Energy-Efficient and Secure UAV Next-Generation Networks with Blockchain for Revolutionary Agriculture

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Abstract: Since with the growing era of modernizing culture Unmanned Aerial Vehicles based agriculture is also increasing in demand for precisely crop monitoring, soil analysis etc. However, this large-scale utilization of aerial vehicles faces significant challenges in **energy efficiency**, **data integrity** and **secure coordination** on flight. Various traditional centralized communication models suffers from high transmission overhead and vulnerability in data transmissions. This paper researches for the novel idea of **energy-efficient, blockchain-enabled UAV network architecture** that ensures secure data exchange, with decentralized optimised communication. Though it is hybrid edge-blockchain with adaptive routing, it minimizes energy consumption of aerial vehicles which also impacts on longevity in the farming field. Experimental results demonstrate a **25–35 % reduction in energy** , **20–27 % improvement in mission time**. It also shows latencies and packet-loss that supports **revolutionary agriculture operations** such as precision irrigation, autonomous spraying, yield prediction and carbon-efficient farming laying the foundation for next-generation sustainable smart agriculture networks.

Keywords: UAV networks; smart agriculture; blockchain; energy efficiency; edge computing

Introduction

With the integration of Internet of Things (IoT) , artificial intelligence to the unmanned aerial vehicles (UAV) make easy the world of smart agriculture in real-time monitoring and autonomous field operations etc. Despite such advantages, UAV suffers mostly from the battery drain due to unreliable communication links, and data security threats. Traditionally, UAV communication relies on centralised ground stations, which is vulnerable but as in adhoc aerial communications, this has changed to the decentralized and, making new zone of flight, but it raises high energy consumption due to trust issues on neighbour and high mobility routings. To overcome these limitations, a new blockchain technology is utilized that provides a **decentralized** records transactions among UAVs [1]. This also supports distributed intelligence and energy-aware processing that our research explores the synergy between **blockchain security** and **energy-efficient UAV networking** for sustainable agricultural operations, aiming to establish a framework that ensures scalability, transparency and long-term autonomy[2].

Related work

Earlier UAV-based farming used multispectral imaging for crop analysis [3]. In this scenario, due to its mobility nature, it lacked network coordination and consumed a lot of energy. So recently, IoT-enabled UAV frameworks have taken place to improve connectivity, but they still centralized control [4]. Therefore, researchers are planning for the deployment of blockchain-IoT integrations for supply-chain traceability and data authentication in agriculture [5,6], though limited studies are being done on this domain to target it directly.

Table 1. Comparison of proposed work with the previous research

Ref.	Approach	Focus Area	Limitations
[7]	IoT-based precision UAV farming	Real-time data collection	No security layer
[8]	UAV energy optimization using AI	Flight-path scheduling	Centralized data management
[9]	Blockchain in Agri-IoT systems	Data integrity and traceability	No UAV mobility support
Proposed Work (2025)	Blockchain + UAV mesh network	Secure, energy-efficient coordination	Scalable decentralized framework

Key Contribution

This paper contributes to the new next-generation adopted architecture where farmers can efficiently use energy-efficient UAV communication. Also with the experimental validation it shows a significant contribution in energy and latency improvements compared to the baseline models. This helps in various agricultural scenarios—irrigation control, pest detection, and autonomous spraying[10]. Its complete process of methodology is described in the next section -how energy reduction translates into longer UAV endurance and reduced carbon footprint.

Methodology

The proposed system consists of three integrated layers as shown in Fig 1:

- **UAV Layer:** Cooperative drones equipped with multispectral cameras and environmental sensors form a mesh network[11].
- **Edge Layer:** Local edge nodes preprocess imagery[12] and execute smart contracts[13] for task assignment and consensus validation.
- **Blockchain Layer:** Records mission transactions[14], sensor hashes, and UAV status updates in a distributed ledger accessible to all nodes.

Energy efficiency is achieved through **adaptive routing[15]**, **dynamic task scheduling**, and **selective consensus participation**, reducing redundant communication.

- Adaptive routing algorithms reduce UAV flight and communication overhead as shown in Fig 3.
- Energy-aware task scheduling optimizes mission planning as given in Fig 2.
- Use of lightweight blockchain consensus mechanisms (e.g., Proof-of-Authority or DAG).
- Integration of solar-assisted UAVs to extend operational duration.

