Analysis and optimization of OLSR and AODV routing protocols for highly mobile autonomous aerial vehicle networks: experimental performance evaluation in various application scenarios

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ABSTRACT

Driven by the rapid evolution of Autonomous Aerial Vehicle (AAV) technology, ad-hoc AAV networks are becoming increasingly significant in diverse domains such as telecommunications, security surveillance, search-and-rescue operations, emergency management, precision agriculture, and cargo transportation. Owing to their flexible deployment and tight coordination capabilities, AAVs enable real-time data exchange, unlocking considerable potential for tasks that demand high accuracy and swift response. Nevertheless, their three-dimensional mobility and continuously changing topology impose substantial challenges on the design of suitable routing solutions, because conventional protocols originally developed for Mobile Ad-hoc Networks (MANETs) are seldom optimized for aerial characteristics. This discrepancy underscores the necessity for a comprehensive analysis and optimal configuration that satisfy the stringent requirements of low latency, high throughput, and reliability in mission-critical AAV applications. Against this backdrop, the present study focuses on the analysis and modelling of two widely adopted routing protocols—Optimized Link State Routing (OLSR) and Ad hoc On-Demand Distance Vector (AODV)—in various deployment contexts of ad-hoc AAV networks. By evaluating the performance of these protocols, we identify their advantages, limitations, and possible enhancement directions, and subsequently propose configuration guidelines that deliver improved link quality.

1 INTRODUCTION

Against the backdrop of swift advances in telecommunication technologies, AAVs are attracting growing research attention and seeing ever-wider practical adoption. Unlike traditional communication approaches that rely on terrestrial infrastructure, AAVs extend network coverage into the airspace, enabling optimized service areas, reduced deployment costs, and flexible adaptation to contemporary connectivity demands. Establishing telecommunications infrastructure based on AAVs, however, poses several challenges, most notably in routing capability, real-time data exchange, and Quality-of-Service (QoS) assurance. This section analyses the broader context and importance of AAVs with a particular emphasis on telecommunications, while also identifying design obstacles that are specific to AAV networks.

Context and significance of Autonomous Aerial Vehicles

Leveraging breakthroughs in electronics, wireless communication, artificial intelligence (AI), and battery technology, AAVs are recognized as a crucial platform for next-generation telecommunications infrastructure. Moreover, the convergence of Edge-Computing solutions [1], 5G-to-6G technologies, and the Internet-of-Things (IoT) trend empowers AAVs not only to collect information but also to process, relay, and even provide connectivity services to external entities [2].

At present, Autonomous Aerial Vehicles (AAVs) are being integrated into numerous practical telecommunication scenarios, including but not limited to the following:

- Temporary mobile broadcasting nodes—During mass gatherings or in disaster-stricken areas, AAVs equipped with on-board gNodeB (5G) or eNodeB (4G) units can promptly augment network capacity and temporarily extend coverage without the costly construction of cumbersome terrestrial infrastructure [2].
- Last-mile connectivity solutions—In mountainous terrain or regions with under-developed infrastructure, AAVs operate as relay entities between end-user equipment and ground base stations, thereby markedly enhancing link quality and service continuity.

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- Monitoring and data acquisition—Owing to their agile maneuverability, AAVs can continuously refresh imagery, video streams, or environmental information and forward these data sets to a processing center, supporting urban management, precision agriculture, and climate-change surveillance [3].

The harmonious convergence of AAV platforms with cutting-edge telecommunication technologies has accelerated the digitalization of diverse socioeconomic activities, yielding improved operational efficiency, cost reduction, and the emergence of novel business models.

In the context of burgeoning applications such as telepresence, virtual reality (VR), smart healthcare, and 5G/6G services, AAVs have further substantiated their role as a flexible, cost-effective, and high-performance solution for monitoring and emergency support [4]. By virtue of sustained radio transmission, real-time data processing, and high mobility, AAVs can rapidly establish communication bridges in regions where the existing infrastructure is impaired or inaccessible. Consequently, rescue teams and command centers can exchange information, high-definition live video, and geospatial data to track evolving situations, localize victims, and implement timely interventions. In telemedicine applications, for instance, AAVs not only facilitate the transport of critical medical data and enable live consultations but also deliver equipment or biological specimens to isolated areas, thereby shortening response times and elevating treatment efficacy. Moreover, the deployment of AAVs obviates the need for extensive terrestrial infrastructure—such as fixed towers or fiber-optic backhaul—conserving financial resources, manpower, and deployment time when compared with conventional solutions. Hence, AAVs constitute a pivotal element within the intelligent-telecommunications ecosystem, underpinning emergency monitoring, enlarging coverage areas, and providing a platform for advanced services—including telepresence, VR, and smart healthcare—in scenarios that demand immediacy and stringent reliability.

Communication and Routing Challenges in AAV-Centric Networking Environments Despite their disruptive potential, AAV systems confront an array of technical hurdles, particularly as requirements for bandwidth, latency, and reliability continue to escalate. These obstacles become increasingly pronounced when AAVs operate in three-dimensional space, exhibit constant mobility, and must uphold stable connectivity.

