The American Journal of Engineering and Technology
ISSN 2689-0984 | Open Access

TYPE Original Research
PAGE NO. 213-219
DOI 10.37547/tajet/Volume07Issue11-13

Check for updates

Routing Strategies In Fanet Networks: A Systematic Review Of Protocol Families, Performance Indicators, And Research Gaps

Jolimbetova E.D.
PhD student, TUIT named after Al-Khwarizmi, Uzbekistan

OPEN ACCESS

SUBMITTED 15 October 2025
ACCEPTED 10 November 2025
PUBLISHED 30 November 2025
VOLUME Vol.07 Issue 11 2025

CITATION

Jolimbetova E.D. (2025). Routing Strategies In Fanet Networks: A Systematic Review Of Protocol Families, Performance Indicators, And Research Gaps. The American Journal of Engineering and Technology, 7(11), 213–219. https://doi.org/10.37547/tajet/Volume07Issue11-13

Abstract: Flying Ad hoc Networks (FANETs) are formed by unmanned aerial vehicles (UAVs) that communicate over wireless links without fixed infrastructure. High node mobility, frequent topology changes and the three-dimensional nature of the environment make routing a challenging task. This paper presents a compact systematic review of routing strategies in FANETs. We classify existing protocols into five main families: topological (proactive, reactive and hybrid), geographic (position-based), cluster-based (hierarchical), opportunistic (delay-tolerant) and intelligent (AI-based and bio-inspired). Typical performance indicators such as packet delivery ratio, end-to-end delay, throughput, routing overhead and energy consumption are summarized, and their relationship with different protocol classes is discussed. The analysis shows that most existing solutions are adaptations of MANET/VANET algorithms and usually optimize only a subset of metrics. Key research gaps include energy-aware routing, stable operation under extreme mobility and sparse topologies, and deeper integration of learning-based methods. The review provides a concise overview of current approaches and outlines directions for future research in FANET routing.

Keywords: FANET, unmanned aerial vehicles, ad-hoc networks, routing protocols, QoS, clustering, delay-tolerant networking, bio-inspired routing.

Introduction

Flying Ad Hoc Networks (FANETs) represent a special class of wireless ad hoc networks in which the nodes are unmanned aerial vehicles (UAVs). Unlike traditional mobile ad hoc networks (MANETs) or vehicular ad hoc networks (VANETs), FANET nodes move with high speed in three-dimensional space, often at varying altitudes and with rapidly changing relative positions. As a result, wireless links are unstable, the network topology changes frequently and routes can break within very short time intervals.

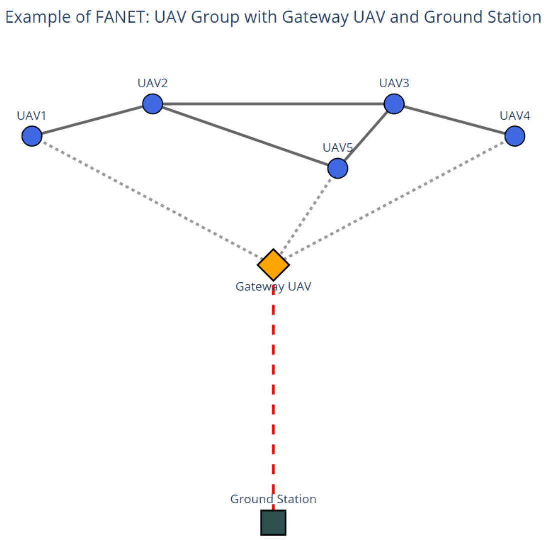

Figure 1. Example of a FANET network

In addition, FANET deployments are often sparse, and communication channels are affected by obstacles, interference and weather conditions.

These specific features make direct application of classical MANET routing protocols (AODV, DSR, OLSR, etc.) insufficient for FANETs. Although such protocols provide basic connectivity, they do not fully account for strong mobility, limited on-board energy and three-dimensional geometry. Consequently, researchers have proposed many adaptations and new routing schemes tailored to multi-UAV environments. Early surveys, such as Bekmezci et al. [1], defined FANETs as a separate family of ad hoc networks with unique constraints, while later works provided more detailed taxonomies of routing strategies [2–4].

