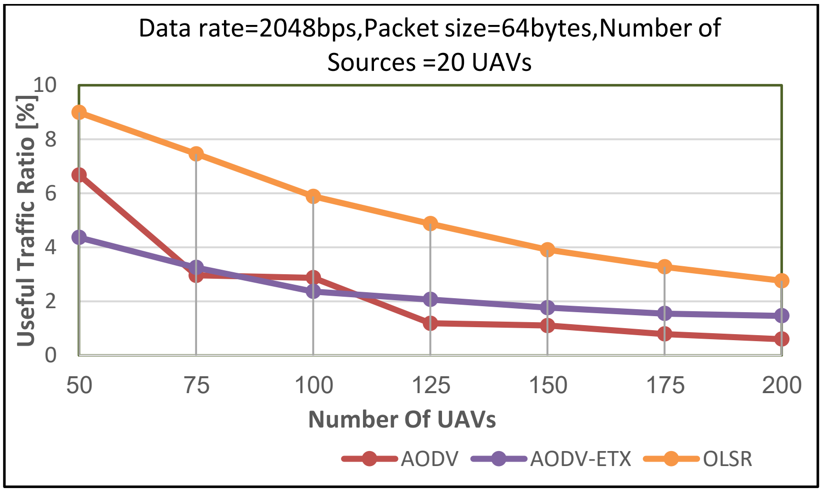

Fig10. UTR versus Number of UAV.

OLSR reliably achieves the highest useful traffic ratio, ranging from 8.9% with 50 UAVs to 7.5% at 75 UAVs, 5.8% at 100 UAVs, 4.8% at 125 UAVs, 4% at 150 UAVs, 3.5% at 175 UAVs and 2.7% at 200 UAVs. Even with the control overhead from periodic topology updates, OLSR maintains the highest useful traffic ratio. It ensures effective bandwidth utilizations for smaller networks. A

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higher proportion of control traffic reduces the useful traffic ratio as the number of UAVs increases. AODV-ETX has the lowest useful traffic ratio; at 50 UAVs, AODV-ETX starts with a useful traffic ratio of around 4.3% and then decreases steadily. 3.2% at 75 UAVs, 2.3% at 100 UAVs, 2% at 125 UAVs, 1.76% at 150 UAVs, 1.54% at 175 UAVs, and 1.46% at 200 UAVs. The AODV-ETX has a significant control overhead by demanding continuous monitoring of link quality, which increases as the network size grows. The severe drop in the useful traffic ratio at large networks highlights AODV-ETX's inefficiency in terms of using bandwidth.

It can be seen from figure 11, all three protocols exhibit decreasing throughput as the number of UAVs increases from 50 to 200, the AODV has the lowest throughput; it ranges from about 829 to 1233 bps, starting at 1233 bps with 50 UAVs and gradually decreasing to 829 bps with 200 UAVs. This is due to its reactive protocol, which increases the number of route discovery processes as an increase in congestion when the network becomes denser. OLSR's throughput varies from 1381 to 1430 bps across different sizes of networks, peaking at 1430 bps with 100 UAVs and thereafter decreasing to about 1330 bps as the UAV count rises to 200. This protocol achieves the greatest throughput of the three by employing a proactive routing strategy and uses multi-point relay to reduce control overhead packet, which prebuilds and maintains routes when the topology changes, ensuring efficient packet delivery with minimal loss in packets. We notice a small decline in throughput when the number of UAVs is 200; this is because of the escalation in the number of control packets overhead that is necessary to build up a route when the topology changes in a denser network, which can be attributed to the growing control packet overhead required to manage the changes in network topology in a denser network, together with heightened interference that impacts data transmission efficiency. In contrast AODV-ETX demonstrates a variable throughput, ranged from 1338 to 1073 bps, commencing at 1338 bps with 50 UAVs, decreasing to 1004 bps at 125 UAVs, reaching a maximum of 1058 bps at 150 UAVs, and then declining to 1200 bps at 200 UAVs. The AODV-ETX measure improves throughput in smaller networks by choosing dependable links; however, the overhead of link quality monitoring and route re-computation in larger networks results in packet loss and reduced throughput.