- Highly dynamic topology in three-dimensional space—Because AAVs move at high velocity while continually changing altitude, radio links are inherently unstable. Conventional MANET-oriented routing protocols struggle to react in a timely manner to sudden link disruptions, necessitating either the fine-tuning of existing algorithms or the development of novel routing schemes that can adapt swiftly to topological perturbations.
- Energy and radio-resource constraints—Beyond sustaining flight, an AAV must uphold uninterrupted data exchange over radio channels characterized by finite capacity. To maximize mission endurance, the system must balance transmission efficiency against power consumption, a trade-off rendered more acute by high-bit-rate requirements such as HD video or real-time services.
- Channel interference and attenuation—Operating at altitude and in open space exposes AAVs to numerous external influences (weather, terrain, obstacles, signal reflections, etc.). The resulting channel instability calls for highly adaptive mechanisms in power control, modulation–coding selection, and routing strategy. Without optimization, fading and interference severely degrade link maintenance capabilities, culminating in elevated packet-loss ratios.
- QoS, low-latency, and security requirements—Many AAV applications, notably in monitoring and emergency support, demand data transmission with exceptional reliability and ultra-low latency. Routing protocols that are not tailored to meet these criteria may incur congestion, violate delay thresholds, or introduce security vulnerabilities.

Against this backdrop, the investigation and assessment of routing protocols for AAV networks are essential for identifying solutions that satisfy responsiveness, connectivity, and resource-efficiency objectives. In this article, we model and analyze two protocols—OLSR and AODV—under varying operational conditions, including AAV velocity, mobility model, fleet size, and mission-area dimension. By measuring throughput, latency, packet-loss ratio, and energy expenditure, we delineate each protocol's merits and limitations and propose configuration-optimization guidelines. The resulting insights facilitate the selection of an appropriate routing paradigm capable of achieving stringent QoS, reliability, and flexibility targets in modern AAV networking environments.

I. Classification of Routing Protocols in Autonomous Aerial Vehicle Networks

In recent years Autonomous Aerial Vehicle (AAV) networks have attracted growing attention, largely because three-dimensional operational space and high vehicle velocities make sustaining a stable communication channel particularly challenging. To address this issue numerous routing strategies have been proposed, all geared toward the agile maintenance and timely update of link information. In general, routing protocols for AAV networks can be grouped into five major families: proactive [5], reactive [6], hybrid [7], geographic [8], and swarm-intelligence/reinforcement-learning-based [9].

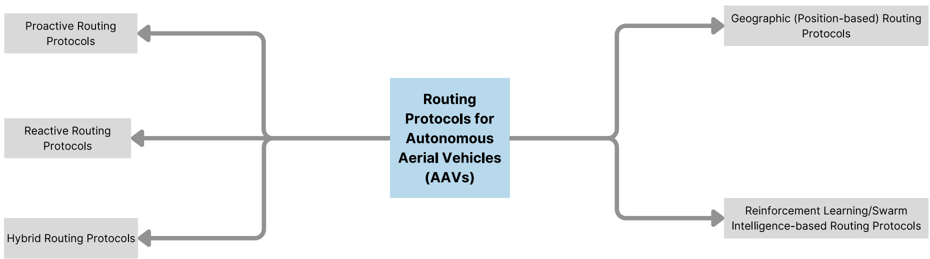


Fig. 1. Classification of routing protocols for Autonomous Aerial Vehicle networks.

1.1 Proactive Routing Protocols

Proactive schemes continuously maintain up-to-date routes to every node by periodically refreshing link-state information or routing tables. Because destination entries already reside in memory, route-establishment latency at data-transmission onset is minimized. Within fast-moving AAV networks these protocols are often favored for their ability to react promptly to incremental topological variations while supplying a global view that simplifies management and monitoring. Nevertheless, when AAVs maneuver incessantly and topology fluctuates rapidly, proactive solutions can consume substantial bandwidth and energy to keep routes current, a drawback that becomes pronounced as network scale increases. Representative examples include OLSR (Optimized Link State Routing), which employs a Multi-Point Relay (MPR) mechanism to curtail broadcast traffic, and DSDV (Destination-Sequenced Distance Vector), which couples classic distance-vector rules with sequence numbers to preserve routing consistency [5], [10].

1.2 Reactive Routing Protocols

In contrast, reactive schemes discover routes only when a data session is initiated, thereby reducing control overhead because topology information is not perpetually maintained. For AAV networks exhibiting bursty traffic or idle periods, this on-demand paradigm affords greater flexibility and conserves both bandwidth and energy. A notable drawback, however, is that initial route discovery can incur additional delay when packets must be dispatched suddenly. Furthermore, at very high AAV speeds the discovery process may be invoked repeatedly, causing network congestion or repeated re-establishment cycles. Widely used reactive protocols include AODV (Ad hoc On-Demand Distance Vector), which leverages sequence numbers to avoid loops, and DSR (Dynamic Source Routing), which relies on a route cache at the source node to reuse previously learned paths [6], [11].

1.3 Hybrid Routing Protocols

To combine the strengths of proactive and reactive approaches, hybrid protocols partition the network into zones or clusters. Within each zone the protocol behaves proactively for immediate responsiveness; between zones it adopts a reactive method to limit unnecessary large-scale broadcasts. For AAV networks this dual strategy mitigates routing-table exchange overhead while retaining prompt local reaction. Nevertheless, maintaining zone boundaries and managing clusters becomes complex when AAVs move continuously or as network size expands. A canonical example is the Zone Routing Protocol (ZRP), originally investigated for MANETs and later proposed for AAV scenarios [12].

1.4 Geographic Routing Protocols

Advances in positioning technologies such as GPS and high-precision inertial sensors have made location-based routing a promising solution for AAV systems. Instead of storing exhaustive link-state data, nodes keep only their current coordinates and those of the destination, forwarding packets via a greedy strategy. This method sharply lowers routing-table maintenance cost, as each node requires knowledge of only its immediate neighborhood rather than an entire multi-hop path. Geographic protocols still face challenges when position information is inaccurate or when voids arise in the three-dimensional space that hinder signal reachability. GPSR (Greedy Perimeter Stateless Routing) is a renowned member of this family, blending greedy forwarding with perimeter traversal to circumvent voids and adapt to diverse AAV scenarios [13], [14].

