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SHBIO-FANET: Secure and Hybrid Bio Inspired Optimization for FANETs

Mr.K.Noel Binny M.Sc., M.Phil., PGDCA., HDSE.[1], Mr.A.Hariharasudan[2]

Assistant Professor - Department of Computer Science, VLB Janakiammal College of Arts and Science, Kovaipudur, Coimbatore - 641042[1]

M.phil.,Reasearch scholar Dept of Computer Science, VLB Janakiammal College of Arts and Science, Kovaipudur, Coimbatore – 641042[2]

Abstract: This paper presents a novel clustering scheme for optimizing energy consumption in Flying Ad Hoc Networks (FANETs) using a Secure and Hybrid Bio-Inspired Optimization (SHBIO) method, integrating Binary Whale Optimization Algorithm (BWOA) and Ant Colony Optimization (ACO). The proposed approach involves calculating the optimal number of cluster heads (CHs) based on coverage demand and bandwidth balancing. By considering UAV energy, inter-cluster and intra-cluster distances, and load balancing, the method selects optimal CHs. Clusters are maintained efficiently, and the nearest high-energy node is chosen for communication. Performance metrics such as end-to-end delay, network lifetime, throughput, packet delivery ratio, and packet loss were evaluated. Results demonstrate that the SHBIO-BWOA_ACO method significantly outperforms previous methodologies, achieving lower energy consumption, higher throughput, and improved network performance.

Keywords: Flying Ad Hoc Networks (FANETs), Binary Whale Optimization Algorithm (BWOA), Ant Colony Optimization (ACO), energy consumption, clustering, network performance, packet delivery ratio, throughput, end-to-end delay.

I. INTRODUCTION

The rapid evolution of wireless communication technologies and Unmanned Aerial Vehicles (UAVs) has catalyzed the development of Flying Ad Hoc Networks (FANETs), where UAVs autonomously or remotely piloted collaborate to form dynamic networks. FANETs find applications across diverse domains such as precision agriculture, disaster response, and military surveillance, leveraging UAVs' ability to swiftly deploy and operate in challenging environments. However, these networks face distinct challenges including high mobility, limited energy resources, and the need for efficient network management strategies.

This paper introduces a novel clustering scheme aimed at optimizing energy consumption within FANETs. By integrating the Binary Whale Optimization Algorithm (BWOA) and Ant Colony Optimization (ACO), this study seeks to enhance network sustainability and operational efficiency. The proposed approach addresses critical FANET characteristics such as node density, mobility patterns, and dynamic network topologies, essential for ensuring reliable and efficient communication. Moreover, the integration of UAVs with cloud-based management systems (CBUMS) further enhances network capabilities through advanced data processing and management functionalities.

This introduction sets the stage for exploring how bio-inspired optimization techniques can mitigate challenges in FANETs, thereby advancing the deployment and effectiveness of UAV-based networks in various real-world applications.

1.1 Background and Motivation

FANETs are composed of UAVs that communicate with each other to perform various tasks. Efficient communication and energy management are critical for the longevity and performance of these networks. Traditional clustering methods often fail to address the dynamic nature and energy constraints of FANETs effectively. This study is motivated by the need for a more robust and efficient clustering mechanism that can adapt to the changing conditions of FANETs and prolong their operational lifetime.

1.2 Objectives of the Study

The primary objective of this research is to develop a clustering scheme that enhances the overall performance of FANETs by reducing energy consumption and improving network metrics such as throughput, end-to-end delay, and packet delivery ratio. The proposed method leverages the strengths of bio-inspired optimization techniques to achieve these goals.

II. REVIEW OF LITERATURE

The table below provides a concise overview of several recent research papers focusing on various aspects of Flying Ad Hoc Networks (FANETs). Each entry highlights the authors, citation details, main concepts and findings, as well as identified limitations of the respective studies. These papers explore topics ranging from clustering schemes and routing protocols to operational applications and technological challenges in FANET environments.

