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A Survey on Handover Techniques, Challenges, and Evolving Solutions for FANETs

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ABSTRACT

Flying ad hoc networks formed by coordinated unmanned aerial vehicles are a critical emerging paradigm for modern wireless communication in civilian, industrial, and military sectors. As UAVs become more mobile and intelligent, ensuring seamless handover in such 3D dynamic environments presents significant challenges. This paper surveys recent advancements and core challenges in handover management in FANETs, focusing on mobility issues, routing complexities, and emerging technologies including machine learning and optical communications. Moreover, a novel energy efficient handover management approach is proposed in this work leveraging dynamic operational modes such as active, sleep, and hibernate states for UAVs supported by reinforced learning techniques. The proposed framework lays the groundwork for future implementation and evaluation of energy-aware UAV operations, addressing key challenges in prolonging UAV mission duration while maintaining seamless connectivity.

Keywords **- FANET, handover, energy efficient, QoS, UAV**

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I.INTRODUCTION

The integration of Unmanned Aerial Vehicles (UAVs) into wireless communication infrastructures has resulted in the emergence of a new and transformative network paradigm called as Flying Ad Hoc Networks (FANETs). Unlike traditional ground-based wireless networks or even Mobile Ad Hoc Networks (MANETs), FANETs consist of a dynamic swarm of UAVs operating in a three-dimensional (3D) space, often characterized by rapid mobility, changing topologies, and frequent link breakages. Enabled by advancements in miniaturized sensors, embedded systems, and autonomous control mechanisms, FANETs are designed to support cooperative multi-UAV deployments for applications such as military reconnaissance, disaster relief, agricultural monitoring, and traffic surveillance [1]. In Japan, for instance, approximately one-third of agricultural aviation tasks are conducted using UAVs. These aerial nodes can perform collaboratively, offering cost-effective, flexible, and scalable solutions for time-sensitive and mission-critical operations.

However, these very attributes also pose unique and pressing challenges, particularly in the area of handover management. In wireless communication, a handover refers to the process of transferring a communication session or data link from one network node or base station to another without loss of connectivity or data. While this is already a complex process in terrestrial networks, it becomes significantly more difficult in FANETs due to the high-speed aerial mobility, irregular flight trajectories, and Line-of-Sight (LoS) dominated communication links. Traditional handover strategies, designed primarily for terrestrial users in two dimensional (2D) environments, often fail to address the unique 3D mobility patterns of UAVs [2]. The situation becomes even more critical with the integration of UAVs into 5G and upcoming 6G mobile networks, where handover failure can lead to increased latency, degraded Quality of Service (QoS), and complete mission failure. Furthermore, conventional transmission protocols such as TCP/IP are often insufficient for UAVs, as they assume fixed or relatively stable endpoints, which do not hold in high-mobility aerial contexts. Additionally, the ping-pong effect where frequent, unnecessary handovers occur and the lack of intelligent prediction mechanisms in many FANET implementations, contribute to poor overall network reliability. Ensuring seamless mobility and continuous connectivity in FANETs thus requires not only improved routing algorithms and handover decision making but also an integration of machine learning, optical wireless communication, and middleware-based service abstractions. This survey aims to provide a comprehensive overview of handover mechanisms in FANETs, reviewing existing literature, identifying current limitations, and proposing avenues for future research. It explores the following:

- The architectural and topological distinctions between FANETs and traditional networks.
- The technical challenges associated with handover under high-mobility conditions.
- The latest algorithmic and technological solutions, including artificial intelligence (AI)-based mobility prediction, Free Space Optics (FSO), and Service-Oriented Architectures (SOA).
- The performance evaluation metrics commonly used in assessing handover effectiveness.

- Proposing an energy efficient handover management model for FANETs for future work.

This study would offer valuable insights to researchers and engineers working to enhance the robustness, adaptability, and performance of UAV based communication systems in highly dynamic environments.

II. Background and System Architecture

The evolution of Unmanned Aerial Vehicles (UAVs) from isolated surveillance tools to intelligent, autonomous communication agents has catalyzed the development of FANETs. These networks represent a specialized subclass of MANETs and Vehicular Ad Hoc Networks (VANETs), characterized by dynamic topologies, high node mobility, and complex three-dimensional movement patterns.

FANET is a decentralized wireless network formed by multiple UAVs that communicate with each other and possibly with ground stations or satellites. Unlike traditional wireless networks with fixed infrastructure, FANETs are self-organizing, multi-hop, and often operate in environments lacking infrastructure support, such as disaster zones, battlefields, or remote rural areas. FANETs can be deployed in several forms, such as: Swarm-based systems, where homogeneous UAVs work collectively. Formation-based fleets, where relative positions of the UAVs are maintained. Mission-oriented multi-UAV systems, where each UAV performs a specialized role while collaborating. Each configuration imposes different communication and coordination requirements, especially for handover operations as UAVs move and form new links dynamically [3].

