Optimizing Clustering through ACO and Secure Waterfall Energy-Efficient Protocol-Enabled Routing in FANETs

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Abstract - Flying Ad-Hoc Networks (FANETs) are an emerging technology that enables communication among multiple Unmanned Aerial Vehicles (UAVs) without relying on fixed infrastructure, but their high mobility and dynamic aerial environments make efficient routing and reliable communication challenging. This project addresses these challenges by integrating the SWEEPER routing protocol with an Ant Colony Optimization (ACO)-based clustering approach to enhance network stability, scalability, and energy efficiency. The SWEEPER protocol supports dynamic routing decisions, while ACO-based clustering organizes UAV nodes into efficient groups for improved data transmission. This combined method reduces packet loss, minimizes communication delay, and enhances overall network performance. Simulation results show improved packet delivery ratio, reduced latency, and increased network lifetime compared to traditional methods, contributing to the development of reliable and efficient communication strategies for applications such as disaster management, surveillance, environmental monitoring, and military operations.

Key Words: FANET, UAV, SWEEPER Protocol, Ant Colony Optimization, Clustering, Routing.

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1. INTRODUCTION

Flying Ad-Hoc Networks (FANETs) extend the capabilities of Wireless Sensor Networks (WSNs) by enabling communication among UAVs, sensor nodes, cluster heads, and base stations without fixed infrastructure. In such networks, source nodes collect and transmit data, intermediate nodes like cluster heads manage communication, and base stations relay information to end users via the internet. Since WSN nodes are battery-powered, energy consumption—especially due to data collection, processing, transmission, replication, and retransmission—is a major challenge. To address this, energy-efficient routing protocols and clustering techniques are used to improve scalability, reduce latency, and extend network lifetime. Clustering also enables data aggregation, load balancing, and reduced communication overhead. FANETs rely on decentralized and dynamic communication architectures, making them suitable for real-time applications despite frequent UAV mobility and lack of permanent connectivity.

2. LITERATURE SURVEY

The development of Flying Ad-Hoc Networks (FANETs) has its roots in Wireless Sensor Networks (WSNs), where sensor nodes are responsible for sensing, processing, and transmitting data to a base station. According to earlier studies [1], FANETs consist of three main types of nodes: source nodes that collect and transmit data, intermediate nodes such as Cluster Heads (CHs) that manage communication and routing, and base stations (BS) that deliver the collected information to end users through internet connectivity. These sensor nodes are typically battery-powered, making energy consumption a critical concern. Research highlights that a significant portion of energy is consumed during data collection, processing, and transmission, while additional factors such as data replication and retransmission further degrade node energy levels [2,3].

To overcome these challenges, various energy-efficient routing protocols have been proposed in the literature. These protocols primarily aim to enhance scalability, reduce energy consumption, and ensure reliable data transmission. Studies indicate that the performance of routing protocols depends on multiple factors, including communication models, network structures, and topology design. Clustering has been widely recognized as an effective technique to improve network efficiency. In clustered networks, nodes are organized into groups, with cluster heads responsible for aggregating and forwarding data, thereby reducing redundant transmissions and conserving energy. Literature also shows that clustering provides several advantages such as improved scalability, reduced communication overhead, minimized collisions, balanced load distribution, lower latency, increased robustness, and extended network lifetime.

Furthermore, research emphasizes the importance of communication architecture in FANETs [4]. Unlike traditional networks, FANETs operate in a decentralized and infrastructure-less environment, where UAVs communicate dynamically without relying on fixed base stations. This makes them highly suitable for real-time applications and scenarios with limited communication range. Due to the high mobility of UAVs, maintaining stable communication links is a major challenge, as nodes frequently connect and disconnect. Therefore, decentralized communication architectures are considered more suitable for FANETs, allowing flexible and adaptive communication among UAVs. Several studies [5,6] have proposed different multi-UAV communication architectures to address these challenges, focusing on improving coordination, reliability, and overall network performance in highly dynamic environments.

3. EXISTING SYSTEM

The SWEEPER protocol enhances FANET communication by integrating secure and energy-efficient routing with trust-based node evaluation to defend against common attacks such as MITM, IP spoofing, and black hole attacks. It uses an AODV-based route discovery process where nodes are authenticated at the initial stage, and only trusted nodes participate in communication, ensuring secure data transmission. The routing strategy is QoS-aware, selecting energy-efficient paths with high packet delivery ratio and low delay while avoiding low-energy nodes to prevent failures. SWEEPER dynamically adapts to network changes caused by UAV mobility, updating routes and clustering decisions in real time for improved reliability. Trust values are computed using factors such as energy level, mobility, packet delivery success, and location, supported by cryptographic mechanisms and RSSI for proximity detection. Additionally, the framework employs key management schemes using Computed Key (CKey) and Dissemination Key (DKey) nodes to ensure secure encryption, authentication, and data integrity, making the network robust, adaptive, and highly secure.

Limitations:

Clustering was not optimal.

