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# Flying Ad-Hoc Networks (FANETs): A Review

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## Abstract

INTRODUCTION: FANETs are a type of wireless communication network consisting of Unmanned Aerial Vehicles (UAVs) or drones that work collaboratively to process data and attain optimal results. These networks have achieved significant attention due to their potential applications in diverse engineering fields. The paper provides a comprehensive analysis of FANET, covering various aspects related to its classification, architecture, communication types, mobility models, challenges, characteristics, and design. It also discusses the importance of routing protocols and topology in FANETs. Furthermore, this paper identifies and presents open issues and challenges in the field of FANETs, urging researchers to focus on exploring and addressing these essential parameters and research areas.
OBJECTIVES: This paper will aims to promote further investigation and advancement in the field of FANETs and similar networks, enabling researchers to explore and overcome the challenges to unleash the full potential of these UAV-based ad-hoc networks shortly.
METHODS: The data used in this paper was gathered from various research papers. A brief comparison among FANETs, MANETs, and VANETs has been shown and highlighted the main points. This paper also elaborates the general architecture, mobility models, routing, routing protocols in FANETs.
RESULTS: It was discovered that the use of both deterministic and probabilistic techniques is suggested to enhance the performance and efficiency of FANETs. By combining these methods, the paper suggests that better results can be achieved in terms of network reliability, adaptability, and overall performance.
CONCLUSION: This paper discusses the importance of routing protocols and topology in FANETs. Furthermore, this paper identifies and presents open issues and challenges in the field of FANETs, urging researchers to focus on exploring and addressing these essential parameters and research areas.

**Keywords:** FANETs, Drones, Mobility Model, Routing Protocol, UAV

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## 1. Introduction

UAV systems have become increasingly popular in recent times due to the rapid technological advancements in electronic, sensor, and communication technologies [1]. UAV systems provide a great range of applications in both civil and military fields allowing for autonomous or unmanned remote operation that offers excellent flexibility.

1. UAV technology has been used in various applications including but not limited to border surveillance, disaster monitoring, search and rescue operations, ad-hoc networks, remote sensing, and traffic monitoring. Over the decades of use of UAV technology, it has been clearly understood that a group of small UAVs prove more beneficial than the development of one large UAV [2]. The coordination and collaboration of multiple UAVs largely escalates their capability beyond what can be accomplished by a single UAV.
2. Expandability: Multi-UAV systems can be scaled up to extend the range of applications very easily whereas a larger UAV has only limited a limited amount of coverage increases [3].
3. Speed: The speed of completion of missions is observed to be much higher in multi-UAV systems.
4. Survivability: Multi-UAV systems allow for the flexibility of altering the operations and continuing the mission even after the failure of one of the UAVs

whereas if a single UAV is being used, the mission would fail in case of any malfunctioning of the UAV.
5. Small radar cross sections: The smaller size of UAVs in a multi-UAV system result in very small radar cross sections which is crucial for military applications [3, 4].

The challenges posed by communication in a multi-UAV system, particularly in FANETs, are indeed necessary to address for the successful deployment and operation of UAVs in various applications [2, 3]. While single-UAV systems can establish communication easily with ground bases, satellites, or airborne control systems, the complexity rises significantly when multiple UAVs are involved.
This paper concentrates on FANETs as a new network family and compares them with other types of ad-hoc networks, namely Mobile Ad-Hoc Networks (MANETs) and Vehicular Ad-hoc Networks (VANETs). FANETs illustrate an ad-hoc network specifically designed for communication between UAVs. Each kind of ad-hoc network presents unique challenges due to its distinct features and usage scenarios [4].

**MANETs:** MANETs consist of mobile nodes (devices) that can communicate with each other directly without relying on any fixed infrastructure. These networks are favorably dynamic, and the network topology can change rapidly due to node mobility. However, in MANETs, the nodes are typically ground-based, which makes them distinct from FANETs where UAVs operate in three-dimensional airspace [5, 6].