Despite significant progress, routing in FANETs remains an open problem. There is no universal protocol that can simultaneously guarantee high packet delivery ratio, low delay, low overhead, high scalability and low energy consumption for all mission scenarios. For dense swarms performing real-time video streaming, latency and reliability are critical. For wide-area monitoring or search and rescue missions with sparse connectivity, guaranteed eventual delivery is more important than delay. Security, robustness against interference and integration with terrestrial and satellite networks further complicate protocol design [3,5]. A typical FANET scenario with multiple UAVs and a ground control station is shown in Figure 1.

The main objective of this paper is to provide a concise, structured, and readable review of routing strategies in FANETs. Based on the existing literature, we classify routing protocols into major families according to their operating principles, summarize typical performance metrics used to evaluate them, and identify the main advantages, limitations, and research gaps associated with each family. The paper is organized as follows: Section 2 briefly explains the materials and methods used in this review, Section 3 presents the main protocol families and key performance metrics, Section 4 discusses tradeoffs and open research issues, Section 5 concludes the paper, and the literature is listed in Section 6.

Methods

This work is based on a focused literature review of routing in FANETs and related UAV ad hoc networks. The main sources include survey and tutorial articles [1–4,7–9], as well as selected protocol proposals and performance studies [6,10]. We considered peer-reviewed journal and conference papers that:

- address multi-UAV or FANET routing at the network layer;
- provide a description or classification of routing protocols;
- report performance results or qualitative evaluations.

The analysis followed two steps.

a) Taxonomy of protocol families.

First, protocols were grouped by their basic routing principle and network organization, yielding five main families:

- Topological protocols (proactive, reactive, hybrid) that use connectivity information and routing tables;
- Geographic protocols that rely on node positions (GPS or other localization);
- Cluster-based (hierarchical) protocols that form clusters and cluster heads;
- Opportunistic / DTN protocols that follow store-carry-forward principles for intermittent connectivity;
- Intelligent and bio-inspired protocols that use machine learning (ML), reinforcement learning (RL) or swarm intelligence.

For each family, representative examples from the literature were identified and their key characteristics were summarized.

b) Analysis of performance indicators.

Second, we collected typical performance metrics used in simulations or experiments: packet delivery ratio (PDR), average end-to-end (E2E) delay, throughput, routing overhead, node energy consumption and reliability. Instead of reproducing detailed numerical results, we focused on qualitative tendencies: which family tends to achieve higher PDR under high mobility, which offers lower delay, and how overhead and scalability behave as the number of UAVs grows.

The combination of a protocol taxonomy and metric-oriented analysis allows us to discuss how each routing family addresses specific FANET challenges and where important research gaps remain.

Results

1. Topological Routing Protocols

Topological (or classical) protocols use information about which nodes are connected and maintain routing tables, similar to MANET routing. They can be divided into:

- Proactive (table-driven) protocols such as OLSR and DSDV, which periodically compute and distribute routes to all destinations. The main advantage is minimal data transmission delay, because a route is already known when a packet is generated. However, they incur high routing overhead, especially in highly dynamic topologies, and may struggle to keep tables up to date.
- Reactive (on-demand) protocols such as AODV and DSR, which initiate route discovery only when data must be sent. This reduces background signaling and is more efficient under high mobility, but introduces initial delay for route discovery and can generate bursts of control traffic when many routes are requested simultaneously.
- Hybrid protocols combine both approaches, typically using proactive routing within a local area or cluster and reactive routing between distant nodes. The Zone Routing Protocol (ZRP) is a classical example that can be adapted to UAV swarms.

Simulation studies indicate that for small and medium FANETs under moderate mobility, reactive AODV often achieves higher PDR and throughput than DSDV, due to fresher routes. As network size grows, properly configured proactive or hybrid schemes can outperform pure reactive approaches because they avoid repeated flood-based discoveries [3,7]. Overall, topological protocols are well understood and easy to implement but do not explicitly exploit geographic information or channel conditions, which limits their efficiency in fast-changing 3D environments. The main routing strategies in FANETs can be grouped into five protocol families, as illustrated in Figure 2.

