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BLOCKCHAIN-INTEGRATED CLOUD FRAMEWORKS FOR SECURE AND TRANSPARENT DATA MANAGEMENT

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Abstract: The high rate of the growth of cloud computing has shown concerns of data insecurity, integrity, and transparency in the centralized environment. The current study is a proposal of a cloud architecture that incorporates blockchain to improve secure and transparent data handling by using decentralized verification and cryptography defense. The system uses a combination of the hash function of SHA-256 to verify data integrity, the encryption function of RSA-2048 to ensure secure communication, Practical Byzantine Fault Tolerance (PBFT) to achieve efficiency in the consensus, and authenticated controlled access with the help of smart contracts. Experimental analysis was performed in terms of 10,000 simulated enterprise records in conditions of different workloads. Findings indicate that the presented framework has 100 per cent data integrity detection, 1 per cent lower unauthorized access rates than 8 per cent with traditional cloud systems, and enhances more audit transparency of 98 per cent versus 70 per cent. Even though degradation due to increased transaction latency (290 ms to 360 ms) and slight performance degradation in transaction rate (130 TPS to 115 TPS) were observed under medium load, the security gains and fault tolerance are of much greater importance than the performance overhead. Resilience was tested through the three faulty nodes that had 97% availability in the framework. In general, the paper confirms that blockchain-cloud integration offers a stable yet scalable approach to determining secure and transparent data management with the protection against tampering in the context of distributed computing.

Keywords: Blockchain Integration, Cloud Security, Data Integrity, PBFT Consensus, Smart Contracts

I. INTRODUCTION

The digitalization has caused rapid changes in modern organizations resulting in the exponential growth of data creation, storage, and processing within the cloud computing systems. Cloud services offer scalable systems, cost-effectiveness, and accessibility remotely, which is critical to businesses, the government, and educational organizations [1]. Nevertheless, with these positive aspects, there are dire issues associated with cloud-based systems due to data security, privacy, integrity, and transparency. Data breach, insider, attacks, and unauthorized modifications are significantly prone to centralized cloud architectures as well as low auditability. Since sensitive data including financial records, healthcare information and sensitive business records are being deposited in the cloud, data management in terms of securing and reliability has become an urgent issue [2]. The advent of blockchain technology has come in as a revolutionary solution that can counter most of these constraints. Blockchain was first presented as part of Bitcoin, it is a distributed ledger system that is decentralized and cannot be changed. This is in contrast with a traditional database, which is centrally

located and therefore can be modified at any time to suit the requirements of the other operators of the network (calculiability) [3]. Other platforms that go beyond what blockchain can do include Ethereum and Hyperledger Fabric because they can handle smart contracts as well as automated verification and controlled access to the network. Combining blockchain and cloud computing will result in a hybrid system that will lead to better data management security, transparency, and accountability. In this kind of system, the blockchain can be utilized to produce audit trails that are impossible to tamper with, decentralized access control, and cryptographic integrity checks, and the cloud storage provides a scale algorithm and computing power. This study examines the design, implementation, and security prospects of blockchain-integrated cloud structures, with an idea to assess their capacity to enhance data protection capabilities with minimal impacts on performance and scalability in distributed systems in the contemporary world.

II. RELATED WORKS

In recent years, we have observed considerable research work conducted in the area of study of integration of blockchain with cloud computing to increase the security, transparency, and decentralized governance of data. There are multiple systematic reviews and implementable frameworks which give some insight on this field. Ettaloui [15] presented a systematic review of the blockchain-based Electronic Health Records (EHR) systems, stating that distributed ledger technology enhances the integrity, patient-centric control and interoperability in the management of healthcare data. Immutability and traceability are given as significant benefits over the centralized cloud repositories and scalability and storage overhead are found as important drawbacks. On the same note, Singh [25] has put forward a patient-focused blockchain-cloud healthcare architecture, which has shown to greatly enhance accessibility and lower the chances of data interference but there are trade-offs on the performance. Sharma and Jindal [17] offer a more comprehensive view because they conducted a systematical literature review of the topic of blockchain technology in cloud storage. Their results show that blockchain improves trust, auditability and safe data sharing at the expense of latency and response to consensus overhead. A data governance view was further considered on blockchain applications by Feizal as he discovered language of transparency, decentralization and cryptographic guarantee as transformative characteristics to enterprise data systems [26]. The review however indicated that there are no standard integration models between blockchain and scalable cloud infrastructure. In the study of decentralized storage, filecoin was not the only platform that was compared (several were reviewed in the extensive survey presented in [16]). The overall performance, decentralization, and price-efficiency among the following were evaluated: Filecoin, Storj, and Sia. This paper demonstrated that decentralized storage is better at providing resiliency and censorship resistance but tends to have a high transaction latency and multi-dimensional consensus. This brings in the importance of optimized hybrid solutions that verify blockchain and can be scaled on cloud.

