Development of a Blockchain-Internet of Things (IoT) Security Framework for Agricultural Data Management System

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ABSTRACT

The proliferation of Internet of Things (IoT) devices in agricultural environments has introduced significant vulnerabilities in farm data transmission and storage, as conventional security architectures are ill-suited to the distributed, resource-constrained nature of agricultural sensor networks. This study develops and evaluates a blockchain-IoT security framework for agricultural data management, integrating AES-256 symmetric encryption, RSA-2048 key distribution, SHA-256 hash chaining, and Ethereum smart contracts into a unified proof-of-concept architecture implemented in JavaScript and Web3.js, specifically targeting soil moisture sensors and weather stations. The framework employs a hybrid cryptographic model combining symmetric encryption with cryptographic nonce and timestamp mechanisms to prevent man-in-the-middle (MITM) and replay attacks, validated through controlled simulation. Security testing confirmed complete resistance to both attack vectors across all simulations. Scalability evaluation, conducted by progressively simulating 100 to 1,000 concurrent IoT device connections, demonstrated stable operation up to 500 devices with confirmation times under 10 seconds at transaction volumes up to 400 TPS; degradation was observed at 600 devices (15 seconds) and became significant at 1,000 devices (25–30 seconds). Throughput peaked at 400 TPS with sub-10-second latency, surpassing Ethereum mainnet benchmarks while remaining within the performance range adequate for precision agricultural monitoring. These results establish the proposed framework as a viable, cost-effective solution for securing agricultural IoT data pipelines, with particular applicability in resource-constrained farming environments.

KEYWORDS

Blockchain-IoT Framework, Agricultural Data Management, IoT Security, Scalability, Soil Moisture Sensors, Weather Stations

I.INTRODUCTION

The Internet of Things (IoT) describes a network of connected devices, sensors, and systems that exchange data to support different applications and services (Gurrammagari & Boopathy, 2025; Ait Mouha et al., 2021). In agricultural contexts, IoT devices have revolutionized farm management by enabling real-time monitoring of soil conditions, weather patterns, and crop health through sensors and automated systems (Rai, 2023). The deployment of agricultural IoT devices has facilitated cost-effective processing and storage of farm data digitally, enabling vast data transmission through computer networks and high-tech retrieval systems. Due to the widespread adoption of agricultural IoT devices, substantial amounts of critical farming data are being collected from sensors monitoring soil moisture, temperature, humidity, and weather conditions (Haroon et al., 2016).

The Internet of Things (IoT) in agriculture represents a transformative technology that facilitates real-time communication between farming devices, monitoring systems, and farm management platforms over the internet (Lampropoulos et al., 2019, Okubanjo et al., 2024). Its rapid adoption in precision agriculture, smart farming, and agricultural supply chain management brings with it critical concerns around data security. The distributed nature of agricultural IoT networks challenges traditional security methods used in farm data management. As highlighted by Al Hwaitat et al., (2023), safeguarding the agricultural data exchanged among numerous connected sensors and monitoring devices is vital. Since farming data is often stored in cloud systems and shared across agricultural networks, breaches can lead to severe operational disruptions, crop management failures, and economic losses, underlining the need for advanced protective strategies specifically designed for agricultural applications (Newaz et al., 2021; Bahalul et al., 2022).
Previous research in blockchain-based IoT security has paved the way for new solutions designed to tackle the specific needs and limitations of interconnected agricultural devices (Majeed et al., 2021). Researchers have investigated different use cases, including supply chain management, asset tracking, precision farming, and agricultural data sharing. However, despite the potential benefits offered by blockchain technology for agricultural applications, several challenges remain to be addressed, including scalability for large farm operations, interoperability between different agricultural devices, privacy of sensitive farming data, and regulatory compliance in agricultural data management. Scalability is a major concern in blockchain-based agricultural IoT systems due

to the rapid growth in connected farming devices and sensors (Alrehaili et al., 2022). Traditional blockchains like Bitcoin and Ethereum struggle with high transaction volumes and low latency demands from real-time agricultural monitoring applications, making them less ideal for time-sensitive farm operations.

Ethereum, conceived by Vitalik Buterin in late 2013 and officially launched in July 2015, is a decentralized and open-source blockchain that supports smart contract functionality. Unlike Bitcoin, which is mainly used as a digital currency, Ethereum was built to enable programmable transactions via smart contracts—self-executing agreements with terms embedded directly in code. This innovation represented a major shift in the blockchain ecosystem, paving the way for a broad array of decentralized applications (dApps) and establishing the foundation for agricultural data management applications that require automated contract execution (Buterin, 2014). Initially, Ethereum used a Proof of Work (PoW) consensus mechanism, similar to Bitcoin. However, due to concerns over energy consumption and scalability limitations of PoW, Ethereum has been transitioning to a Proof of Stake (PoS) model through its Ethereum 2.0 or "Serenity" upgrade, which is particularly relevant for energy-conscious agricultural applications (Buterin, 2020). As Ethereum continues to develop, various challenges and research opportunities persist for agricultural applications. The ongoing rollout of Ethereum 2.0, the integration of Layer 2 scaling solutions, and the introduction of EIP-1559 (which revised the fee structure) are anticipated to address some of the existing scalability and usability challenges, particularly relevant to agricultural IoT implementations. However, regulatory scrutiny, particularly concerning agricultural data privacy and compliance remains a significant obstacle (Auer and Claessens, 2020).