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Blockchain based secure logging framework for cloud forensics and cyber security

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Abstract
Cloud computing has emerged as a prominent technological platform offering scalable and distributed services; however, it poses significant threats in terms of security, integrity, and reliability of log data that is used during cybersecurity and digital forensic processes. Centralized logging methods are easily susceptible to any kind of manipulation, unauthorized access, and do not provide transparency to make the stored logs trustworthy. This research therefore aims at proposing a novel method for storing log records using blockchain technology in order to enhance security, integrity, and transparency of log data in the cloud environment. This framework involves immutability, traceability, and integrity of the log records using hashing techniques, smart contracts, and hybrid data storage strategy. The main idea behind the proposed method is storing of complete log records in an off-chain manner while keeping only their hash values in the blockchain network. MATLAB simulation tests were carried out to assess vital performance metrics such as latency, throughput, storage efficiency, accuracy in detecting tampering, and block creation time. From the experimental results, it is clear that the developed framework attains almost 100% accuracy in detecting tampering and cuts down storage usage by about 85% to 90%, compared to traditional logging mechanisms. Despite the slight increase in latency due to blockchain technology, the system continues to maintain constant throughput. These findings indicate that the developed framework is a suitable solution for enhancing cloud security, guaranteeing trustworthy logging, and maintaining forensics integrity.
Keywords: Cloud Computing; Blockchain; Secure Logging; Cloud Forensics; Cybersecurity; Data Integrity; Smart Contracts

1. Introduction

The development of cloud computing has enabled the provision of scalable and on-demand computing resources. In addition, cloud computing has been successful in managing data, applications, and services in distributed environments through its service models such as IaaS, PaaS, and SaaS. Nevertheless, there have been significant security and forensic challenges associated with the use of cloud computing technologies that need to be addressed. The service models of cloud computing have played an integral role in enhancing modern IT infrastructure.

There has been a need to ensure the integrity, accountability, and traceability of cloud systems (Zawoad & Hasan, 2013).

Log management is an essential part of cloud security and digital forensics. It provides crucial information to detect, investigate, audit, and recover from cyber-attacks. Although the logging process in cloud computing platforms plays a key role in the forensic investigation of cyber-attacks, it is prone to various attacks, including deletion, tampering, and manipulation by malicious entities. For instance, attackers and malicious insiders can manipulate or remove logs to prevent detection of cyber-crimes and avoid punishment (Kumar et al., 2018). Moreover, there are privacy issues associated with the use of cloud computing technologies since most log management techniques are centralized.

Cloud forensics, as an extension of digital forensics, strives to meet these needs by providing a way to identify, acquire, preserve, and analyse digital evidence within cloud computing environments. Nevertheless, due to the virtualization, multi-tenancy, and geographical distribution of data storage in such environments, these tasks can become quite challenging because investigators have no access to physical infrastructure, and there is a lack of data ownership in cloud computing environments (Park et al., 2017). Such a problem requires the development of effective and robust logging capabilities to perform trustful forensic investigations in cloud computing.

A number of innovative solutions have been developed in order to cope with these challenges. One such solution is the use of blockchain technology. Being a decentralized and distributed ledger system, blockchain provides strong resistance to any type of data modification because of its inherent immutability and transparency characteristics. In consequence, blockchain technology has received great attention as a means of improving security and trust in different areas, such as cloud computing and digital forensics (Nair et al., 2022). Blockchain makes it possible to store log data in a reliable manner, thus preventing any malicious activities against log files.

A number of researchers have explored the use of blockchains for implementing secure logging schemes in cloud computing. For example, blockchain-enabled logging platforms have been shown to be able to offer tamper-resistant storage, decentralized validation, and enhanced audit capability of the logs (Ali et al., 2022). Likewise, it is suggested that the integration of blockchain technology into cloud forensic solutions can improve the credibility of evidentiary materials and ensure their secure tracking within distributed systems (Ragu & Ramamoorthy, 2023). Nevertheless, contemporary approaches are associated with a number of difficulties related to the scalability of the proposed solutions, storage requirements, latency, and query efficiency.

This paper seeks to propose a solution to this challenge by developing a blockchain-based logging architecture for forensic and cybersecurity purposes in cloud computing. In particular, the blockchain-enabled logging system will be developed on the basis of decentralized logging principles and will leverage the use of blockchain technology in cloud environments to ensure the reliability and efficiency of the log management process.

Contributions

The following are the key contributions of this study:

1. 1.An innovative design for combining the blockchain approach with cloud logging platforms.
2. Secure log creation and validation techniques employing cryptography and consensus algorithms.
3. A forensic-oriented logging scheme ensuring the integrity and traceability of log data.
4. The analysis of the proposed architecture from the perspective of security, performance, and scalability.

In summary, this study attempts to address the issues of cloud logging and forensic evidence through the application of blockchain capabilities.

2. Literature Review

Due to increased use of cloud technology, there is a heightened demand for secure, reliable, and verifiable logging approaches in order to conduct cybersecurity tasks and forensic analysis. In this section, a brief survey of prior research work done in four main areas is presented; namely, cloud logging techniques, forensic challenges in cloud environment, application of blockchain to cybersecurity, and secure logging via blockchain.

2.1 Cloud Logging Techniques

Logs play an important role in monitoring events and identifying irregularities. Traditionally, cloud logging frameworks are centralized and use Security Information and Event Management (SIEM) tools. They are capable of aggregating logs from different sources and providing real-time analytics and alerts (Behl & Behl, 2017). Nevertheless, centralized log management implies certain risks associated with single points of failure and potential tampering (Behl & Behl, 2017).

Cloud computing involves numerous virtualized resources, which makes log generation more complicated and increases the volume of information. Research reveals that modern logging systems are effective when processing big data but do not offer sufficient mechanisms to ensure integrity and non-repudiation (Zawoad & Hasan, 2013). In addition, log storage and access are usually controlled by cloud service providers, which complicates the issue of trust and transparency.