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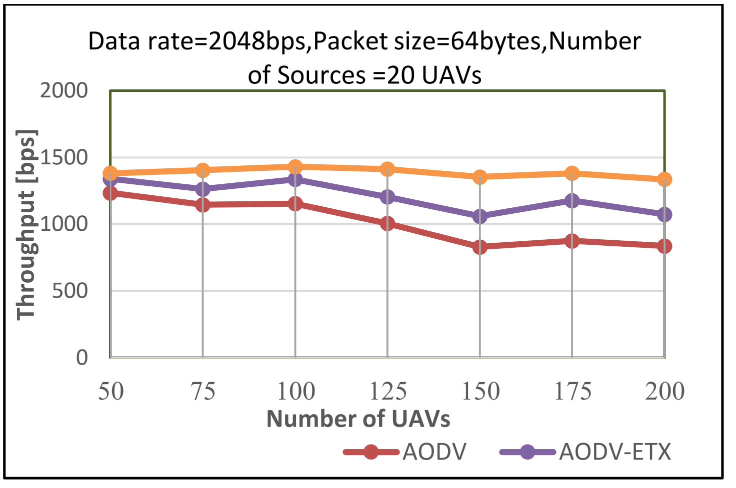

Fig11.Throughput. versus. Number of UAVs

3. Varying number of traffic Sources

The performance of routing protocols is evaluated with the number of sources (i.e., flows) varying from 10 to 50. In the number of sources, the simulation settings are as follows: data rate = 2048 bps, packet size = 64 bytes, number of nodes = 75, and mobility speed = 60m/s.
The purpose of this study is to analyze the capacity of the UAVs networks.

As shown in Figure 12, AODV starts with the lowest initial delay of 64 ms and a gradual increase to 212 ms as the number of sources grows to 50. As a reactive protocol, AODV discovers routes on demand, which results in low latency in sparse traffic conditions (10 sources). Nonetheless, the delay rises with more sources due to an increase in potential congestion, as more routes need to be discovered. With 10 sources, the average end-to-end delay of AODV begins at approximately 64 ms. the delay progressively escalates to 100 ms with 20 sources, 178 ms with 30 sources, 190 ms with 40 sources, and 212 ms with 50 sources. This delay indicates that AODV operates effectively under low traffic conditions but struggles to scale efficiently with higher traffic. OLSR maintains a moderate and comparatively stable delay, which is between 180 and 200 ms. the slight decrease in delay at 20 sources may reflect a balance between network load and route availability, despite the minor increase in delay caused by the added traffic from

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50 sources. AODV-ETX experiences the highest delay (250-350ms) with 30-40 sources, which priorities routes based on link quality that takes more overhead to analyses and pick options, increasing initial delays. As traffic increases, monitoring link quality might need extra route discovery and queueing delay. Although the minor drop at 50 sources may reflect adaptation, the overall high delay implies inefficiency, especially under heavy source traffic.

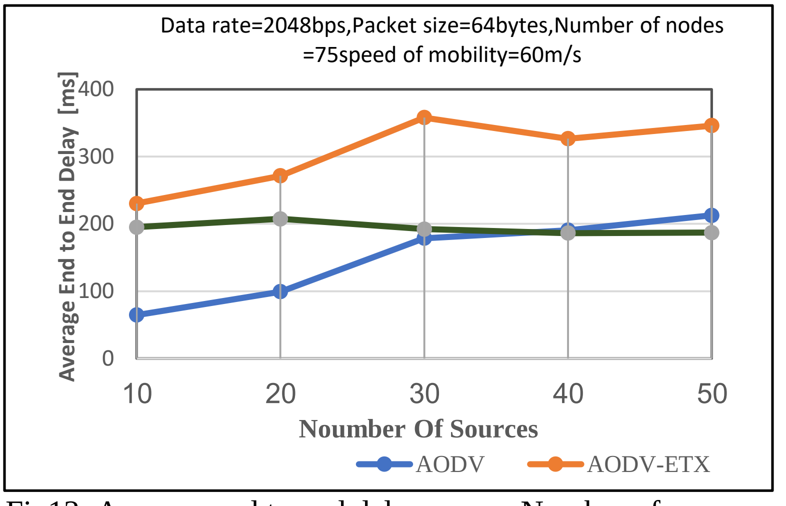

Fig12. Average end to end delay versus Number of sources.

Based on Figure 12, as we can see from the figure 13, The PDR decreases across all protocols as the number of sources increases, indicating the difficulties of handling more traffic within a FANET environment. The AODV, achieves a PDR of around 68% when the number of sources is 10, which is moderate compared to AODV-ETX and OLSR. When the number of sources is minimal, the network load is light, allowing AODV to establish routes with low contention and less control packet overhead, lead to a reasonable PDR. As the number of sources increases to 20, the PDR drops to 65% and further to 43% at 30 sources, 33% at 40 sources, and reaches 31% at 50 sources, and it is the lowest among the three protocols, as more nodes sending packets lead to higher network traffic and potential congestion causing packet drops. AODV's reactive protocol struggles to keep up, as the overhead of route discovery and maintenance process grow, resulting in a substantial reduction in PDR.OLSR has maintained the highest PDR, ranging from 69.9% to 60.75% with a slow decline; its performance is superior to both AODV and AODV-ETX. As a proactive protocol,

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OLSR precomputes routes and updates topology continuously, ensuring better reliability even with 50 sources. The AODV-ETX starts with a PDR of 72% at number of sources is 10 but drops gradually up to 50.7% when the number of sources is 50, showing a steeper decline but better than AODV and worse than OLSR. The AODV-ETX selects routes based on link quality; it is obviously struggling at high traffic, suggesting that the additional overhead outweighs the benefits of the selection of the best link quality in a high-traffic scenario.