1.5 Swarm-Intelligence/Reinforcement-Learning-Based Routing

Beyond conventional designs, the application of swarm intelligence (SI) and reinforcement learning (RL) opens new avenues in AAV routing. Rather than relying solely on static routing tables, AAV nodes can learn mobility patterns and channel conditions, autonomously refining forwarding decisions over time. Inspired by the evolutionary behavior of insects or bird swarms, SI/RL schemes allow AAV networks to adapt gracefully to abrupt topological changes and channel dynamics. Yet computational complexity and the need to synchronize learned information across nodes can impose significant overhead—especially in resource-constrained environments. Ant Colony Optimization (ACO) and bee-inspired protocols use virtual pheromones to guide packet delivery, whereas Q-learning applies reward–penalty mechanisms to optimize objectives such as throughput or latency.

2 OPERATIONAL PRINCIPLES OF THE OLSR PROTOCOL

The Optimized Link State Routing (OLSR) protocol is grounded in the classical link-state paradigm but achieves greater efficiency through its Multipoint Relay (MPR) mechanism. Every node periodically exchanges link-state and routing information with its neighbors, thereby building a global routing table without waiting for a data-forwarding request. This proactive behavior enables swift packet delivery both in conventional ad-hoc networks and—more critically—in Autonomous Aerial Vehicle (AAV) environments. The key innovation lies in OLSR's selective use of MPRs: each node chooses a minimal subset of neighbors as relays such that every node in the network is reachable through at least one MPR, thus eliminating redundant broadcast transmissions. MPR selection is driven by link-quality and coverage criteria that markedly reduce control-traffic overhead.

OLSR defines three core control messages. HELLO packets discover and refresh neighbor relations; TC (Topology Control) packets advertise selected MPR links; and MID (Multiple Interface Declaration) packets list additional addresses when a node owns multiple interfaces. Parameters such as HELLO_INTERVAL and TC_INTERVAL specify the periodicity of HELLO and TC messages and hence directly influence link-state freshness versus bandwidth consumption. The WILLINGNESS parameter quantifies a node's readiness to forward traffic and thereby shapes MPR selection and the resulting global topology. For highly dynamic AAV applications, careful tuning of these parameters' balances control-update granularity against spectral efficiency. Numerous OLSR enhancements tailored to AAVs have been proposed, concentrating on adaptive MPR selection as node density or velocity grows and on dynamic adjustment of HELLO/TC rates to accommodate three-dimensional mobility while meeting stringent reliability and throughput demands. These efforts collectively aim to minimize delay and energy cost while preserving adaptability under incessant topology changes.

3 OPERATIONAL PRINCIPLES OF THE AODV

Protocol Ad hoc On-Demand Distance Vector (AODV) routing emphasizes bandwidth and resource conservation in highly mobile scenarios through its reactive (on-demand) philosophy. When a source must transmit but lacks a route, it broadcasts a Route Request (RREQ); any intermediate node possessing a fresh route may respond with a Route Reply (RREP). To preclude loops and guarantee route freshness, AODV incorporates monotonically increasing sequence numbers. Route maintenance is likewise meticulous: upon detecting a link break, the responsible node issues a Route Error (RERR) to affected sources, prompting them to invalidate the stale path. Frequently, AODV invokes local repair to re-establish connectivity near the failure point, thereby curtailing delay relative to network-wide RREQ re-broadcast. Parameters such as ACTIVE_ROUTE_TIMEOUT and ALLOWED_HELLO_LOSS govern route-lifetime thresholds and tolerated HELLO losses, allowing AODV to adapt to frequent AAV maneuvers and tight throughput/latency budgets. Owing to these design choices, AODV remains a viable option for many AAV missions in which routing performance is pivotal to overall system reliability.

II. Performance Evaluation Parameters

To evaluate the performance of OLSR and AODV routing protocols in Autonomous Aerial Vehicle networks, this study uses the following key evaluation parameters:

1. Packet Delivery Ratio (PDR).

PDR quantifies reliability as the fraction of packets that reach their destinations:

$$\mathrm{PDR_{avg}} = \frac{1}{n}\sum_{i=1}^{n} \frac{\left|P_{recv}^{i}\right|}{\left|P_{sent}^{i}\right|} \times 100\%$$

Where:

- n is the number of traffic sessions,
- $|P_{sent}^{i}|$ is the number of packets issued in session i,
- $|P_{recv}^{i}|$ is the number successfully received.

PDR reflects the level of reliability and efficiency of the routing protocol in ensuring packet transmission from source to destination. The higher the PDR value, the better the protocol performance. In the AAV network environment, PDR is a critical parameter when evaluating routing protocol performance due to high mobility and rapid topology changes that increase the probability of packet loss.

2. End-to-End Delay (EED).

EED measures temporal efficiency:

$$\mathrm{EED_{avg}} = \frac{\sum_{p\in P_{recv}} \left(T_{arr}(p) - T_{dep}(p)\right)}{|P_{recv}|},$$

Where:

- P_{recv} is the set of received packets,
- $T_{dep}(p)$ the departure time,
- $T_{arr}(p)$ the arrival time of packet p.

These metric aggregates routing, queuing, MAC, and transmission delays.

3. Average Throughput.

Throughput reflects data-transfer capacity:

$$\mathrm{Throughput_{avg}} = \frac{\sum_{i=1}^{n} |P_{recv}^{i}| S}{T} \cdot \frac{8}{1000}\ \text{(kbit/s)},$$

Where:

- S the packet size (bytes),
- T the active transmission duration (s).

