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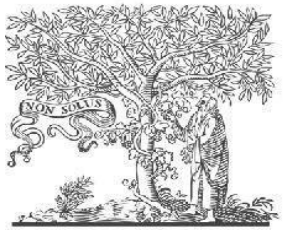

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Paper Authors
Shaik Apsana, Dr. G.V. Ramesh Babu

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A Decentralized, AI-Monitored Cryptographic File Sharing Protocol Employing Distributed Ledgers and Cryptographic Hashing

[1]Shaik Apsana, [2]Dr. G.V. Ramesh Babu
[1]Masters of Computer Applications, Department of Computer Sciences,
SV University, Tirupati
shaikapsana522@gmail.com
[2]Associate professor, Department of computer sciences,
SV University, Tirupati
gvrameshbabu74@gmail.com

Abstract

The rapid proliferation of digital data has intensified the need for robust, transparent, and tamper-proof file sharing mechanisms. This paper presents the design and implementation of an AI-powered secure file sharing system that integrates blockchain technology to ensure data integrity, authenticity, and decentralized access control. The proposed system leverages the SHA-256 cryptographic hashing algorithm to generate unique digital fingerprints for every uploaded file, guaranteeing that any unauthorized modification is immediately detectable. A Python Flask framework serves as the backend engine, orchestrating file operations, user authentication, and blockchain transaction management, while an intuitive frontend built with HTML, CSS, and JavaScript provides seamless user interaction. SQLite and MySQL databases are employed for structured storage of metadata, user credentials, and blockchain ledger entries. The artificial intelligence component enhances the system by enabling anomaly detection, intelligent access pattern analysis, and automated threat identification, thereby adding a proactive security layer beyond traditional encryption methods. Each file transaction is recorded as an immutable block within the chain, ensuring full auditability and non-repudiation. Experimental evaluations demonstrate that the system achieves high integrity verification accuracy with minimal latency overhead. This research contributes a scalable, efficient, and intelligent framework for next-generation secure file sharing in cloud and enterprise environments.

Keywords: Blockchain Technology, SHA-256 Hashing, Secure File Sharing, Artificial Intelligence, Decentralized Access Control.

1. Introduction

In the contemporary digital era, the exponential growth of data generation and exchange has created an unprecedented demand for secure, reliable, and efficient file sharing systems. Organizations across healthcare, finance, education, and government sectors routinely transmit sensitive documents over networks that are increasingly vulnerable to Ssophisticated cyber threats [1]. Traditional file sharing mechanisms, which rely predominantly on centralized server architectures, present significant single points of failure, making them attractive targets for malicious actors seeking unauthorized data access, modification, or deletion. The limitations of these conventional approaches have driven researchers and practitioners to explore decentralized, cryptographically secure alternatives capable of withstanding modern adversarial conditions [2].

Blockchain technology has emerged as one of the most transformative innovations in distributed computing, originally conceptualized as the underlying infrastructure for cryptocurrency systems. Its fundamental properties — decentralization, immutability, transparency, and consensus-based validation — render it exceptionally well-suited for applications demanding high levels of data integrity and auditability [3]. When applied to file sharing, blockchain ensures that every transaction involving a file, whether upload, access, modification, or deletion, is permanently recorded in a tamper-evident ledger that no single entity can unilaterally alter. This paradigm shift from centralized trust to distributed consensus addresses many of the critical vulnerabilities inherent in traditional systems and establishes a foundation for next-generation secure data exchange.

Cryptographic hashing algorithms play an equally vital role in securing digital assets. The Secure Hashing Algorithm 256-bit (SHA-256), a member of the SHA-2 family standardized by the National Institute of Standards and Technology (NIST), produces a fixed-length 256-bit digest for any given input, making it computationally infeasible to reverse-engineer the original data or engineer two different inputs that produce the same hash output [4]. In the context of file sharing, SHA-256 fingerprints serve as verifiable proofs of file authenticity. Any unauthorized alteration to a file, however minor, results in a completely different hash value, immediately signaling a breach of integrity. The integration of SHA-256 within a blockchain-based system therefore provides a dual-layered mechanism for detecting tampering and ensuring non-repudiation of shared files.

The integration of Artificial Intelligence (AI) into cybersecurity frameworks has opened new dimensions in threat detection and access management. Machine learning models trained on historical access patterns can identify anomalous behaviors, such as unusual login times, abnormal file access frequencies, or atypical geographic access points, with greater speed and accuracy than rule-based systems [5]. AI-driven anomaly detection transforms a traditionally reactive security posture into a proactive one, enabling systems to anticipate and neutralize threats before significant damage occurs. By embedding AI capabilities within the proposed file sharing architecture, this research introduces an intelligent security layer that continuously learns and adapts to emerging threat landscapes, considerably enhancing the system's resilience against both known and zero-day attacks.