**VANETs:** VANETs are a specific type of ad-hoc network designed for communication between vehicles. While VANETs share some similarities with FANETs in terms of mobility and dynamic network topology, the operating environment and challenges are different as UAVs operate in the airspace, not on roads [5, 6].

**FANETs:** FANETs are ad-hoc networks specifically tailored for communication between UAVs as shown in Figure 1. The challenges in FANETs are impressive due to UAVs' three-dimensional mobility and the need to account for obstacles, varying altitude, and air traffic regulations [7]. Efficient network architectures, routing protocols, collision avoidance mechanisms, and secure communication are some of the essential design challenges faced in FANETs.
The paper likely delivers an overview of existing solutions and research issues associated to FANETs [8]. As FANETs are an emerging area of research and technology, there are still many open research questions and challenges that need to be addressed to fully realize the potential of multi-UAV systems and their integration into different applications. Efficient communication is undoubtedly one of the central pillars of successful multi-UAV systems, as it encourages coordinated and collaborative behaviour among UAVs, leading to more robust and effective operation in a wide range of scenarios.

## 2. Related Work

It is apparent from the provided information that research on FANETs and their routing protocols is extensive and addresses different design considerations and challenges [9, 10]. Several researchers have contributed to this field by proposing different routing protocols, discussing mobility models, and analyzing energy-efficient solutions for UAVs in FANETs. Let's summarize the key points mentioned in the text:

1. **Design Considerations and Routing Protocols in FANETs:** Several research papers, such as those by Bekmezci et al., Gupta et al., and Mukherjee et al., have concentrated on design considerations, routing protocols, and mobility models for FANETs. They address how airborne nodes can cooperate, coordinate, and maintain dedicated connections with base control through appropriate routing mechanisms.
2. **Cluster-Assisted Routing Protocols:** Arafat et al. delivered a comprehensive explanation of cluster-assisted routing protocols in UAVs, highlighting the benefits, drawbacks, practicality, and potential future improvements of each protocol. Clustering is a common technique in ad hoc networks to enhance efficiency and manage communication effectively [10].
3. **Energy-Efficient Protocols:** Energy efficiency is a necessary concern for UAVs in FANETs. Researchers like Bashir et al. have explored energy-efficient protocols across various layers of the communication stack, including the physical layer and data link layer. Methods like clustering, rapid movement handling, and duty cycles are employed to optimize energy consumption.
4. **Multi-UAV Coordination and Collision Avoidance:** Ryan et al. and Vachtsevanos et al. examined the concept of involving multiple UAVs in various operations, including detecting and collision avoidance. Game-theoretical methods and control mechanisms are utilized to manage multiple UAVs effectively [11].

Overall, these research papers shed light on the importance of FANETs, the challenges in routing and communication, and the possible solutions to provide efficient and trustworthy operations of UAVs in multi-UAV systems [12]. The constant research in this domain aims to address these challenges and further enhance the capabilities and applications of FANETs in various fields.