Jitter (Delay Variation). Jitter captures fluctuation in inter-packet delay and is recursively estimated per RFC 3550:

$$J_i = J_{i-1} + \frac{|D_i - D_{i-1}| - J_{i-1}}{16},$$

Where: D_i and D_{i-1} are successive packet delays and the $1/16$ factor smooths short-term variations.

Collectively, these metrics enable a comprehensive appraisal of routing-protocol effectiveness for AAV networks, balancing reliability, responsiveness, bandwidth utilization, and temporal stability.

III. Performance Evaluation of Routing Protocols for Autonomous Aerial Vehicle Networks

The performance of Autonomous Aerial Vehicle networks is determined by factors such as routing protocol, movement speed, node density, and movement model. In this study, we evaluate two popular routing protocols (OLSR and AODV) in various scenarios to find the optimal solution for the operation of Autonomous Aerial Vehicle networks.

We use the Network Simulator 3 (NS-3.34) to simulate the operation of Autonomous Aerial Vehicle networks in four different scenarios: analysis by number of nodes, analysis by movement speed, analysis by movement model, and analysis by coverage area.

Table 1 General simulation parameters

Parameter	**Value**	**Parameter**	**Value**
Wi-Fi standard	IEEE 802.11g	CCA threshold	–90 dBm
PHY mode	ErpOfdm	Packet size	512 bytes
Data rate	6 Mbit s^{-1}	Application rate	128 kbit s^{-1}
Tx power	18 dBm	Propagation model	LogDistance (exponent = 2.0)
Receiver sensitivity	–85 dBm	Simulation time	200 s

In these simulations, we use the LogDistance attenuation model with parameter Exponent=2.0 to model signal attenuation in the radio transmission environment of Autonomous Aerial Vehicle networks. The value Exponent=2.0 corresponds to the Free Space Path Loss attenuation model, which is suitable for radio wave propagation conditions of aerial base stations in open space, where there are few obstacles and complex reflection and refraction phenomena. The LogDistance model is a common channel attenuation model based on experimental observation that signal intensity decreases as a logarithmic function of distance, calculated using the formula:

$$PL(d) = PL(d_0) + 10 \times n \times \log_{10}\left(\frac{d}{d_0}\right)$$

Where:

$PL(d)$ - signal attenuation (path loss) at distance d,
$PL(d_0)$ - signal attenuation at reference distance d_0,
n - attenuation exponent, in our simulation taken as 2.0,
d - distance between transmitter and receiver.

2. Performance Analysis Based on Number of Nodes

In this simulation, we analyze the performance of OLSR and AODV protocols when changing the number of Autonomous Aerial Vehicle nodes from 5 to 60. The movement model used is GaussMarkov with a speed of 10 m/s.

Table 2. Simulation Parameters Based on Number of Nodes

Parameter	Value
Number of Nodes	5–60
Speed	10 m/s
Mobility model	GaussMarkov
Flight Area	800 m × 800 m × 100 m

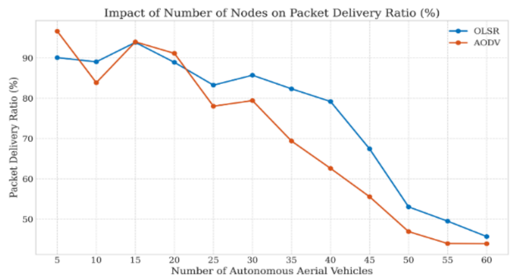


Fig. 2. Impact of Number of Nodes on Packet Delivery Ratio

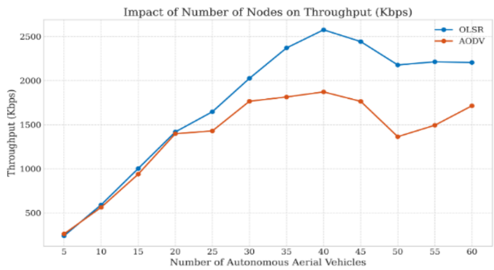


Fig. 3. Impact of Number of Nodes on Throughput

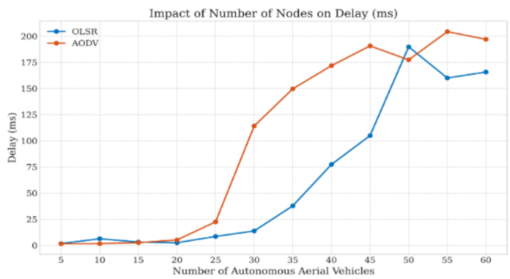


Fig. 4. Impact of Number of Nodes on Delay

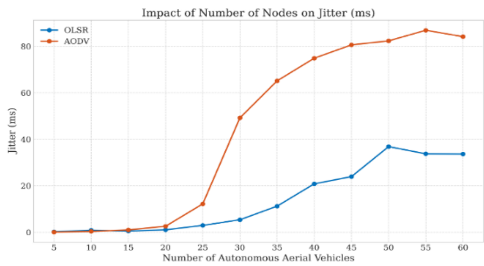


Fig. 5. Impact of Number of Nodes on Jitter

Initially, we compared the performance of protocols for Autonomous Aerial Vehicle networks, AODV and OLSR, in terms of Packet Delivery Ratio (PDR) to determine the appropriate choice for reconnaissance scenarios. In the Autonomous Aerial Vehicle network model, node density is typically sparse, which complicates maintaining connections between nodes. Therefore, we evaluated the performance of AODV and OLSR by gradually increasing the number of nodes during the simulation, thereby determining the impact of node density on network performance.