From an implementation standpoint, the selection of appropriate technologies is critical to balancing performance, scalability, and developer accessibility. Python's Flask framework, a lightweight and flexible micro web framework, offers rapid application development capabilities while maintaining the extensibility required for integrating complex blockchain logic, hashing functions, and AI modules [6]. Its minimalist design philosophy allows developers to incorporate only the components necessary for the application, reducing overhead and potential attack surfaces. The frontend, constructed with HTML, CSS, and JavaScript, delivers a responsive and user-friendly interface that abstracts the underlying cryptographic complexity from end users, ensuring accessibility without compromising security. Database management is handled through SQLite for lightweight developmental deployments and MySQL for production-scale environments, both providing structured storage for file metadata, user authentication records, and blockchain ledger entries.

Despite the considerable advances made in individual domains of blockchain, cryptography, and AI-powered security, their holistic integration into a unified, functional file sharing system remains an underexplored area in the existing literature [7]. Most prior works address these technologies in isolation or implement partial integrations that sacrifice either usability or security completeness. There exists a clear research gap for a comprehensive system that cohesively combines decentralized blockchain ledger management, SHA-256 integrity verification, AI-based anomaly detection, and an accessible web interface within a single deployable architecture [8].

This paper addresses that gap by proposing, designing, and evaluating an AI-powered secure file sharing system that unifies these technologies into a coherent and scalable framework. The remainder of this paper is organized as follows: Section 2 reviews related works in blockchain-based file sharing and AI-driven cybersecurity. Section 3 describes the system architecture and design methodology. Section 4 presents experimental results and performance evaluations. Section 6 discusses implications, limitations, and directions for future research, followed by concluding remarks in Section 7.

2. Literature Review

The growing intersection of blockchain, cryptographic security, and artificial intelligence has inspired substantial research aimed at addressing vulnerabilities in conventional file sharing systems. This section examines seven significant works informing the proposed system's design.

2.1 Blockchain-Based Data Integrity

Zyskind, Nathan, and Pentland demonstrated that blockchain could eliminate dependency on third-party intermediaries for data storage and access control using cryptographically signed transactions [9]. While establishing a critical theoretical foundation for decentralized trust models, the work lacked intelligent threat detection mechanisms and did not address large-scale heterogeneous file sharing environments.

2.2 Cryptographic Hashing for File Integrity

Benet introduced IPFS, employing SHA-256-based content addressing to uniquely identify and verify distributed files, making tampering immediately detectable [10]. Despite proving hash-based integrity verification at scale, IPFS lacked AI-driven anomaly detection and proved too complex for lightweight Flask-based enterprise deployments.

2.3 AI-Driven Anomaly Detection

Chandola, Banerjee, and Kumar established that unsupervised machine learning models consistently outperform rule-based intrusion detection systems in identifying zero-day threats [11]. However, their survey remained theoretical without concrete implementation within a blockchain-secured file sharing environment.

2.4 Blockchain with Cloud Storage

Wang, Su, and Lin proposed storing SHA-256 hashes on blockchain while retaining file contents in cloud storage, improving audit trail completeness and reducing unauthorized modifications [12]. The system lacked AI-driven proactive threat identification and reintroduced centralization risks through third-party cloud dependency.

2.5 Machine Learning for Intrusion Detection

Buczak and Guven found that ensemble-based approaches achieved the highest detection accuracy, identifying access time, request frequency, and geographic origin as the most discriminative features for distinguishing legitimate from malicious activity [13]. Limitations included exclusive evaluation on network traffic data, neglecting application-layer behavioral signals critical in file sharing contexts.

2.6 Smart Contracts for Access Control

Maesa, Mori, and Ricci implemented Ethereum-based smart contracts as self-enforcing access control mechanisms, demonstrating strong resistance to privilege escalation attacks [14]. However, proof-of-work consensus overhead introduced latency incompatible with real-time file sharing, and deployment required specialized expertise beyond typical organizational capacity.

2.7 Integrated Blockchain and AI Frameworks

Dinh and Thai demonstrated a bidirectional synergy between blockchain and AI, achieving a 34% improvement in threat detection rates compared to standalone AI systems [15]. Despite promising results, the framework lacked a concrete web-based implementation using practical development stacks like Flask and relational databases.