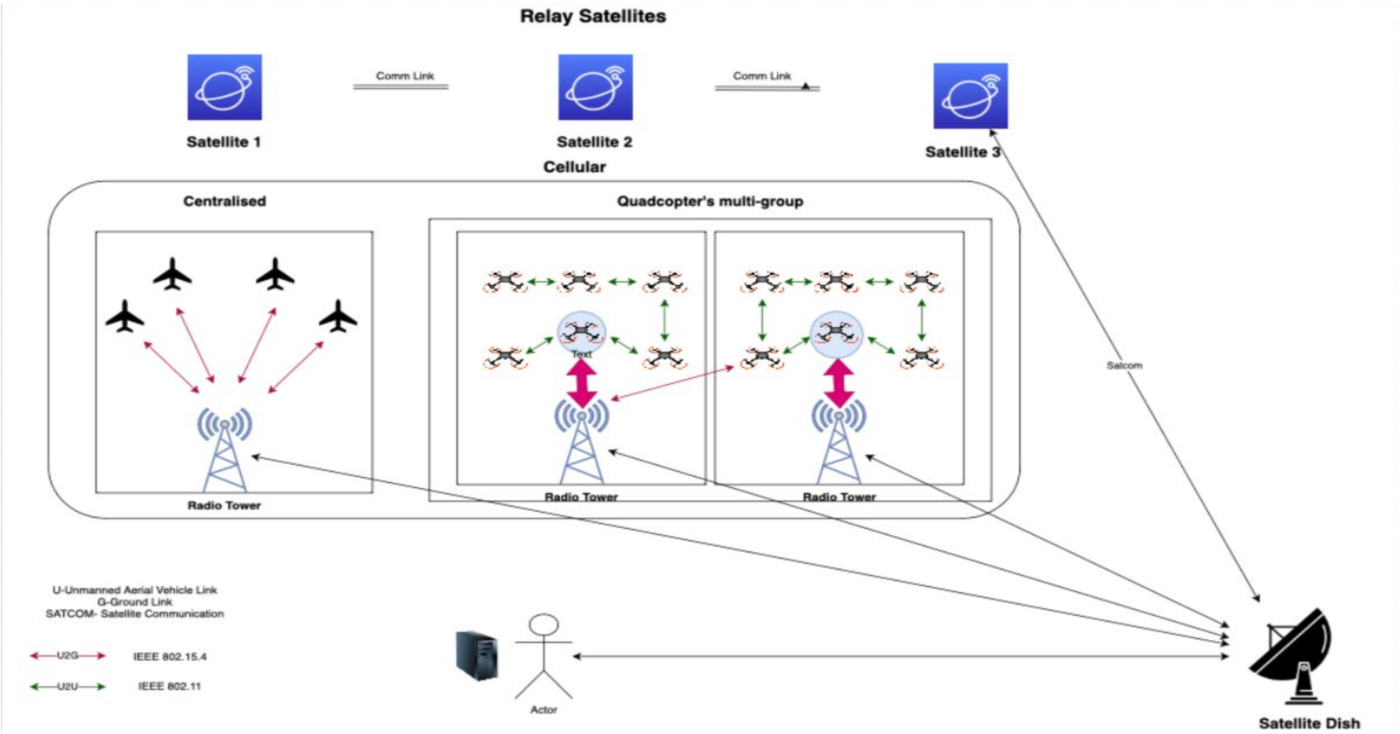


Fig. 1. FANETs Network overview

## 3. Comparison Between FANETs, MANETs, and VANETs

Based on the furnished information, we can recognize and center on the functionality, usage, communication, and goals of different ad hoc networks [13, 14]:

1. **MANETs:**
   - (i) Functionality: A self-configuring, self-maintaining, and self-controlled network consisting of mobile nodes linked wirelessly without any fixed infrastructure.
   - (ii) Communication: Nodes communicate with each other directly, creating a dynamic and varying network topology.
   - (iii) Goals: Facilitating communication and data exchange among mobile nodes in a decentralized manner.
   - (iv) Limitations: Limited battery power, bandwidth, as well as storage capacity in mobile devices.

2. **VANETs:**
   - (i) Functionality: A special type of MANET that specifically allows communication among vehicles and between vehicles and roadside infrastructure.
   - (ii) Communication: Supports three main communication types: Infrastructure-to-Vehicle (I2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Vehicle (V2V).
   - (iii) Goals: Improving road safety, traffic management, and providing comfort applications for drivers and passengers.
   - (iv) Limitations: Dependent on road models for predicting vehicle movements and interactions.

3. **FANETs:**
   - (i) Functionality: A subclass of ad hoc networks specifically designed for communication among flying vehicles, such as drones or unmanned aerial vehicles (UAVs).
   - (ii) Communication: Promotes communication and coordination among flying vehicles in the absence of a fixed infrastructure.
   - (iii) Goals: Facilitating autonomous and efficient communication and data sharing among flying vehicles.
   - (iv) Limitations: May face challenges connected to flight dynamics, airspace regulations, and energy constraints for airborne vehicles.

It's important to note that FANETs are a subclass of ad hoc networks, just like VANETs, but each has its special characteristics and application areas [15]. Some researchers consider that FANETs are a subset of VANETs, and VANETs, in turn, are a separate category from MANETs. However, this classification may vary relying on different researchers' perspectives and criteria for differentiation.