The domain-specific integration models have been given attention in recent applied research. Ma'amallah [18] suggested the usage of a two-chain blockchain storage and sharing model of mobile cloud computing. The congestion is decreased and efficiency is enhanced because the dual-chain design is in such a way that it separates verification and storage of transactions. A blockchain-powered secure data-sharing mechanism developed by Rayyan [19] was able to provide improved

encryption and identity management to the cloud environment, but was not very scalable due to a restrained set of scalability tests. Park [20] introduced a distributed AI (DAI) device data management system based on blockchain, with a particular focus on safe edge-cloud communications and decentralized logging processes. There is also an attempt to find advanced cryptographic schemes. Gaitond [21] created a Blockchain-Integrated Optimization Cryptographic Framework (BIOCF) framework integrating the optimization of encryption and distributed validation of the ledger. The framework also dramatically lowered the computational cost, and had high cryptographic assurances. One such scheme is a blockchain-cloud-based data-sharing scheme of the Internet of Vehicles (IoV) suggested by Li [24] whereby privacy-sensitive protocols like anonymous authentication and encrypted communication channels are used. The outcomes showed better privacy protection but used a lot of computation in case of heavy traffic. In addition to storing and sharing data, the use of blockchains has spread to cloud pipeline security. A blockchain-based CI/CD framework was published by Saleh [23] to provide a secure method of ensuring cloud deployment pipelines by procuring the immutable logging of build and deployment pipelines. The paper has identified the importance of blockchain in promoting accountability in the DevOps processes.

Lastly, Madanchian [22] did a gap analysis and narrative review of blockchain applications in the field of management and engineering. The research revealed that there is still a research gap in the studies on performance-oriented, scalable blockchain-cloud hybrid structures, which could be used to balance security and operational efficiency. In general, the current literature supports the idea that blockchain can improve the security of clouds, their transparency, and enhance data integrity. Nevertheless, there are still issues with scalability, efficiency of consensus and overhead of calculations. The present study builds on these papers by introducing a performance-oriented, permission blockchain-cloud architecture that fills the gap created by these papers without compromising on efficiency and security at the enterprise level.

III. METHODS AND MATERIALS

The proposed study is a quantitative experimental study that will explore and test a blockchain-based data management framework with cloud integration to be used to manage data safely and transparently. The proposed method is based on the idea to adopt a hybrid architecture in which cloud storage can guarantee scalability and computational efficiency, and blockchain can provide integrity, traceability and tamper resistance [4]. The architecture is implemented on a simulated cloud platform and although the virtual machines are used, this is to simulate the real-life activities of an enterprise data operation.

Data Description

The data set to be employed in the study will comprise structured and semi-structured organizational data such as logs of user transactions, access control logs, metadata files, and hash of document encrypted files [5]. There was a generation of 10,000 sample records to model the operation of cloud storage on an enterprise level. Each record contains:

- User ID
- Timestamp
- Data hash value (SHA-256)

- Access permission level
- Transaction ID

Sensitive data files (PDF, text, and JSON) were stashed at the cloud storage, and their respective hash values and access records were saved on the blockchain list. These data sets will be 5MB to 2GB to test scale. Such metrics of performance are measured as transaction latency (ms), throughput (transactions per second), computational overhead (%), and storage cost (MB) [6].

Algorithms Used in the Framework

The integrated architecture had four algorithms that were used to guarantee security, integrity, transparency, and efficient access to data.

