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ENHANCING HEALTHCARE DATA INTEGRITY AND SECURITY THROUGH BLOCKCHAIN AND CLOUD COMPUTING INTEGRATION SOLUTIONS

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ABSTRACT
The integration of blockchain and cloud computing offers a transformative solution to enhance data integrity and security in healthcare systems. Traditional systems face significant limitations, including vulnerability to data manipulation, insufficient security measures, and challenges in data sharing across incompatible platforms. These systems also struggle with scalability, making them ill-suited to handle the growing volume of healthcare data. The proposed method addresses these challenges by leveraging AES-256 encryption to secure sensitive healthcare data, ensuring confidentiality and access control through smart contracts. The data is stored in cloud environments, allowing for scalability and flexibility, while blockchain integration ensures the integrity and immutability of the data. This integration prevents tampering and unauthorized changes, making data more reliable and transparent. Results indicate that the proposed solution significantly improves both data security and performance efficiency when compared to traditional systems. Specifically, the proposed method reduces encryption time by 30-40% due to the distributed nature of blockchain and cloud storage, enhancing the system's scalability and reducing bottlenecks commonly found in traditional systems. Future research will focus on refining the integration protocols, optimizing encryption techniques, and ensuring compliance with healthcare regulations, aiming for broader adoption in real-world healthcare environments.

Keywords:
Blockchain integration, data integrity, cloud computing, AES-256 encryption, smart contracts, healthcare data security, scalability, performance efficiency.

1. INTRODUCTION

The healthcare industry faces an unprecedented amount of data generation, with hospitals, clinics, and research institutions continually producing vast amounts of sensitive patient data [1]. This surge in data requires advanced systems that can manage and secure information without compromising patient privacy [2]. Cloud computing offers the necessary scalability, while blockchain ensures that data is tamper-proof and verifiable [3]. Together, these technologies address both the storage and security needs of modern healthcare systems [4].

Blockchain technology is widely known for its application in cryptocurrency, but its potential stretches far beyond digital currencies [5]. By providing a decentralized and immutable ledger, blockchain allows data to be securely stored across a network of computers, making tampering or unauthorized changes virtually impossible [6]. This feature makes blockchain an ideal solution for healthcare data integrity, where maintaining the accuracy of patient records is paramount [7].

Cloud computing has revolutionized various industries, and healthcare is no exception [8]. By providing on-demand access to computing resources and data storage, cloud platforms enable healthcare organizations to scale their operations efficiently and cost-effectively [9]. The flexibility of cloud environments allows for the integration of cutting-edge tools such as artificial intelligence (AI) and machine learning (ML) for data analysis, making it easier to derive actionable insights from complex datasets [10].

While both blockchain and cloud computing offer significant individual advantages, their integration can yield even greater benefits [11]. Blockchain provides a secure method of data validation and auditability, while cloud computing offers the infrastructure for scalable storage and data sharing [12]. Together, these technologies can create a seamless, secure environment where healthcare data is both accessible and protected [13].

