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BLOCKCHAIN APPLICABILITY FOR STORING IOT TELEMETRIC DATA IN LOGISTIC

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***Abstract*: The rapid growth of the Internet of Things (IoT) has revolutionized the logistics industry by enabling real-time tracking and monitoring of goods throughout the supply chain. However, the immense volume of telemetric data generated by IoT devices presents significant challenges in terms of scalability, data integrity, and security for traditional database solutions. This paper explores the applicability of blockchain technology as an alternative for storing and managing IoT telemetric data in logistics. The blockchain's decentralized structure, immutable ledger, and smart contract capabilities to address these challenges have been investigated. An ability to enhance data security, automation, and transparency has been disclosed. A comparative analysis between blockchain-based storage and traditional databases, has benn presented, focusing on key criteria such as scalability, data integrity, security, and cost efficiency.**

***Index Terms*: architecture, blockchain, cloud computing, database, Internet of Things, smart contracts, supply chain management**

I. INTRODUCTION

In recent years, the logistics industry has been transformed by the rise of the Internet of Things (IoT). IoT technology enables companies to track and monitor goods in real time as they move through the supply chain. Devices equipped with IoT sensors collect a vast amount of telemetric data, including information on location, temperature, humidity, and other factors that are crucial for managing logistics effectively.

In the context of supply management, IoT plays a significant role by providing enhanced visibility and control over inventory and shipments. With IoT devices, companies can optimize inventory levels by receiving real-time updates on stock availability, delivery schedules, and demand fluctuations. This leads to more efficient order fulfillment, reduced waste, and minimized stockouts or overstock situations [1].

The volume and speed at which IoT data is generated require storage systems that can scale efficiently. Moreover, since this data is vital for day-to-day operations, it must be stored in a way that is both reliable and secure to prevent loss or unauthorized access [2].

Traditional databases often have difficulty meeting these demands. They may not scale adequately to handle large data volumes and can be susceptible to security vulnerabilities. This can lead to inefficiencies in the supply chain, such as delays or errors in tracking shipments, and can increase the risk of data breaches or loss.

Unlike traditional relational databases, NoSQL databases are designed to handle unstructured and semi-structured data, making them well-suited for managing the large volumes of signals, collected, transmitted and processed in logistics. NoSQL databases can store diverse data types such as sensor readings, GPS locations, geolocation data and shipment statuses in real-time, providing greater flexibility compared to the schema-based relational databases.

These challenges pose growing interest in blockchain utilization for storing and managing IoT data in logistics. It offers a decentralized and secure method of data storage. Blockchain's features like its immutable ledger and distributed network can enhance data integrity and security [3].

Additionally, the use of smart contracts in blockchain allows for the automation of key logistics processes, enabling automatic execution of agreements based on predefined conditions, such as triggering alerts for temperature fluctuations or automating payments upon successful delivery.

This paper explores how blockchain technology can be applied to store IoT telemetric data in the logistics industry and defines how blockchain is addressing the current challenges in data storage and improves overall efficiency in the supply chain.

II. LITERATURE REVIEW AND PROBLEM STATEMENT

Storing and managing IoT telemetric data is a complex task due to the large volumes, variate source of data, different data format utilized by equipment vendors, the requirements for quick access, fast processing, and security [4-6].

Relational databases, such as those using SQL, are designed for structured data but often lack the flexibility and scalability required for the unstructured and rapidly growing data from IoT devices.

Set of non-relational or NoSQL databases have been adopted to address challenges mentioned above, able to handle large amounts of unstructured data and offer scalability through horizontal expansion across multiple servers. They are more flexible in accommodating different data types and payload structures, which is beneficial for the varied data generated by IoT sensors.

However, NoSQL databases have issues with long-term data integrity and consistency. As data accumulates over the years, ensuring that it remains accurate and uncorrupted becomes more difficult. While these databases are good at handling big data, they may not provide the robust mechanisms needed to maintain data reliability over extended periods [7].

Inefficient data storage systems can negatively impact the entire supply chain. Research indicates that improving data management can significantly boost supply chain performance [8]. Therefore, finding a robust solution for storing and managing IoT data is not just a technical concern but a strategic imperative for the logistics industry.

III. SCOPE OF WORK AND OBJECTIVES

The purpose of this work is to research design of data storage systems using blockchain technology as alternative for storing IoT telemetric data in logistics. This aims to enhance data security and integrity, improve scalability, and ultimately increase the efficiency and reliability of supply chain operations.

