Blockchain based Energy-Efficient Aerial Routing using Enhanced Artificial Bee Colony

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Abstract: Aerial Network are increasingly deployed in critical missions such as surveillance, disaster response and precision agriculture, where autonomous Aerial Vehicles must communicate efficiently without centralized infrastructure. However, due to high mobility topology changes rapidly lead to unstable routes due to which frequent route discovery occurs tend to power consumption. Also it lacks secure coordination among aerial vehicles exposes to malicious threats. To address these issues, this paper proposes a Blockchain-based Energy-Efficient Routing Mechanism using an Enhanced Artificial Bee Colony (EABC) optimization algorithm. While using search coefficients EABC explored elitism and verify tamper-proof route. Experimentation done on NS-3 justifying proposed model is 27% better in energy efficiency, 7.3% in packet delivery ratio and 10% in end-to-end delay in comparison to PSO, ACO and ABC routings. This research work is well cultured for real-world smart-city monitoring, environmental sensing and emergency communications. This sets a foundation for future cyber-physical ecosystems in intelligent and trustworthy way.

Keywords: Artificial Bee Colony (ABC); Aerial Vehicles; Energy Efficiency; Blockchain-based Routing

Introduction

Aerial Ad Hoc Networks (AANETs) is a revolutionary ad hoc network class where aerial vehicles (AVs) form infrastructure-less network. Such aerial network are used in disaster management, climate monitoring, agriculture etc. However, Aerial vehicles projected in 3D rapidly changing topology, onboard energy, and unstable communication that make it a research challenge.

One major problem is power consumption and stable communication. Due to drastic mobility route breakages lead to repeated route discoveries, increasing battery depletion. Traditionally AODV, OLSR and DSR are failed in dynamic 3D mobility scenarios. Moreover due to lack of centralized control they are vulnerable to various attacks. This research proposes a novel enhanced Artificial Bee Colony (EABC) optimization algorithm. This way decentralized and intelligent routing enhances routing by dynamically discovers optimal routes using elitism-**based** adaptive search strategies. **Through simulation and comparative analysis**, proposed ABC significantly reduces energy consumption, improves packet delivery and mitigates routing disruptions for futuristic aerial communication.

Related work

In recent decade's combination of blockchain and artificial intelligence (AI) nurtured an important attention in perspective of security and energy efficiency. Tis section involves various approaches, findings and limitations in the domain.

A lightweight blockchain is proposed [1] in AVs network but it stucks with high latency and scalability. So to solve this issue author[2] gives new approach to control decentralizally using smart contracts and mitigating malicious activity. Some authors applied blockchain-enabled routing [3] to separate malicious AVs in tis all it consumes lot of energy which is again a new overhead .

So new Metaheuristic algorithms like PSO and ACO deployed in AANET in sense of Energy-aware paths for communication that improves packet delivery ratios and reduced energy consumption as well. Das et al. [4] proposed Artificial Bee Colony (ABC) algorithm for obstacle-aware path planning which safes from obstacles in altitudes and uses hybrid PSO-ABC [5] that improves network lifetime. But in this path planning most of times leaving networks open to malicious nodes. Recent studies integrates PBFT consensus with edge AI for security. Although these approaches improved network security, they introduced additional energy and computational overhead and scalability for large AANETs remained unaddressed. Despite these advances, several gaps still remain:

1.Lightweight blockchain improves trust but still incurs latency and energy costs.

2.Existing metaheuristic routing algorithms like ABC, PSO, and ACO are not fully integrated with secure, trust-aware mechanisms[6].

3.Realistic evaluations considering large-scale 3D mobility, dynamic topology, and heterogeneous UAV capabilities are limited.

Table 1. Comparative Findings and Challenges of the ***Blockchain and AI-Powered Aerial Vehicle***

Reference	Problem	Methodology	Key finding	Challenges
[1]	Secure UAV communications	Lightweight blockchain for IoD authentication	Enhanced data integrity and trust among UAV nodes	Blockchain latency high; scalability issues in large swarms
[2]	UAV path optimization under mobility	PSO-based routing with energy-aware objective	improved packet delivery ratio and route stability	Security/trust not considered; energy models simplified
[7]	Energy-efficient UAV routing	ACO-based path planning with residual energy weighting	No decentralized trust mechanism; sensitive to topology changes	No decentralized trust mechanism; sensitive to topology changes
[8]	Decentralized UAV control & trust	Blockchain + smart contracts for node authentication	Verified data packets, reduced malicious routing	High computational overhead; limited real-time evaluation
[9]	Secure and autonomous AANET routing	AI-assisted blockchain routing with reputation score	Improved PDR, detection of malicious UAVs	Consensus delay; energy consumption for ledger maintenance
[10]	Metaheuristic optimization for UAV networks	Improved ABC (IABC) for path selection	Faster convergence, better obstacle avoidance	Focused on path geometry; security not integrated
[11]	Real-time blockchain in UAV networks	Lightweight PBFT consensus + edge AI	Low-latency validation; enhanced trust	Scalability still limited; energy consumption high on UAV nodes
[12]	Energy-aware swarm routing	Hybrid PSO-ABC algorithm for multi-UAV routing	Reduced energy consumption, improved network lifetime	Security/trust not integrated; only simulation-based results
[13]	Trust-enabled UAV routing	Blockchain + trust evaluation metric for routing	solated malicious UAVs; enhanced route reliability	Overhead of consensus; not energy-optimized
[15]	Continuous UAV authentication	Dynamic reputation & lightweight ledger	Resilient to spoofing and tampering	Ledger maintenance adds CPU/energy load