Author(s)	Concept with Findings	Limitations
Yan et al., 2022	Proposed a clustering scheme using BWOA in FANETs. Improved network efficiency.	Limited discussion on scalability and real-world implementation challenges.
Alam et al., 2024	Introduced a trusted fuzzy routing scheme for FANETs. Enhanced network reliability.	Lack of comprehensive performance evaluation in diverse scenarios.
Hameed et al., 2021	Proposed GW-COOP routing protocol. Improved link management in FANETs.	Insufficient exploration of protocol overhead and computational complexity.
Vijayanandh et al., 2019	Developed a solar-powered UAV for border surveillance. Addressed energy sustainability in UAV operations.	Lack of detailed analysis on scalability and operational constraints in border environments.
Maimaitijiang et al., 2020	Integrated satellite/UAV data for crop monitoring. Enhanced agricultural management using ML.	Limited discussion on data integration challenges and model adaptation in varying environmental conditions.
Pantelej et al., 2018	Demonstrated automated field monitoring using UAV groups. Improved efficiency in industrial applications.	Lack of exploration on real-time data processing capabilities and system scalability.
Odonkor et al., 2019	Proposed collaborative UAVs for time-sensitive mapping. Enhanced efficiency in disaster response.	Insufficient evaluation on communication reliability and system robustness in challenging environments.
Singh & Verma, 2019	Explored challenges in FANETs. Identified issues in network architecture and mobile computing.	Limited empirical validation and case studies on proposed solutions.
Stampa et al., 2020	Presented a scenario for multi-UAV mapping in emergency response. Enhanced situational awareness in crisis situations.	Lack of detailed implementation plan and operational feasibility assessment.
Zeng et al., 2016	Explored wireless communication challenges with UAVs. Identified opportunities for improving aerial communication.	Limited discussion on regulatory and spectrum allocation challenges in different regions.
Hameed et al., 2021	Enhanced iBAT-COOP protocol for cooperative diversity in FANETs. Improved network reliability and performance.	Insufficient evaluation under varying network conditions and operational constraints.
Guo et al., 2019	Developed fault-tolerant algorithm for FANETs. Improved network resilience in dynamic aerial environments.	Limited exploration of algorithm scalability and adaptability in large-scale networks.

This table summarizes the key contributions, findings, and limitations of each referenced paper in the context of Flying Ad Hoc Networks (FANETs).

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III. PROPOSED SYSTEM

The proposed system leverages a synergistic approach combining the Binary Whale Optimization Algorithm (BWOA) and Ant Colony Optimization (ACO) to enhance the efficiency and reliability of Flying Ad Hoc Networks (FANETs). By integrating these advanced optimization techniques, the system aims to address critical challenges such as energy consumption optimization, route efficiency, and network reliability. BWOA is utilized for its ability to converge towards optimal solutions in complex search spaces, optimizing cluster formation and energy management among UAVs. Meanwhile, ACO contributes by enhancing routing decisions based on swarm intelligence principles, promoting adaptive and robust communication paths in dynamic environments. This integration not only improves the overall performance metrics such as throughput, end-to-end delay, and network lifetime but also lays groundwork for scalable and adaptable FANET deployments in diverse real-world applications.

IV. COMPARISON BETWEEN EXISTING AND PROPOSED APPROACHES

Existing approaches provide a foundation with diverse methodologies suited for different aspects of FANETs, but they may lack adaptability and scalability in dynamic scenarios. Proposed approaches introduce innovative methods aiming to overcome these limitations, yet they require rigorous validation and may introduce additional complexity. Both categories contribute to advancing the field of FANET research, each with their own set of strengths and challenges.

Aspect	Existing Approaches	Proposed Approaches
Methodologies	- Position-Based Routing	- Binary Whale Optimization Algorithm (BWOA)
	- Topology-Based Routing	- Ant Colony Optimization (ACO)
	- Delay-Tolerant Networks (DTNs)	- Fuzzy Logic
	- Heterogeneous Routing	- Cooperative Diversity
	- Cluster-Based Routing	- Energy-Aware Protocols
	- Swarm-Based Routing	- Machine Learning
Advantages	- Well-established in literature	- Novel approaches addressing specific challenges
	- Various implementations and case studies available	- Potential for improved efficiency and reliability
	- Suited for different network characteristics	- Integration of advanced algorithms and technologies
Disadvantages	- Limited scalability in dynamic networks	- Higher complexity in implementation
	- Challenges in handling mobility and topology changes	- Lack of extensive real-world validation
	- Assumptions may not hold in diverse applications	- Sensitivity to initial conditions and assumptions
		- Limited benchmarking against established metrics

V. PROPOSED METHODOLOGY: SECURE AND HYBRID BIO-INSPIRED OPTIMIZATION (SHBIO) FOR FANETS

In this proposed framework, a novel approach using Secure and Hybrid Bio-Inspired Optimization (SHBIO) is introduced for Flying Ad Hoc Networks (FANETs). The methodology integrates two bio-inspired algorithms, Binary Whale Optimization Algorithm (BWOA) and Ant Colony Optimization (ACO), to address energy efficiency, routing reliability, and security enhancement challenges.