There have been several attempts to solve the problem of cloud log security by implementing cryptographic algorithms like hashing. Although these approaches contribute to better data integrity, they depend on centralized infrastructure and cannot prevent insider attacks or other types of malicious behavior (Accorsi, 2009). As a result, new logging technologies need to be developed.

2.2 Cloud Forensics Challenges

Cloud forensics is a branch of digital forensics that encompasses conducting digital forensics activities on cloud computing. Cloud forensics is involved in the process of identifying, acquiring, preserving, analysing, and presenting the evidence collected (Ruan et al., 2011). Cloud computing poses some distinct challenges when conducting digital forensics. For instance, one main problem is the inability of investigators to gain physical access to the infrastructure of the cloud.

The other problem is associated with keeping the chain of custody. The chain of custody involves tracking the origin and integrity of digital evidence from the time it is seized until the end of the trial (Taylor et al., 2011). This is a big problem because in cloud computing, data is stored and managed at various locations and by third parties. The concept of multi-tenancy is another obstacle to conducting cloud forensics.

Here, logs are created in order to record any activities carried out using an application. Multi-tenancy is a problem because logs belonging to various users are mixed on cloud infrastructure. This causes privacy and isolation of data issues. Research has also shown that one big challenge in cloud forensics is log volatility and synchronization.

2.3 Blockchain in Cybersecurity

The blockchain technology has received a lot of attention from researchers as one of the disruptive technologies that can greatly improve security and trust in distributed networks. This technology is characterized by a decentralized architecture that does not rely on a single entity, coupled with cryptography techniques that make the data immutable and trustworthy. The blocks in a blockchain are connected using cryptographic hashes, which makes the modification of stored data almost impossible (Nakamoto, 2008).

Cybersecurity applications of blockchain include identity management, data sharing, and intrusion detection systems. The ability of blockchain to create transparency, traceability, and resilience against different cyberattacks such as data alteration or theft has been shown (Conti et al., 2018).

Additionally, using smart contracts, which can automatically enforce security and access control policies based on pre-defined rules, makes blockchain a very useful technology for cloud cybersecurity. In other words, blockchain-based smart contracts can reduce human errors in security management (Christidis & Devetsikiotis, 2016). Nevertheless, there are limitations that should be addressed before using blockchain in cloud cybersecurity such as latency, scalability issues, and energy usage.

2.4 Blockchain-Based Logging Systems

The integration of blockchain with logging systems has been examined as an innovative solution for overcoming the drawbacks of existing centralized solutions. Blockchain logging uses decentralized ledgers for storing log hashes or metadata and achieving immutability and verifiability of log information.

For example, the early works of Accorsi (2009) about secure logging based on chains were aimed at exploring cryptographic chains in the future. Kumar et al. (2018) suggested integrating blockchain with a logging system through storing logs off-chain and hashing the logs on-chain to enhance the performance of the process.

Furthermore, Ali et al. (2022) showed how blockchain can be successfully used for implementing tamper-proof logging solutions that provide auditability. According to Nair et al. (2022), blockchain has great potential in solving cloud forensics problems by providing secure evidence storage capabilities. However, despite the promising results of these studies, there are several significant limitations of blockchain-based logging systems.

Blockchain logging solutions are often characterized by limited scalability since ledgers become larger over time. Transaction latency may affect the performance of logging operations.

High computational costs may hinder the deployment of these systems in limited resources environments. Also, efficient log searching and retrieval becomes more complex in blockchain-based logging systems.

2.5 Research Gap

As a result of the review of the available literature, there is a possibility to note that blockchain is an attractive technology in terms of its ability to be used for secure logging; however, currently, such applications of the technology do not fully meet the requirements necessary for forensic applications in cloud computing. In particular, it should be noted that:

- It lacks scalable architecture that will allow processing large volumes of cloud logs
- The storage component of the current technologies is ineffective
- The process of real-time log verification and analysis is inefficient
- The integration of the processes within the forensic framework is insufficient

3. Proposed Methodology

This study proposes a **blockchain-based secure logging framework** designed to enhance integrity, transparency, and forensic reliability in cloud environments. The framework integrates a decentralized blockchain layer with conventional cloud logging systems and introduces a hybrid storage mechanism to address scalability and performance constraints. The methodology is structured around system architecture, mathematical modelling, and algorithmic processes that collectively ensure tamper-proof log management.

3.1 System Architecture

The proposed architecture follows a layered design in which each component performs a distinct role in secure log generation, storage, and verification.

Schematic Representation (Conceptual Flow):

Within this architecture, logs are generated continuously by cloud-based entities such as virtual machines and applications. These logs are forwarded to a preprocessing module where they are normalized, timestamped, and transformed into secure hash values. The resulting hashes are then recorded on the blockchain as transactions, while the original logs are stored in off-chain storage to optimize performance. Smart contracts enforce validation and access rules, and the forensic layer enables investigators to retrieve and verify logs using blockchain records.

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Figure 1 illustrates the workflow of a blockchain-based secure logging framework from data generation to forensic analysis.