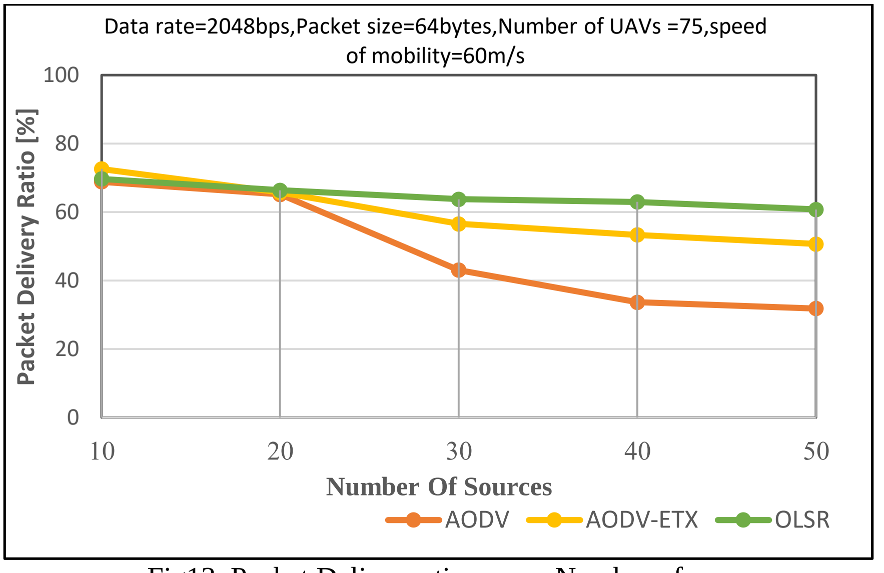

Fig13. Packet Deliver ratio versus Number of sources.

From figure 14, we can see that AODV starts at 7.5% when the number of sources is 10, which is higher than AODV-ETX; OLSR demonstrates AODV's poor scalability with an increasing number of sources, as its UTR drops from 7.5% to 2.5%. The low number of sources results in a reduced need for route discovery mechanisms. With 20 sources, the UTR slightly decreases to 6.98%, indicating the AODV's ability to manage moderate traffic effectively. The UTR is higher than AODV-ETX (2.7%) and OLSR (6.928%). It is indicating AODV operates efficiently within this range. At 30 sources, the ratio drops sharply to around 2%, reflecting a significant decrease in UTR. We notice the UTR has steadied at 2% when the number of sources ranges from 30 to 50; this means it has poor UTR under heavy traffic loads. While in OLSR, the UTR has started at 5.1% at 10 sources and increases slowly to 8.4% at 50

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sources, showing the best performance. OLSR has maintained routing tables via periodic updates, which allows it to handle higher traffic loads efficiently. We can observe that OLSR's control overhead becomes more manageable relative to data traffic as more sources are added. On the other hand, the AODV-ETX starts with a useful traffic ratio of 2% at 10 sources, increases slightly to 3% at 20 sources, drops to 2.5% at 30 sources, and stabilises around 3% from 30 to 50 sources. AODV-ETX has a consistently low ratio, reflecting the additional overhead from continuous link quality monitoring. This bandwidth efficiency makes AODV-ETX less efficient than AODV in this scenario, especially under high traffic.