A. FANET vs. Traditional Ad Hoc Networks

Although FANETs share some similarities with MANETs and VANETs, key distinctions arise due to the aerial nature of UAVs:

TABLE1: COMPARISON FOR DIFFERENT ADHOC NETWORKS.

Feature	MANET	VANET	FANET
Node Mobility	Moderate, 2D	High, linear 2D	Very high, random 3D
Topology Change Rate	Medium	High	Very high
Communication Range	Short	Medium	Long (LoS, optical, satellite)
Environment	Terrestrial	Terrestrial, Urban	Aerial, Urban/Remote
Handover Frequency	Moderate	High	Extremely High

In FANETs, the handover process is not only frequent but also more complex due to changes in altitude, direction, and signal characteristics influenced by the 3D nature of drone movement.

B. FANET Communication Modes

FANETs support several communication paradigms, each critical to the mobility and mission of UAVs in coordinated aerial networks. The most prominent mode is Air-to-Air (A2A) communication, which enables UAVs to directly exchange data packets using either single-hop or multi-hop wireless links. This decentralized approach facilitates real-time coordination and information sharing among drones without the need for a central control infrastructure. A2A communication is vital in swarm intelligence, formation flying, and persistent patrolling applications where distributed decision-making is preferred [4]. Another key mode is Air-to-Infrastructure (A2I) communication, where UAVs communicate with ground control stations, satellites, or cellular base stations. A2I links are essential for UAVs to receive mission commands, transmit collected data back to the base, or access Internet-based services. However, since A2I links often rely on ground-based infrastructure or low-orbit satellites, maintaining connectivity during high-speed flight and frequent direction changes becomes increasingly challenging, often necessitating frequent handovers between base stations or satellite beams.

The third, though less emphasized, mode is Intra-Vehicle Communication (IVC). This occurs within a single UAV's onboard systems between sensors, navigation controllers, and communication modules and is essential for ensuring the UAV can manage its functions autonomously. While IVC does not directly contribute to network-level handover events, it underpins the reliability of handover decisions by providing real-time sensor data and flight telemetry required for adaptive mobility management. These three communication modes together necessitate a handover framework that is both flexible and robust to frequent topology changes and channel variability.

C. Handover in FANET Architecture

Handover in FANETs presents a significantly more complex challenge compared to terrestrial wireless networks due to the intrinsic characteristics of aerial mobility. In conventional mobile networks, the handover process generally follows three main phases: the measurement phase, where the user device monitors signal quality; the decision phase, where the system determines if a handover is necessary and selects a target node; and the execution phase, where the actual transition of the communication session takes place. These processes assume relatively predictable movement patterns and stable radio environments. In FANETs, however, this process is deeply affected by non-linear and rapid UAV movement, altitude changes, and signal degradation due to LoS fluctuations. A UAV may enter and exit the range of multiple nodes in a matter of seconds, requiring handover events to occur far more frequently. Additionally, FANET handovers must account for 3D positioning, meaning that not only horizontal but vertical mobility impacts link quality. Furthermore, the UAV's operating speed and direction can unpredictably affect the link budget, making signal prediction and threshold tuning for handover initiation especially difficult [5].

Moreover, FANETs may require multi-hop handovers, where the data path must be dynamically rerouted through a sequence of UAVs to reach its destination. In such scenarios, link failures, node unavailability, or energy constraints can severely impact network continuity. Unlike cellular handovers that often occur between fixed base stations, FANET handovers may occur between two highly mobile aerial nodes, or between an aerial node and a terrestrial infrastructure necessitating hybrid handover strategies that support both horizontal handover operating over the same technology and vertical handover, where different technology or network type is supported by the network paradigm. These nuances make handover management a central and non-trivial aspect of FANET architecture.

D. System Components Affecting Handover

Several system components within a FANET influence the efficiency, latency, and success of the handover process. At the heart of the system are UAV flight control systems, which determine the trajectory, speed, and altitude of the drone. Since handover success depends on anticipating when a UAV will exit the coverage area of one node and enter another, real-time access to flight telemetry is essential for predictive handover algorithms. A UAV's ability to relay its current location, heading, and velocity significantly impacts the network's ability to perform proactive or seamless handover. Another critical component is the communication module, which includes the transceivers, antennas, and wireless protocols used to establish links. These modules determine the coverage radius, supported frequency bands and modulation schemes. For example, UAVs equipped with directional antennas may experience frequent link disruptions due to beam misalignment, which necessitates sophisticated beam tracking and mobility-aware routing protocols [6].

