2025 Design, Automation & Test in Europe Conference (DATE 2025)

Decentralizing IoT Data Processing: the Rise of Blockchain-Based Solutions

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***Abstract*—The rise of the Internet of Things has introduced new challenges related to data security and transparency, especially in industries like agri-food where traceability is critical. Traditional cloud-based solutions, while scalable, pose security and privacy risks. This paper proposes a decentralized architecture using Blockchain technology to address these challenges. We deploy IoT sensors connected to a Raspberry Pi for edge processing and utilize Hyperledger Fabric, a private Blockchain, to manage and store data securely. Two approaches are evaluated: computation of a Discomfort Index on the Raspberry Pi (edge processing) versus performing the same computation on-chain using smart contracts. Performance metrics, including latency, throughput, and error rate, are measured using Hyperledger Caliper. The results show that edge processing offers superior performance in terms of latency and throughput, while Blockchain-based computation ensures greater transparency and trust. This study highlights the potential of Blockchain as a viable alternative to centralized cloud systems in IoT environments and suggests future research in scalability, hybrid architectures, and energy efficiency.**

***Index Terms*—Blockchain, Smart contract, IoT, Ethereum, Hyperledger Fabric**

I. Introduction

The rapid growth of the Internet of Things (IoT) has enabled a vast array of devices to communicate within interconnected networks, exchanging sensed data in real-time. Together with the number of devices linked to the internet expands, concerns arise about securing these networks from potential threats. Blockchain technology offers a promising solution to this issue [1]. Blockchain, a prominent example of Distributed Ledger Technology (DLT), is characterized by its immutable record of data, which makes it highly secure and resistant to tampering.

One of the key features that makes Blockchain particularly well-suited for IoT applications is its ability to execute code directly on the network. Ethereum [2] pioneered this concept with smart contracts, which have since become widely used for managing transactions and data, as well as for generating digital assets like Non-Fungible Tokens (NFTs) and cryptocurrencies. Recent works, such as the one proposed in [3], implement context-aware smart contracts, focusing on employing Blockchain to securely store data in formats like JavaScript Object Notation (JSON).

This paper explores the use of Blockchain and smart contracts as an alternative to traditional centralized cloud solutions, with a specific focus on monitoring air quality. Air quality is affected by numerous environmental elements, with temperature and humidity serving as two key influences. These factors hold significant importance in industries such as agriculture, where preserving ideal environmental conditions is crucial for maximizing crop yield and ensuring product quality. Advances in sensors and wireless technology provide an efficient method to improve food safety and certification throughout the supply chain of perishable goods [4]. As a case study, we focus on the real-time monitoring of temperature and humidity data to assess air quality, leveraging the decentralized nature of Blockchain to ensure secure, tamper-proof data storage and analysis. In this scenario, we analyze two distinct methodologies on a Blockchain platform: firstly, executing computations on an edge device, and secondly, running a smart contract to carry out the necessary calculations. We assess the performance and suitability of these methods for IoT-based air quality monitoring applications.

II. Architecture

This paper considers a scenario where IoT sensors are deployed in an agricultural setting to monitor environmental conditions, such as temperature, humidity, soil moisture, and sunlight exposure. Conventional approaches would take advantage of centralized solutions. However, this centralization poses security risks, including potential data breaches, unauthorized access, and loss of control over sensitive agricultural data [5]. To mitigate these risks, we propose a decentralized architecture that combines IoT devices, edge computing, and Blockchain technology. This architecture ensures that data remains secure, traceable, and immutable throughout the supply chain without relying on a third-party cloud provider.

The proposed architecture is shown in Fig. 1 and consists of IoT sensors deployed in the field to continuously gather data on environmental conditions; a Raspberry Pi that collects data from the IoT sensors and performs initial computations; a private Blockchain, namely Hyperledger Fabric; smart contracts employed to automate the data handling process.

The DHT 11 sensor, taking into account the sensor specs, has an 8 bit resolution and a temperature range of 0-50°C +/-2°C. Relative humidity readings have an accuracy of ±5% and a range of 20%-90%, according to the standard. Monitoring comfort and discomfort of interior environment in relation to