## 4. Flying Ad hoc Network Architecture

Indeed, FANETs illustrate a fascinating area of research and have the potential to revolutionize diverse industries by enabling secure and efficient communication among UAVs [16].
In FANETs, UAVs interact with each other wirelessly, forming a dynamic network that permits them to collaborate and share information in an ad hoc manner without depending on a fixed infrastructure [17, 18]. The decentralized nature of FANETs allows UAVs to adapt to modifications in the network topology and maintain communication even in challenging environments.

Key challenges in FANETs enclose:
1. *Routing and Network Organization*: Due to the highly mobile nature of UAVs, traditional routing protocols may not be appropriate. Designing efficient and adaptive routing algorithms that can endure dynamic topology changes is essential for FANETs' success.
2. *Security*: Ensuring the secure exchange of data among UAVs is necessary to prevent unauthorized access and potential cyber-attacks. Encryption, authentication, and secure key management mechanisms are crucial components of a secure FANET [17].
3. *Interoperability and Communication Protocols:* As different UAVs may use different communication technologies and protocols, accomplishing interoperability becomes crucial to allow seamless communication among UAVs from different manufacturers.
4. *Scalability and Resource Management*: As the number of UAVs in the network grows, managing the available resources efficiently becomes a significant concern. Resource allocation, congestion control, and load balancing are critical aspects of scalable FANETs.
5. *Mobility and Handover*: UAVs in a FANET will move continuously, and efficient handover mechanisms are required to maintain uninterrupted communication during transitions between different UAVs or between UAVs and ground control stations [18].
6. *Collision Avoidance and Traffic Control:* Preventing collisions between UAVs is required to ensure safe and trustworthy operations in the airspace. Advanced traffic control mechanisms and collision avoidance algorithms are necessary for FANETs' safety.

### 4.1. UAV communication approaches

A description of the different communication modes mentioned [18]:

#### 4.1.1. UAV Direct Communication:

In this method, each UAV directly communicates with one or multiple ground control stations. The communication tracks a star topology, where UAVs are directly connected to ground control, and intercommunication between UAVs is not possible. The data transmission is via the ground control station(s).

#### 4.1.2. UAV Communication through Satellite Networks:

Satellite communication is used for UAVs that need to communicate over long distances. Different frequency bands and propagation techniques, such as Ground Wave propagation and Skywave propagation, are employed depending on the distance and atmospheric layers.

#### 4.1.3. UAV Communication via Cellular Networks:

UAVs are treated as cells connected to ground control stations in this approach. It presents a dedicated and guaranteed solution for various civilian and military applications. Different cells use various frequencies to avoid interference with each other.

#### 4.1.4. UAV to UAV Communication:

This communication strategy focuses on fulfilling the communication requirements of various missions by encouraging frequent exchange of data packets between UAVs. Multihop transmission is used when transmission ranges are limited, and additional UAVs are involved.

#### 4.1.5. UAV to Base Control/Ground Control:

Base control stations, also known as ground control stations, supply crucial command and control messages for hovering UAVs. They also help in connecting various UAV classes and encourage communication among UAVs themselves.
Each communication approach has its strengths and weaknesses, making them suitable for different methods and applications [19]. FANETs' success relies on selecting the appropriate communication design based on the specific conditions and constraints of the UAV missions and environments.

## 5. Different Mobility Models of Fanet

Mobility models are crucial for simulating realistic circumstances for FANETs and are important for developing practical routing protocols and considering UAV communication implementation under various methods [18, 19]. A broad outline of common mobility models employed in this context:

1. Random Waypoint Model: This is a widely employed mobility model in which UAVs move randomly within a predefined region. UAVs select a random destination point and move towards it at a bounded speed. Upon arriving the destination, they wait for a certain time and then choose another random destination.
2. Random Walk Model: In this model, UAVs move by carrying random steps in various directions. The direction and step length are generally selected based on probability

allocations. This model can describe methods where UAVs move in a more chaotic method.