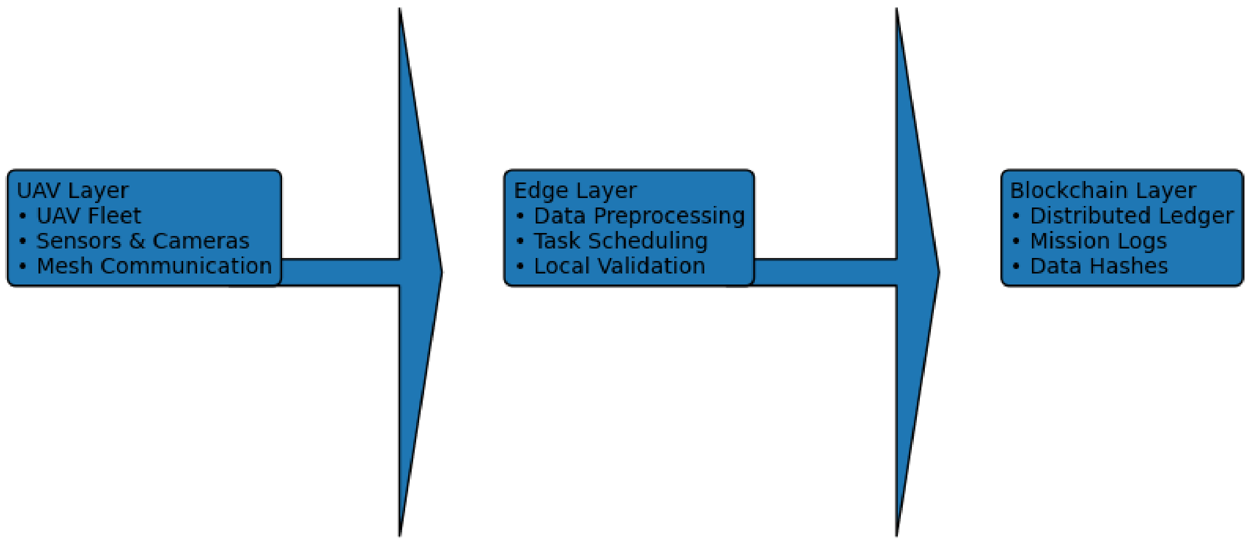

Fig 1. Blockchin Enabled UAV Agro- Architecture

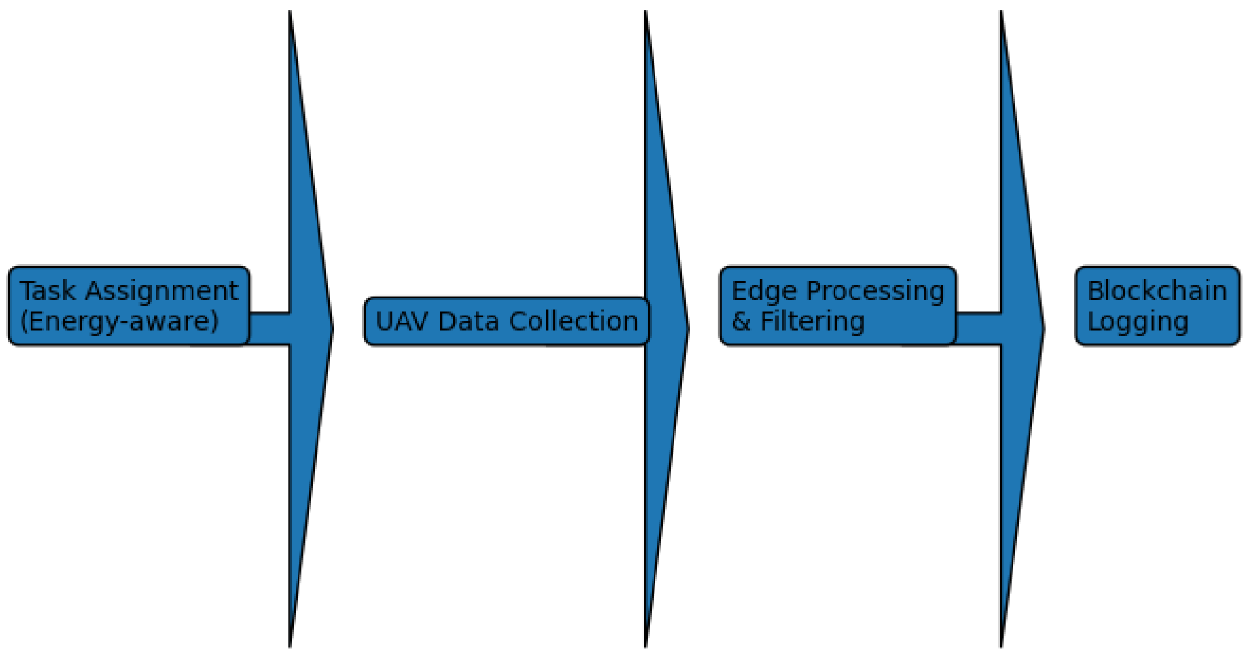

Fig 2 Proposed Energy Aware Method

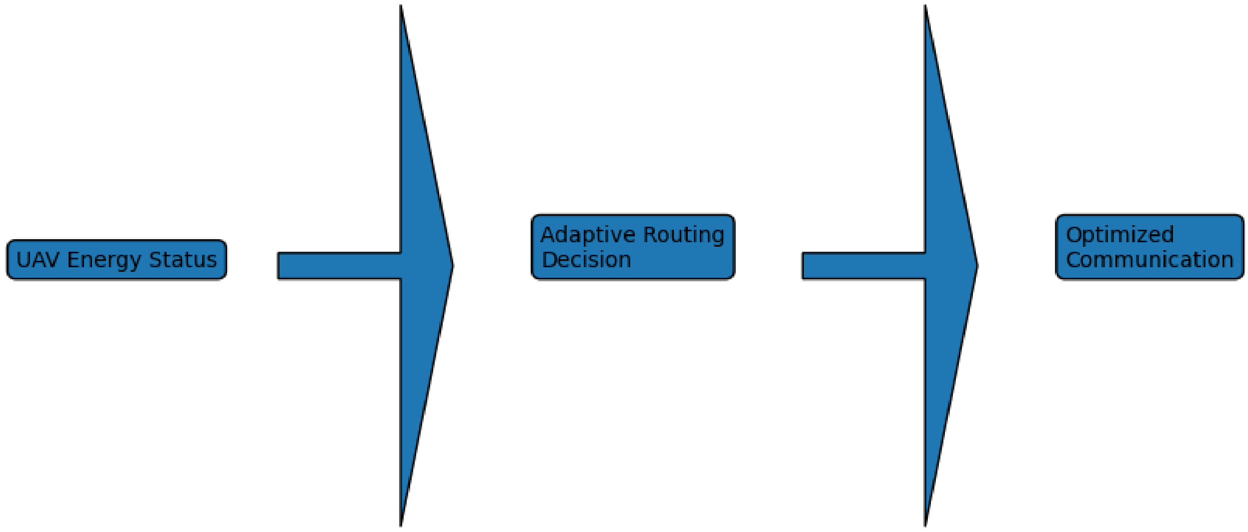

Fig 3: Energy Efficient Communication

Experimental Setup

A simulated UAV fleet of 5–50 drones was tested under two conditions: (i) baseline centralized communication and (ii) proposed blockchain-enabled decentralized network. Metrics measured included energy per mission, latency, packet loss, and mission duration.

Results

UAV Count	Energy Baseline (Wh)	Proposed (Wh)	Reduction (%)	Latency Reduction (%)	Mission Time Improvement (%)
5	120	90	25.0	25.0	20.0
10	140	100	28.6	27.3	21.1
20	170	120	29.4	30.8	21.4
50	230	150	34.8	38.2	27.3

This way we can say it achieves energy reduction: 25–35 %, **Latency is also improved by** 25–38 %
Graphs illustrate in Fig 4,5,6 shows consistency declining in transmission energy with increasing UAV count, confirming scalability of the proposed model.