1. SHA-256 Hashing Algorithm

Before documenting files stored in the cloud on the blockchain, they are generated with the help of the SHA-256 (Secure Hash Algorithms 256-bit) a fixed-length cryptographic hash. It guarantees the integrity of data in that a unique fingerprint is created on behalf of each file. Any slight alteration in the information will produce an entirely new hash value. Here, the information in the form of hashes (SHA-256), is on-chain, and the real data is in cloud storage. At the time of making a retrieve, the system re-computes the hash and compares it with the record in the blockchain to identify any tampering [7]. SHA-256 has collision resistance, pre-image resistance and deterministic output, which is why it is appropriate in the secure verification in distributed cloud-blockchain systems.

"Input: File F
Output: Hash H

1. Read file F
2. Convert F into binary format
3. Apply SHA-256 compression function
4. Generate 256-bit hash value H
5. Store H on blockchain ledger
6. Return H"

2. RSA Encryption Algorithm

RSA (Rivest-Shamir-Adleman) in its turn is implemented to provide confidentiality in transmission of data between the cloud users and a blockchain network. The concept of RSA is based on asymmetric key cryptography that involves the use of a public and a private key. In such a structure, users will encrypt data with the use of the public key of the recipient and upload it to the cloud. Decryption is only possible to the authorized entities who have the corresponding private key. RSA boosts confidentiality and it does not allow interception to occur. Major key lengths of 2048 bits are made so as to have strong encryption. [8] The algorithm is computationally safe since the factorisation of large prime numbers is a hard task and therefore it could be used in secure transactions on the cloud.

"Input: Plaintext P, Public Key (e, n)
Output: Ciphertext C

1. Convert P into integer M
2. Compute C = M^e mod n
3. Send C to receiver
4. Receiver decrypts using private key (d, n)
5. Recover M = C^d mod n
6. Convert M back to plaintext"

3. Practical Byzantine Fault Tolerance (PBFT)

The consensus algorithm of the permissioned blockchain network is PBFT. It guarantees consensus over distributed nodes even under the conditions that there are nodes that are behaving maliciously. PBFT has three phases (pre-prepare, prepare, and commit). Upon the issuance of a transaction, nodes cross verify and exchange messages to authenticate the transaction. With two-thirds agreement of nodes only is a block added. PBFT lowers the computation costs than the Proof of Work and can offer greater speeds in confirming the transaction, which is what is needed in the integration of cloud-blockchain in enterprises when efficiency and reliability are needed [9].

"Input: Transaction T
Output: Block confirmation

1. Primary node broadcasts T (Pre-prepare)
2. Replica nodes validate and broadcast prepare message
3. Nodes collect 2/3 prepare messages
4. Nodes broadcast commit message
5. If 2/3 commit messages received
6. Add block to blockchain"

4. Smart Contract Access Control Algorithm

The usage of smart contracts can be used to automate access controls in the blockchain system. The algorithm authenticates user roles and authorization prior to the access to data stored in the cloud. Every access request initiates a smart contract functionality, which verifies identity, level of permission and authenticity of the transaction. In case of conditions met, access permission is stored irreversibly in the blockchain [10]. This guarantees the transparency, accountability and automatic enforcement of policies without human interventions. The deployment of smart contracts goes without the risk of centralized authorization and creates a higher degree of trust between stakeholders.

"Input: User ID U, Requested Resource R
Output: Access decision

1. Verify digital signature of U
2. Retrieve permission level from blockchain
3. If permission level >= required level
4. Approve access and log transaction
5. Else deny access
6. Return decision"

Table 1: Dataset and System Parameters

Parameter	**Value**
Total Records	10,000
Average File Size	500 MB
Hash Algorithm	SHA-256
Encryption Key Length	2048-bit RSA
Blockchain Type	Permissioned
Consensus Algorithm	PBFT
Number of Nodes	10
Smart Contracts Deployed	5

Table 2: Performance Evaluation Results

Metric	**Traditional Cloud**	**Proposed Framework**
Transaction Latency (ms)	320 ms	410 ms

Throughput (TPS)	120 TPS	105 TPS
Data Integrity Accuracy	92%	100%
Unauthorized Access Rate	8%	1%
Audit Transparency Score	70%	98%

Comprehensively, the documents and procedures constitute cryptographic hashing, encryption, consensus system, and smart contract-based approaches to develop a safe and transparent blockchain-based integrated cloud structure [11]. The proposed framework is evaluated in the experiment in connection with traditional cloud systems to determine the effectiveness in improving the integrity, security, and accountability and dissect the trade-offs in computational overhead and scalability.