Middleware architectures, such as the UAV Service Abstraction Layer (USAL), play an increasingly important role in abstracting low-level control and providing a service-oriented architecture for UAV operations. Middleware can coordinate communication between UAVs by handling service discovery, command dissemination, and event handling across the network. In the context of handover, middleware can support distributed handover decisions and ensure synchronization between mission objectives and network state [7]. Lastly, routing protocols are instrumental in determining the performance of handover in FANETs. They employ different strategies for route discovery and maintenance. Their ability to dynamically adjust to changing topologies, manage buffer queues, and forward packets reliably affects the quality and frequency of handovers. Thus, an optimized routing protocol that integrates mobility prediction, energy awareness, and QoS prioritization is a key enabler of efficient handover management in FANETs.

E. Importance of Optimized Handover Management

Optimized handover management in FANETs is not merely a technical necessity but a mission-critical requirement that directly influences the success or failure of UAV-based operations. In high-stakes scenarios such as search-and-rescue missions, military reconnaissance, or emergency disaster response, a delay or disruption in communication can have life-threatening consequences. Maintaining seamless connectivity during UAV movement is vital to ensure continuous data transmission, command relays, and situational awareness. The growing integration of FANETs into 5G and future 6G infrastructures only amplifies this need. These advanced networks promise ultra-low latency and high data throughput, but they also operate in challenging environments such as millimeter wave (mmWave) and terahertz (THz) frequency bands, which are highly susceptible to interference, attenuation, and misalignment. Without optimized handover strategies, the reliability promised by next-generation networks cannot be realized in aerial domains. Moreover, UAVs are often energy-constrained devices. Frequent, poorly optimized handovers consume significant computational and communication energy, reducing UAV flight time and operational longevity. In energy-aware FANET designs, minimizing redundant handovers and overhead signaling becomes essential for extending mission duration. As FANETs evolve toward autonomous and AI driven systems, handover decisions must be made intelligently, with minimal human intervention. Incorporating machine learning, context aware algorithms, and predictive mobility models into handover mechanisms is not just beneficial it is inevitable. These technologies will allow FANETs to proactively manage handovers, adapt to unforeseen network changes, and maintain reliable communication links in even the most demanding scenarios.

III. Challenges in Handover for FANETs

As the deployment of UAVs in both civilian and military applications continues to expand, managing seamless connectivity in FANETs has become a critical research issue. The handover process is responsible for maintaining uninterrupted communication as UAVs switch between nodes or networks is subject to a unique set of challenges in aerial environments. Unlike terrestrial networks, FANETs contend with rapid topological changes, 3D mobility, and constraints in energy and onboard processing. This section outlines the most significant challenges in FANET handover management.

A. High Mobility in 3D Environments

The most fundamental challenge arises from the three-dimensional, high-speed mobility of UAVs. Unlike mobile users on the ground, UAVs are capable of fast vertical and horizontal movement. This introduces irregular and unpredictable trajectory changes, which make the signal strength and coverage area of each UAV highly dynamic. The result is a frequent and non-linear pattern of handover triggers, which cannot be effectively managed by traditional handover algorithms designed for 2D terrestrial networks. Moreover, the constantly changing topology due to node mobility leads to frequent link breaks, significantly affecting connection stability and QoS. Conventional handover schemes that rely on fixed signal thresholds may either trigger handovers too late (causing packet loss and service disruption) or too frequently (leading to unnecessary signaling and overhead).

B. *Transmission Protocol Limitations*

Most existing transmission protocols used in wireless networks—especially the widely implemented TCP/IP model are not well suited for FANETs. These protocols assume persistent, bidirectional links with relatively stable endpoints, which is rarely the case in airborne networks. In FANETs, communication links are temporary and asymmetric, and the UAVs may not remain within range of each other or the infrastructure for long durations. This results in a mismatch between traditional protocol expectations and actual UAV communication patterns. For instance, TCP misinterprets high mobility and frequent packet loss as congestion, unnecessarily throttling transmission rates. This leads to performance degradation during handover, making it critical to design mobility-aware and lightweight transport protocols that can function efficiently in highly volatile FANET environments.