IV. BLOCKCHAIN AS A DATABASE FOR STORING IOT TELEMETRIC DATA IN LOGISTICS

Blockchain technology has emerged as a promising solution for addressing the challenges of storing and managing IoT telemetric data in logistics. By leveraging its decentralized and secure architecture, blockchain enhances data integrity by ensuring that once data is recorded, it cannot be altered or deleted. Additionally, blockchain's transparency allows all authorized participants in the supply chain to verify and audit transactions in real time, fostering trust and collaboration among stakeholders.

A. GENERAL OVERVIEW OF BLOCKCHAIN AS A DATABASE

A blockchain is a distributed ledger technology that records transactions across a network of computers in a way that ensures the data is secure, transparent, and tamper-proof [9].

Unlike traditional centralized databases, blockchain operates without a central authority, reducing the risk of single points of failure and enhancing data resilience.

At its core, a blockchain is a chain of blocks that contain a list of transactions. When transactions occur, they are grouped together into a block. Each block includes a unique identifier called a cryptographic hash, which is generated based on the data within the block and the hash of the previous block (Fig. 1). This linkage creates an unbroken chain from the newest block back to the very first block.

Blockchain networks operate on a consensus mechanism, often referred to as the "rule of majority." Before a new block can be added to the chain, most nodes (computers participating in the network) must agree that the block's transactions are valid. This decentralized validation process ensures that no single entity can control the data or manipulate the system without consensus from the network.

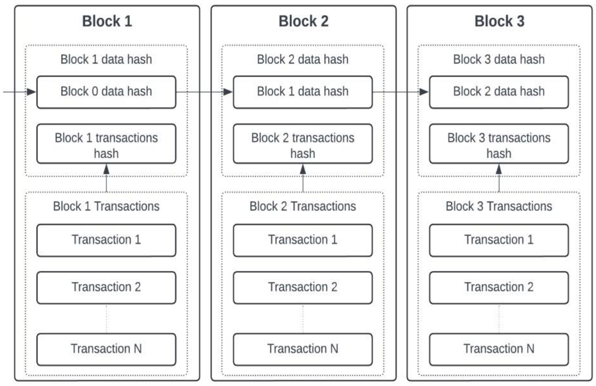

Fig. 1. Chain of blocks in a blockchain

This structure means that any change to the data in a block would alter its hash, which would then invalidate all subsequent blocks in the chain. As a result, it becomes impossible for anyone to tamper with the data without being detected by other participants in the network (Fig. 2).

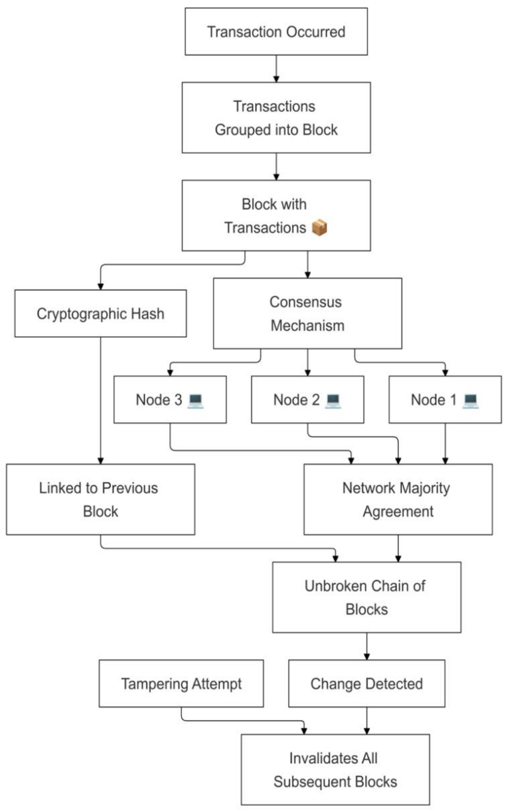

Fig. 2. Transaction validation in a blockchain

By combining transactions into linked blocks and requiring majority approval for changes, blockchain provides a secure and transparent method of recording data. In the context of IoT data storage, blockchain offers several advantages:

1. data is stored across multiple nodes in the network, preventing data loss and reducing dependency on a central server.
2. once data is recorded on the blockchain, it cannot be altered or deleted, ensuring the integrity of IoT telemetric data over time.
3. all participants in the network can view and verify the data, fostering trust among supply chain partners.
4. advanced cryptographic techniques protect data from unauthorized access and cyber-attacks.