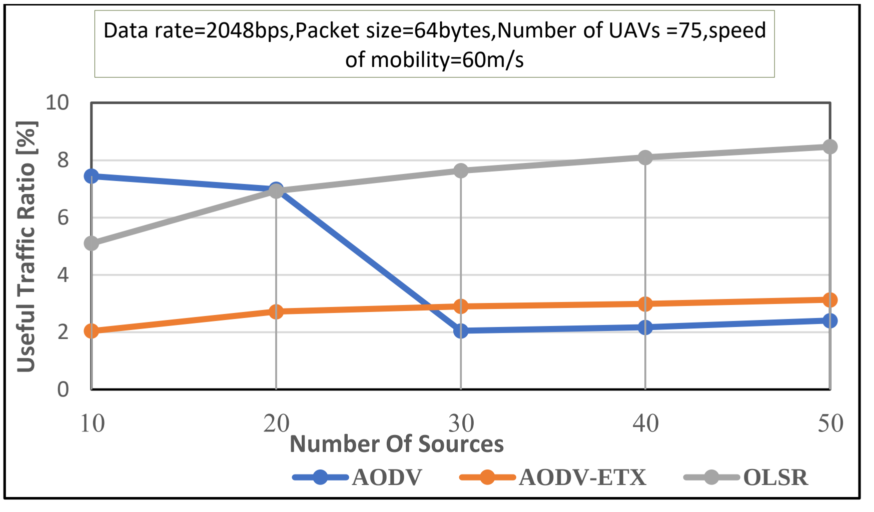

Fig14. Useful traffic ratio versus Number of sources.

Figure 15 depicts that throughput of all protocols decreases as the number of sources increases. AODV shows the lowest throughput, starting at 1413 bps with 10 sources and decreasing to 653 bps with 50 sources. We notice that as more nodes attempt to transmit packets simultaneously, contention on the channel arises, which will contribute to the likelihood of collisions. Because AODV is reactive, it has trouble handling this traffic since it doesn't have any pre-calculated routes to handle fast traffic spikes. This makes it even less efficient.

While in AODV-ETX, probe packets are required to evaluate link quality, contributing to the contention channel. While this approach improves route selection, the additional overhead control packet increases collisions, resulting in packet loss. The throughput starts

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at 1489.143 bps when the number of sources is 10 and is reduced to 1040.48 bps; however, it shows its throughput is better than AODV because it selects the route based on link quality, which will lead to lower packet loss and higher throughput.

As a proactive protocol, OLSR's control messages are periodic and predictable, reducing contention compared to on-demand messages in reactive protocols. This results in lower packet loss and high throughput; it has lower packet loss among other protocols. Although of that, the throughput has reduced as the number of sources increases. The throughput starts at about 1430.80 when the number of sources is 10 and reaches 1247 when the number of sources is 50.

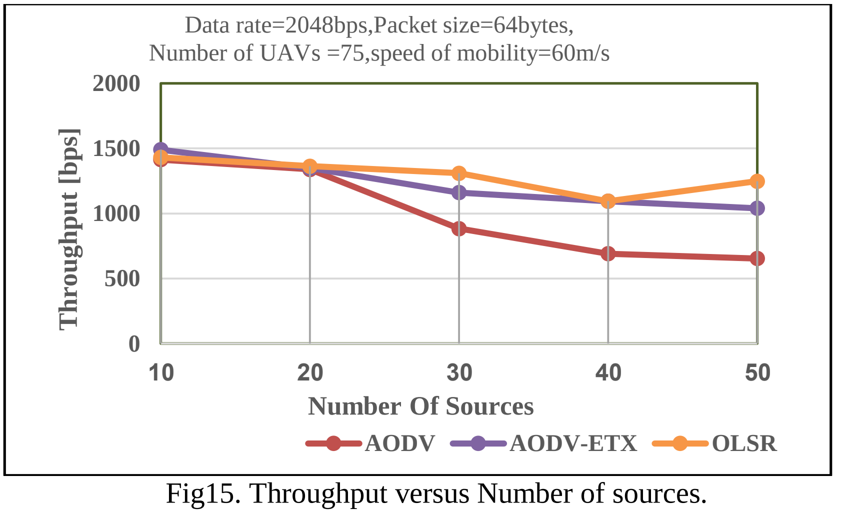

Fig15. Throughput versus Number of sources.

V.CONCLUSION

This research explored the performance of Optimized Link State Routing OLSR, AODV and AODV-ETX routing protocols in FANETs, using the NS-3 network simulator, since there is no previous studies comprehensively compare AODV, OLSR, and AODV-ETX in FANETs as our knowledge.
Simulations were conducted across network sizes ranging from small to large, the UAV mobility speeds ranging from low to high and network loads ranging from low to high for evaluating key metrics, including useful traffic ratio, packet delivery ratio, end to end delay and throughput. The results demonstrate that OLSR consistently outperforms AODV and AODV-ETX, offering

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superior reliability despite contention challenges that significantly impact reactive protocols.
In situations when mobility speeds vary, AODV outperforms AODV-ETX, while AODV-ETX excels under varying traffic loads and network sizes. These findings advocate for OLSR in dynamic and dense FANETs, providing a foundation for protocol selection in UAV communication networks. Future studies could investigate adaptive or hybrid routing algorithms to enhance FANETs performance.

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