CHs placement was also not optimal

4. PROPOSED SYSTEM

The Computed Key (CKey) and the Dissemination Key (DKey) are two separate nodes in our method. The secret keys will be generated, verified, and dispersed by the two nodes. As a result, other nodes won't have to waste time on key management or computation and may concentrate entirely on transmission. Effective treatment is also provided for malignant nodes and security breaches. Our system is able to choose only genuine nodes that will relay packets along the identified path since the nodes along the route are selected based on a trust factor. We use wellestablished methods to analyze our work. SecRIP and MDRMA are FANETs. Our technique outperforms current protocols in terms of PDR, energy conservation, and minimal delay. This contributes to a high throughput.

Because the nodes along the route are chosen based on a trust factor, our system can select only authentic nodes that will relay packets along the designated path. Although the routing was optimized using the SWEEPER protocol, the clustering phase is experiencing issues with unequal energy use. We are using Ant Colony Optimization (ACO) to build balanced clusters in order to solve this. Our method performs better than existing methods in terms of low latency, energy conservation, and PDR. This results in the lowest energy use and maximum throughput .

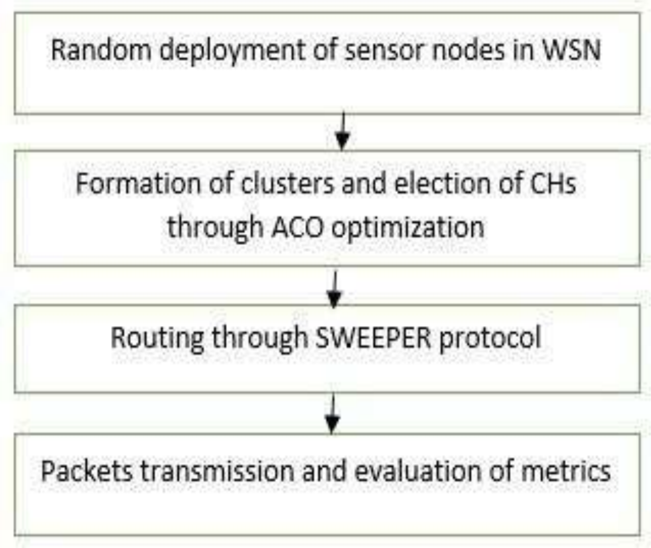

Fig 1: Flow of Proposed Method

5. IMPLEMENTATION AND RESULTS

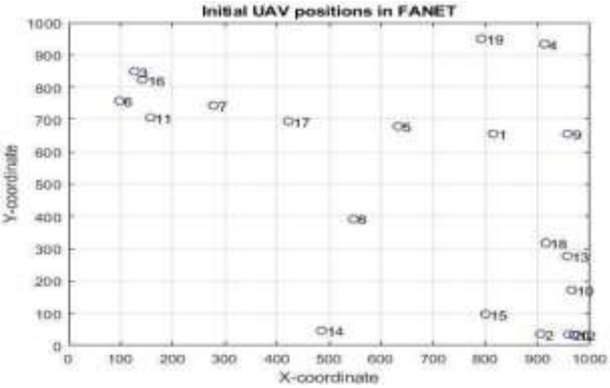

Fig.2: Initial UAV positions in FANET

The graph helps visualize how far apart the UAVs are, which directly affects communication range, connectivity, and routing performance. Some nodes are clustered closer together (better communication chances), while others are isolated, which may require multi-hop communication.

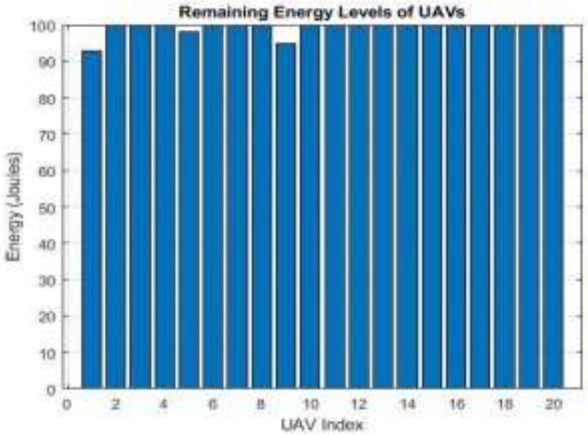

Fig.3: Remaining energy positions in FANET

Each bar corresponds to a UAV (indexed from 1 to 20 on the X-axis), and the Y-axis shows the energy in joules. Most UAVs still have energy levels close to the initial value (around 100 J), while a few nodes show slightly lower values (around 90–95 J). fairly balanced across the network, which is a good sign of an efficient routing protocol.