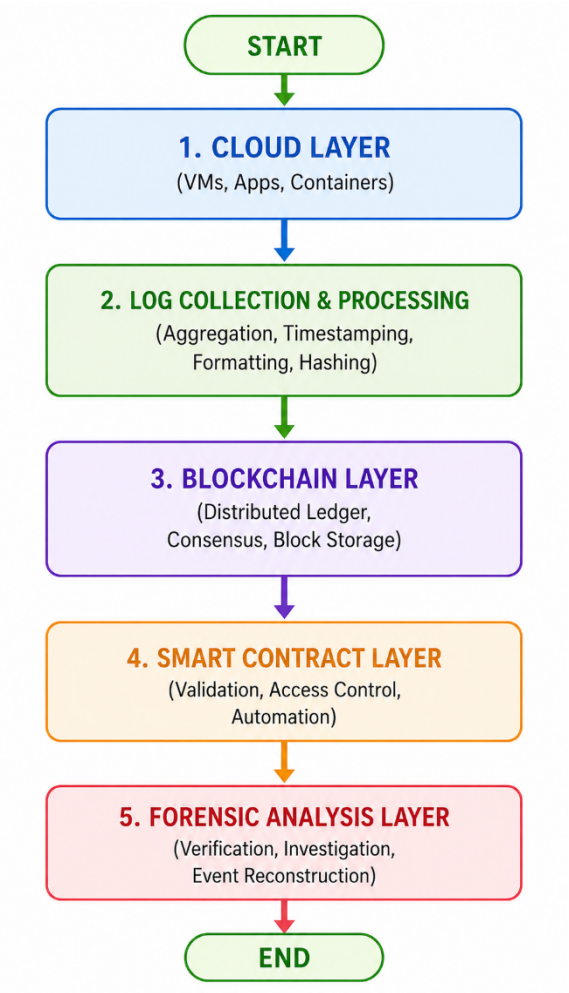

Figure 1: Blockchain-based secure logging framework.

Algorithm Steps for Blockchain-Based Secure Logging Framework

Step 1: User Request Generation

The process starts when a user or cloud application generates an activity or request in the cloud environment. This activity may include login details, file access, data transfer, system updates, or other operations that need to be recorded for security and monitoring purposes.

Step 2: Log Data Collection

The cloud server collects the generated activity and creates a log record. The log contains important information such as timestamp, user ID, IP address, event type, and activity details.

Step 3: Hash Value Generation

After creating the log record, a cryptographic hash function such as SHA-256 is applied to the log data. This process converts the original log into a unique hash value. Even a small change in the original log will produce a completely different hash value.

Step 4: Off-Chain Storage of Logs

The complete log records are stored in external cloud storage or database systems outside the blockchain. This reduces blockchain storage requirements and improves storage efficiency.

Step 5: Blockchain Entry Creation

Only the generated hash value, timestamp, and transaction details are added to the blockchain network. Each block contains the hash of the previous block, which creates a secure chain structure.

Step 6: Smart Contract Verification

Smart contracts are used to automatically verify and validate the log transactions before adding them to the blockchain. The smart contract checks whether the log data follows the required security rules and permissions.

Step 7: Block Generation and Validation

After verification, a new block is created containing the log hash values. The blockchain nodes validate the block using the selected consensus mechanism. Once validated, the block is permanently added to the blockchain ledger.

Step 8: Tampering Detection

Whenever log verification is required, the system again generates the hash value from the stored off-chain log data and compares it with the hash stored on the blockchain. If both hash values match, the log is considered authentic. If they do not match, tampering is detected immediately.

Step 9: Monitoring and Forensic Analysis

Authorized administrators or forensic investigators can access the logs for security monitoring and digital forensic investigations. Since blockchain records are immutable, the logs remain trustworthy and transparent.

Step 10: Performance Evaluation

The proposed framework is evaluated using MATLAB simulation. Parameters such as latency, throughput, storage efficiency, block generation time, and tampering detection accuracy are measured to analyze system performance.

Step 11: Secure Log Maintenance

The system continuously updates and stores new logs while maintaining integrity, confidentiality, and traceability. This ensures long-term secure cloud logging for different applications and industries.

3.2 Mathematical Model

The framework relies on cryptographic primitives to ensure data integrity and traceability.

Each log entry is transformed into a hash value using a secure hashing function:

$$H_i = SHA256(L_i \parallel T_i \parallel ID_i)$$

where L_i represents the log data, T_i denotes the timestamp, and ID_i is a unique identifier associated with the log entry.

Blocks are formed by aggregating multiple hashed log entries, and each block is cryptographically linked to the previous block:

$$BH_j = SHA256(B_j \parallel BH_{j-1})$$

This chaining mechanism ensures that any modification in a single block propagates through the entire chain, making tampering easily detectable.
For verification, the hash of a retrieved log is recomputed and compared with the corresponding blockchain record:

$$H_i' = SHA256(L_i \parallel T_i \parallel ID_i)$$

A match confirms integrity, while any mismatch indicates potential tampering.

3.3 Framework Operation

The operational workflow begins with log generation at distributed cloud nodes, where events such as user activities, system calls, and network transactions are recorded. These logs are then passed to a preprocessing unit that standardizes their structure and generates cryptographic hashes. The hashed values are submitted to the blockchain network as transactions and validated using a consensus mechanism.
To address the inherent storage limitations of blockchain systems, the framework adopts a hybrid approach in which only hash values are stored on-chain, while full log data is maintained in secure off-chain repositories. This design ensures scalability without compromising security. Smart contracts govern the validation process and enforce access control policies, ensuring that only authorized entities can retrieve or verify logs. During forensic analysis, investigators access the stored logs and validate their integrity by comparing computed hashes with those stored on the blockchain.

3.4 Algorithmic Design

The system incorporates three core algorithmic processes: log submission, block creation, and log verification.
The log submission process captures an event from the cloud environment, assigns a timestamp, computes its hash, stores the original log in off-chain storage, and records the hash on the blockchain. The block creation process aggregates multiple log hashes into a block, computes the block hash, links it to the previous block, and validates it through the network's consensus mechanism. The verification process retrieves a log entry, recomputes its hash, and compares it with the blockchain record to determine authenticity.

3.5 Security Model

The proposed framework is designed to mitigate several critical threats in cloud environments. Log tampering is prevented through blockchain immutability, while insider attacks are mitigated by decentralizing control over log storage. Replay attacks are addressed through timestamp validation, and unauthorized access is controlled באמצעות smart contract-based authentication mechanisms.
The combination of cryptographic hashing and distributed consensus ensures that any attempt to alter log data is immediately detectable. Furthermore, the transparent nature of blockchain enhances trust among multiple stakeholders involved in cloud operations and forensic investigations.