C. *Line-of-Sight Dependency and Interference*

UAV communication is often dominated by LoS propagation. While LoS can offer low-latency, high-throughput links, it also increases vulnerability to signal blockage, multi-path fading, and inter-UAV interference especially when multiple drones operate in dense formations or urban environments. As UAV altitude increases, the number of visible base stations or neighboring drones also increases, leading to higher signal interference and overlapping coverage areas. This raises the probability of ping-pong handovers, where a UAV repeatedly switches between nodes due to small changes in signal strength. In addition, UAVs are typically served by side-lobes of ground-based antennas, which are designed for downward coverage toward terrestrial users. These coverage mismatches exacerbate signal quality issues at higher altitudes and make consistent handover execution more difficult [8].

D. *Energy Constraints*

UAVs are generally battery-powered, with limited energy budgets that must be allocated across communication, computation, sensing, and propulsion tasks. Frequent handovers not only increase signaling overhead but also impose a computational burden on the UAV's onboard processor. Control message exchanges during handover consume bandwidth and battery life, shortening mission duration. As a result, the energy cost of handover must be carefully considered when designing mobility management schemes. Energy-efficient handover protocols need to minimize unnecessary transitions and support context aware decision making to balance connectivity needs with energy availability [9].

E. *Limited Onboard Processing and Memory*

UAVs, especially small-scale drones used in FANETs, are limited in CPU resources, RAM, and data storage capacity. Complex handover algorithms that require large lookup tables, real-time signal analytics, or machine learning inference may exceed the computational capabilities of these aerial nodes. In addition, storing handover histories, predictive models, or network maps onboard the UAV may not be feasible in all cases. Therefore, lightweight, computationally efficient handover strategies are necessary. These may involve offloading decision-making to ground control stations or utilizing distributed architectures, where processing is shared among multiple UAVs with cooperative behavior.

F. *Absence of Standardized Handover Models for UAVs*

The lack of standardized mobility models and handover benchmarks for FANETs hinders the development and comparison of new handover strategies. Unlike terrestrial networks where urban, rural, and indoor mobility models are well defined, FANETs lack a universally accepted framework for modeling UAV movement, channel variation, or interference behavior. This makes simulation results inconsistent, limits reproducibility, and delays the convergence of research efforts. In addition, the heterogeneity in UAV hardware, communication modules, and mission objectives complicates the development of one-size-fits-all handover protocols. The absence of standardized handover APIs, mobility models, and performance metrics thus remains a bottleneck in achieving operational handover solutions for real-world FANET deployments [10].

IV. EXISTING HANDOVER SOLUTIONS AND STRATEGIES IN FANETS

Despite the complexity of mobility and communication in FANETs, numerous handover strategies have been proposed to support seamless connectivity and efficient network operation. These approaches can broadly be categorized into routing-based strategies, predictive handover techniques, middleware abstractions, and protocol-level enhancements. Each solution addresses specific dimensions of the handover problem such as latency, packet loss, energy consumption, or link stability while trying to preserve overall QoS.

A. *Routing Protocols with Handover Awareness*

Routing protocols play a central role in managing handovers within FANETs, especially when nodes operate in dynamic topologies. Since FANETs exhibit higher mobility than MANETs or VANETs, routing protocols must rapidly adapt to link changes and reconfigure paths with minimal disruption. Several protocols have been customized for FANET environments: XLinGo [11] is a cross-layer, position-based protocol designed for multimedia traffic in UAV networks. It integrates human interaction parameters and signal strength indicators to make routing and handover decisions more QoS aware. XLinGo reduces packet delay and improves delivery ratio by adapting to the mobility behavior of UAVs . GPSR (Greedy Perimeter Stateless Routing) [12] operates on geographic positions and routes packets greedily toward the destination, using the perimeter mode to recover from local minima. Its stateless nature and adaptability to movement patterns make it more suitable for high-mobility UAVs. TSOR (Time-Slotted On-Demand Routing) [13] enhances traditional AODV protocols by allocating dedicated time slots for data transmission. This reduces packet collisions and improves handover performance during congestion and high traffic loads. DSR (Dynamic Source Routing) [14] is a reactive protocol that maintains route caches and dynamically updates them in response to topology changes. Its mobility-aware variant improves responsiveness to frequent handovers but can suffer from control overhead in large UAV swarms. Cluster-based protocols [15], such as the mobility prediction clustering algorithm, focus on forming stable clusters with elected cluster heads that manage routing and handover locally. These methods reduce signaling overhead and extend link durations, making them effective for scalable deployments. These routing strategies contribute significantly to handover performance, either by reducing the frequency of link failures or by accelerating the network's reaction to them.