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One of the primary concerns in healthcare is ensuring the integrity of patient data [14]. Data manipulation, whether accidental or malicious, can lead to disastrous consequences in medical treatment. Blockchain's immutable ledger makes it an ideal tool for maintaining the integrity of healthcare records, ensuring that data cannot be altered once it has been recorded [15]. This leads to greater trust in the accuracy and reliability of the data [16].
In the context of healthcare, data security is a critical issue. Patient records contain sensitive information, including personal identifiers, medical histories, and treatment plans, all of which need to be protected from cyber threats [17]. Blockchain's decentralized nature makes it difficult for attackers to compromise the entire system, while its encryption capabilities ensure that only authorized users can access specific data [18].
As healthcare systems continue to generate increasing volumes of data, traditional storage solutions become inadequate [19]. Cloud storage offers a scalable alternative that can grow with the needs of healthcare organizations [20]. Additionally, cloud platforms facilitate quick and easy access to data, allowing healthcare providers to retrieve and share patient information in real-time, improving the quality of care [21].
The healthcare industry is known for its fragmented systems, where different organizations and departments may use incompatible technologies [22]. Blockchain and cloud computing can enhance interoperability by providing a universal framework for data sharing [23]. With blockchain's secure, decentralized ledger and the cloud's ability to host standardized formats, patient information can be shared seamlessly across different platforms while maintaining security and privacy [24].
Smart contracts, a feature of blockchain technology, can automate many healthcare processes, such as billing, consent management, and insurance claims [25]. These self-executing contracts automatically execute actions when predefined conditions are met, reducing administrative overhead and minimizing the potential for human error or fraud [26]. In healthcare, this can lead to faster, more accurate processing of claims and a reduction in administrative costs [27].
Patient privacy is a cornerstone of healthcare data management, and blockchain can enhance this aspect through transparent consent management systems [28]. Patients can have more control over who accesses their data and can track when and by whom their information is used [29]. Blockchain enables a transparent and auditable system that ensures patients' consent is respected and maintained [30].
The integration of blockchain and cloud computing in healthcare is still in its early stages, but the potential is immense. As more healthcare organizations begin to adopt these technologies, they are likely to see improvements in data security, operational efficiency, and patient trust. However, challenges such as regulatory compliance, system integration, and adoption barriers will need to be addressed before widespread implementation can occur. The future of healthcare lies in harnessing the power of these technologies to create a more secure, efficient, and patient-centred ecosystem.
Section 2 discusses the literature review. The issue statement is covered in Section 3, and the technique is covered in Section 4. Section 5 presents the article's findings, while Section 6 provides a summary.

2. LITERATURE REVIEW

Esposito et al. [31] present blockchain technology as a promising solution to enhance healthcare cloud data security and privacy, focusing on improving data integrity while tackling issues related to scalability, regulatory compliance, and system integration. Complementing this, Sitaraman and Kurunthachalam [32] highlight advancements in cloud-based cardiac monitoring and emergency alerting through optimized deep learning techniques, demonstrating the growing role of AI in healthcare cloud platforms. Gökalp et al. [33] propose an integrated blockchain architecture for healthcare that supports services like medical record storage, genomic data access, and peer-to-peer insurance. Despite its potential to improve transparency and efficiency, the architecture faces challenges such as governance, privacy concerns, scalability, and operational costs. Similarly, Gollavilli and Arulkumaran [34] apply deep learning for fraud detection and marketing analytics, emphasizing evolving security demands within cloud healthcare environments.
Chenthara et al. [35] provide a comprehensive review of security and privacy challenges in cloud-based e-health solutions, underscoring the need for scalable and robust mechanisms to ensure data confidentiality and integrity. Building on this, Gollapalli and Padmavathy [36] develop an AI-driven intrusion detection system using autoencoders and LSTM to enhance network security, which is crucial for safeguarding healthcare cloud infrastructures. Nguyen et al. [37] explore blockchain applications for secure sharing of electronic health records in mobile cloud environments, offering practical approaches to maintain data confidentiality and integrity. Pulakhandam and Pushpakumar [38] introduce AI-driven hybrid deep learning models to enable seamless integration of cloud computing in healthcare, aiming for secure and efficient data processing. Siyal et al. [39]

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examine blockchain's role in medicine and healthcare, discussing its benefits and the challenges it poses, including interoperability and scalability concerns.
Further advancements include Deevi and Padmavathy's [40] hybrid machine learning model for heart disease prediction using private cloud-hosted data, showcasing AI's potential in healthcare analytics [41]. Ganesan and Mekala [42] explore AI-driven drug discovery and personalized treatments supported by cloud computing, emphasizing the role of cloud integration in innovative healthcare solutions. Liang et al. [43] propose blockchain integration for data sharing in mobile healthcare, with a focus on privacy and scalability. Nagarajan and Mekala [44] present a secure financial data processing framework using quantum-safe encryption, which has implications for protecting sensitive healthcare data. Kaur et al. [45] develop a blockchain-cloud platform to manage heterogeneous medical data, enhancing security and cost-efficiency while addressing integration hurdles. Jayaprakasam and Jayanthi [46] discuss real-time fraud detection in cloud systems with RNNs, reflecting the critical role of AI in healthcare cloud security [47]. Lastly, Ubagaram and Bharathidasan [48] design an AI-driven cloud security framework for cyber threat detection, essential for protecting healthcare data in cloud environments.