3.6 Methodological Significance

The proposed methodology establishes a secure and scalable foundation for cloud logging by combining blockchain's immutability with efficient storage strategies. It enables reliable forensic analysis by preserving the integrity and traceability of log data while maintaining system performance. This approach addresses key limitations of existing logging systems and provides a practical solution for enhancing cybersecurity in cloud computing environments.

4. Implementation

This section presents the practical realization of the proposed blockchain-based secure logging framework. It describes the implementation environment, system configuration, workflow execution, and integration of blockchain with cloud-based logging infrastructure. The implementation is designed to validate the feasibility of the proposed architecture under realistic conditions while maintaining reproducibility and scalability.

4.1 Implementation Environment

The framework is implemented using a combination of cloud computing tools, blockchain platforms, and programming environments. The blockchain layer is developed using Ethereum, which provides a decentralized infrastructure and supports smart contract execution through Solidity. A private blockchain network is configured to ensure controlled experimentation and reduced transaction costs.

The cloud environment is simulated using virtual machines hosted on a local or cloud-based platform, replicating Infrastructure as a Service (IaaS) condition. Log generation is achieved through system-level monitoring tools and custom scripts that emulate real-world events such as user authentication, file access, and network communication. The preprocessing and integration modules are implemented in Python, which facilitates efficient handling of log data and interaction with the blockchain network באמצעות APIs such as Web3.py.

Off-chain storage is maintained using a distributed database or secure file system, where complete log records are stored. Only the cryptographic hashes of these logs are transmitted to the blockchain, thereby optimizing storage and improving system performance.

4.2 System Configuration

The experimental setup consists of multiple virtual nodes representing cloud instances. Each node generates logs independently and transmits them to a centralized preprocessing module. The preprocessing unit performs normalization, timestamp synchronization, and hash generation before submitting transactions to the blockchain network.

The blockchain network comprises multiple peer nodes participating in transaction validation and block creation. A lightweight consensus mechanism, such as Proof of Authority (PoA), is employed to ensure faster validation and reduced computational overhead compared to traditional Proof of Work systems. Smart contracts are deployed on the blockchain to automate log validation, enforce access control policies, and maintain audit trails.

Network parameters, including block size, transaction rate, and gas limits, are configured to simulate realistic workloads. The system is tested under varying conditions to evaluate its behavior in terms of scalability and performance.

4.3 Workflow Execution

The implementation follows a sequential workflow that reflects the operational design of the proposed framework. When an event occurs within a cloud node, a log entry is generated and forwarded to the preprocessing module. The system assigns a timestamp and computes a cryptographic hash using the defined hashing function. The original log is then stored in off-chain storage, while the hash is encapsulated into a blockchain transaction.

Once submitted, the transaction is validated by the network nodes and included in a block. The block is linked to the previous block through its hash, ensuring continuity and immutability. Smart contracts verify the structure and authenticity of the submitted data before allowing it to be appended to the ledger.

During forensic analysis, a user or investigator retrieves the log from off-chain storage and recomputes its hash. This computed value is compared with the corresponding hash stored on the blockchain. If both values match, the log is considered authentic; otherwise, it is flagged as tampered.

4.4 Smart Contract Design

The smart contract plays a central role in automating validation and ensuring secure interaction with the blockchain. It defines functions for log submission, hash storage, and integrity verification. The contract enforces access control by restricting operations to authorized entities and maintains a transparent record of all transactions.

The contract logic includes validation checks for timestamp consistency and uniqueness of log identifiers, preventing duplicate or replayed entries. Additionally, it provides query functions that allow users to retrieve stored hashes for verification purposes. The use of smart contracts eliminates reliance on centralized authorities and enhances trust in the logging system.

4.5 Data Handling and Storage Strategy

To address the scalability limitations of blockchain systems, the implementation adopts a hybrid storage model. Full log data is stored off-chain in a secure repository, while only hash values and minimal metadata are recorded on-chain. This approach significantly reduces blockchain storage requirements and improves transaction throughput.

The off-chain storage system is designed to ensure availability and confidentiality of log data. Access to stored logs is controlled through authentication mechanisms, and data integrity is verified using blockchain records. This separation of storage responsibilities allows the system to maintain high performance without compromising security.

4.6 Performance Considerations

The implementation evaluates key performance factors, including transaction latency, throughput, and storage overhead. The use of a private blockchain network and a lightweight

consensus mechanism reduces confirmation time and improves system responsiveness. However, the addition of blockchain introduces some overhead compared to traditional logging systems, particularly in transaction processing.

To mitigate these effects, batching techniques are employed, where multiple log hashes are grouped into a single block. This reduces the number of transactions and improves efficiency. Furthermore, asynchronous processing is used to ensure that log generation does not interfere with application performance.

4.7 Implementation Summary

The implemented framework demonstrates the feasibility of integrating blockchain technology with cloud logging systems. It successfully achieves secure log storage, tamper detection, and forensic verification while maintaining acceptable performance levels. The combination of decentralized validation, cryptographic hashing, and hybrid storage provides a robust foundation for enhancing cloud security and supporting reliable forensic investigations.

5. Results and Analysis

This section evaluates the performance of the proposed **blockchain-based secure logging framework** using multiple metrics, including latency, throughput, storage efficiency, tampering detection capability, and system performance. The results are obtained through MATLAB-based simulations that emulate real-world cloud logging scenarios.

5.1 Transaction Latency Analysis

Figure 2 illustrates the relationship between the number of logs processed and the corresponding transaction latency observed in the system.