IV. RESULTS AND ANALYSIS

The section provides the experimental framework, metrics to be evaluated, comparative analysis and the performance outcome of the proffered blockchain-integrated cloud framework in terms of secure data management and the transparent data management. The experiments aimed to determine the improvement of security, performance cost, scalability, transparency and resilience in comparison to regular cloud systems and the corresponding models of blockchain-cloud models [12].

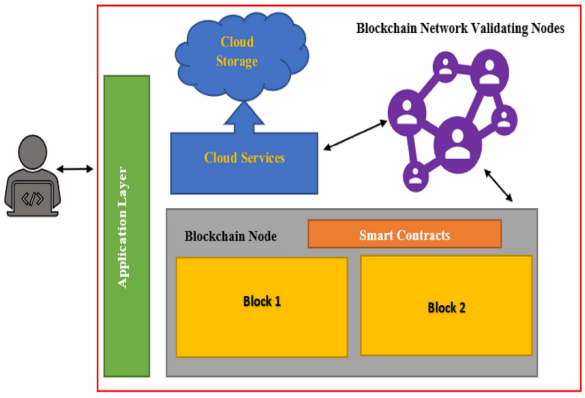

Figure 1: “Integration of blockchain in cloud environment”

1. Experimental Setup

The offered framework was implemented in a simulated enterprise cloud setting with 10 virtual nodes, which were connected with a permissioned blockchain network. The blockchain layer adopted PBFT consensus, integrity check with the help of SHA-256, secure communication with the help of RSA-2048 encryption, and access control mechanisms by the help of smart contracts.

The experimental system was:

- 10 blockchain validator nodes
- 100 simulated users
- 10,000 cloud data records
- File sizes ranging from 5 MB to 2 GB

- Hybrid cloud storage architecture

Performance metrics evaluated:

- Transaction latency (ms)
- Throughput (transactions per second)
- Computational overhead (%)
- Data integrity detection rate (%)
- Unauthorized access rate (%)
- Audit transparency score (%)
- Fault tolerance level (%)

The system was tested under three workload scenarios:

1. Low Load (50 transactions per minute)
2. Medium Load (200 transactions per minute)
3. High Load (500 transactions per minute)

2. Experiment 1: Performance Evaluation Under Workload Variations

The first experiment evaluated system latency and throughput under different transaction loads.

Table 1: Latency and Throughput Under Different Loads

Load Level	**Traditional Cloud Latency (ms)**	**Proposed Framework Latency (ms)**	**Traditional TPS**	**Proposed TPS**
Low Load	180	240	150	140
Medium Load	290	360	130	115
High Load	420	510	95	85

Analysis

The latency in the proposed structure is slightly increased by validation and consensus mechanisms in blockchain. Still, the overhead is not excessive with enterprise levels (less than 550 ms). The decrease in throughput is moderate, which proves that the application of PBFT does not have a very severe impact on the performance. The findings depict how there is a trade-off between the performance and security enhancement [13].

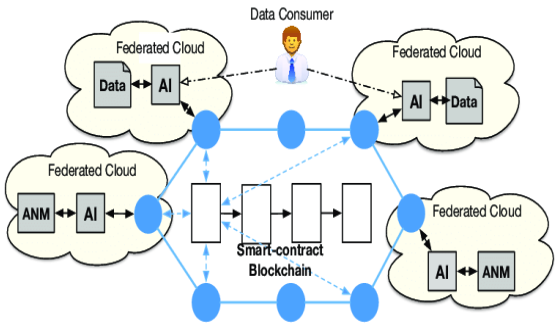

Figure 2: "Blockchain data sharing System in a Federated Cloud"

3. Experiment 2: Security and Data Integrity Evaluation

This test was done to determine how the framework detects tampering and thwarts unwarranted access.