Storing and managing IoT telemetric data in logistics requires selecting a specific blockchain platform that supports the necessary features and scalability [10]. Among the various blockchain platforms available, the Ethereum Virtual Machine (EVM) stands out as the most popular and widely adopted. It is also the blockchain platform available across major cloud service providers [11-12].

B. INTEGRATION WITH INTERPLANETARY FILE SYSTEM (IPFS)

While blockchain provides security and immutability, it is not optimized for storing large amounts of data due to limitations in storage capacity and costs. To overcome this, blockchain can be integrated with the InterPlanetary File System (IPFS), a distributed peer-to-peer file storage protocol.

In IPFS, data is stored across a network of nodes rather than on a central server. When you add a file to IPFS, it is broken down into smaller chunks, each assigned a unique cryptographic hash called a content identifier (CID). This CID is derived from the content itself, so if the content changes, the CID changes as well. This ensures data integrity because any tampering with the data is immediately detectable.

To ensure that data remains available over time, it needs to be "pinned" on multiple nodes within the IPFS network. Pinning tells a node to store the data indefinitely, preventing it from being removed during routine garbage collection. By pinning data across several nodes, redundancy is achieved, which safeguards against data loss if some nodes go offline. This is crucial for maintaining the availability of important data in a decentralized environment.

When someone requests a file, IPFS uses the CID to locate and retrieve the data from the nodes storing the relevant chunks, often pulling pieces from multiple sources simultaneously for efficient retrieval.

The decentralized architecture of IPFS allows it to scale naturally as more nodes join the network. This scalability makes it well-suited for IoT applications, where vast amounts of data are generated continuously and need to be stored and accessed in a performant manner.

The proposed solution comprises several key components: IoT sensors, an IoT gateway, application server, a blockchain network, the InterPlanetary File System (IPFS) and cloud services (Fig. 3).

IoT Devices and Sensors: These are physical devices installed on vehicles or storage facilities that collect telemetric data such as location, temperature, humidity, and movement. They serve as the primary data sources in the logistics supply chain.

V. PROPOSED BLOCKCHAIN-BASED IOT TELEMETRIC DATA STORAGE SOLUTION

A. SOLUTION OVERVIEW

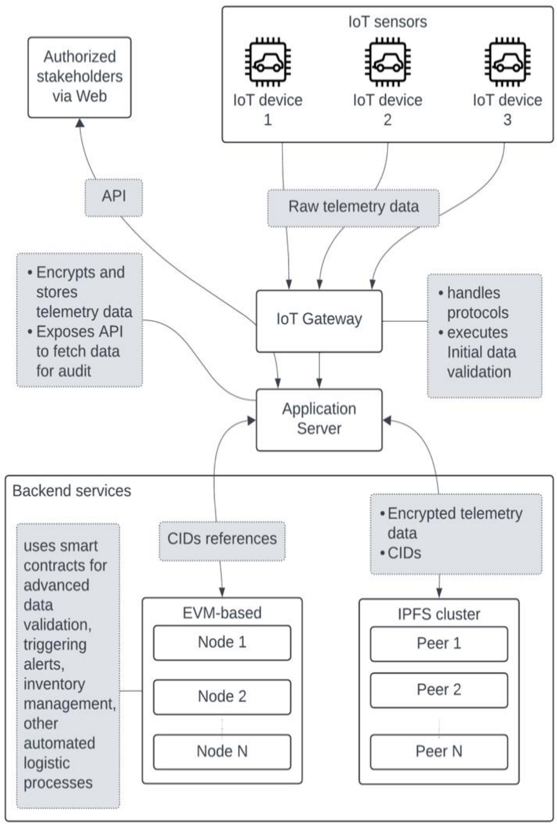

Fig. 3. Proposed solution

IoT Gateway: Acting as middleware, IoT gateway connect the IoT devices to the network infrastructure. It handles communication protocols and initial data validation. By performing these tasks, IoT gateway reduce the complexity of data transmission and ensure that data is efficiently forwarded to the application servers.

IPFS: a distributed peer-to-peer file storage system that ensures data integrity through content-addressable storage. IPFS accepts data from application server, stores it within the system and returns a CID indicating the data location.

Blockchain Network: An EVM-based blockchain network serves as the decentralized ledger. Blockchain accepts essential data from application server together with CIDs provided by IPFS. Smart contracts deployed on the blockchain handle this essential data validation and is responsible for logistic process automation.