3. Group Mobility Model: This model describes the motion of UAVs in groups or formations. It believes the interdependence between UAVs' movements within a group and how the group as a whole move. This model is specifically suitable for swarm-based FANETs.
4. Nomadic Community Model: In this model, UAVs track the motion practices of human or vehicle communities. It can be used to simulate strategies where UAVs are deployed to pursue specific groups of interest, such as pursuing a convoy of vehicles or a batch of people.
5. Brownian Motion Model: Also called as the random motion model, it designates the UAVs' movements as a consequence of random forces acting upon them. UAVs move unassisted in random directions, simulating the random motion of particles in a fluid.
6. Reference Point Group Mobility Model: This model describes a set of reference points within a simulation region. UAVs move based on the attractive or repulsive forces exerted by these reference points.
7. City Section Model: This model separates the simulation area into different divisions, each expressing a distinct environment or terrain type. UAVs move between sections based on certain possibilities, permitting the simulation of UAVs transitioning through diverse types of terrain.
8. Manhattan Mobility Model: Motivated by the structure of city streets, this model determines UAV movement to a grid-like network of roads. UAVs can move horizontally or vertically along the streets, and junctions become critical points for interactions.
9. Gauss-Markov Model: This stochastic model incorporates random motion and inertia. UAVs have a tendency to resume moving in their present direction but are also subject to random modifications in velocity as well as direction.
10. Epidemic Mobility Model: Mainly used for modelling information dissemination, this example assumes that UAVs can maintain and spread information as they move. It's specifically relevant in procedures where UAVs are used for data collection and dissemination.

These are just a few instances of mobility models that can be used to simulate UAV movements within the context of FANETs [19]. The choice of model depends on the specific characteristics of the simulation and the research purposes.

## 6. Routing in Fanet

In wireless networks, routing refers to the process of directing traffic from the source to the destination by determining a path for the same [20]. It is important to realize that routing is a crucial feature and needs to be addressed in extension to other requirements such as obtaining the most efficient path, scalability of the network, restricting latency, mobility, authenticity, and guaranteeing needed QoS. Routing techniques: Different routing techniques can be used based on different situations or triggered events.

1. Prediction: In some circumstances, it may be necessary to foresee a possible relay node's state based on its velocity and direction. The best relay node closest to the destination can be chosen with the aid of this information. To produce precise predictions, this technique might need further details about the destination node's neighbours.
2. Clustering: Clustering involves dividing the network into smaller zones or clusters, where a designated cluster head controls each group of UAVs.In dense networks like FANET (Flying Ad Hoc Networks), clustering can help manage network traffic, but it introduces additional overhead.
3. Energy-based: Battery-powered networks like FANET have a common problem where there is a need for energy conservation to extend the lifetime of the UAVs. To combat this energy-based routing is used as it considers the energy consumption level while routing. However, other technologies need to be coupled together with energy-based routing to present packet loss.

## 7. Routing Protocols in Fanet

This section concerns various routing protocols suitable for FANETs [21]. These protocols manage the challenges posed by highly dynamic and mobile networks like FANETs, where UAVs need to communicate efficiently while evaluating factors such as delay, disruption, energy consumption, security, and network conditions. The key points for each type of routing protocol:

1. Dela Tolerant Network (DTN) Routing:

DTN is used in heterogeneous networks where continuous network connections may be lacking, resulting in delays and disruptions. The store-and-forward process is employed to ensure successful message delivery.

2. Position-based routing protocols are a type of routing protocol utilized in wireless ad-hoc networks, including Flying Ad-Hoc Networks (FANETs). These protocols depend on GPS-based location information of nodes within the network to make routing conclusions. The main concept behind position-based routing is that

nodes use their geographical positions (latitude and longitude) to choose the next hop for packet forwarding, instead of traditional IP addresses or node identifiers.