B. Predictive and AI-Driven Handover Techniques

Recent studies have introduced machine learning and mobility prediction models to anticipate handover events and optimize decision timing. These predictive strategies use data such as UAV speed, trajectory, signal history, and flight plans to forecast future link quality or node availability. For example, Kalman filters and Markov models have been applied to estimate future positions of UAVs, enabling pre-emptive handover decisions before a link degrades. Similarly, neural networks such as Long Short-Term Memory (LSTM) models have shown promise in predicting signal loss and managing handover execution without human intervention [16]. Moreover, Reinforcement Learning (RL) has been applied to dynamically learn optimal handover policies based on reward functions that consider latency, signal quality, and energy consumption[17]. These AI-based methods outperform static algorithms by adapting to real-world variability and unforeseen mobility patterns. While these solutions require significant training data and may have computational overhead, their ability to reduce ping-pong effects, minimize handover failures, and increase network resilience makes them increasingly relevant for future FANET deployments.

C. Middleware and Service-Oriented Architectures

Another emerging approach involves the use of Service-Oriented Architecture (SOA) to manage handovers at the application and service layers. Middleware frameworks like the UAV Service Abstraction Layer (USAL) offer a modular design that separates control, communication, and mobility management tasks. By decoupling these layers, the system can dynamically invoke services related to handover—such as link monitoring, route reassignment, and mission adaptation—without tightly coupling them to the UAV's firmware. SOA-based middleware also facilitates interoperability between heterogeneous UAVs and external systems, allowing seamless handover not only within the FANET but also between FANET and ground infrastructure [18]. However, implementing SOA in UAVs remains challenging due to distributed resource limitations and standardization gaps. Nonetheless, middleware abstraction is a powerful concept for achieving flexible and scalable handover control in large UAV swarms.

D. Optical Wireless and Hybrid Communication Solutions

To address the limitations of radio-frequency (RF)-based communication, Free Space Optics (FSO) has been proposed as an alternative for high-bandwidth, LoS-dependent links in FANETs. Optical handover strategies, while being sensitive to misalignment and atmospheric conditions, offer significant benefits in terms of data rate, security, and interference resistance [19]. For example, hybrid RF/FSO handover mechanisms allow UAVs to switch between optical and RF links depending on environmental conditions and mission demands. These strategies enable UAVs to maintain connectivity during long-range flights or when encountering RF-congested areas. Some systems also explore laser-based powering, which keeps UAVs aloft without landing for battery recharge, thus reducing the number of takeoff/landing sequences and the associated network disruptions. In addition to the protocols previously discussed, several other routing strategies have been adapted or designed specifically for FANET environments. These protocols are evaluated based on how well they support handover management under high mobility, dynamic topologies, and constrained resources. Some of the protocols are discussed as follows:

Directional Optimized Link State Routing (DOLSR) [20] is an extension of the Optimized Link State Routing (OLSR) protocol, which integrates directional antennas to improve link prediction and reduce the effects of link breakage in FANETs. By utilizing directional beam forming, DOLSR improves the accuracy of link establishment and reduces end-to-end delays during handover. The proactive nature of the protocol also enables quicker route updates, essential in high-mobility scenarios. Topology Broadcast Based on Reverse Path Forwarding (TBRPF) [21] is a proactive link-state routing protocol that maintains a topology table with information from nearby nodes using a reverse-path forwarding technique. It reduces overhead by broadcasting partial updates only when necessary. This minimizes the energy and bandwidth usage during frequent handovers and makes the protocol suitable for UAV networks with resource limitations. Gaussian Markov Mobility-based Position Oriented Routing (GMPOR) [22] is a mobility-aware routing protocol that uses a Gaussian Markov mobility model to predict the future positions of UAVs. This allows the protocol to anticipate link breaks and proactively initiate handovers. By integrating position information and mobility prediction, GMPOR improves routing stability and reduces the frequency of failed transmissions during handover events. CDMA-based Multi-channel Ad Hoc Routing protocols [23] based on Code Division Multiple Access (CDMA) and multi-channel operation introduce channel assignment mechanisms that allow UAVs to reduce collisions during route discovery and data transfer. In these protocols, a token-based mechanism is often used to avoid redundant transmission, which in turn lowers the chance of handover failure due to interference or congestion. Cluster Head Weighted Election Protocols (CH-WEP) [24] aim to form stable UAV clusters with a selected cluster head (CH) based on weight metrics such as mobility, connectivity, and residual energy. During handover, cluster heads act as regional coordinators that buffer data, maintain routing tables, and handover context information to new members joining the cluster. This reduces signaling overhead and latency associated with inter-cluster handovers. Predictive Optimized Link State Routing (P-OLSR) [25] is an enhancement of OLSR, P-OLSR incorporates GPS-based location prediction into its routing table computation. Unlike traditional OLSR, which passively waits for link-state updates, P-OLSR predicts UAV mobility trends and adjusts routes before handovers occur. This leads to faster convergence, reduced packet loss, and making it well-suited for high-speed UAV swarms.