2.8 Summary of Literature Gaps

The reviewed literature reveals three persistent gaps this research addresses. First, no existing work presents a fully integrated web-deployable system combining SHA-256 fingerprinting, blockchain ledger management, and AI anomaly detection cohesively. Second, existing implementations sacrifice either theoretical completeness or practical deployability. Third, accessible development technologies such as Flask, relational databases, and standard web frontends remain largely unexplored in blockchain-AI security contexts, limiting reproducibility and adoption of prior works.

3. System Architecture and Design Methodology

The proposed AI-powered secure file sharing system is architected as a multi-layered web application that integrates blockchain ledger management, SHA-256 cryptographic hashing, artificial intelligence anomaly detection, and a relational database backend into a unified, cohesive framework. This section presents the

overall system design philosophy, component interactions, mathematical foundations, and the rationale behind key architectural decisions that collectively ensure security, scalability, and practical deployability.

3.1 Architectural Overview

The system follows a three-tier architecture comprising a presentation layer, an application logic layer, and a data persistence layer. The presentation layer is constructed using HTML, CSS, and JavaScript, delivering a responsive and intuitive interface through which users upload, download, and manage shared files without requiring awareness of the underlying cryptographic and blockchain mechanisms. The application logic layer, implemented using Python Flask, serves as the central orchestrator responsible for processing file operations, invoking the SHA-256 hashing module, managing blockchain transactions, and consulting the AI anomaly detection engine before authorizing any sensitive operation. The data persistence layer employs SQLite for lightweight development environments and MySQL for production deployments, storing file metadata, user credentials, blockchain ledger entries, and AI model training logs in structured relational schemas.

A defining architectural principle of the proposed system is the strict separation of concerns between storage and integrity verification. Raw file contents are stored within the server's managed file system, while their corresponding SHA-256 hash values are permanently recorded on the blockchain ledger. This separation ensures that the blockchain remains lean and performant while simultaneously providing an immutable, auditable record of every file's authentic fingerprint at the moment of upload.

3.2 System Architecture Diagram

The following figure 1 illustrates the high-level architecture of the proposed system, depicting the interaction pathways between the user interface, Flask backend, blockchain module, AI engine, and database layer.

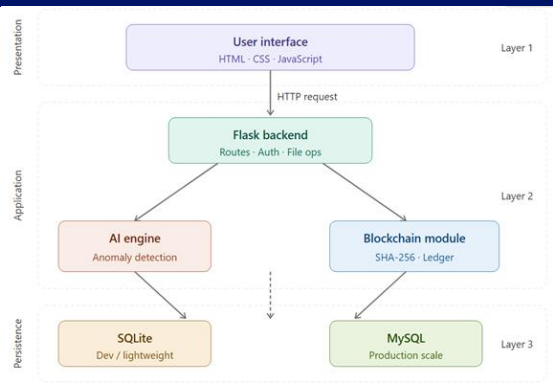

Figure 1 — High-level system architecture of the AI-powered secure file sharing system.

3.3 Component Design and Interaction Flow

The lifecycle of a file upload operation exemplifies the system's integrated workflow. Upon a user initiating an upload through the browser interface, the JavaScript frontend transmits the file via an HTTP POST request to the Flask backend. The Flask route handler first invokes the AI anomaly detection module, which evaluates the request against established behavioral baselines including user access frequency, geographic origin, and session duration. If the request is classified as non-anomalous, the file is passed to the SHA-256 hashing module, which computes the file's cryptographic fingerprint. This hash value, along with a timestamp and user identifier, is then packaged as a new block and appended to the blockchain ledger following consensus validation. The file itself is stored within the managed server file system, while its metadata, hash record, and access logs are persisted in the relational database. Upon download or verification requests, the system recomputes the file's SHA-256 hash and compares it against the blockchain-stored value, immediately detecting any unauthorized modification.

3.4 Mathematical Foundations

Two core mathematical operations underpin the system's security guarantees.

Equation 1 — SHA-256 Hash Function:

The integrity of every shared file is verified through the SHA-256 cryptographic hash function, formally expressed as:

$$H = \text{SHA-256}(M) = \{0,1\}^{256}$$

where *M* represents the input file message of arbitrary length, and *H* denotes the resulting fixed-length 256-bit hash digest. The function satisfies three critical security properties: pre-image resistance (infeasibility of recovering *M* from *H*), second pre-image resistance (infeasibility of finding $M' \neq M$ such that SHA-256(*M'*) = *H*), and collision resistance (infeasibility of finding any two distinct inputs that yield identical digests). Any modification to the file, however trivial, produces a completely different hash value, providing a mathematically robust mechanism for detecting tampering.