Application Server: The application server is a custom backend application build with any of popular modern programming languages. It receives data from the IoT gateway and performs necessary data processing tasks such as aggregation, normalization, encryption, and preparation of data for storage. It is responsible for interfacing with the blockchain network and IPFS, handling the storage of data references and the actual data. During data preparation, application server extracts the most essential data to be stored in the blockchain and sends the other data to IPFS to get the CID references.

B. ROLE OF THE SMARTCONTRACTS

Smart contracts play a crucial role in this solution by automating processes and maintaining data integrity within the blockchain. Being in facts pieces of programmable logic, implemented with solidity programming language and deployed to blockchain, they might be used for [14]:

Advanced Data Validation: Smart contracts may validate essential data included before it is recorded on the blockchain. For example, they can automatically check if sensor readings, such as temperature or humidity levels, are within predefined acceptable ranges.
Triggering Alerts: If specific conditions or thresholds are breached (e.g., temperature exceeds the limit), smart contracts may automatically trigger alerts to stakeholders, enabling quick response actions.

Inventory Management: Smart contracts may automate inventory updates in real-time as goods move through the logistics network, ensuring precise stock management.

Automation of Logistics Processes: Other automated processes facilitated by smart contracts may include automated compliance checks, real-time shipment tracking, and payment settlements upon delivery confirmations, reducing manual intervention and enhancing the efficiency of logistics operations. Automation reduces manual intervention, minimizes errors, and fosters trust among supply chain partners by ensuring that business rules are consistently and transparently applied [15].

C. CLOUD DEPLOYMENT

Cloud providers are proven approach for hosting IoT-based applications. Deploying any architecture on cloud platforms like AWS, Azure, and GCP enhance scalability and reliability.

In context of blockchain-based storage, these platforms typically offer ready-to-use managed services for blockchain and IPFS, simplifying deployment and reducing operational overhead.

Application Server Deployment: Being a regular backend application, it can be compiled into a docker container and can be deployed to cloud platform utilizing any container orchestration services like AWS ECS, Azure Container Apps, Kubernetes (via AWS EKS, Azure AKS, Google GKE) etc. Container orchestration ensures that the server can handle variable data loads efficiently, with minimal downtime.

IPFS: IPFS peer-node might be represented by a docker container, therefore IPFS clusters can be deployed using container orchestration service for distributed, high-performance data storage with global access, just like the application server.

Blockchain: Managed blockchain services (e.g., AWS Managed Blockchain, Azure Blockchain Service) allow easy setup and scaling of blockchain nodes without deep technical expertise. Fig. 4 illustrates an example of a possible deployment for the proposed solution using AWS-managed services.

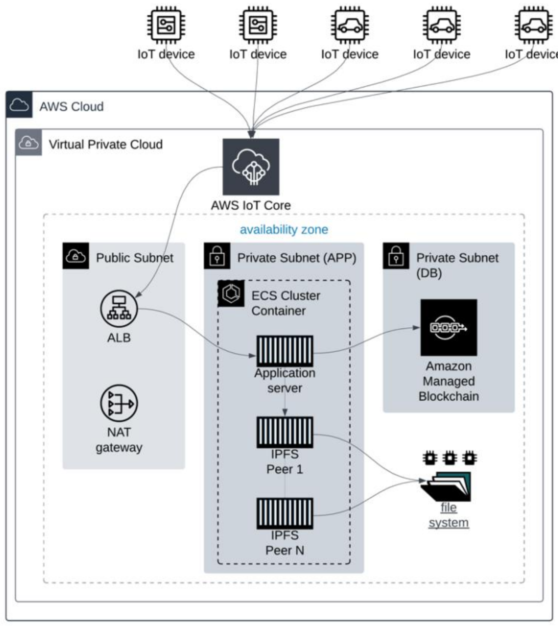

Fig. 4 Cloud deployment diagram of the architecture solution deployed to AWS.

VI. COMPARATIVE ANALYSIS OF BLOCKCHAIN-BASED STORAGE VS TRADITIONAL DATABASE SOLUTION

The comparison between the blockchain-based storage solution and traditional databases is structured around the following criteria: scalability, data integrity and immutability, security, data retrieval speed, cost efficiency, automation capabilities, data management flexibility. These criteria were selected to evaluate how well each storage solution aligns with the evolving needs of modern logistics [16-18].