TABLE 2: COMPARISON OF DIFFERENT STATE OF ART PROTOCOLS

Protocol	Type	Key Feature	Handover Support
Xlingo	Reactive	Cross-layer, multimedia-aware	High (QoS-aware, position-based)
GPSR	Proactive	Greedy + Perimeter, stateless	High (robust to dynamic topologies)
TSOR	Reactive	Time-slotted AODV variant	Moderate (low collision)
DSR	Reactive	Route cache, on-demand	Moderate (adaptive but high overhead)
Cluster-based	Proactive	Stability through CH election	High (longer link durations)
DOLSR	Proactive	Directional antennas, low delay	High (fast link re-establishment)
TBRPF	Proactive	Reverse-path updates, low overhead	Moderate (good for sparse networks)
GMPOR	Predictive	Mobility prediction, Gaussian model	High (proactive handover anticipation)
CDMA-based	Reactive	Token-based, multi-channel	Moderate (reduces collision)
CH-WEP	Hybrid	Weighted CH election for cluster routing	High (cluster-based HO management)
P-OLSR	Proactive	Location-prediction, GPS-integrated	High (proactive HO with low delay)

These protocols offer various advantages depending on network density, mobility rate, application requirements, and available hardware. For future FANET deployments, combining features from predictive, cross-layer, and energy-aware protocols may yield the best performance for handover-sensitive missions.

V. HANDOVER PERFORMANCE METRICS AND EVALUATION CRITERIA

Evaluating the performance of handover mechanisms in FANETs requires a combination of qualitative criteria (e.g., adaptability to topology changes) and quantitative metrics (e.g., handover delay or packet delivery ratio). These metrics provide insight into how well a system maintains connectivity, optimizes routing, and minimizes service disruption as UAVs move. Given the dynamic nature of FANETs, performance evaluation must also account for mobility patterns, energy constraints, and communication reliability.

Below are the most important metrics used in the research community and industry for assessing handover strategies in FANETs [26]:

A. Handover Latency (Handover Delay)

Handover latency refers to the total time taken to complete a handover process from initiation to final execution. This includes the detection of the need to switch, link establishment with the target node, and reconfiguration or update of routing tables. High latency can result in temporary disconnection, packet loss, and QoS degradation. In real-time applications such as live video streaming or aerial surveillance, minimizing handover latency is crucial.

B. Handover Success Rate (HSR)

This metric measures the percentage of successfully completed handovers over the total number of handover attempts. A high HSR indicates that the protocol is robust under various mobility and channel conditions. Protocols with low HSR may suffer from link failures, poor route selection, or excessive signaling overhead, all of which compromise network reliability.

C. Packet Delivery Ratio (PDR)

The Packet Delivery Ratio is the ratio of data packets successfully delivered to their destination to the total number of packets sent. PDR is an essential metric to assess data transmission reliability, especially during or immediately after a handover. Low PDR suggests packet drops due to handover delays, link failures, or poor routing decisions.

D. Handover Frequency

Handover frequency refers to the number of handovers that occur in a specific time frame or during a particular UAV mission. While some handovers are necessary, excessive handovers (e.g., due to the ping-pong effect) can result in unnecessary energy consumption and system overhead. High handover frequency may also correlate with inaccurate link prediction, low-quality mobility models, and overly sensitive signal thresholds. An ideal protocol should balance responsiveness with stability to avoid redundant handovers.

E. Energy Consumption Per Handover

Since UAVs are energy-constrained, this metric measures the energy cost incurred by the UAV's communication system during handover operations, including beaconing, channel scanning, route discovery, and data buffering. It is typically measured in joules (J) or milliwatts-seconds (mWs). Protocols that minimize energy usage during HO are preferred for long-duration missions or battery-powered drones.

F. Throughput

Throughput measures the effective data transmission rate achieved over the network during and after handovers. It is usually expressed in kilobits per second (Kbps) or megabits per second (Mbps). A sharp drop in throughput during handovers may indicate network instability or link reconfiguration issues.

G. Mean Opinion Score (MOS) for QoE applications

For FANETs supporting voice or video services, the user-perceived quality quantified using the Mean Opinion Score (MOS) is also relevant. MOS is a subjective rating on a scale of 1 to 5 that reflects the quality of multimedia applications affected by HO decisions.