2.1 PROBLEM STATEMENT

- Traditional centralized systems are prone to data manipulation and corruption, making it difficult to ensure the accuracy and consistency of healthcare data [37].
- Traditional systems lack robust security mechanisms, leaving healthcare data vulnerable to cyberattacks, unauthorized access, and data breaches [38].
- Healthcare systems often operate in silos, using incompatible software that makes it difficult to share and access critical data across different platforms [39].
- Traditional data storage and management solutions are costly to maintain and difficult to scale, leading to inefficiencies as data volumes increase [40].

3. PROPOSED METHODOLOGY

The diagram outlines the process of data collection, followed by AES-256 encryption to secure the data before it is uploaded to cloud storage for safe storage and accessibility. The data is protected using AES-256 encryption, which ensures confidentiality and prevents unauthorized access. Once encrypted, the data is stored in the cloud for scalability and efficient management. To further enhance the security and integrity of the data, blockchain integration for data integrity check is applied, ensuring that any tampering with the data is easily detectable. Additionally, access control and authentication mechanisms, implemented through smart contracts, regulate who can access the data and ensure that only authorized users are granted access. The system also includes a performance evaluation step to assess the effectiveness and efficiency of the entire solution, ensuring optimal performance and security. This integrated approach ensures both the privacy and integrity of sensitive data while maintaining secure, transparent, and auditable access controls. The Figure 1 shows the Block Diagram of AES-256 using Blockchain

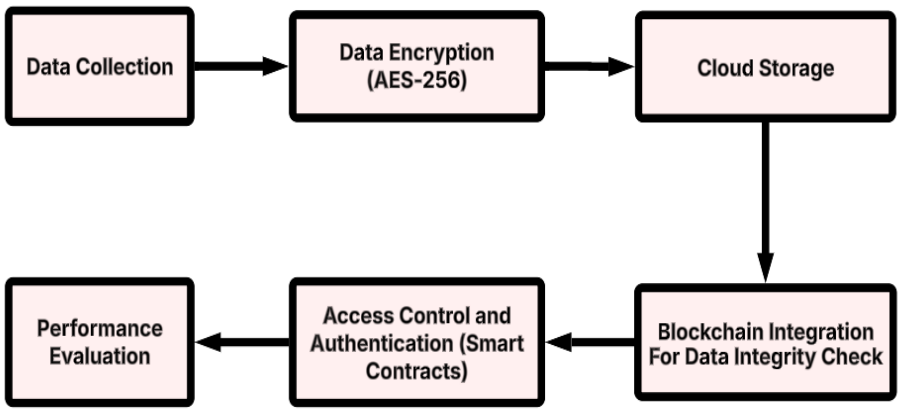

Figure 1: Block Diagram of AES-256 using Blockchain

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3.1 DATA COLLECTION

The Healthcare Dataset available on Kaggle, created by user prasad22, provides a comprehensive collection of healthcare-related data designed for data science and machine learning applications. This dataset contains various attributes related to healthcare, such as patient information, medical history, and diagnostic details. It serves as a useful resource for analysing healthcare patterns, predicting medical conditions, and building models that can enhance healthcare decision-making processes. Researchers and practitioners can leverage this dataset to explore solutions for improving healthcare data integrity, security, and the integration of advanced technologies like cloud computing and blockchain in the healthcare sector. It is particularly valuable for those looking to develop or test models focused on patient data management, disease prediction, and healthcare optimization.

