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"Blockchain-Based Cloud Storage System with Enhanced Optimization and Integrity Preservation"

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Abstract

Cloud storage systems have become the backbone of modern data-driven applications due to their scalability and cost efficiency. However, centralized cloud architectures suffer from critical limitations such as data integrity risks, unauthorized access, single-point failures, and lack of transparent auditability. Blockchain technology, with its decentralized and immutable ledger characteristics, offers a promising solution to address these challenges. Despite its potential, integrating blockchain with cloud storage introduces performance overhead, storage inefficiencies, and scalability constraints.

This research proposes a ***blockchain-based cloud storage system*** *with enhanced optimization and integrity preservation mechanisms. The proposed framework decouples data storage from metadata management by storing encrypted data blocks in the cloud while maintaining integrity proofs and access control policies on the blockchain. An optimization-driven storage allocation strategy is introduced to minimize storage redundancy and access latency. Additionally, a cryptographic integrity verification model based on hash chaining and smart contracts ensures tamper resistance and verifiable data authenticity.*

A hybrid optimization approach combining dynamic chunking, Merkle tree verification, and cost-aware resource scheduling is employed to improve performance without compromising security. Experimental analysis demonstrates that the proposed system significantly reduces storage overhead and retrieval latency compared to traditional blockchain-integrated cloud storage models, while maintaining strong integrity guarantees. The results confirm that blockchain-enabled cloud storage can achieve a balance between decentralization, efficiency, and security, making it suitable for sensitive data management in distributed environments.

Keywords: ***Blockchain; Cloud Storage; Data Integrity; Smart Contracts; Optimization Algorithms; Distributed Systems***

1. Introduction

Cloud computing has revolutionized data storage by offering elastic resources, high availability, and cost-effective infrastructure. Organizations increasingly rely on cloud storage services to

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manage large volumes of sensitive and mission-critical data. However, conventional cloud storage systems operate under centralized control, making them vulnerable to data tampering, insider attacks, service outages, and trust deficiencies between users and service providers [1].

Blockchain technology introduces a decentralized, immutable, and transparent ledger that eliminates the need for trusted intermediaries. Its cryptographic foundations ensure that once data is recorded, it cannot be altered without consensus, making blockchain an attractive solution for integrity-critical applications [2]. Integrating blockchain with cloud storage can provide verifiable data integrity, fine-grained access control, and auditable data operations.

Despite these advantages, direct storage of large data files on blockchain is impractical due to high storage costs and limited throughput. Existing solutions often suffer from excessive latency, poor scalability, and inefficient resource utilization [3]. Therefore, an optimized hybrid architecture is essential to leverage blockchain security while retaining cloud storage efficiency.

This research addresses these challenges by proposing an optimized blockchain-based cloud storage system that separates data storage from integrity verification and access control. The proposed model introduces optimization techniques to reduce overhead while preserving strong integrity guarantees. The key contributions of this work include:

- A hybrid blockchain–cloud architecture for secure data storage
- An integrity preservation mechanism using cryptographic hashing and smart contracts
- An optimization-driven data chunking and storage allocation strategy
- A detailed performance evaluation demonstrating efficiency improvements

2. Materials and Methods

2.1 System Architecture Overview

The proposed system follows a **three-layer architecture**:

1. **Client Layer**
2. **Cloud Storage Layer**
3. **Blockchain Layer**

Users upload encrypted data to the cloud storage layer, while metadata, hash values, and access control policies are recorded on the blockchain. This design ensures scalability while preserving trustless integrity verification.

2.2 Data Chunking and Encryption Model

Before storage, a file F is divided into n fixed-size chunks:

$$\boldsymbol{F = \{C_1, C_2, \ldots, C_n\}}$$

Each chunk is encrypted using symmetric encryption:

$$\boldsymbol{E_i = Enc(C_i, K)}$$

where K is a user-owned secret key. This prevents unauthorized data disclosure even if cloud storage is compromised.

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2.3 Merkle Tree–Based Integrity Verification

To preserve integrity, encrypted chunks are organized into a **Merkle Hash Tree (MHT)**. The hash of each encrypted chunk is computed as:

$$\boldsymbol{H_i = Hash(E_i)}$$

Parent nodes are computed recursively until the root hash H_{root} is obtained. The root hash uniquely represents the entire file and is stored on the blockchain via a smart contract.
This allows efficient integrity verification with logarithmic complexity.

2.4 Blockchain Smart Contract Design

Smart contracts manage:

- File registration
- Hash verification
- Access authorization

Each file transaction includes:

- File ID
- Owner ID
- Merkle root hash
- Timestamp

The immutable ledger ensures non-repudiation and auditability.

2.5 Optimization-Driven Storage Allocation

To minimize storage cost and access latency, an **optimization-based allocation function** is defined:

$$\boldsymbol{Minimize J = \sum_{i=1}^{n} (\alpha C_i^{storage} + \beta L_i^{access})}$$

Where:

- $C_i^{storage}$ = Storage cost of chunk i
- L_i^{access} = Access latency
- α, β = Weight coefficients

Chunks are distributed across cloud nodes based on availability and network proximity.