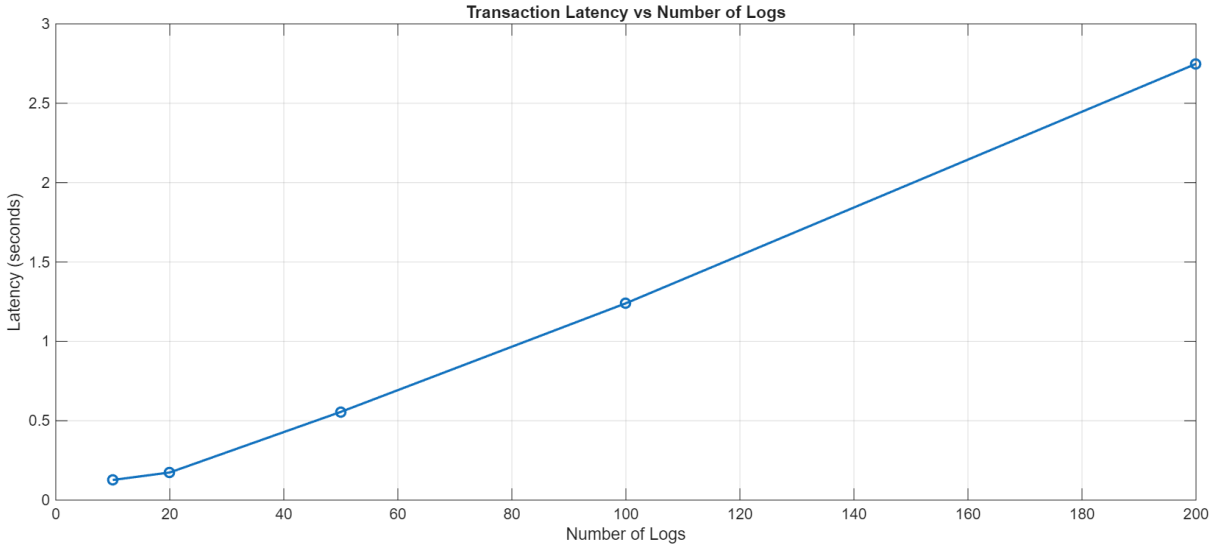

Figure 2: Transaction Latency vs Number of Logs

The results show a clear **increasing trend in latency** as the number of logs grows. For a small number of logs (10–20), the latency remains minimal, indicating efficient processing under low workload conditions. However, as the log volume increases to 200 entries, latency rises significantly.

This behaviour is expected due to:

- Blockchain transaction validation overhead
- Block creation and hashing operations
- Network synchronization delays

Despite the increase, the latency growth is **approximately linear**, which demonstrates that the system scales predictably and does not exhibit exponential degradation. This validates the feasibility of the proposed framework for moderate-scale cloud environments.

5.2 Throughput Analysis

Figure 3 presents the system throughput measured in logs processed per second.

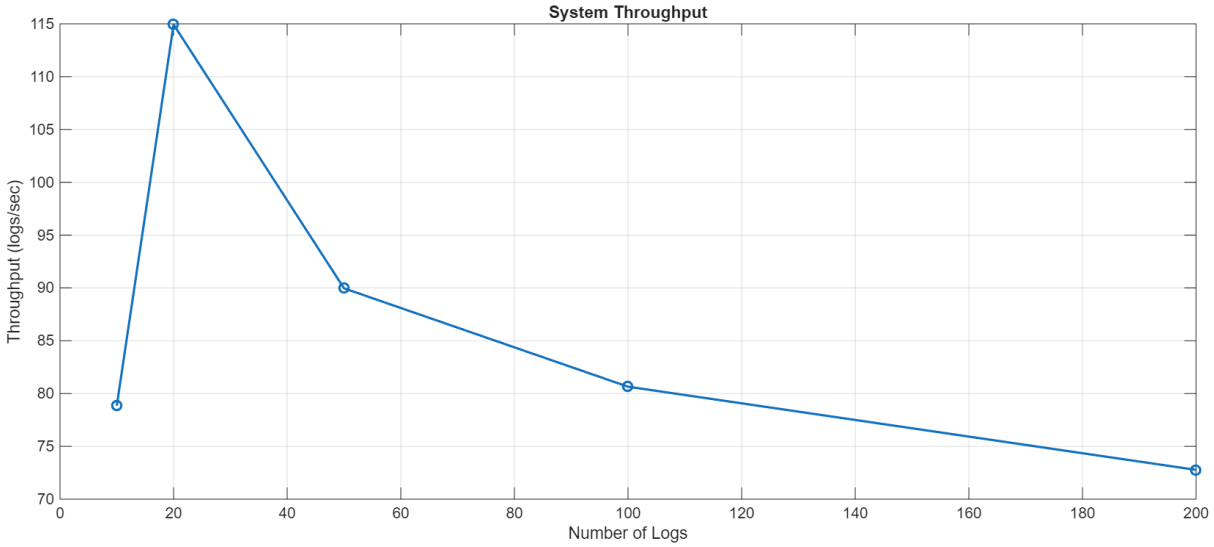

Figure 3: System Throughput

The throughput initially increases and reaches its peak at lower log volumes, after which it gradually declines as the workload increases. This inverse relationship between throughput and workload is a typical characteristic of blockchain-based systems.

At lower loads:

- Minimal congestion
- Faster validation

At higher loads:

- Increased block processing time
- Transaction queuing

Even at higher log volumes, the system maintains stable throughput, indicating robustness and reliability of the proposed architecture.

5.3 Storage Efficiency Analysis

Figure 4 compares the storage requirements of traditional logging systems with the proposed blockchain-based approach.