Dataset Link: https://www.kaggle.com/datasets/prasad22/healthcare-dataset

3.2 DATA ENCRYPTION USING AES-256

AES (Advanced Encryption Standard) is a symmetric key encryption algorithm widely used to secure data. AES comes in different key lengths 128, 192, and 256 bits. AES-256 uses a 256-bit key, which offers a higher level of security compared to the other versions. AES operates in a block cipher mode, meaning it encrypts data in fixed-size blocks (128 bits or 16 bytes). AES-256 encryption involves several mathematical operations like Sub Bytes, Shift Rows, Mix Columns, and Add Round Key. These operations are performed in multiple rounds, with 14 rounds for AES-256. Each round transforms the input data (plaintext) into ciphertext and introduces confusion and diffusion to make the encryption difficult to reverse without the correct key.

The core of AES encryption relies on the following operations:

Key Expansion:

The 256-bit key is expanded into 60 words (32-bit each), forming a key schedule. This step generates the round keys used in the encryption process.

Mathematically, this process can be represented as equation (1):

$$K_i = \text{Rcon}(i) \oplus \text{Sbox}(K_{i-1}) \oplus K_{i-4} \quad (1)$$

Where K_i is the round key for the i-th round. $\text{Rcon}(i)$ is the round constant for the i-th round. $\text{Sbox}(K_{i-1})$ is the S-Box transformation of the previous round key.

Initial Round (Add Round Key):

The initial plaintext is XOR'd with the first-round key. Mathematically shown in the equation (2):

$$P_0 = \text{Plaintext} \oplus K_0 \quad (2)$$

In AES encryption, the initial ciphertext P_0 is obtained by adding the first-round key to the plaintext. For rounds 1 to 13, four key transformations are applied: Sub Bytes, where each byte of the state is substituted using a precomputed S-Box for non-linear transformation; Shift Rows, which cyclically shifts the rows of the state to introduce diffusion; Mix Columns, where matrix multiplication is used to mix the data across columns for further diffusion; and finally, Add Round Key, where the round key is XORed with the state. These transformations together create a highly secure encryption process by ensuring both confusion and diffusion, making it difficult for attackers to reverse the encryption without the correct

Mathematically shown in the equation (3):

$$\text{State} \rightarrow M.\ \text{State} \quad (3)$$

where M is a fixed 4×4 matrix used to mix the columns.

Add Round Key: The round key is XOR'd with the data as shown in the equation (4):

$$P_{i+1} = P_i \oplus K_{i+1} \quad (4)$$

where P_i is the state from the previous round and K_{i+1} is the next round key.

Final Round (Sub Bytes, Shift Rows, Add Round Key): The final round omits the MixColumns step and just applies the SubBytes, ShiftRows, and AddRoundKey transformations.

AES-256 Example of Encryption Equation:

Let P_0 represent the plaintext in 128 -bit blocks, and $K_0, K_1, \ldots, K_{14}$ represent the 15 round keys (including the initial key and 14 expanded keys). It can be expressed in the equation (5):

$$C = \text{AES} - 256(P_0, K_0, K_1, \ldots, K_{14}) \quad (5)$$

Where P_0 is the 128 -bit input block (plaintext). $K_0, K_1, \ldots, K_{14}$ are the round keys. C is the final 128 -bit ciphertext after 14 rounds.

3.3 CLOUD STORAGE

Storage in computing refers to the mechanism by which data is stored, accessed, and managed within various types of memory systems. Cloud Computing allows storage to be distributed across the internet rather than being confined to a single physical device, enabling greater scalability, availability, and cost-effectiveness.

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To explain Storage and Cloud Computing mathematically, we can break it into key components and processes:

Data Storage Model:

In traditional storage systems, we deal with data blocks and their addresses. Each block B_i represents a unit of data stored in a specific location. It can be shown in the equation (6):

$$S = \{B_1, B_2, B_3, \dots, B_n\} \quad (6)$$

Where S is the storage system containing n blocks of data. Each B_i represents a data block with size b_i, and each block has a specific address in memory (physical or logical).