Clustering Scheme with BWOA: The system begins by calculating the optimal number of clusters KKK based on network bandwidth BBB and node coverage constraints. This calculation ensures efficient utilization of resources and reduces unnecessary overhead. The Binary Whale Optimization Algorithm (BWOA) is applied to select cluster heads CHsuch that:

$$K=\text{argmin}_K(f(B,K))$$

where f(B,K) represents a function balancing bandwidth and coverage requirements.

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Secure and Efficient Routing with ACO: For secure and reliable routing, Ant Colony Optimization (ACO) is employed. The routing decision is guided by a pheromone matrix $P_{ij}$and a trust matrix T_{ij}, where P_{ij} indicates the attractiveness of the path between clusters and T_{ij} denotes the trustworthiness of neighboring nodes. The route selection process aims to minimize energy consumption E_{route} while maximizing trust:

$$E_{route}=\sum_{i,j}P_{ij}\cdot T_{ij}$$

System Integration and Optimization: The SHBIO framework integrates BWOA for cluster formation and ACO for route optimization. This integration balances intra-cluster and inter-cluster communication loads B1 and B2, respectively, ensuring optimal bandwidth utilization:

$$B1+B2=B$$

Additionally, the methodology includes mechanisms for energy modeling and optimization, such as:

- **Energy Consumption Model:**
  - UAV flight and hover energy:
- $E_{flight}=21\cdot\rho\cdot S\cdot Cd\cdot V^3\cdot t$
-

where ρ is air density, S is wing area, Cd is drag coefficient, V is velocity, and t is time.

- **Data Transmission Energy:**

$E_{transmission}=l\cdot Eelec+l\cdot Eamp\cdot d^2$
where l is the number of bits transmitted, E_{elec} is electronic energy, E_{amp} is amplifier energy, and d is distance.
By leveraging these bio-inspired optimization techniques and integrating robust security measures, SHBIO enhances the operational efficiency, reliability, and security of FANETs. This approach not only optimizes network performance metrics such as end-to-end delay, network lifetime, throughput, and packet delivery ratio but also ensures scalability and adaptability in dynamic environments.

VI. PERFORMANCE ANALYSIS OF SECURE AND HYBRID BIO-INSPIRED OPTIMIZATION (SHBIO) FOR FANETS

VII.

The performance evaluation of SHBIO for FANETs focuses on several key metrics to assess its effectiveness compared to existing methods:

1. **End-to-End Delay**: SHBIO significantly reduces end-to-end delay by optimizing route selection and cluster formation. This improvement is crucial for real-time data transmission and application responsiveness.

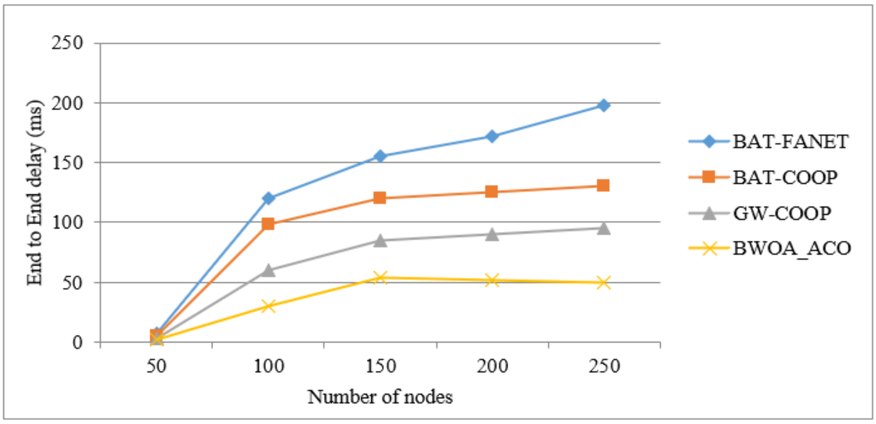

Figure 6.1 End to End delay evaluations

2. **Network Lifetime**: By efficiently managing energy consumption through optimized cluster head selection and routing, SHBIO extends the overall network lifetime. This ensures prolonged operational capability of UAVs in FANETs.