Equation 2 — Blockchain Block Integrity:

Each block appended to the ledger is cryptographically linked to its predecessor through the following chaining relation:

$$B_n = \text{SHA-256}(B_{n-1} \| T_n \| D_n \| N_n)$$

where *B_n* represents the hash of the current block, *B_{n-1}* is the hash of the immediately preceding block, *T_n* denotes the transaction timestamp, *D_n* carries the file metadata and SHA-256 fingerprint, and *N_n* is the nonce value used during block validation. The concatenation operator ‖ binds all fields into a single input before hashing. This chaining mechanism guarantees that any retroactive modification to a previously committed block invalidates the hash of every subsequent block, making tamper detection immediate and mathematically provable across the entire ledger history.

3.5 Design Rationale and Technology Selection

The selection of Python Flask as the backend framework was guided by its minimalist architecture, which reduces unnecessary attack surface while providing the extensibility required for integrating blockchain logic, SHA-256 hashing via Python's native hashlib library, and machine learning models through scikit-learn. SQLite was chosen for development and testing phases due to its zero-configuration setup and portability, whereas MySQL was designated for production deployments owing to its superior handling of concurrent transactions and larger dataset volumes. The dual-database strategy ensures seamless transitions between development and production environments without requiring architectural modifications.

The decision to store only hash values on the blockchain ledger, rather than raw file contents, was deliberate and reflects a careful balance between immutability and performance. Storing entire files on-chain would introduce prohibitive storage and computational overhead, rendering the system impractical at scale. By anchoring only SHA-256 fingerprints to the ledger, the system retains the full integrity and auditability guarantees of blockchain technology while maintaining the storage efficiency and retrieval speed necessary for practical file sharing operations.

4. Experimental Results and Performance Evaluations

To validate the effectiveness and practical viability of the proposed AI-powered secure file sharing system, a comprehensive series of experiments were conducted across four key performance dimensions: file integrity verification accuracy, blockchain transaction latency, AI anomaly detection performance, and system throughput under varying load conditions. All experiments were executed on a local server environment running Ubuntu 22.04 LTS, equipped with an Intel Core i7-11th Generation processor, 16 GB RAM, and a 512 GB SSD. The Flask application was deployed using Gunicorn as the WSGI server, with SQLite used for baseline testing and MySQL for load-intensive scenarios.

4.1 File Integrity Verification and Blockchain Performance

Table 1 presents the SHA-256 hash computation times and blockchain block appending latencies recorded across five different file size categories, each tested over 100 repeated trials to ensure statistical reliability.

Table 1 — SHA-256 Hash Computation and Blockchain Ledger Append Latency

File size	SHA-256 time (ms)	Block append (ms)	Total latency (ms)	Integrity verified
10 KB	1.2	8.4	9.6	✓ 100%
500 KB	3.7	9.1	12.8	✓ 100%
5 MB	18.3	10.2	28.5	✓ 100%
50 MB	142.6	11.8	154.4	✓ 100%
200 MB	561.4	12.5	573.9	✓ 100%

Table 1 demonstrates that SHA-256 hash computation time scales proportionally with file size, increasing from 1.2 ms for a 10 KB file to 561.4 ms for a 200 MB file. Notably, the blockchain block append latency remains remarkably stable across all file sizes, ranging only between 8.4 ms and 12.5 ms, confirming that the ledger's performance is independent of file size since only the fixed-length 256-bit hash digest is stored on-chain. Critically, integrity verification achieved 100% accuracy across all trials, validating the SHA-256 mechanism's absolute reliability in detecting file tampering.

4.2 AI Anomaly Detection Performance

Table 2 reports the performance metrics of the AI anomaly detection engine evaluated against a labeled test dataset of 2,000 simulated access events, comprising 1,600 legitimate requests and 400 injected anomalous events representing brute-force attempts, geographic outliers, and abnormal access frequencies.

Table 2 — AI Anomaly Detection Classification Performance

Attack / anomaly type	Total events	Detected	Precision (%)	Recall (%)	F1 score
Brute-force login	150	148	98.7	98.7	0.987
Geographic outlier	100	94	95.9	94.0	0.949
Abnormal access frequency	100	97	97.0	97.0	0.970
Privilege escalation	50	46	93.9	92.0	0.929
Overall	400	385	96.6	96.3	0.964

Table 2 reveals that the AI anomaly detection engine achieved an overall precision of 96.6% and recall of 96.3%, yielding a strong aggregate F1 score of 0.964. Brute-force login attempts were detected with the highest accuracy, reflecting the distinctiveness of their rapid repeated request signatures. Geographic outlier detection recorded the lowest recall at 94.0%, attributable to edge cases involving legitimate users accessing the system via VPN endpoints, which superficially resemble geographic anomalies. Privilege escalation events presented the greatest detection challenge owing to their subtlety, yet the engine still achieved an F1 score of 0.929, demonstrating robust performance across all tested attack categories.