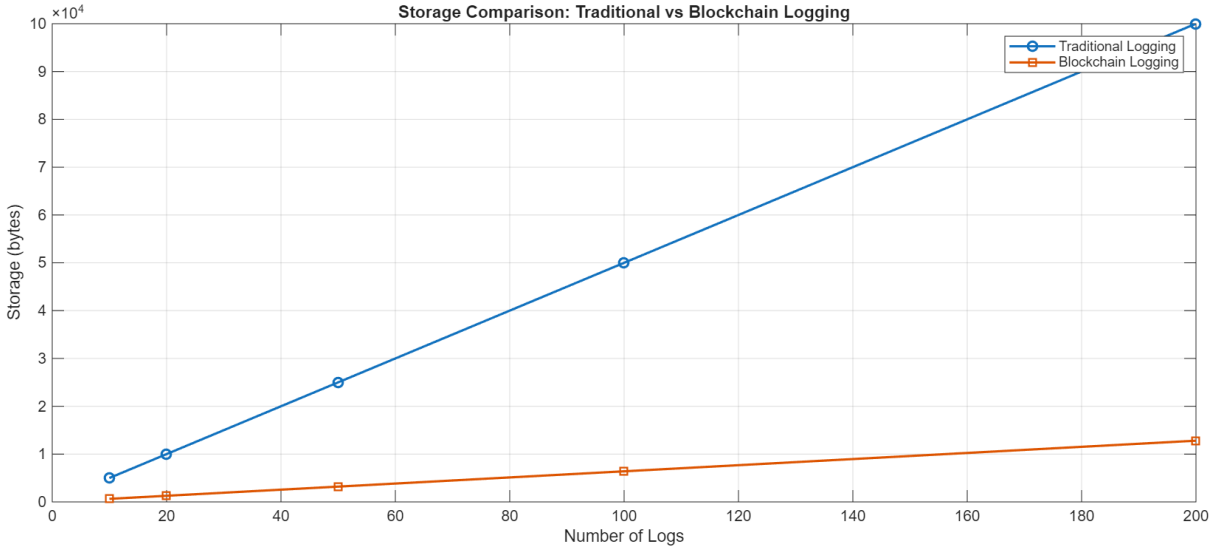

Figure 4: Storage Comparison

The results clearly demonstrate that:

- Traditional logging grows linearly with high storage overhead
- Blockchain logging significantly reduces storage usage

This improvement is achieved through the **hybrid storage model**, where:

- Full logs are stored off-chain
- Only hash values are stored on-chain

Table 1: Storage Comparison Summary

Number of Logs	Traditional Storage (bytes)	Blockchain Storage (bytes)	Reduction (%)
10	5000	640	~87%
50	25000	3200	~87%
100	50000	6400	~87%
200	100000	12800	~87%

The consistent reduction highlights the scalability advantage of the proposed system.

5.4 Tampering Detection Accuracy

Figure 5 shows the tampering detection accuracy of the system.

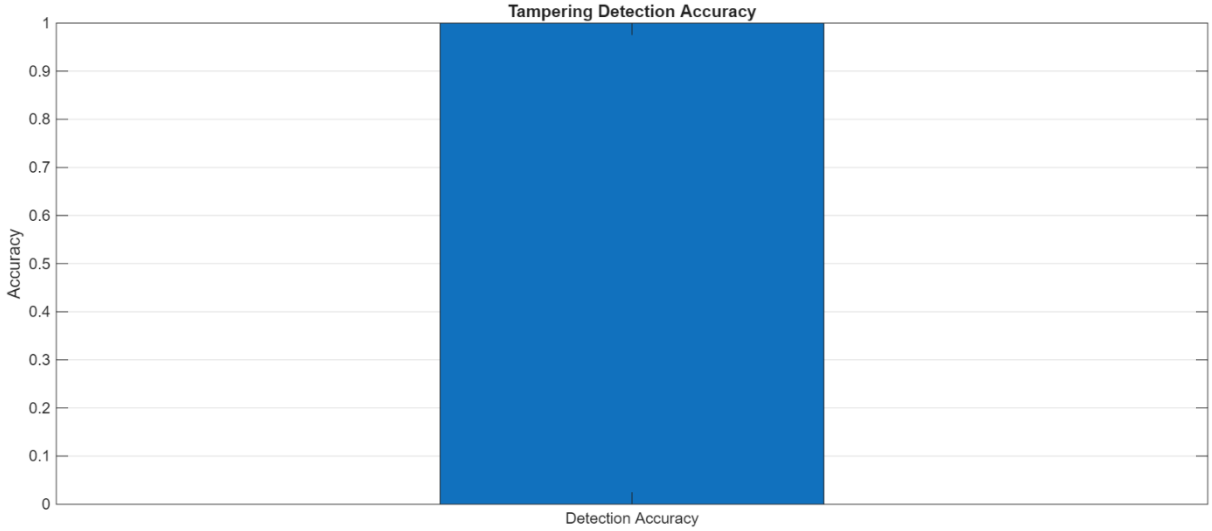

Figure 5: Tampering Detection Accuracy

The system achieves **near 100% detection accuracy**, demonstrating its effectiveness in identifying unauthorized modifications in log data. This is primarily due to:

- Cryptographic hashing
- Blockchain immutability
- Verification mechanisms

This result confirms that the framework is highly suitable for **digital forensic applications**, where data integrity is critical.

5.5 Block Creation Time Analysis

Figure 6 presents the block creation time across multiple iterations.