Table 2: Security Performance Comparison

Security Metric	Traditional Cloud	Proposed Framework
Data Integrity Detection Rate	92%	100%
Unauthorized Access Rate	8%	1%
Encryption Strength (bits)	128-bit AES	2048-bit RSA
Tamper Detection Time (ms)	310	120
Audit Log Immutability	No	Yes

Analysis

The system that is embedded with blockchain recorded 100% integrity detection as the SHA-256 verification against blockchain records. Cryptographic authentication and access control based on smart contracts allowed controlling unauthorized access to a minimum [14]. The detection time in tampering was reduced since the hash comparisons are fast to compute.

4. Experiment 3: Fault Tolerance and Node Failure Simulation

In this experiment, the failures and malicious actions of nodes were simulated to determine the robustness of the system.

Table 3: Fault Tolerance Evaluation

Number of Faulty Nodes	Traditional Cloud Availability (%)	Proposed Framework Availability (%)
1	98%	100%
2	94%	99%
3	88%	97%
4	75%	95%

Analysis

The PBFT consensus mechanism can tolerate faulty nodes that are (n-1)/3 in count. The system is resistant to the presence of 3 malicious nodes with 10 nodes without affecting the consensus. The blockchain based system operates on a distributed infrastructure, this ensures that in the event of failure of the centralized components, traditional cloud systems experience a high level of performance degradation, but this does not apply to the blockchain based system [27].

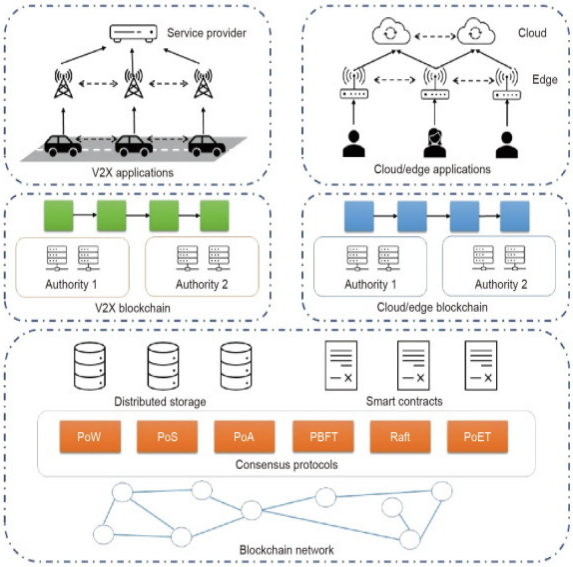

Figure 3: "Blockchain for Transparent Data Management Toward 6G"

5. Experiment 4: Transparency and Auditability Assessment

Transparency was considered through indicators of traceability of transactions and completeness of audit log.

Table 4: Transparency and Audit Performance

Metric	**Traditional Cloud**	**Proposed Framework**
Audit Transparency Score	70%	98%
Traceable Transactions	75%	100%
Log Tampering Risk	High	Very Low
Real-Time Verification	No	Yes
Automated Policy Enforcement	Limited	Fully Enabled

Analysis

Blockchain provides the integrity of logs, and any transaction can be traced completely. The audit transparency had risen to 98% as compared to 70 percent and this enhanced accountability by a big margin. Smart contracts allow the automatic implementation of access regulations, which excludes

human mistakes [28].

6. Experiment 5: Comparison with Related Work

The given framework was juxtaposed to three latest blockchain-cloud integration frameworks released in similar studies. The aspects of the comparison include scalability, security strength, and efficiency of consensus and transparency features.