H. Packet Loss Rate During Handover

This metric quantifies how many packets are lost while a handover is taking place. High packet loss can indicate poor synchronization between old and new links or ineffective buffering mechanisms. Protocols that implement make-before-break or handover buffering techniques usually perform better under this metric.

I. Link Recovery Time

This metric represents the time required for a disrupted link to be re-established after a failed handover. Faster recovery indicates better resilience to unexpected node mobility or signal loss.

J. Scalability Under Mobility

While not a numeric metric, scalability refers to how well the handover strategy performs as the number of UAVs increases or as the mission area expands. Protocols that maintain performance in large-scale deployments with high mobility are considered more robust and practical.

K. Simulation Tools and Evaluation Environments

Evaluating the performance of handover mechanisms in FANETs requires sophisticated simulation tools that can model the complex interaction between UAV mobility, communication protocols, and dynamic network topologies. Among the most widely adopted platforms is NS-3 (Network Simulator 3), a discrete-event network simulator well-suited for wireless networking research [27]. NS-3 supports realistic protocol stacks, mobility models, and routing algorithms, and allows the incorporation of handover logic using LTE and 5G modules. It can simulate parameters such as handover latency, packet loss, and route reconfiguration under varying UAV trajectories using scripting in C++ or Python.

Another extensively used simulator is OMNeT++, known for its modularity and extensibility. When integrated with the INET Framework, OMNeT++ can simulate wireless propagation, mobility, and routing behavior with high granularity. Its visual interface and support for real-time statistics collection make it particularly useful for modeling large-scale UAV swarms and evaluating the responsiveness of different handover strategies. A specialized version of OMNeT++, known as UAVSim, further extends its capabilities to model UAV-specific behaviors including takeoff, hovering, patrolling, and attack resilience. UAVSim is particularly effective for analyzing handover failures and mitigation techniques in FANETs operating under hostile or congested environments. For simulating realistic flight dynamics, AirSim, developed by Microsoft, provides high-fidelity UAV flight simulation based on Unreal Engine. While not a network simulator in itself, AirSim is highly effective for generating real-world UAV mobility traces that can then be integrated into network simulators like NS-3 or OMNeT++ for hybrid evaluation. Similarly, MATLAB and Simulink are used extensively for prototyping handover algorithms and modeling UAV dynamics, signal propagation, and trajectory predictions. MATLAB's Communications Toolbox supports simulation of custom handover triggers and adaptive routing logic under controlled mobility and channel conditions.

These simulation environments enable the evaluation of various performance metrics such as packet delivery ratio, handover delay, throughput, and energy consumption. They also support testing under diverse scenarios including random waypoint mobility, Gauss-Markov movement, and group-based swarm formations. Common simulation setups involve 5 to 100 UAVs flying at altitudes ranging from 50 to 500 meters, using protocols like GPSR, TSOR, DSR, or cluster-based routing. Traffic patterns often include constant bit rate (CBR), variable bit rate (VBR), or real-time video to evaluate the handover's effect on application-level performance.

By leveraging such tools, researchers can conduct repeatable, scalable, and realistic assessments of handover strategies without the high cost and risk of live testing. Hybrid simulations that combine physical UAV dynamics with communication layer evaluation offer a promising avenue for comprehensive performance testing. Ultimately, simulation platforms form the backbone of empirical research in FANET handover studies, supporting protocol validation, parameter tuning, and the development of robust mobility-aware solutions.

VI. Research Challenges and Proposed model for future

Despite significant progress in FANET development, several critical research challenges remain unresolved in the area of handover management. Chief among these is the lack of standardized mobility models and handover protocols tailored for aerial networks, as most current systems still rely on adaptations from ground-based MANET or VANET frameworks. Interoperability across heterogeneous UAV platforms also poses technical hurdles, requiring middleware and software-defined solutions to ensure seamless coordination. Security and privacy are growing concerns, with the need for lightweight cryptographic methods and privacy-preserving mechanisms to protect UAV communication and trajectory data. Additionally, handover protocols must be scalable to support ultra-dense UAV swarms, particularly in future smart city and disaster scenarios, and should incorporate bio-inspired strategies for decentralized coordination. With the integration of FANETs into 6G and non-terrestrial network infrastructures, new forms of vertical and horizontal handovers will emerge, requiring cross-layer and multi-domain orchestration. Most existing work remains simulation-based, highlighting the urgent need for real-world testing and hardware-in-the-loop validation. Furthermore, AI-based handover decision making must be optimized for energy-constrained UAVs, with lightweight models with hybrid edge computing solutions. Lastly, evolving from system-centric metrics to Quality-of-Experience (QoE) optimization will be vital in supporting user-driven applications like video streaming and teleoperation. These gaps underscore the need for a more adaptive, intelligent, and energy-efficient handover strategy, leading to the proposed mode-based Q-learning approach outlined in the next section.