Fig. 2 illustrates the PDR for each protocol, where the horizontal axis represents the number of nodes, and the vertical axis represents the PDR. The results show that at low node density, AODV achieves a higher packet delivery ratio. In a reconnaissance scenario, the network topology changes rapidly and frequently, allowing AODV (a reactive protocol) to optimize route discovery, when necessary, thereby maintaining a relatively good PDR at small scales. In contrast, OLSR stores a routing table for all nodes, resulting in higher costs to maintain the routing table, reducing PDR in an environment with a small number of nodes.

We also tested the hypothesis that the PDR of Autonomous Aerial Vehicle network protocols would increase with the growth in the number of nodes. In practice, both AODV and OLSR show an increase in PDR up to a certain maximum, followed by a decline. For example, AODV reaches a PDR of about 94% with 15 nodes, after which a decrease is observed; similarly, OLSR reaches 93.87% also with 15 nodes and decreases starting from 20 nodes. This indicates that the optimal node density for both protocols in our simulation environment is around 15 nodes. Regarding throughput, both AODV and OLSR tend to increase with the number of nodes up to a certain threshold before declining. OLSR reaches a peak throughput of about 2575.86 Kbps with 40 nodes, while AODV reaches approximately 1871.53 Kbps. This result shows that at medium and high node densities, OLSR is capable of processing data more efficiently. Considering delay, both protocols show a notable increase in delay as the network expands. AODV maintains lower delay at low node densities but grows faster compared to OLSR with a large number of nodes. At 40 nodes, OLSR registers about 77.39 ms, while AODV reaches 171.82 ms. This demonstrates the advantage of OLSR in terms of delay in networks with many nodes. Finally, the jitter value also increases proportionally to the network size, and AODV typically has higher jitter than OLSR. The reason lies in the "reactive" nature of AODV, which must frequently search for new routes when the topology is constantly changing.

Findings: In a reconnaissance scenario with low node density, AODV proves to be more suitable. At the same time, OLSR works more efficiently at medium and high node densities. Additionally, the PDR performance of Autonomous Aerial Vehicle network protocols does not increase continuously with the growth in the number of nodes but begins to decline after a certain threshold due to increased costs for exchanging routing information.

3. Performance Analysis Based on Autonomous Aerial Vehicle Velocity

In this section, we evaluate the impact of node movement velocity on the performance of AODV and OLSR routing protocols. In Autonomous Aerial Vehicle networks, nodes move at medium to high velocities, leading to rapid and frequent changes in network structure. Therefore, we conduct simulations varying node velocities from 5 m/s to 60 m/s to assess the protocols' ability to adapt to changes in network structure.

Table 3. Simulation Parameters Based on Node Velocity

Parameter	**Value**
Number of Nodes	20
Velocity	5–60 m/s
Mobility model	GaussMarkov
Flight Area	800 m × 800 m × 100 m

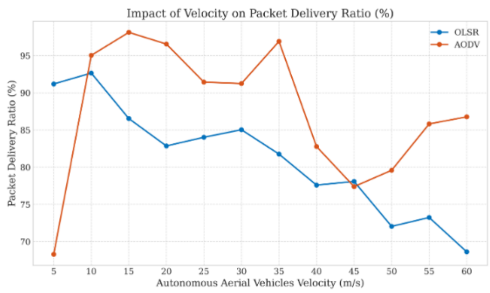


Fig. 6. Impact of Velocity on Packet Delivery

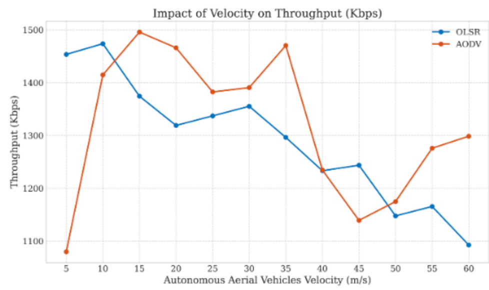


Fig. 7. Impact of Velocity on Throughput

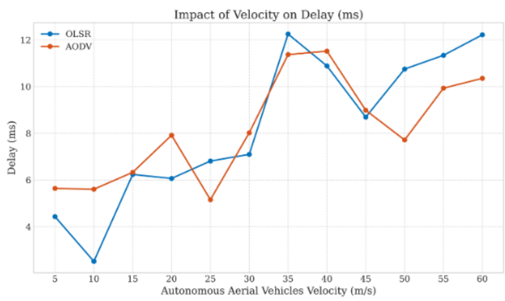


Fig. 8. Impact of Velocity on Delay

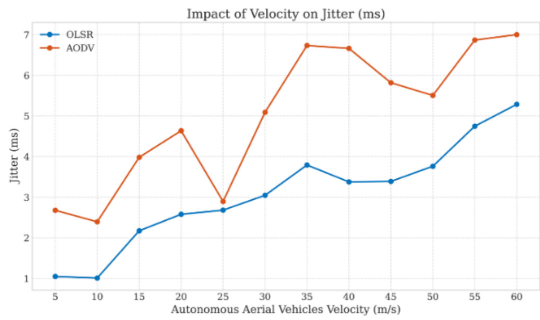


Fig. 9. Impact of Velocity on Jitter

Fig. 6 shows the Packet Delivery Ratio (PDR) as node velocity changes. In the figure, the x-axis represents node velocity (m/s), and the y-axis represents the PDR. From Fig. 6, we observe that the PDR performance of OLSR gradually decreases with increasing node velocity. Specifically, the PDR of the OLSR protocol decreases from 91.18% at a velocity of 5 m/s to 68.63% at a velocity of 60 m/s. This shows that OLSR, a proactive routing protocol, experiences difficulties maintaining an up-to-date routing table at high node velocities. In contrast, AODV demonstrates better adaptability to high node velocities. The PDR of the AODV protocol remains above 95% at velocities of 15 m/s and 20 m/s, and decreases only to approximately 86.77% at a velocity of 60 m/s. This proves that AODV, a reactive routing protocol, can effectively establish routes on demand, even when the network topology changes rapidly.