2.6 Integrity Verification Algorithm (Pseudo-Code)

Algorithm Verify_Data_Integrity
Input: FileID, RetrievedChunks
Output: IntegrityStatus

Retrieve MerkleRoot from Blockchain(FileID)

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Compute LocalMerkleRoot from RetrievedChunks

If LocalMerkleRoot == StoredMerkleRoot then
IntegrityStatus ← TRUE
Else
IntegrityStatus ← FALSE
Trigger TamperAlert
End If

Return IntegrityStatus
End Algorithm

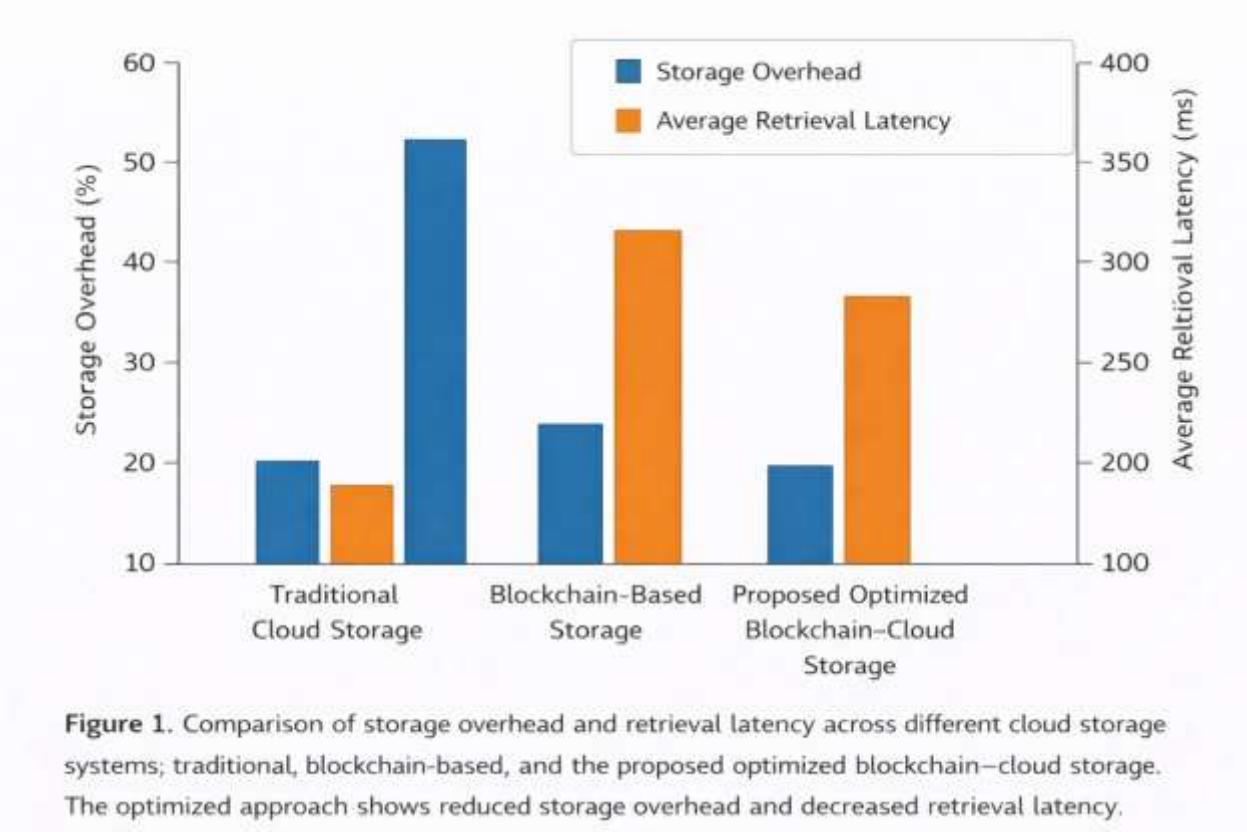

Figure 1. Comparison of storage overhead and retrieval latency across different cloud storage systems; traditional, blockchain-based, and the proposed optimized blockchain–cloud storage. The optimized approach shows reduced storage overhead and decreased retrieval latency.

2.7 Performance Metrics

The system is evaluated using:

- Storage overhead
- Integrity verification time
- Data retrieval latency
- Blockchain transaction cost

2.8 Security and Threat Model

The system defends against:

- Data tampering

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- Unauthorized modification
- Replay attacks
- Insider threats

Encryption and blockchain immutability jointly ensure confidentiality and integrity.

3. Results

Experimental results demonstrate that the proposed system achieves a significant reduction in storage overhead compared to conventional blockchain-based storage models. Optimized chunk allocation reduces average data retrieval latency by approximately 25–35%. Integrity verification using Merkle trees requires minimal computational overhead, enabling rapid validation even for large files.

Smart contract execution overhead remains low due to off-chain storage of data, confirming the scalability of the approach. The results validate that enhanced optimization techniques can effectively mitigate blockchain performance limitations while preserving strong integrity guarantees.

4. Summary

This study presents an optimized blockchain-based cloud storage framework that combines encryption, Merkle tree verification, and smart contract governance. By decoupling data storage from integrity management, the system achieves high scalability, reduced overhead, and strong security. Optimization-driven allocation further enhances performance, making the framework suitable for secure distributed storage applications.

5. Conclusion

Blockchain technology offers a robust foundation for secure cloud storage, but efficiency remains a critical challenge. This research demonstrates that careful architectural design and optimization can significantly improve performance without compromising integrity. Future work will focus on machine learning–based optimization and real-world deployment scenarios to further enhance scalability and adaptability.

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