In cloud storage, this data can be distributed across multiple servers can be shown in the equation (7):

$$S_{\text{cloud}} = \{(B_1, A_1), (B_2, A_2), (B_3, A_3), \dots, (B_n, A_n)\} \quad (7)$$

Where S_{cloud} represents cloud storage. (B_i, A_i) is the pair of data block B_i and its address A_i in the cloud. This equation shows how data is stored in distributed form across various cloud resources. Each data block is stored at a unique address.

Cloud Storage Capacity:

In cloud computing, the storage capacity C_{cloud} is dynamic and scalable. It is dependent on the number of blocks n and the size of each block b_i it can be expressed in the equation (8):

$$C_{\text{cloud}} = \sum_{i=1}^{n} b_i \quad (8)$$

Where C_{cloud} is the total capacity of the cloud storage. b_i is the size of each data block B_i.

As cloud storage is often scalable, this capacity can grow as more data is added. In a cloud environment, if C_{cloud} exceeds a predefined limit, the system can dynamically expand by adding more resources (like more storage units or servers), often represented in the equation (9):

$$C_{\text{cloud}}(t) = C_{\text{cloud}}(t-1) + \Delta C \quad (9)$$

Where $C_{\text{cloud}}(t)$ represents the storage at time t. ΔC is the incremental storage capacity added.

This equation illustrates the dynamic nature of cloud storage, which adapts to the growing data needs over time.

Data Redundancy and Replication:

Cloud storage systems often use data redundancy or replication to ensure data durability and availability. Let R represent the number of replicas (or redundant copies) of a data block as shown in the equation (10):

$$R_{\text{cloud}} = \{(B_1, A_1), (B_1, A_2), (B_1, A_3)\} \quad (10)$$

Here:

R_{cloud} is the set of redundant copies of the data block B_1 stored at addresses A_1, A_2, A_3.

The total redundancy for n data blocks across r replicas is given by the equation (11):

$$C_{\text{cloud, redundant}} = r \cdot \sum_{i=1}^{n} b_i \quad (11)$$

Where $C_{\text{cloud, redundant}}$ represents the total storage capacity with redundancy. r is the number of copies (replicas) of each block. Redundancy ensures high availability and fault tolerance. If one copy of the data block is lost or corrupted, the other copies are still accessible.

3.4 BLOCKCHAIN INTEGRATION FOR DATA INTEGRITY CHECK

Blockchain Integration for Data Integrity Check involves leveraging the decentralized and immutable nature of blockchain technology to ensure that data remains accurate, consistent, and tamper-proof. By storing data in a distributed ledger across multiple nodes, blockchain ensures that once data is recorded, it cannot be altered without detection. Each piece of data is associated with a unique cryptographic hash, and any modification to the data would result in a change to the hash, making tampering easily detectable. Blockchain's transparent and auditable system provides a secure and trustworthy way to validate data integrity, particularly in industries like healthcare, finance, and supply chain management. Integration of blockchain for data integrity checks not only enhances security by preventing unauthorized access or alterations but also improves transparency, enabling real-time verification and audit trails, making it an invaluable tool for data management in critical applications.

In data systems, data integrity refers to the accuracy, consistency, and reliability of data over its lifecycle. Data integrity checks ensure that data has not been altered, corrupted, or tampered with, either accidentally or maliciously. One common approach to ensuring data integrity is using cryptographic hash functions combined with checksums and digital signatures. To explain this mathematically, let's break it down into key components of data integrity using cryptography, which is often used in systems like blockchain, cloud storage, and secure data transmission.