Regarding throughput, AODV maintains higher throughput than OLSR at most node velocities. At a velocity of 20 m/s, AODV achieves a throughput of about 1465.91 Kbps, while OLSR reaches 1318.86 Kbps. When the velocity increases to 60 m/s, AODV's throughput decreases to 1298.48 Kbps, while OLSR significantly drops to 1092.45 Kbps. In terms of delay, we found that AODV has higher delay than OLSR at most velocities. At a velocity of 20 m/s, AODV has a delay of about 7.91 ms, while OLSR has 6.06 ms. When the velocity increases to 60 m/s, AODV's delay increases to 10.35 ms, while OLSR increases to 12.21 ms. This shows that at high velocities, the cost of maintaining OLSR's routing table increases significantly, leading to higher delay. The jitter of both protocols increases with node velocity, but AODV demonstrates higher jitter than OLSR in most cases. At a velocity of 60 m/s, AODV's jitter is about 7.00 ms, while OLSR's is 5.28 ms. This is due to the reactive nature of AODV, which requires more frequent establishment of new routes in an environment with constantly changing topology.

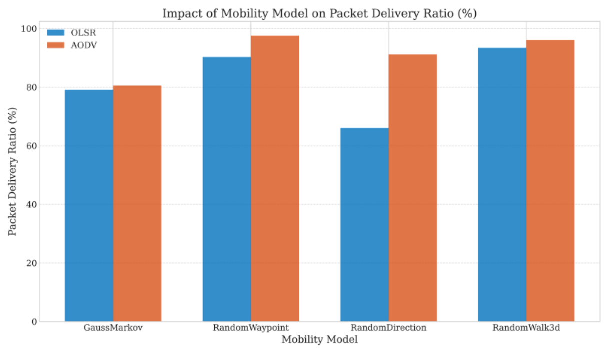
Findings: The AODV routing protocol demonstrates better adaptability to high node velocities in Autonomous Aerial Vehicle networks. AODV's PDR performance remains at a higher level than OLSR's as node velocity increases, showing that AODV is more suitable for high-mobility reconnaissance scenarios. However, AODV has higher delay and jitter, which may affect delay-sensitive real-time applications.

4. Performance Analysis Based on Mobility Model

In this simulation, we analyze the performance of OLSR and AODV protocols with four different mobility models: GaussMarkov, Random Waypoint, Random Direction, and RandomWalk3d. The number of nodes is fixed at 20, and the velocity is 25 m/s.

Table 4. Simulation Parameters Based on Mobility Model

Parameter	Value
Number of Nodes	20
Velocity	25 m/s
Mobility Model	GaussMarkov, Random Waypoint, Random Direction, RandomWalk3d
Flight Area	800 m × 800 m × 100 m



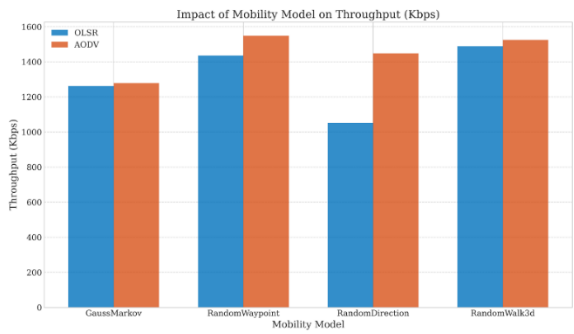


Fig. 10. Impact of Mobility Model on Packet Delivery Ratio

Fig. 11. Impact of Mobility Model on Throughput

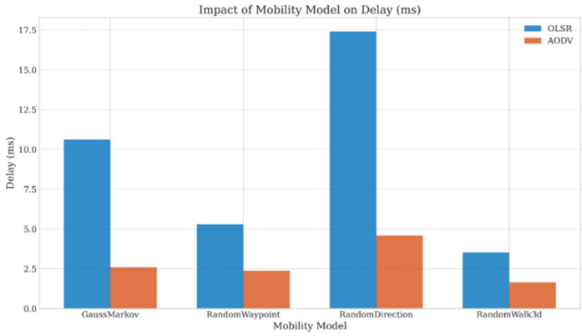


Fig. 12. Impact of Mobility Model on Delay

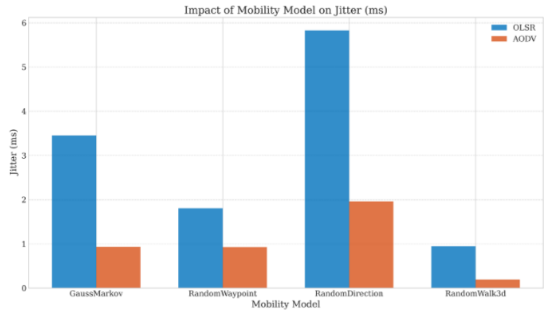


Fig. 13. Impact of Mobility Model on Jitter

From the simulation data, it is evident that the PDR of the OLSR protocol ranges from 66.05% to 93.39% depending on the mobility model. The RandomWalk3d model provides the highest PDR for OLSR (93.39%), followed by Random Waypoint (90.26%), GaussMarkov (79.12%), and the lowest performance with Random Direction (66.05%).