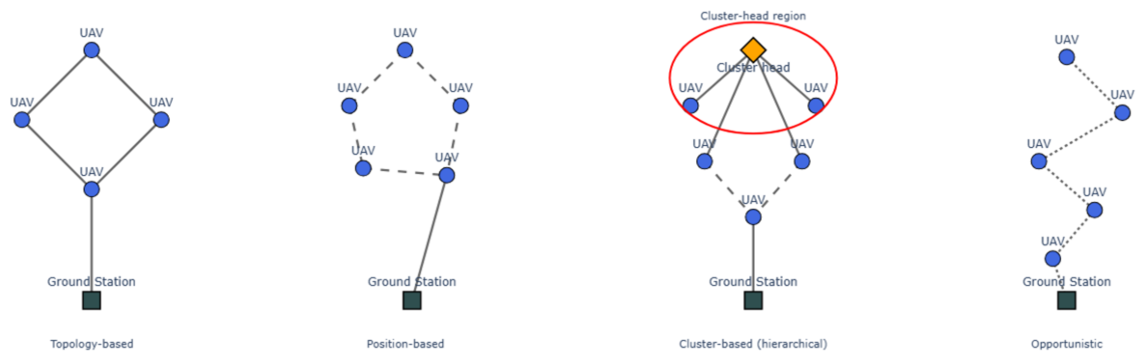

Figure 2. Classification of FANET routing protocols: topology-oriented, position-oriented, clustered (hierarchical), and opportunistic schemes.

2. Geographic (Position-Based) Protocols

Geographic protocols use nodes' coordinates, typically obtained via GPS or other localization methods, to make forwarding decisions. Each UAV knows its own position and those of its neighbors; packets carry the destination position. A simple strategy is greedy forwarding, where each node forwards a packet to the neighbor closest to the destination. When greedy forwarding fails (local minimum), recovery strategies such as perimeter routing are used. GPSR is the classical reference protocol [2].

For FANETs, geographic routing is attractive because it does not require global routing tables and reacts naturally to topology changes: if a neighbor moves out of range, another neighbor can be selected on-the-fly. This strongly reduces routing overhead and improves scalability. Numerous improvements have been proposed, including adaptive beaconing (changing beacon rate according to mobility), mobility prediction to choose more stable neighbors, and schemes that combine location with link quality or jamming awareness.

The main limitations are dependence on accurate position information and the risk of "geographic dead ends", especially in sparse or obstacle-rich environments. Purely greedy strategies may also overload certain nodes that lie on many shortest paths. Nevertheless, in many FANET scenarios with moderate or high density and good localization, position-based protocols achieve low delay and low overhead, making them a key direction in FANET routing research [2,4].

3. Cluster-Based (Hierarchical) Protocols

Cluster-based protocols improve scalability by organizing UAVs into clusters, each led by a cluster head (CH). Ordinary nodes communicate mostly with their CH; inter-cluster communication is handled by CHs or designated gateway nodes. This hierarchical structure reduces the amount of control information that must be propagated through the entire network and allows local decisions within clusters.

Energy-efficient clustering algorithms, such as EECA and EALC, have been proposed to form clusters and select CHs based on node position, connectivity and residual energy [1,5]. Bio-inspired solutions like BICSF use metaphors from natural systems (e.g., fireflies) to self-organize clusters and balance load.

Advantages of hierarchical routing include reduced overhead in large swarms, better energy distribution and the possibility to reflect the geographical or functional structure of the mission (e.g., one cluster per region). However, cluster formation and maintenance introduce additional complexity. In highly mobile FANETs, clusters may frequently break and reform, which can generate extra delay and signaling overhead. Failure of a CH can temporarily disrupt inter-cluster communication until a new leader is elected. Cluster size and election criteria must therefore be carefully designed for the expected mobility and density.

4. Opportunistic and Delay-Tolerant Protocols

Opportunistic and Delay/Disruption Tolerant Networking (DTN) protocols are designed for scenarios in which a stable end-to-end path often does not exist. In such cases, nodes follow a store-carry-forward principle: if no route is available, a UAV stores the packet, carries it while flying, and forwards it when it encounters a suitable relay or the destination.

In FANETs, opportunistic routing is relevant for sparse deployments, long-range reconnaissance or missions where drones periodically return to a base station. Approaches such as LCAD and context-aware beaconless schemes transmit data only when useful contacts occur, significantly saving energy compared to constant beaconing. More advanced protocols combine location and link quality (e.g., XLinGO) or consider message importance in forwarding decisions.

The main advantage is robustness to disconnections: data is not immediately dropped but eventually delivered. The price is potentially very high delay and the need for sufficient buffer capacity on UAVs. DTN schemes are unsuitable for real-time control or time-critical data, but they are valuable as a backup mechanism when conventional routing fails.