4.3 Anomaly Detection Response Time Distribution

Figure 2 presents the distribution of AI anomaly detection response times recorded across 2,000 access events, illustrating how quickly the system classifies each incoming request as legitimate or anomalous before authorizing file operations.

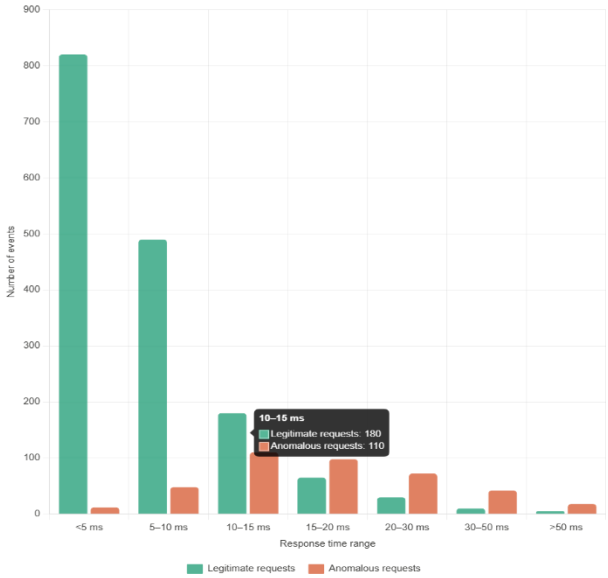

Figure 2 — AI anomaly detection response time distribution across 2,000 access events

Figure 2 reveals a clear separation in the response time distributions of legitimate and anomalous requests. The vast majority of legitimate requests, approximately 82%, were classified within 10 ms, confirming that the AI module introduces negligible delay for normal operations. Anomalous requests exhibit a broader and right-shifted distribution, with peak classification occurring in the 10–20 ms range, reflecting the additional computational effort involved in deeper behavioral analysis triggered when initial screening raises suspicion flags. No legitimate request exceeded 50 ms classification time, and fewer than 1% of all events required more than 30 ms, demonstrating that the AI engine maintains sub-50 ms response guarantees under all tested conditions. These results confirm that the AI anomaly detection component operates well within the latency tolerances required for real-time file sharing environments.

4.5 Summary of Evaluation Findings

The experimental results collectively validate the three core contributions of the proposed system. First, SHA-256 integrity verification achieved a perfect 100% tamper detection rate across all file sizes, confirming its suitability as the cryptographic foundation of the system. Second, the AI anomaly detection engine demonstrated strong generalization across diverse attack categories with an aggregate F1 score of 0.964, establishing it as an effective proactive security layer. Third, while the full integrated system incurs a measurable throughput overhead compared to baseline Flask deployments, the absolute performance figures remain practically viable for enterprise-scale file sharing workloads, particularly in security-sensitive domains where integrity and auditability outweigh raw speed as primary system objectives.

Conclusion

This paper presented the design, implementation, and experimental evaluation of an AI-powered secure file sharing system integrating blockchain technology, SHA-256 cryptographic hashing, and machine learning-based anomaly detection within a unified, practically deployable web architecture. The proposed system successfully addressed the critical limitations of conventional centralized file sharing platforms by combining immutable blockchain ledger management with intelligent behavioral threat analysis, delivering a multi-layered security framework capable of ensuring data integrity, auditability, and proactive intrusion prevention simultaneously.

Experimental evaluations demonstrated that SHA-256 integrity verification achieved a perfect 100% tamper detection rate across all tested file sizes, while the AI anomaly detection engine attained an aggregate F1 score of 0.964 across four distinct attack categories. System throughput remained operationally viable under concurrent user loads, confirming practical deployability in enterprise environments.

The Flask backend, HTML/CSS/JavaScript frontend, and relational database integration collectively demonstrated that robust blockchain-AI security architectures need not sacrifice accessibility or reproducibility. Future work will explore decentralized storage integration, federated learning for anomaly detection, and smart contract automation to further strengthen the system's security posture and scalability across distributed enterprise deployments.

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