The detailed comparison between the proposed blockchain-based architecture for IoT telemetric data in logistics and traditional database solutions, specifically Postgres, MySQL, Gremlin, Cassandra, Cosmos DB, and MongoDB collected in Table.

Comparison table

Criteria	Blockchain (EVM-based + IPFS)	Postgres	MySQL	Gremlin	Cassandra	Cosmos DB	MongoDB
Scalability	High (supports large volumes through decentralization)	Moderate (vertical scaling)	Moderate (vertical scaling)	High (graph data scaling)	High (horizontal scaling)	High (global distribution)	High (horizontal scaling)
Data Integrity and Immutability	Very High (immutable ledger)	Low (data can be altered)	Low (data can be altered)	Moderate (graph constraints)	Moderate (eventual consistency)	High (multi-region)	Moderate (document validation)
Security	High (cryptographic protection, decentralized)	Moderate (centralized, role-based)	Moderate (centralized, role-based)	High (encryption possible)	High (distributed, encryption)	High (built-in encryption)	High (field-level encryption)
Automation Capabilities	Very High (smart contracts)	Low (manual triggers, stored procedures)	Low (manual triggers, stored procedures)	Low (requires custom code)	Low (requires custom code)	Moderate (integrated logic)	Moderate (integrated logic)
Data Retrieval Speed	Moderate (depends on block time)	High (optimized queries)	High (optimized queries)	High (graph traversals)	High (fast read performance)	High (multi-model queries)	High (indexed searches)
Cost Efficiency	Variable (transaction fees, storage costs)	Moderate (depends on size)	Low (cost-effective)	High (specialized use cases)	Low (cost-efficient)	Moderate (depends on scale)	Moderate (open-source options)
Data Management Flexibility	High (supports structured and unstructured data via IPFS)	Moderate (structured data only)	Moderate (structured data only)	High (complex graph relationships)	High (wide-column flexibility)	High (multi-model flexibility)	High (document-oriented)

The comparative analysis highlights that traditional databases have advantages in specific areas such as query speed and cost-effectiveness for small-scale applications [17-18].

However, the blockchain-based architecture offers significant advantages in scalability, security, data integrity, and automation capabilities. These benefits are crucial for handling the dynamic and large-scale data needs of modern logistics operations driven by IoT technologies [16-19].

Additionally, the blockchain-based approach is particularly well-suited for use cases requiring tamper-proof records, and secure multi-party data sharing. In scenarios where logistics operations rely heavily on real-time data validation and compliance, blockchain's ability to automate responses using smart contracts can provide a strategic advantage over traditional database solutions [15, 19].

VII. CONCLUSION

This study devoted to blockchain technology and its applicability – to serve as an alternative to traditional databases for storing and managing IoT telemetric data in logistics. A new solution was proposed that combines blockchain's decentralized network, smart contracts, and integration with the InterPlanetary File System (IPFS). It addressed the major problems for traditional databases while dealing with the vast and ever-changing data generated by IoT devices in modern logistics operations.

The proposed solution was compared to the traditional databases like MySQL, PostgreSQL, and NoSQL systems like MongoDB, Cassandra, and others. The result showed advantages of traditional databases: faster data retrieval and cost-effectiveness for smaller applications. However, there were serious limitations: they struggled to scale up effectively, had concerns about data integrity, were vulnerable to security threats, and lacked automation capabilities. These issues reduced the efficiency and reliability of logistics operations, especially as the volume and complexity of IoT data continued to grow.

The proposed blockchain-based solution effectively addressed these challenges. By using a decentralized network and integrating with IPFS for distributed storage, the system improved scalability and coud handle large amounts of IoT data without significant performance loss. Blockchain's unchangeable ledger ensures data integrity and security because data recorded on the blockchain could not be altered or tampered with, and cryptographic methods protected it from unauthorized access. The use of smart contracts allowed for automation of logistics processes like real-time tracking, compliance checks, and payment settlements, reducing manual work and boosting operational efficiency.

The blockchain-based architecture offered scalable, secure and automated platform for managing IoT telemetric data in logistics. It effectively tackled critical issues of data integrity, security, and operational efficiency that were essential for modern logistics operations. This system implementation led to improved efficiency, stronger data security, better scalability, and increased trust among supply chain partners.

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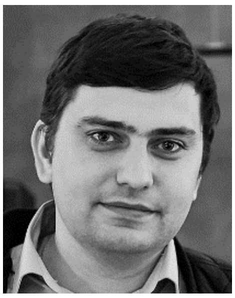

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