5. Intelligent and Bio-Inspired Protocols

Intelligent routing protocols apply artificial intelligence and bio-inspired algorithms to adapt routing decisions. Bio-inspired approaches use metaphors like ant colony optimization (ACO) or bee foraging: special control packets (ants, scouts) explore multiple paths and update virtual "pheromone" values or path scores based on delay, reliability or congestion. Paths with better performance gradually become preferred.

Machine learning-based protocols employ reinforcement learning (e.g., Q-learning) or neural networks. Each UAV learns, based on local rewards (successful deliveries, low delay, stable links), which neighbors are good next hops. The CHNN-DSR protocol, for example, integrates a neural network into DSR to dynamically select better routes, improving PDR and throughput at high speeds.

Intelligent schemes are promising because they can adapt to complex and changing environments, optimize multiple metrics simultaneously and exploit experience. However, they require additional computation and control traffic, careful parameter tuning and extensive training. Their behavior can be difficult to analyze formally, which is a concern for safety-critical applications. At present, intelligent routing in FANETs remains mainly a research topic, but early results indicate noticeable gains in stability and QoS [6,8,9].

6. Performance Indicators

The diversity of protocols makes it very difficult to compare their performance. Researchers use a number of performance indicators to assess the quality of routing. Table 1 below lists the main ones and their importance.

Table 1. Key metrics used to evaluate routing in FANET

Efficiency indicator	Description and value for FANET
Packet Delivery Ratio (PDR)	The percentage of packets delivered to the destination. Describes the reliability of the protocol: a high PDR means that the protocol can overcome connection failures and overloads, minimizing packet loss.
Average E2E Latency	The average path time of a packet from the sender to the receiver (end-to-end delay). Important for real-time applications (drone video, swarm control): low delay indicates fast routing without long round trips and queues.
Throughput	The amount of useful data transmitted over the network per unit of time (usually kbit/s or packets/s). Reflects the overall efficiency of network usage. High bandwidth is desirable for transmitting large amounts of data (e.g. video streams).
Overhead	The amount of service traffic generated by the protocol to support routing (control packets, beacon messages, table updates). Measured as a percentage of total traffic or the number of service packets delivered per unit of time. Low overhead is especially important in FANETs due to limited path and energy.
Node Energy Consumption	The UUA energy consumption associated with the operation of the protocol (sending, receiving, computing packets). It is usually evaluated indirectly (via the node's lifetime before discharge). Energy efficiency is very important because drones have limited battery life and saving energy during communication extends the mission time.
Reliability and Stability	The ability of the protocol to maintain network connectivity and restore routes when nodes fail or encounter interference. It can be evaluated by recovery time after an outage, probability of successful delivery under interference, etc. High reliability is necessary for the secure use of FANETs, especially for mission-critical tasks.

It is generally impossible to optimize all metrics at once. Proactive protocols reduce delay but raise overhead; reactive protocols lower overhead but may temporarily reduce PDR while routes are repaired; geographic protocols achieve low delay and overhead in many cases, but may suffer in sparse or complex topologies; clustering improves scalability and energy balance at the cost of cluster maintenance; intelligent schemes promise gains in several metrics but increase complexity. Therefore, protocol selection must be tailored to the mission's dominant requirements.

Discussion

A comparative analysis of routing families shows that each approach addresses certain aspects of the FANET routing problem, but none provides a complete solution. Topological protocols reuse mature ideas from MANETs and are easy to implement, but they are not well-adapted for very high mobility and 3D traffic: proactive schemes are vulnerable to frequent topology changes, while reactive schemes lead to repeated route discoveries and temporary outages. Geographic routing, using node coordinates, is better suited to UAV movement and usually achieves short paths with low latency and low overhead in dense networks with reliable localization, but it depends on precise location information and can create overloaded "hotspot" nodes; in sparse FANETs it often needs to be combined with DTN techniques. Cluster-based routing scales well for large swarms and reduces global signaling when drones can be grouped, but maintaining a stable cluster hierarchy in fast, chaotic motion is difficult, and enhancements such as energy-aware clustering, mobility prediction, and backup cluster heads add complexity. Opportunistic and DTN-based schemes provide robustness in highly degraded or sparse networks without continuous three-to-three paths and are critical for end-to-end delivery, but their high latency and buffer requirements make them more suitable as add-on mechanisms than standalone solutions. Intelligent and bio-inspired protocols add flexibility and enable multi-objective optimization with promising gains in PDR, latency, and energy balance, but they are not mature enough for large-scale practical deployment due to training overhead, sensitivity to parameter settings, and limited real-world validation. From this overview, several research gaps emerge:

- Energy-aware routing: Most existing protocols do not explicitly optimize energy consumption, although UAVs are strictly battery-limited. Future work should incorporate residual energy and communication cost into routing metrics and use clustering or sleep modes to prolong network lifetime.