For AODV, PDR values vary from 91.21% to 97.52%, with Random Waypoint providing the highest performance (97.52%), followed by RandomWalk3d (96.00%), Random Direction (91.21%), and GaussMarkov (80.50%). Regarding throughput, both OLSR and AODV achieve their highest values with the Random Waypoint model, 1435.17 Kbps and 1548.92 Kbps respectively. The Random Direction model gives the lowest throughput for OLSR (1052.12 Kbps), while GaussMarkov gives the lowest throughput for AODV (1278.63 Kbps). Delay also varies significantly depending on the mobility model. AODV has the lowest delay with RandomWalk3d (1.65 ms) and the highest with Random Direction (4.59 ms). OLSR has the lowest delay with RandomWalk3d (3.53 ms) and the highest with Random Direction (17.40 ms).

Findings: These results show that the mobility model has a strong influence on the performance of routing protocols in Autonomous Aerial Vehicle networks. Random Waypoint and RandomWalk3d models generally provide better performance for both OLSR and AODV, while Random Direction creates more serious challenges due to frequent and unpredictable changes in network topology.

5. Performance Analysis Based on Coverage Area

In this simulation, we analyze the performance of OLSR and AODV protocols when changing network density, maintaining a constant number of nodes (25), but varying the simulation area size from 500 m × 500 m to 2000 m × 2000 m. This is equivalent to changing node density from 100 nodes/km² to 6.25 nodes/km². The purpose of this simulation is to investigate the effect of node density on routing protocol performance. By varying the flight area size from 500×500 m² to 2000×2000 m² with a fixed number of nodes, we create environments with different node densities, from dense (100 nodes/km²) to sparse (6.25 nodes/km²).

Table 5. Simulation Parameters Based on Area Dimensions

Parameter	Value
Number of Nodes	25
Velocity	10 m/s
Mobility Model	GaussMarkov
Flight Area	500×500, 800×800, 1200×1200, 1600×1600, 2000×2000 m²

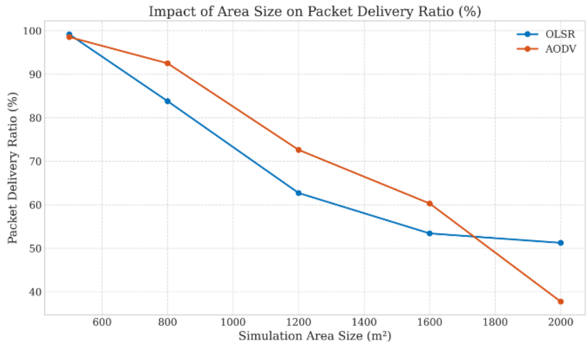


Fig. 14. Impact of Simulation Area Size on Packet Delivery Ratio

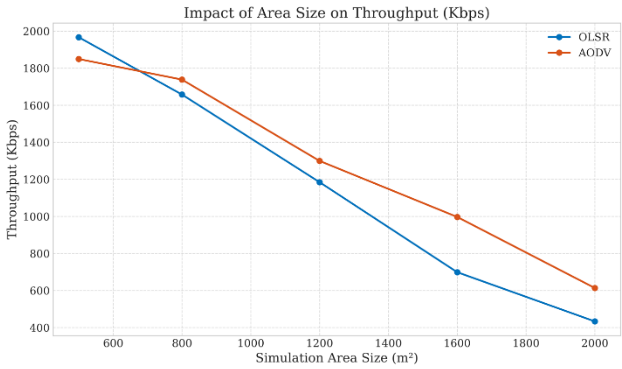


Fig. 15. Impact of Simulation Area Size on Throughput

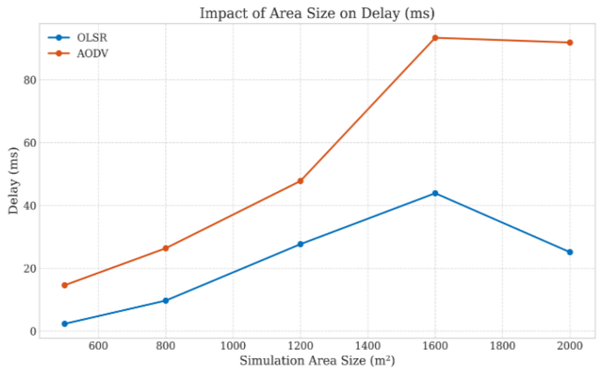


Fig. 16. Impact of Simulation Area Size on Delay

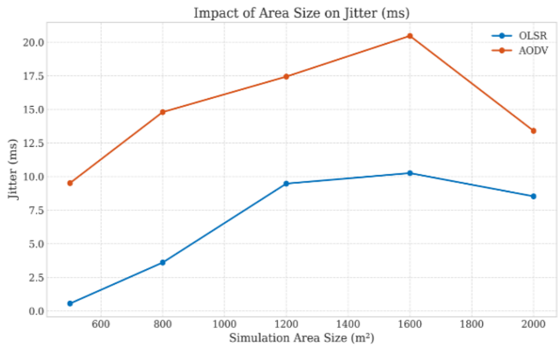


Fig. 17. Impact of Simulation Area Size on Jitter

The purpose of this simulation is to study the effect of node density on routing protocol efficiency. By varying the flight area size from 500×500 m² to 2000×2000 m² with a fixed number of nodes, we create different conditions with varying node densities - from high (100 nodes/km²) to extremely low (6.25 nodes/km²). The results show that the Packet Delivery Ratio (PDR) in both OLSR and AODV protocols decreases as node density decreases. At the highest density (100 nodes/km²), PDR in OLSR reaches 99.18%, and in AODV - 98.55%. However, at the lowest density level (6.25 nodes/km²), PDR in OLSR decreases to 51.24%, and in AODV - to 37.73%. Throughput also significantly drops as node density decreases. In OLSR, the maximum value is 1967.18 Kbps at 100 nodes/km² and decreases to 433.18 Kbps at 6.25 nodes/km². Similarly, in AODV, throughput reaches 1849.75 Kbps at maximum density and decreases to 613.46 Kbps at low density.