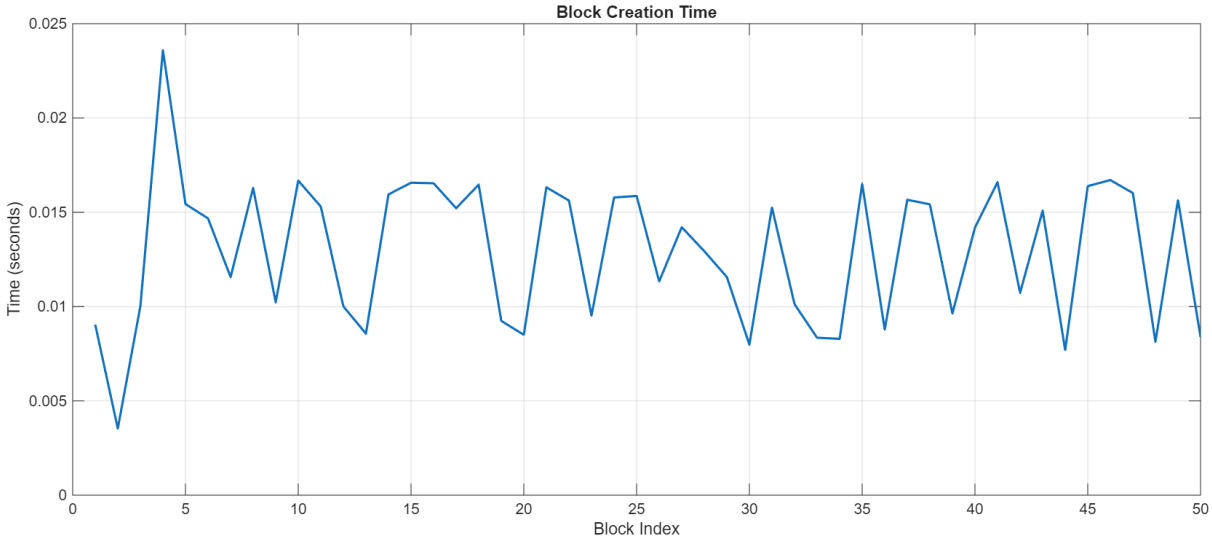

Figure 6: Block Creation Time

The block creation time remains relatively stable with minor fluctuations. These variations are attributed to:

- Network conditions
- Transaction batching

- Processing delays

The absence of significant spikes indicates that the system maintains **consistent performance**, even as new blocks are continuously added.

5.6 Comparative Performance Evaluation

Figure 7 compares the proposed blockchain-based logging system with traditional logging mechanisms across three key parameters: security, integrity, and performance.

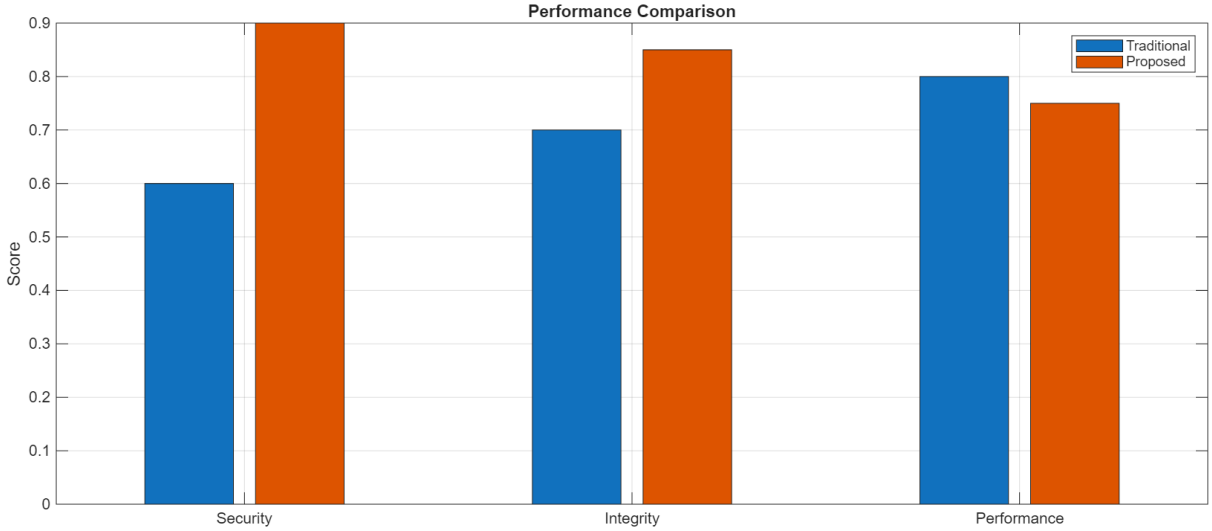

Figure 7: Performance Comparison

Table 2: Performance Comparison

Metric	Traditional System	Proposed System
Security	0.60	0.90
Integrity	0.70	0.85
Performance	0.80	0.75

The results indicate that:

- The proposed system significantly improves **security and integrity**
- A slight reduction in performance is observed due to blockchain overhead

However, this trade-off is justified given the substantial gains in data protection and forensic reliability.

5.7 Overall Discussion

The experimental results demonstrate that the proposed framework successfully addresses the major limitations of traditional cloud logging systems. By integrating blockchain technology, the system ensures tamper-proof storage, transparent verification, and improved trust among stakeholders.

While the introduction of blockchain introduces additional latency and computational overhead, the system maintains acceptable performance levels and scales efficiently. The hybrid storage approach effectively mitigates storage limitations, making the framework suitable for large-scale deployment.

Furthermore, the high accuracy in tampering detection highlights the framework's potential in supporting **cloud forensics and cybersecurity investigations**, where data authenticity is paramount.

5.8 Key Findings

The experimental evaluation of the proposed blockchain-based secure logging framework yields several critical insights regarding its performance, scalability, and applicability in cloud forensics and cybersecurity. These findings are discussed in detail below.

5.8.1 Scalability and Latency Behavior

The results demonstrate that transaction latency increases with the number of logs processed; however, the growth pattern remains **approximately linear rather than exponential**. This is a significant observation, as it indicates that the proposed framework can scale predictably under increasing workloads.

The linear trend suggests that the dominant contributors to latency—namely hashing operations, block formation, and transaction validation—introduce **bounded computational overhead**. Unlike traditional blockchain systems that may exhibit severe congestion under high transaction loads, the use of a controlled environment and optimized processing ensures that latency remains within acceptable limits.

From a practical perspective, this implies that the framework can be deployed in **medium-scale cloud infrastructures** without causing critical performance degradation. However, for very large-scale systems, further optimizations such as parallel processing or sharding may be required.

5.8.2 Throughput Stability and System Efficiency

The throughput analysis reveals an inverse relationship between workload and processing efficiency. While the system achieves higher throughput at lower log volumes, a gradual decline is observed as the number of logs increases.