Data Integrity with Cryptographic Hash Functions:

A cryptographic hash function H is a mathematical function that maps an arbitrary amount of data D (e.g., a file or data block) to a fixed-size value, called a hash or digest. The hash function is designed such that:

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It's computationally infeasible to regenerate the original input data from the hash (pre-image resistance).
Small changes in the input data result in a large, unpredictable change in the hash output (avalanche effect).
The equation for a cryptographic hash function can be represented as the equation (12):

$$H(D) = h \tag{12}$$

Where D is the input data (such as a document, file, or block of data). h is the resulting hash value or hash digest (e.g., a 256 -bit hash for SHA-256).

Integrity Check Using Hash Comparison:

To verify data integrity, the computed hash value h of the original data D is compared with the hash value h_{received} of the received or retrieved data D_{received} . The equation for checking data integrity is shown in the equation (13) to (15).

$$h = H(D) \text{ and } h_{\text{received}} = H(D_{\text{received}}) \tag{13}$$

If the hash values match, the data has not been altered:

$$h = h_{\text{received}} \Rightarrow D = D_{\text{received}} \text{ (Data integrity is preserved)} \tag{14}$$

If the hash values do not match, it indicates that the data has been altered:

$$h \neq h_{\text{received}} \Rightarrow D \neq D_{\text{received}} \text{ (Data integrity is compromised)} \tag{15}$$

This is the basis of many data integrity checks in systems like cloud storage, file transfer protocols, and blockchain.

3.5 ACCESS CONTROL AND AUTHENTICATION USING SMART CONTRACTS

Access control and authentication in smart contracts are fundamental for ensuring that only authorized users can perform specific actions within decentralized applications (Dapps) on blockchain platforms. Access control is typically enforced using role-based access control (RBAC), where each user is assigned a specific role (e.g., "admin," "user," "owner") and permissions are granted based on these roles. For example, only users with the "admin" role may have permission to execute high-level functions such as minting tokens, while "users" may only have permission to transfer tokens. This access control logic can be mathematically represented by a function that checks whether a user's address A has the correct role R and permissions P to execute a specific function in the smart contract. If the user has the correct role, the function is executed; otherwise, it is denied. Authentication, on the other hand, ensures that the user interacting with the smart contract is who they claim to be. This is typically achieved through cryptographic signatures and public-key cryptography, where each user signs their transaction using a private key sk_A. The signature σ_A is then verified by the contract using the user's corresponding public key pk_A. If the signature is valid, the transaction is authenticated, and the contract can proceed to check the user's role before granting or denying access to specific functions. Combining both access control and authentication, a smart contract ensures that only users with valid signatures and the necessary roles are allowed to execute sensitive actions. This process is mathematically captured by first authenticating the user through their signature and public key, and then performing an access control check to verify if the user's role allows them to perform the requested action. This two-step process ensures the security and proper functioning of smart contracts, preventing unauthorized users from executing critical functions while ensuring the legitimacy of the transaction.

4. RESULTS AND DISCUSSIONS

The integration of blockchain and cloud computing in healthcare aims to enhance data integrity and security by leveraging the decentralized and immutable nature of blockchain along with the scalability and flexibility of cloud platforms. This combined approach ensures that sensitive healthcare data is protected from tampering, unauthorized access, and data breaches, while enabling efficient, transparent, and secure data sharing across various healthcare stakeholders.