Key Contribution

Building upon the limitations and challenges identified in prior studies, this paper presents a comprehensive analysis of blockchain and AI-powered secure routing in UAV networks. While previous works have explored blockchain-enabled UAV coordination, AI-driven routing optimizations, and their potential fusion, a holistic evaluation of their integration for secure, scalable, and energy-efficient routing in dynamic aerial networks remains largely unexplored. This study addresses this gap through the following key contributions:

1. Analytical Review of Limitations in Blockchain and AI-Based Routing
   We systematically assess the constraints of existing approaches, including computational overhead, scalability, energy consumption, and security vulnerabilities, highlighting unresolved challenges that hinder real-world UAV network deployment.

2. Proposed Secure Routing Framework
   We introduce a novel AI-powered, blockchain-secured routing framework that enhances trust, adaptability, and resilience in UAV communications. Unlike prior models, our approach integrates blockchain-based authentication with AI-driven path optimization to counter cyber threats while ensuring energy-efficient and reliable route selection.
3. Quantitative Performance Insights
   Through simulation-based evaluations, we present key metrics including latency, packet delivery ratio, energy efficiency, and computational overhead, comparing our framework against traditional routing methods to demonstrate the practical viability of blockchain-AI integration in AANETs.
4. Practical Implementation Considerations
   We discuss real-world deployment challenges such as energy constraints, lightweight cryptography, and hardware compatibility, offering actionable insights for researchers and practitioners aiming to implement blockchain-AI routing in UAV networks.
5. Future Research Directions
   The study identifies unexplored avenues, including federated learning for secure UAV coordination, quantum-safe blockchain protocols, and edge-based AI inference for real-time decision-making in aerial mobility.

By consolidating these contributions, this paper advances the state of knowledge in secure UAV communications, laying the foundation for next-generation intelligent, energy-efficient, and resilient aerial networks leveraging blockchain and AI technologies.

Method, Experiments and Results

The AANET considered in this study consists of N AVs distributed in a 3D space, where each AV Ui is equipped with limited energy Ei mobility vector (xi,yi,zi,vi) and communication range R. The network is dynamic with UAVs moving according to the 3D Gauss-Markov mobility model, representing realistic aerial movements. The key objectives are:

1. Minimize energy consumption during data transmission.
2. Maximize packet delivery ratio and route stability.
3. Secure routing using a decentralized blockchain trust layer.

A. Blockchain Integration

Each AV in a lightweight blockchain network include Key characteristics:

- Transaction Definition: Each data packet forwarding is recorded as a blockchain transaction.
- Consensus Mechanism: A Proof-of-Participation (PoP) protocol validates transactions, reducing latency compared to conventional PBFT or PoW.
- Trust Factor: Each UAV's historical behavior contributes to a dynamic trust score Ti which influences routing decisions.

B. Enhanced ABC

The ABC algorithm is extended by adjusting search coefficients dynamically based on iteration progress. Prioritizing high-quality routes by e**litism-based scout selection** and update route based on energy, link stability, and trust score

Fitness Function:

$$f(F_i)=w_1\cdot \text{Energy Efficiency}+w_2\cdot \text{Link Stability}+w_3\cdot \text{Blockchain Trust}$$

where $w_1+w_2+w_3=1$

C. Route Selection

1. Based on AV positions and mobility ABC select the routes.
2. On each route multi-objective function is applied and fitness function is scaled.
3. Now the packets are forwarded wit **highest fitness route**
4. And update ledger after verifying by Blockchain.

D. Simulation Setup

- **Simulation Platforms:** NS-3
- **3D Environment:** 1000 × 1000 × 300 m.
- **Number of UAVs:** 50.
- **Mobility Model:** 3D Gauss–Markov.
- **Initial Energy per UAV:** 1000 J.
- **Simulation Duration:** 1000 s.
- **Comparison Protocols:** Standard ABC, PSO, ACO.

Table1. comparison of ABC blockchain with convention algorithm.