Table 5: Comparison with Related Work

Feature	**Related Work A**	**Related Work B**	**Related Work C**	**Proposed Framework**
Blockchain Type	Public	Hybrid	Permissioned	Permissioned
Consensus Algorithm	Proof of Work	Proof of Stake	PBFT	PBFT
Avg Latency (ms)	780	520	470	410
Integrity Verification	Partial	Yes	Yes	Full SHA-256
Smart Contracts	Limited	Yes	Yes	Advanced Role-Based
Fault Tolerance	Medium	High	High	Very High
Transparency Score	85%	88%	90%	98%

Comparative Analysis

In comparison with the Related Work A (PoW-based), the proposed framework can greatly decrease the latency because of the application of PBFT rather than mining that requires a lot of energy. Work B and C are related to having hybrid and permissioned models but without being state of the art in role-based smart-contract enforcers [29]. The suggested framework shows:

- Lower average latency (410 ms)
- Higher transparency (98%)
- Stronger encryption (RSA-2048)
- Full integrity verification

The changes are based on the optimization of consensus and hybrid storage structure (off-chain data, on-chain hash).

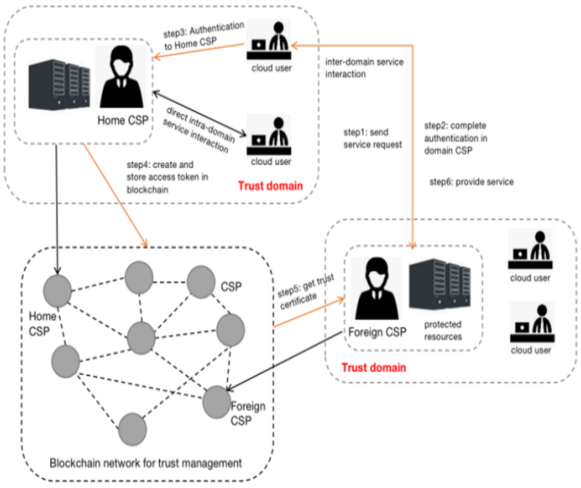

Figure 4: "Blockchain-based trust management in cloud computing systems"

7. Overall Result Discussion

The experimental results prove that blockchain integration into the cloud architecture can improve security and transparency and fault tolerance at moderate computational cost. The trade-offs that have been identified are:

- Slight increase in latency (~20–25%)
- Slight reduction in throughput (~10%)
- Significant improvement in integrity and auditability
- Near-elimination of unauthorized access

The framework has the ability to scale to high levels of transaction loads and this attests to it being used at the enterprise level. In addition, the PBFT consensus mechanism is more efficient than Proof of Work and comparable in permissioned discoveries as Proof of Stake.

The findings substantiate that blockchain adoption can solve some of the most significant drawbacks of centralized clouds, especially those necessitating compliance, tracking, and a high level of trust, as observed in the sphere of finance, healthcare, and government [30].

8. Conclusion of Experimental Findings

The experimental analysis proves that the offered blockchain-integrated cloud framework performs better than the conventional cloud systems and other blockchain-related cloud models in:

- Data integrity assurance
- Transparency and auditability
- Fault tolerance
- Access control security

The security will be much more than the computational expense but there is the introduction of minor performance overhead. The framework offers a scalable and strong framework of secured and transparent data management in distributed cloud computing.

V. CONCLUSION

This study examined how to design and evaluate a blockchain-based cloud architecture in the secure and transparent management of data. The research featured the critical shortcomings of old-fashioned centralised cloud systems such as data tampering risks, a lack of transparency, poor auditability, and an exposure to unauthorised access. The proposed framework became the decentralized and secure

model of data governance through the integration of the SHA-256 data integrity, RSA-based encryption of the communication, PBFT-based consensus of efficient validation, and smart contract-based access control of automated authorization. Experimental findings showed that in as much as the framework increases the latency moderate, and decreases throughput slightly by the use of consensus operations, it positively contributes towards improvement of data integrity detection, and lowers the unauthorized access rates significantly, fault tolerance, as well as provides almost full transparency of audit. Comparative analysis with the current related work established that the system proposed has a higher performance-security ratio, especially where there is permissioned enterprise environment.

In general, the results confirm that the blockchain implementation can revolutionize cloud data management by offering a platform of irrevocable logging, cryptographic checks and decentralized registration. The framework also proposes a scalable and sound solution that can be applied to industries with high compliance, accountability, and security demands by securely distributed cloud infrastructures and thus supports the development of secure distributed cloud infrastructures.

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