Regarding delay, an interesting trend is observed: as node density decreases from high to medium, delay increases, but then decreases at extremely low density. In OLSR, delay increases from 2.30 ms (at 100 nodes/km²) to 43.88 ms (at 9.77 nodes/km²) and then decreases to 25.12 ms (at 6.25 nodes/km²). A similar trend is found in AODV: from 14.59 ms (maximum density) to 93.38 ms (9.77 nodes/km²) and a further decrease to 91.87 ms (6.25 nodes/km²). This phenomenon can be explained by the specifics of routing protocols. At high density, nodes have multiple alternative routes, ensuring low delay. However, as density decreases, the number of available paths decreases, and routes need to be rebuilt more frequently, increasing delay. At extremely low density, many packets do not reach their destination at all due to lack of connectivity, and the average delay only considers successfully delivered packets, usually with a short transmission path. Comparing OLSR and AODV shows that OLSR generally demonstrates better results at most density levels, especially in terms of PDR and delay at low density. This may be related to the proactive nature of OLSR, allowing it to maintain more stable routing information even in conditions of weak connectivity.

Findings: Node density significantly affects the efficiency of routing protocols in Autonomous Aerial Vehicle networks. As node density decreases, PDR and throughput significantly decrease. OLSR proves to be more adaptive to low node density compared to AODV. In reconnaissance scenarios over a large area with a limited number of Autonomous Aerial Vehicles, optimization of node placement or implementation of intermediate relays may be required to maintain the required level of network performance.

IV. Practical Applications

Based on comprehensive analysis, we found that neither protocol completely outperforms the other in all situations. AODV and OLSR each have their advantages depending on the deployment scenario. The choice of an appropriate protocol should be based on the specifics of the application, the expected number of deployed Autonomous Aerial Vehicles, mobility velocity, and QoS requirements. Based on simulation results, we propose the following suitable applications for OLSR and AODV in real-world Autonomous Aerial Vehicle scenarios:
Applications Suitable for OLSR:

1. Large-scale Infrastructure Monitoring: In tasks requiring the deployment of multiple Autonomous Aerial Vehicles for monitoring power lines, pipelines, or transportation systems, OLSR demonstrates an advantage in handling a large number of nodes with high performance. The ability to maintain stable throughput above 1500 Kbps at densities of 25-40 nodes makes OLSR suitable for transmitting high-quality images and real-time video.
2. Autonomous Aerial Vehicle Networks with Static or Slow Movement: For long-term monitoring scenarios such as environmental monitoring, precision agriculture, or wildlife research, where Autonomous Aerial Vehicles move at low velocities (5-15 m/s) or fly along fixed trajectories, OLSR provides low delay and reasonable routing information forwarding costs.
3. Deployment in Concentrated Coverage Areas: OLSR is most effective when Autonomous Aerial Vehicles operate in high-density areas such as urban areas, large events, or concentrated combat zones. With PDR above 99% at a density of 100 nodes/km^2, OLSR ensures reliable data exchange between Autonomous Aerial Vehicles and ground stations.
4. Applications for 3D Mapping and Spatial Modeling: When deploying Autonomous Aerial Vehicles to create 3D models of structures or complex terrain, OLSR with the RandomWalk3d mobility model provides high PDR (93.39%) and low delay (3.53 ms), suitable for continuous transmission of sensor data.

Applications Suitable for AODV:

1. Reconnaissance Missions and Moving Target Tracking: With the ability to maintain high PDR (above 95%) at velocities up to 35 m/s, AODV is suitable for rapid reconnaissance missions, tracking moving targets, or search and rescue operations where Autonomous Aerial Vehicles need to move quickly and flexibly.
2. Deployment in Vast Areas with Low Density: AODV shows greater flexibility when Autonomous Aerial Vehicles operate dispersed in vast areas, especially with the Random Waypoint model (PDR 97.52%). This is an appropriate choice for missions exploring border territories, forested mountains, or islands.

V. Conclusion and Directions for Future Research

In this study, we conducted a comprehensive performance evaluation of two representative routing protocols (OLSR and AODV) in Autonomous Aerial Vehicle network environments through four highly practical simulation scenarios. The results show that no protocol has absolute superiority, but each protocol has its advantages depending on deployment conditions. OLSR demonstrates high performance in high-density and low-velocity environments, while AODV is more suitable for scenarios with high velocity and rapidly changing topology.

Based on the analysis, we proposed several potential improvements for both protocols, as well as a hybrid protocol to overcome existing limitations. In particular, the integration of parameters such as velocity, energy, and link quality into the routing process, as well as the application of reinforcement learning, promise to significantly enhance the performance of Autonomous Aerial Vehicle networks in practical applications.

Directions for future research will focus on implementing and evaluating the proposed improvements through more detailed simulations and practical tests. We plan to:

1. Develop and implement improved versions of OLSR and AODV on the NS-3 platform, evaluating their performance compared to the original protocols.
2. Expand simulations to include more realistic factors such as energy disruptions, environmental interference, and visibility limitations.
3. Study the impact of encryption and security protocols on routing performance in Autonomous Aerial Vehicle networks.
4. Develop analytical models based on machine learning to predict network performance in complex scenarios.
5. Test hybrid routing architecture in real deployment scenarios such as disaster monitoring and support for rescue operations.

Through these efforts, we aim to create optimal routing solutions for Autonomous Aerial Vehicle networks, contributing to the application of Autonomous Aerial Vehicles in many important areas of modern society.

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