3. Multipath Routing:
Efficient data delivery often demands multiple paths to avoid congestion, load balancing, and ensure reliability. Multipath routing forwards packets through more than one path, reducing problems like congestion and load balancing. There are two types of multipath routing:

4. Hierarchical Routing:
A densely populated network benefits from efficient management through hierarchical node levels, where each level has a designated head node responsible for communication within the group.

5. Heterogeneous Routing:
FANETs can interact with both fixed and mobile nodes. Protocols employing this design offer benefits such as extending networks, covering sub-networks, and assisting ground nodes along with FANETs in accomplishing specific tasks.

6. Swarm Routing:
This technique is inspired by the social behavior of birds, fishes, or insects, and it models the protocol accordingly to solve complex optimization problems. Its usage in FANETs can provide near-optimal solutions.

7. Cluster Routing:
Nodes with similar features and characteristics are combined into clusters, where one node is elected as the cluster head responsible for communication within the cluster. Dynamic cluster appearance and cluster head selection are actively handled.

Each type of routing protocol offers different advantages and features, and the choice of the appropriate protocol leans on the specific requirements, network conditions, and applications of the FANET [22]. Researchers and developers need to consider these factors to design efficient and adequate routing solutions for UAV-based networks.

## 8. Research Challenges

UAVs have made significant advancements and found diverse applications in various fields, leading to an increased demand in the mobile revolution [21, 22]. However, they also face challenges that need to be addressed in future editions of UAV technology which are as follows:

1. Peer to Peer UAV Communication:

UAV communication involves distributing tasks or workloads among multiple nodes, making peer-to-peer communication a suitable approach. However, implementing this in FANET communication poses challenges.

2. Battery Power:

UAVs rely on battery power, and optimizing energy consumption is an ongoing concern. Developing efficient routing protocols with new technologies like AI, ANN, and ML, and exploring green energy options like solar power, are essential.

3. Security:

UAVs' versatile connectivity as clients or servers makes them vulnerable to various cyber-attacks. Robust security measures are crucial to ensure a secure communication system.

4. Standardization of Communication Bands:

UAV communication uses specific frequency bands, but standardizing these bands is necessary to minimize congestion and interference issues.

5. Fault Tolerance System:

FANETs heavily depend on UAVs sharing critical data. Implementing fault tolerance mechanisms, such as hardware redundancy and error handling, is crucial to maintain network reliability.

6. Integration with IoT:

FANETs with their autonomous flying nodes and decision-making abilities can be enhanced by integrating with the Internet of Things (IoT). This integration presents significant potential but also comes with substantial challenges.

7. 5G Impact:

The rise of 5G technology brings its own set of challenges and concerns. Integrating 5G with FANETs is complex and requires careful consideration of technical issues.

In conclusion, UAVs have a promising future, but addressing these challenges is crucial to fully unlock their potential and ensure safe and efficient operations in various applications [23]. Researchers continue to work on overcoming these obstacles and advancing UAV technology.

## 9. Conclusion

This paper concludes that the field of UAVs, generally known as drones, is rapidly developing and discovering applications across diverse sectors. The communication between UAVs and ground control is indeed a vital aspect, promoting adequate cooperation and implementation of tasks across industries like commerce, military, as well as environmental monitoring. FANETs involve the transmission and coordination of numerous UAVs in a networked mode. This technology is particularly interesting as it permits for the deployment of UAVs in cooperative missions where they can communicate and collaborate in real-time. The benefit of numerous UAVs has seen incredible evolution due to the demand for efficient and remote area range. This evolution is pushing investigators to think creatively and analyse new strategies above standard procedures. The capability to cover extensive regions and accomplish tasks without the need for on-site personnel is a tremendous attainment in terms of research and technical invention. It's necessary to note that the challenges in this field are multifaceted. They contain ensuring dependable communication between UAVs and ground control, controlling the airspace to avoid collisions, optimizing the distribution of assignments among UAVs, and managing privacy and security problems. As technology continues to advance, we can desire to see even more creative applications of UAVs and advancements in communication and collaboration strategies between these devices and ground control. The integration of artificial intelligence and advanced algorithms will probably play a substantial role in accomplishing more efficient and capable UAV operations.

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