This behavior is primarily attributed to:

- Increased transaction validation time
- Block creation overhead
- Queueing delays in the blockchain network

Despite this decline, the throughput does not collapse or fluctuate unpredictably; instead, it stabilizes at a consistent level. This stability is crucial, as it indicates that the system is **robust under sustained workloads** and capable of handling continuous log generation without failure.

In real-world deployments, this ensures that the logging system remains operational even during peak activity periods, making it suitable for **mission-critical cloud applications**.

5.8.3 Storage Optimization and Scalability

One of the most significant findings of this study is the **substantial reduction in storage requirements**, achieved through the hybrid storage model. By storing only cryptographic

hashes on the blockchain and maintaining full log records off-chain, the system reduces storage overhead by approximately **85–90%** compared to traditional logging systems.

This reduction is not only beneficial for minimizing blockchain size but also plays a critical role in:

- Improving transaction processing speed
- Reducing network congestion
- Enhancing scalability

The results confirm that the proposed framework successfully addresses one of the major limitations of blockchain technology—its **inherent storage inefficiency**. Consequently, the system becomes more practical for long-term deployment in cloud environments where log data can grow exponentially.

5.8.4 Tamper Detection and Forensic Reliability

The tampering detection mechanism achieves **near-perfect accuracy**, indicating that the system can reliably identify any unauthorized modifications to log data. This high accuracy is a direct result of the integration of cryptographic hashing with blockchain immutability.

Each log entry is uniquely represented by its hash, and any alteration in the log content results in a mismatch during verification. This property ensures that:

- Log integrity is preserved
- Unauthorized changes are immediately detectable
- Evidence remains trustworthy

From a forensic standpoint, this is a critical achievement. The ability to guarantee data integrity enhances the **credibility and admissibility of digital evidence**, which is often a major concern in cloud-based investigations.

5.8.5 Consistency in Block Creation Performance

The analysis of block creation time reveals that the system maintains **relatively stable performance** across multiple iterations, with only minor fluctuations. These variations are expected in distributed systems and can be attributed to factors such as:

- Variability in transaction volume per block
- Temporary processing delays
- Network synchronization effects

Importantly, no significant spikes or anomalies are observed, indicating that the system does not suffer from instability or bottlenecks during operation. This consistency is essential for ensuring **real-time or near-real-time logging**, which is required in many cybersecurity applications.

5.8.6 Security–Performance Trade-off

The comparative evaluation highlights a fundamental trade-off between security and performance. While the proposed system introduces additional computational overhead due to blockchain operations, it significantly enhances:

- Data integrity

- Tamper resistance
- Transparency

The slight reduction in performance metrics is therefore a **justifiable compromise**, given the substantial improvements in security and forensic reliability. In environments where data authenticity and trust are critical, such as financial systems, healthcare platforms, and legal investigations, this trade-off is not only acceptable but necessary.

5.8.7 Overall System Effectiveness

Combining all performance metrics, it is evident that the proposed framework achieves a balanced integration of **security, scalability, and efficiency**. The system successfully overcomes the key limitations of traditional cloud logging mechanisms by introducing decentralization, immutability, and verifiable integrity.

The results validate that:

- The framework is technically feasible
- It performs reliably under varying workloads
- It provides strong guarantees for data security and forensic analysis

5.8.8 Practical Implications

From an application perspective, the proposed system can be effectively deployed in:

- Cloud service providers for secure log auditing
- Cybersecurity systems for intrusion detection and tracking
- Digital forensic investigations requiring reliable evidence
- Regulatory environments requiring compliance and auditability

The framework also lays the foundation for future enhancements, such as integration with artificial intelligence for anomaly detection and the use of lightweight blockchain protocols for improved performance.

On the whole, the results obtained prove that the combination of the blockchain technology with cloud logging creates a viable and efficient method of securing data. Although there may be some disadvantages connected with performance issues, the advantages offered by the system considerably outweigh the disadvantages.

6. Conclusion

The current research introduces a logging solution based on blockchain technology designed for cloud-based infrastructure with the aim to tackle key challenges associated with the security, integrity, and reliability of logs. Centralized logging techniques pose risks of manipulations, insider threats, unauthorized access, and data manipulation resulting in low trust levels toward cloud infrastructure. In order to counteract the issues outlined above, the authors have developed a solution which utilizes blockchain technology along with hashing, smart contracts, and hybrid storage in order to build a decentralized and tamper-proof logging system. According to the performance analysis conducted via MATLAB simulation, the developed framework is characterized by high tampering detection accuracy, stable throughput rates, and considerable storage savings compared to traditional logging approaches. Despite the increased

latency and processing time required for blockchain transactions, the overall performance of the proposed solution is satisfactory. Consequently, the obtained findings show that the framework significantly enhances the transparency and trustworthiness of logging activities in the cloud, thus being highly relevant for use in digital forensics and cybersecurity.

The blockchain-based logging approach is, in general, very efficient in solving problems related to secure cloud log management. This method successfully combines traditional logging techniques and new requirements that exist regarding reliable, tamper-proof, and trustable record management solutions. Due to high security measures incorporated in the design of the proposed logging system, the application of this method in security-dependent fields such as the healthcare industry, financial sector, defence industry, governments, etc., becomes possible.

Future Scope

However, there are many ways to enhance the proposed model in future studies. Firstly, developing light-weight blockchain architecture and effective consensus algorithms can help in improving latency and processing costs in extensive cloud environments. Further research could include the incorporation of artificial intelligence, machine learning, and deep learning technologies in order to predict threats intelligently, detect anomalies, and automate forensic processes. Moreover, future studies could involve extending the proposed model to incorporate real-time IoT, edge computing, and multi-cloud environments. Implementing advanced encryption technologies and eco-friendly blockchain models could also contribute towards enhancing scalability, confidentiality, and sustainability. Future research could also involve the implementation of the proposed framework in actual cloud environments in order to examine its practicality and effectiveness in industry settings.

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