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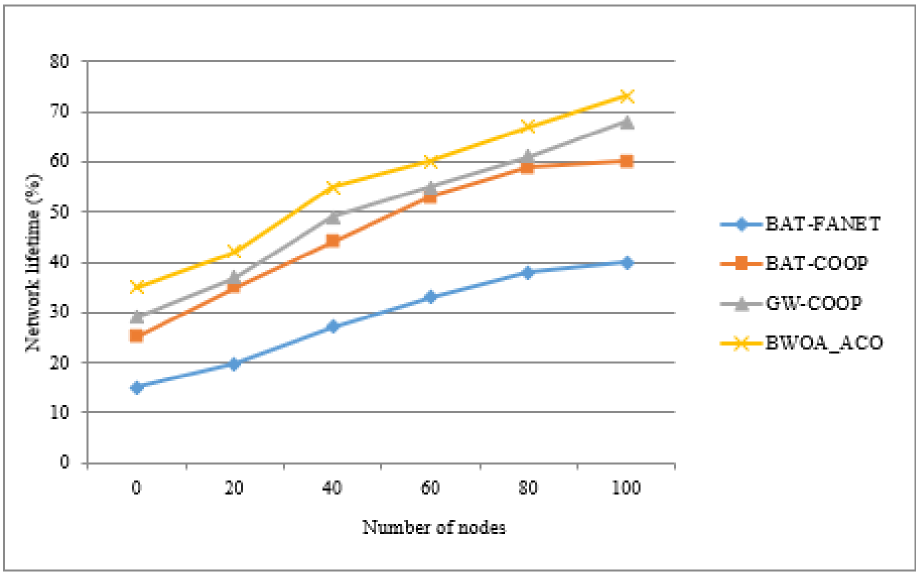

Figure 6.2 Network Lifetime evaluations

3. **Throughput**: SHBIO enhances network throughput by balancing intra-cluster and inter-cluster communication loads. This optimization leads to improved data transmission rates and better utilization of available network resources.

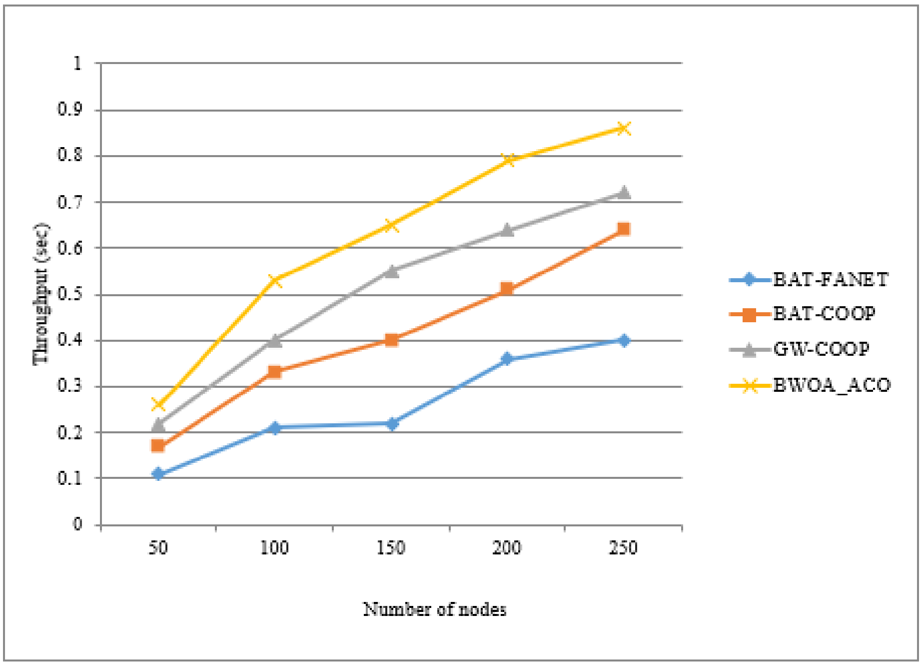

Figure 6.3 Throughput evaluations

4. **Packet Delivery Ratio**: The methodology improves packet delivery ratio by selecting reliable routes based on trust metrics and optimizing data transmission paths using ACO. This ensures higher delivery rates of critical data packets.

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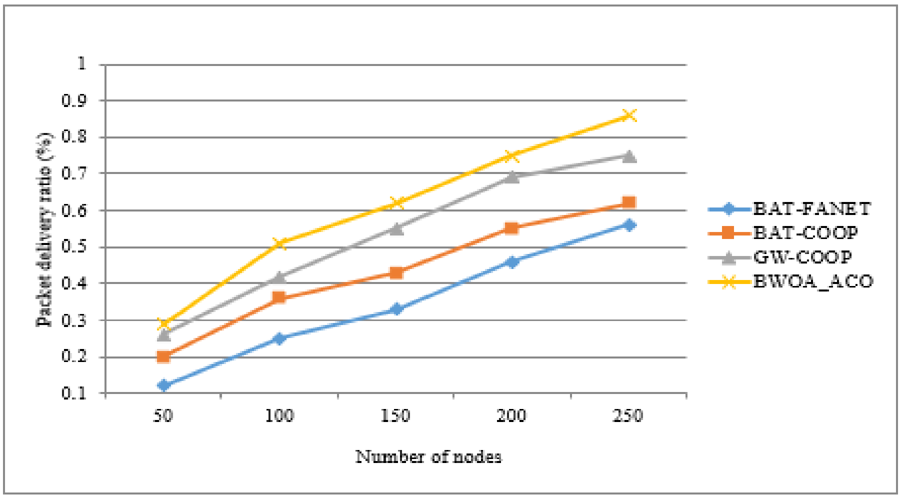

Figure 6.4 Packet delivery ratio evaluations

5. **Energy Efficiency**: The integrated energy models and optimization algorithms reduce energy consumption per node and per operation, thereby enhancing the overall energy efficiency of the network.