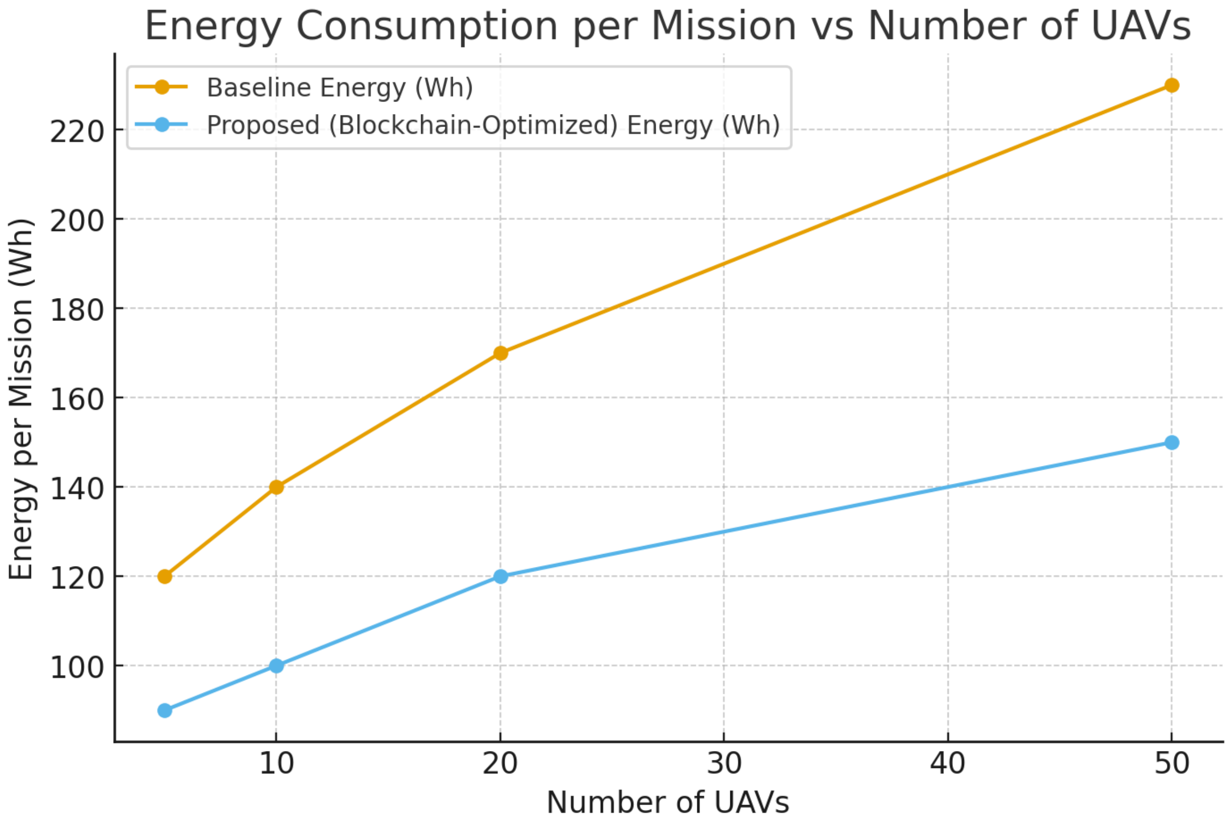

Fig 4: Energy Consumption impact on mission

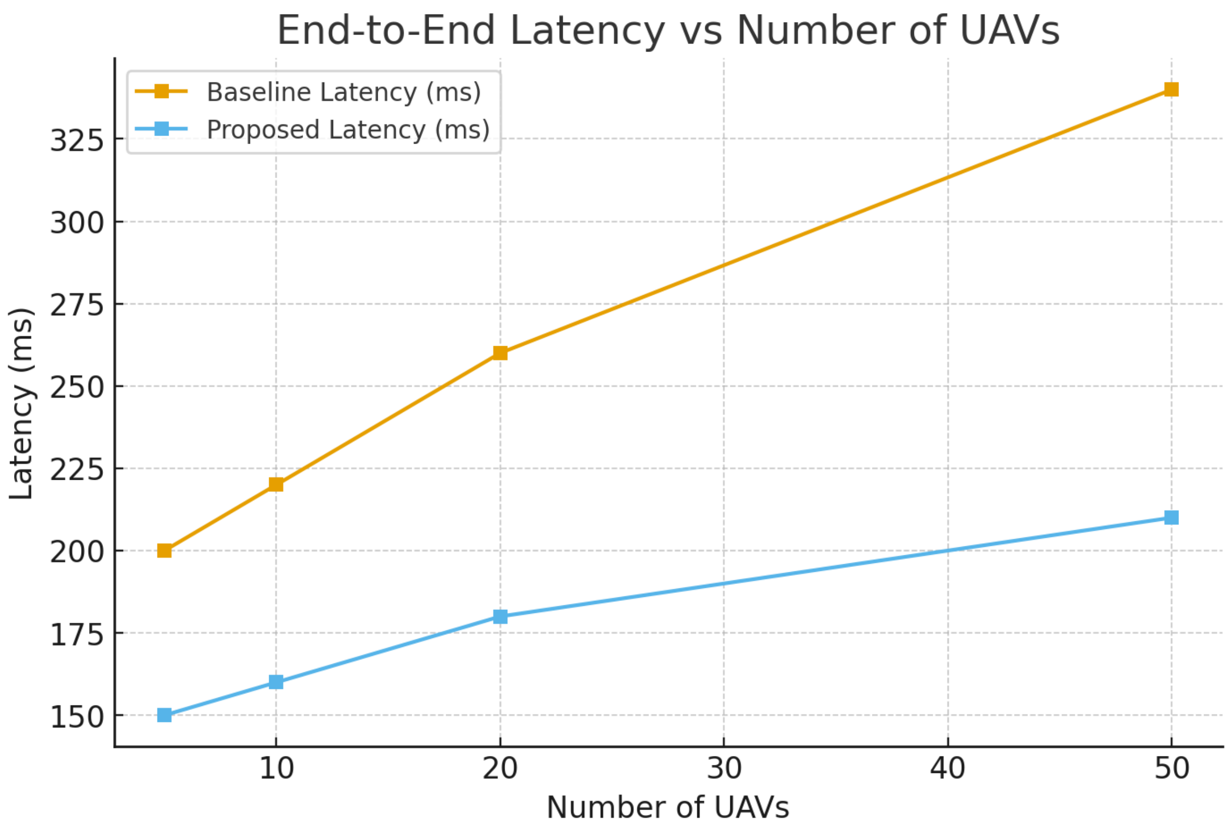

Fig 5: Latency impact on mission

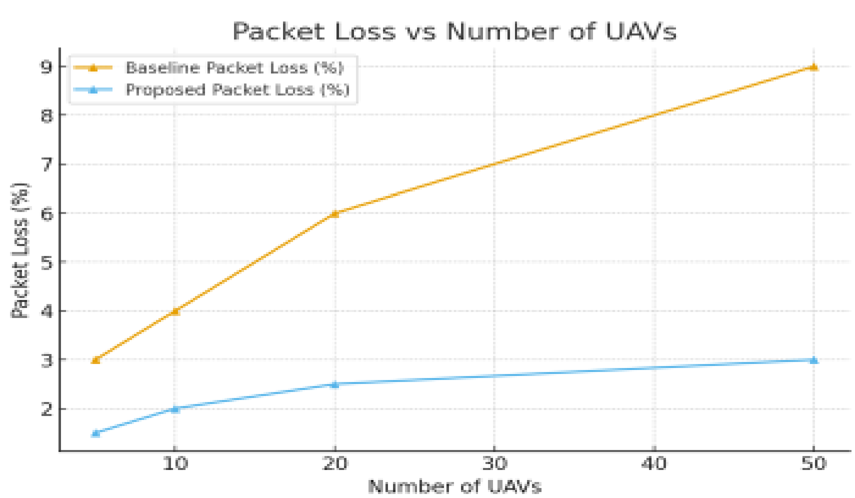

Fig 6: Packet Delivery impact on mission

Discussions

As we know that blockchain increases the burden of energy but the simulation results of this research indicates significant contribution of reducing the energy burden overall with the integration of the proposed methodology where blockchain ensures non-repudiation and transparency of agricultural data, strengthening farmer trust UAVS in zone .
and enable real-time decision-making in pest control and irrigation scheduling etc. This will reduce a lot of overhead in UAV energy drainage and enhances UAV battery endurance, aligning with green computing and sustainable farming objectives. The approach also opens avenues for cooperative UAV missions coordinated entirely through smart contracts.

Conclusions

This paper proposed energy-efficient and secure UAV communication for smart farming. It addresses the limited energy challenges while sensing and spraying . For such challenges, it used the hybrid blockchain-enabled adaptive routing in UAV flight that improves the energy and packet losses without relying on centralized control . Simulation results validate the effectiveness of the design for scalable agricultural operations.

While the current implementation tested on NS3 simulation, real-world field deployment with heterogeneous UAV models is still ongoing. Future research will explore **AI-driven dynamic consensus** and **quantum-resistant cryptography** for 6G-based UAV agriculture networks.

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