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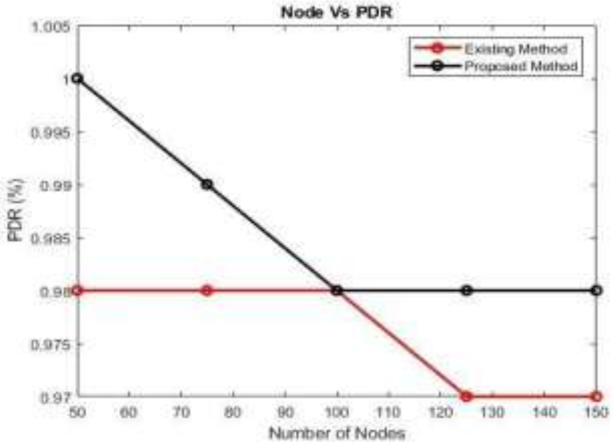

Fig.4: Node vs PDR

This graph shows the Packet Delivery Ratio (PDR) comparison between the existing method and the proposed method as the number of nodes increases.

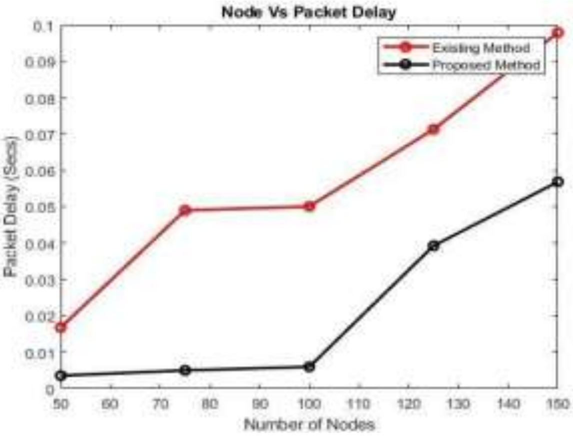

Fig:5 :Node vs Packet delay

This graph shows how a network performance metric (likely delay or packet loss) changes as the number of nodes increases, comparing an existing method (red line) with a proposed method (black line).

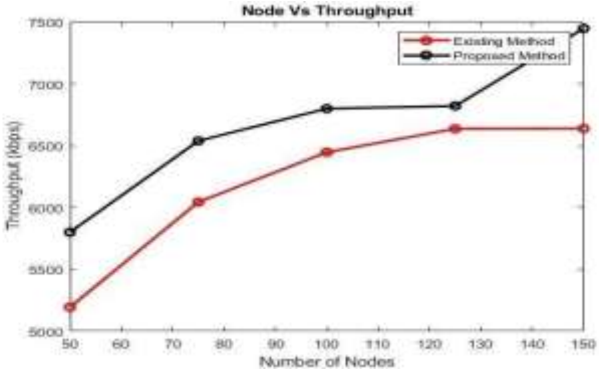

Fig 6 : Node vs Throughput

This graph shows the relationship between the number of nodes and throughput (in kbps) for two methods: an existing method and a proposed method. As the number of nodes increases from 50 to 150, the throughput also increases for both methods.

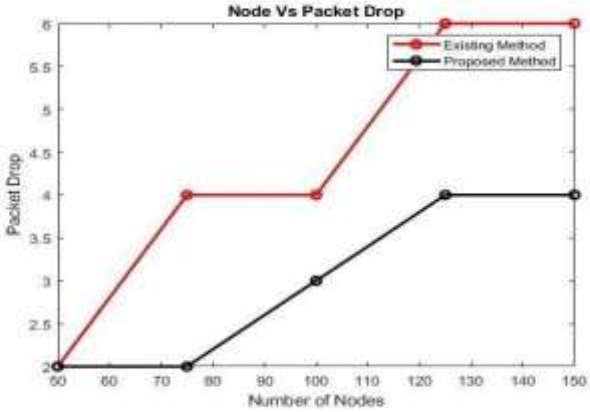

Fig 4.6: Node vs Packet drop

This graph shows how packet drop changes with the number of nodes for both the existing and proposed methods. As the number of nodes increases, packet drop rises in both cases, but the existing method experiences a higher increase compared to the proposed method.

6. DISCUSSION

The SWEEPER project, which stands for Secure Waterfall Energy-Efficient Protocol Enabled Routing, plays a significant role in improving communication in Flying Ad Hoc Networks (FANETs). In the discussion context, SWEEPER is mainly designed to address the major challenges of FANETs such as high mobility of UAV nodes, frequent topology changes, limited battery power, and security threats. It introduces a secure and energy-efficient routing mechanism where data is transmitted through trusted nodes selected based on a calculated trust value.

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7. CONCLUSION

The integration of Ant Colony Optimization (ACO) for clustering and the Secure Waterfall Energy-Efficient Protocol (SWEEPER) for routing significantly enhances the performance of FANETs by optimizing key network metrics. The adaptive clustering mechanism of ACO helps in balancing energy consumption, leading to reduced packet delay by minimizing unnecessary hops and congestion. Moreover, the intelligent routing of SWEEPER improves throughput, ensuring a higher data transmission rate by selecting energy-efficient paths. The combined approach also effectively reduces packet drop, as UAVs with optimized energy levels and strategic clustering can sustain longer network operation. Furthermore, the Packet Delivery Ratio (PDR) remains high, demonstrating the robustness of ACO and SWEEPER in maintaining reliable communication within the FANET. This synergy between ACO and SWEEPER ensures a more energy-efficient, delay-sensitive, and high-performance UAV network.

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