- Robustness under extreme mobility and sparse topologies: Protocols must handle very fast topology changes and intermittent connectivity. Mobility prediction, link expiration estimation and combined geographic–DTN strategies are promising directions.

- Hybrid and cross-layer designs: Combining the strengths of different families (e.g., geographic + DTN, cluster + ML) and exploiting information from lower layers (link quality, interference) can provide better trade-offs than any single approach.

- Security and trust: Routing must be resilient not only to failures but also to malicious behavior, false routes and jamming. Lightweight authentication and trust management adapted to UAV constraints remain underexplored.

- Real-world validation: Many protocols are evaluated only in simulations with simplified models. More experiments on real UAV platforms are needed to capture hardware limitations, channel variability and synchronization issues.

Addressing these gaps will be essential for deploying FANETs in mission-critical applications.

Conclusion

FANETs introduce new challenges to routing due to high node mobility, three-dimensional movement, dynamic topology and energy constraints. This paper has provided a concise systematic review of routing strategies for FANETs, organized into five main protocol families: topological, geographic, cluster-based, opportunistic and intelligent.

Topological protocols remain useful as a baseline and for relatively stable scenarios. Geographic protocols are particularly suitable for dense swarms with reliable localization and offer good scalability. Cluster-based approaches improve manageability and energy balance in large networks. Opportunistic and DTN protocols guarantee delivery under intermittent connectivity but with high latency. Intelligent and bio-inspired protocols open a promising research direction, offering adaptive and multi-objective behavior at the cost of increased complexity.

No single protocol family satisfies all requirements of

FANET applications. Future routing solutions are likely to be hybrid and adaptive, able to switch behavior according to current topology, density, traffic pattern and mission constraints. Integrating energy awareness, mobility prediction, security and learning mechanisms into routing design is a key step towards robust multi-UAV systems.

By summarizing existing strategies and highlighting remaining challenges, this review aims to support researchers and practitioners in selecting, improving and designing routing protocols that can provide reliable, efficient and scalable communication in future FANET deployments.

References

1. Bekmezci, I., Sahingoz, O. K., & Temel, Ş. (2013). Flying ad-hoc networks (FANETs): A survey. Ad Hoc Networks, 11(3), 1254-1270.
2. Oubbati, O. S., Lakas, A., Zhou, F., Güneş, M., & Yagoubi, M. B. (2017). A survey on position-based routing protocols for Flying Ad hoc Networks (FANETs). Vehicular Communications, 10, 29-56.
3. Arafat, M. Y., & Moh, S. (2019). Routing protocols for unmanned aerial vehicle networks: A survey. IEEE access, 7, 99694-99720.
4. Oubbati, O. S., Atiquzzaman, M., Lorenz, P., Tareque, M. H., & Hossain, M. S. (2019). Routing in flying ad hoc networks: Survey, constraints, and future challenge perspectives. IEEE access, 7, 81057-81105.
5. Gupta, L., Jain, R., & Vaszkun, G. (2015). Survey of important issues in UAV communication networks. IEEE communications surveys & tutorials, 18(2), 1123-1152.
6. Zheng, Z., Sangaiah, A. K., & Wang, T. (2018). Adaptive communication protocols in flying ad hoc network. IEEE Communications Magazine, 56(1), 136-142.
7. Lakew, D. S., Sa'ad, U., Dao, N. N., Na, W., & Cho, S. (2020). Routing in flying ad hoc networks: A comprehensive survey. IEEE communications surveys & tutorials, 22(2), 1071-1120.
8. Khan, M. F., Yau, K. L. A., Noor, R. M., & Imran, M. A. (2019). Routing schemes in FANETs: A survey. Sensors, 20(1), 38.
9. Sang, Q., Wu, H., Xing, L., & Xie, P. (2020). Review and comparison of emerging routing protocols in flying ad hoc networks. Symmetry, 12(6), 971.
10. Sharma, V., Kumar, R., & Kumar, N. (2018). DPTR: Distributed priority tree-based routing protocol for FANETs. Computer Communications, 122, 129-151.