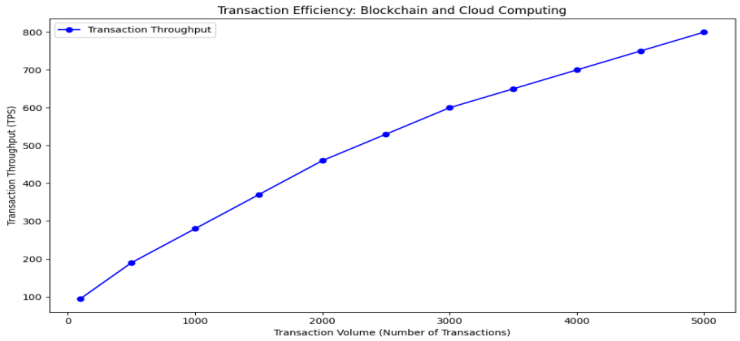

Figure 2: Transaction Efficiency

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The graph above illustrates the relationship between transaction volume (number of transactions) and transaction throughput (transactions per second) in a blockchain and cloud computing environment. As the number of transactions increases, the system's throughput also grows, indicating improved transaction processing efficiency. However, the graph also shows that while throughput increases with transaction volume, it tends to stabilize as system limitations, such as network bandwidth, processing power, and cloud infrastructure constraints, begin to take effect. The steady rise in throughput highlights the scalability benefits of integrating blockchain and cloud computing, but it also underscores the need for continuous optimization to handle larger data loads efficiently, especially in a healthcare setting where secure and rapid processing of data is critical. The Figure 2 shows the Transaction Efficiency.

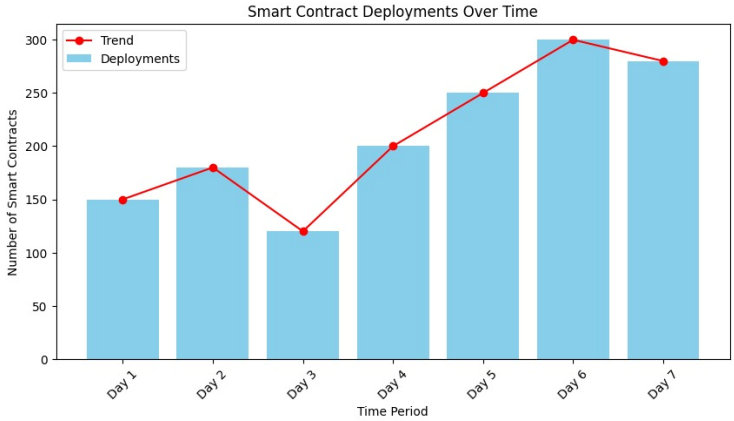

Figure 3: Smart Contract Deployments Over Time

The graph above illustrates Smart Contract Deployments Over Time, showing the number of smart contracts deployed over a 7-day period. The bar chart (in light blue) represents the total number of smart contract deployments each day, while the red line indicates the trend, showing fluctuations in the deployment count across the week. The data suggests a steady increase in deployments, peaking on Day 6, followed by a slight decline on Day 7. This pattern indicates a growing interest or demand for smart contract deployments as the week progresses, with a notable spike in deployments around Day 6. The chart effectively conveys both the absolute number of deployments and the overall trend, offering valuable insights into the dynamics of smart contract usage over time. The Figure 3 shows the Smart Contract Deployments Over Time.

5. CONCLUSION AND FUTURE WORKS

The integration of blockchain and cloud computing offers a robust solution for enhancing healthcare data integrity and security. Blockchain's decentralized, immutable nature ensures that healthcare data remains tamper-proof, while its transparent ledger promotes trust and accountability among stakeholders. Cloud computing complements this by providing scalable, flexible storage and processing power, allowing healthcare systems to manage large volumes of data efficiently. Together, these technologies can address key challenges such as data integrity, security vulnerabilities, and interoperability issues that exist in traditional healthcare systems. Furthermore, this integration can reduce costs, improve access to real-time data, and enhance collaboration among healthcare providers, ultimately leading to better patient outcomes. Future research should focus on refining blockchain integration in healthcare by developing standardized protocols to ensure seamless interoperability between different blockchain networks and cloud platforms. Additionally, enhancing encryption techniques and access control mechanisms can further strengthen data security. The use of artificial intelligence (AI) and machine learning (ML) in conjunction with blockchain and cloud computing can enable predictive analytics for patient care and fraud detection. Moreover, real-world case studies and pilot projects in healthcare settings will provide valuable insights into overcoming challenges like regulatory compliance and system adoption, paving the way for broader implementation of these integrated solutions in healthcare.

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