978-3-9826741-0-0/DATE25/© 2025 EDAA

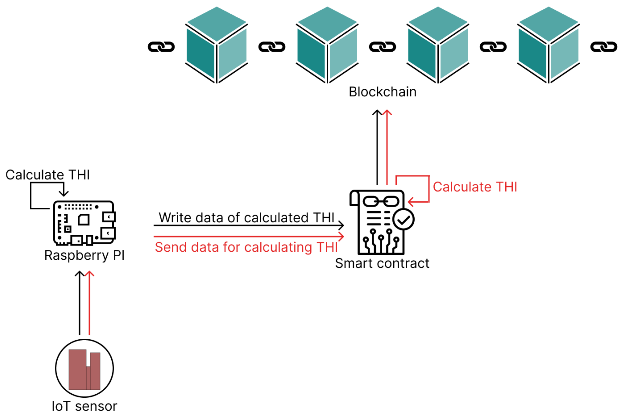

Fig. 1. Architecture showing two different approaches for calculating THI

a specific temperature and humidity combination has been the main focus. The Temperature Humidity Index (THI) is used to aggregate the sensed temperature and humidity. Also referred to as the Discomfort Index, it provides some context for the potential implications of the detected data. The calculation of the THI is as follows:

$$THI = (1.8 * T - ((1 - RH/100) * (T - 14.3))) + 32 \quad (1)$$

where T is the temperature in Celsius and RH is the relative humidity. Various assessments of the discomfort can be made based on the value the index assumes.

In the proposed implementation, only the computed THI is uploaded to the Blockchain, rather than the raw temperature and humidity data. This approach reduces the amount of potentially unuseful information stored on the Blockchain, which is important given that Blockchain is an add-only storage solution. By focusing on the THI, we streamline the data stored, improving efficiency and ensuring that only relevant, trust-enhancing information reaches the end user, such as consumers in an agri-food traceability platform.

Tests have been run on a Fedora 40 machine, powered by a 12th Gen Intel Core i7-12700 processor, 32 GB of RAM, NVIDIA RTX 3070ti graphics card, and 1 TB of disk space. The two Fabric configurations have been benchmarked using Hyperledger Caliper, a tool used to calculate performance metrics of Blockchain platforms. Table I shows obtained results.

TABLE I
BENCHMARK REPORT IN HYPERLEDGER CALIPER

Approach	# Txs	Input TPS	Error (%)	Max L (s)	Min L (s)	Avg L (s)	Throughput
THI (edge)	100	50	0	0.21	0.07	0.13	50.6
	500	50	0	0.19	0.06	0.12	50.2
	1000	50	0	0.19	0.06	0.12	50.1
	100	100	0	0.13	0.06	0.10	98.3
	500	100	0	0.13	0.06	0.09	99.6
	1000	100	0	0.15	0.06	0.09	99.9
THI (Blockchain)	100	50	0	0.19	0.06	0.13	50.5
	500	50	0	0.20	0.06	0.13	50.1
	1000	50	0	0.18	0.06	0.12	50.1
	100	100	0	0.13	0.06	0.09	98.6
	500	100	0	0.14	0.06	0.10	99.3
	1000	100	0	0.13	0.06	0.09	99.8

Each approach was tested under different loads, with varying numbers of transactions (100, 500, and 1000) and input transaction rates (50 TPS and 100 TPS).

While both approaches perform well across all key metrics, the edge processing method has a slight edge in terms of latency and throughput consistency, particularly under heavier loads (1000 transactions at 100 TPS). This is likely due to the local processing capabilities of the Raspberry Pi, which reduces the load on the Blockchain and speeds up overall transaction handling. The Blockchain-based computation, on the other hand, provides additional transparency and trust since all computations are done directly on-chain. However, it incurs a slightly higher processing overhead compared to edge computing, as expected from performing smart contract-based calculations on a distributed ledger.

III. Conclusions

This paper explored the use of Blockchain and smart contracts as a decentralized alternative to traditional cloud-based solutions for IoT applications. We proposed an architecture in which IoT sensor data is processed by a Raspberry Pi device and then transmitted to a private Blockchain network (Hyperledger Fabric) through smart contracts. Two approaches were tested: one where the THI was calculated locally on the Raspberry Pi (edge processing), and another where the computation was performed directly on the Blockchain via smart contracts. The results demonstrate the feasibility of using Blockchain technology, specifically Hyperledger Fabric, as a secure and decentralized alternative for managing IoT sensor data, particularly in sensitive industries such as agri-food. Both approaches displayed 0% error rates, underscoring the robustness of the proposed architecture.

This is a first step towards the development of an hybrid and energy efficient architecture. Investigating hybrid architectures where certain computations are performed at the edge while others are handled on-chain could provide the best of both worlds—combining real-time processing with the transparency and immutability of Blockchain. Further research could also focus on additional layers of security for IoT data, such as privacy-preserving algorithms, encryption techniques, or using zero-knowledge proofs to enhance the security of data transmitted to the Blockchain.

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