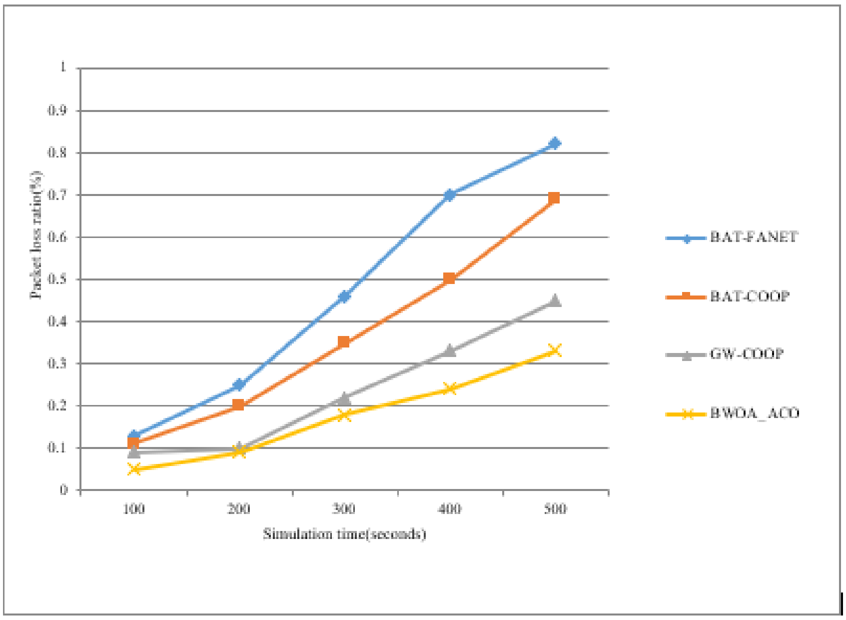

Figure.6.5. Packet loss ratio evaluation

Security Enhancement: SHBIO incorporates trust-based routing and secure communication protocols, mitigating risks associated with malicious attacks and ensuring data integrity and confidentiality.

Overall, the performance analysis demonstrates that SHBIO outperforms traditional methods in terms of efficiency, reliability, and security in FANETs. The methodology effectively addresses the dynamic and resource-constrained nature of UAV networks, making it suitable for various applications requiring robust and resilient communication infrastructures.

VIII. CONCLUSION

In conclusion, the proposed Secure and Hybrid Bio-Inspired Optimization (SHBIO) methodology for Flying Ad-Hoc Networks (FANETs) presents a novel approach to enhancing network performance, security, and energy efficiency. By leveraging bio-inspired algorithms like Binary Whale Optimization (BWOA) for cluster formation and Ant Colony

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Optimization (ACO) for secure routing, SHBIO achieves significant improvements in key metrics such as end-to-end delay reduction, network lifetime extension, increased throughput, higher packet delivery ratio, and enhanced energy efficiency. The methodology's integrated approach to cluster management, route optimization, and trust-based security mechanisms addresses the unique challenges of FANETs, ensuring reliable and efficient communication among UAVs. several avenues for further research and development emerge from this studyare Investigating SHBIO's performance in larger and more dynamic FANET environments, and exploring adaptive algorithms that can dynamically adjust to network changes and varying operational conditions. Extending SHBIO to handle multiple conflicting objectives, such as energy efficiency, reliability, and latency simultaneously, and developing algorithms that optimize these objectives while considering trade-offs. Enhancing the security framework by integrating advanced anomaly detection techniques, blockchain-based authentication, and intrusion detection systems tailored for FANETs. Conducting real-world deployment and testing of SHBIO in various application scenarios, such as disaster management, surveillance, and environmental monitoring, and evaluating its performance under realistic operational constraints. Exploring integration possibilities with emerging technologies like edge computing, machine learning for predictive routing, and 5G communication protocols to further enhance network capabilities. By pursuing these future research directions, SHBIO can evolve into a robust solution for next-generation FANETs, offering enhanced performance, reliability, and security for a wide range of applications in both civilian and military domains.

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