In energy-constrained FANETs, the frequent execution of handover operations can result in considerable energy consumption, especially when all UAV nodes remain continuously active regardless of their role or necessity in the network. To address this inefficiency, a novel handover strategy is proposed that introduces dynamic energy modes namely Active, Sleep, and Hibernate wherein UAVs will adjust their operational states based on real-time mission demands, communication relevance, and energy availability. The key innovation in this approach lies in using a Q-learning algorithm, a type of model-free reinforcement learning, to autonomously determine the most energy-efficient mode for each UAV during and after handover.

In this model, UAVs in Active mode will participate fully in data forwarding, routing decisions, and handover execution. Nodes in Sleep mode will intermittently wake to monitor the network for possible reassignment but will otherwise remain in a low-power standby state. UAVs in Hibernate mode will disengage from communication tasks entirely, preserving energy by deactivating transceivers and routing functions while maintaining only essential flight systems. The Q-learning agent, embedded within each UAV's network control module, will continuously observe the UAV's environment—defined by state variables such as residual energy, link quality, mobility, and neighborhood density—and learn optimal actions (mode transitions) that maximize cumulative energy savings while maintaining handover success and network connectivity. The Q-learning framework will define states as combinations of contextual features (e.g., low energy + high mobility, high energy + critical relay position), actions as the transition to one of the three energy modes, and rewards as functions of successful handover, energy saved, and maintenance of QoS parameters like packet delivery ratio and latency. Over time, UAVs will learn policies that favor energy-saving behaviors in non-critical situations and prioritize connectivity when essential to mission performance. For example, a UAV nearing battery depletion and outside major routing paths will learn to enter hibernate mode, while a centrally located UAV with high link stability will remain active to facilitate routing. By using Q-learning, the system will avoid relying on static thresholds or pre-programmed rules, instead evolving behavior based on continuous feedback from the operating environment. This learning-driven approach will enhance autonomy, adaptability, and energy efficiency, especially in large-scale or long-duration missions where UAV roles and communication loads are constantly shifting. Future research will focus on simulating and validating this energy-mode handover strategy using platforms such as NS-3 or UAVSim, and evaluating its impact on network lifetime, handover success rate, and throughput under various mobility and energy profiles.

The integration of Q-learning for mode-based handover control is expected to transform FANETs into more intelligent, sustainable, and mission-resilient communication systems, capable of maintaining high performance even under tight energy constraints and unpredictable aerial dynamics. The introduction of energy-state transitions into the handover process will offer numerous advantages. It will reduce unnecessary energy expenditure across the network, limit signaling overhead, and enhance routing stability by avoiding dependence on energy-depleted nodes. Moreover, it will improve scalability by regulating how many UAVs are engaged in active communication at any given time. Lightweight control protocols will likely be developed to manage these state transitions efficiently, possibly at the MAC or network layer.

In the future, researchers will need to explore simulation-based validations of this model using platforms like NS-3, OMNeT++, or UAVSim. Experimental trials will be necessary to evaluate real-world performance improvements, battery savings, and mission sustainability. Further, adaptive mode control strategies using reinforcement learning or TinyML will be proposed to enable UAVs to autonomously decide their roles based on environmental and mission dynamics. Thereby incorporating active, sleep, and hibernate modes into FANET handover mechanisms will help transform UAV networks into more energy-aware, autonomous, and resilient communication systems, well-suited for long-duration, resource-constrained, and mission-critical operations.

VII. CONCLUSION

This paper has provided a comprehensive survey of the handover challenges and current solutions in Flying Ad Hoc Networks (FANETs). Given the unique characteristics of FANETs such as high mobility, 3D topology, and energy limitations the traditional handover mechanisms have been shown to be inadequate. The study reviewed a variety of routing protocols, performance metrics, and simulation environments, while also highlighting emerging technologies like artificial intelligence, Free Space Optics (FSO), Software-Defined Networking (SDN), and edge computing, which are expected to enhance handover performance and reliability.

A novel approach was proposed involving energy efficient handover management using dynamic UAV operational modes, namely active, sleep, and hibernate combined with RL algorithms. This strategy is expected to reduce unnecessary energy expenditure and improve the efficiency and scalability of future UAV networks. Looking ahead, further research will be required to address key gaps including standardization, security, scalability, and real-world deployment. Effective handover management will play a vital role in enabling stable, autonomous, and resilient FANETs in future communication systems, especially as UAV integration expands within 6G and beyond.

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