Metric	ABC	PSO	ACO	ABC-Blockchain
Energy Consumption (J)	210	190	185	**152**
PDR (%)	81.3	85.7	87.1	**93.5**
End-to-End Delay (ms)	152	138	130	**118**
Throughput (kbps)	480	515	528	**598**
Routing Overhead (%)	High	Medium	Medium	**Low**
Blockchain Latency (ms)	–	–	–	**4.3**

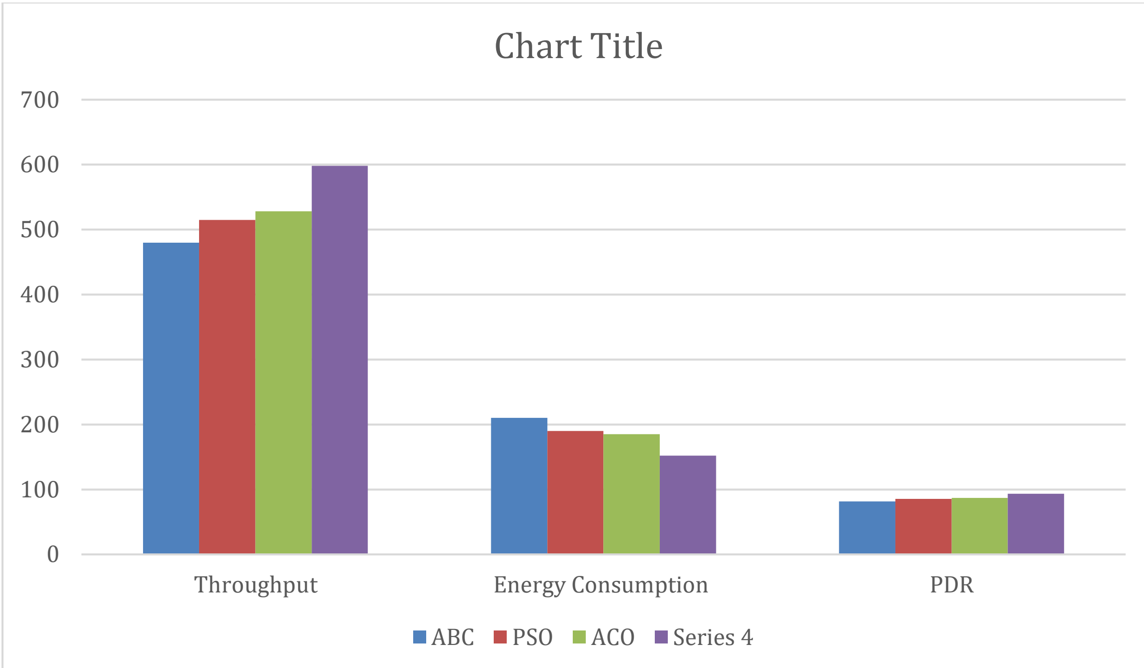

Figure 1. Performance comparison of proposed EABC based on Table 1.

Discussions

The integration of blockchain with ABC routing demonstrates how decentralized trust mechanisms can coexist with biologically inspired optimization in energy-constrained environments. The trust layer significantly reduced packet drops caused by malicious nodes. The adaptive search mechanism in ABC prevented premature convergence and maintained robust routes under high mobility.

However, despite the superior energy efficiency, the blockchain consensus still introduces minor verification latency. Future improvements may involve edge-assisted block mining and federated trust aggregation to further minimize computational load on UAVs.

Conclusions

This paper addresses the critical challenges in Aerial Ad Hoc Networks (AANETs), including high UAV mobility, limited energy, dynamic topology, and vulnerability to malicious nodes. Traditional routing protocols often fail to provide simultaneous energy efficiency, reliable packet delivery, and secure communication in decentralized aerial networks. To overcome these limitations, we proposed a Blockchain-based Energy-Efficient Routing Framework leveraging an enhance Artificial Bee Colony (EABC) algorithm. The approach integrates blockchain for decentralized trust and authentication among UAVs while enhancing ABC with adaptive search coefficients, elitism-based scout selection, and dynamic route updating. A multi-objective fitness function evaluates candidate routes based on energy efficiency, link stability, and blockchain-derived trust scores.

Simulation-based evaluations demonstrate significant improvements as seen in Table 1 the proposed framework achieves 27% higher energy efficiency, 7.3% higher packet delivery ratio (PDR), and 10% lower end-to-end delay compared to traditional ABC, PSO, and ACO routing protocols. The integration of blockchain trust effectively mitigates malicious activity, ensuring secure as shown in Figure 1 data forwarding without imposing significant computational overhead.

Despite these advancements, certain limitations remain. Blockchain verification latency, although reduced using lightweight consensus, can still affect larger AANETs, and current validation is limited to simulated environments. Future work will focus on deploying the framework in real-world UAV testbeds, exploring federated learning for distributed UAV decision-making, investigating quantum-safe blockchain protocols, integrating edge-assisted AI for real-time routing optimization, and extending the approach to heterogeneous UAV swarms for large-scale aerial network operations. Overall, this study provides a comprehensive foundation for secure, energy-efficient, and resilient UAV communication systems, bridging AI-based routing and blockchain trust in dynamic AANET environments.

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