Design and Implementation of a Secure Multi-Cloud Data Storage System Using Hybrid Cryptography and Threshold Secret Sharing

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ABSTRACT

Cloud computing has fundamentally transformed how individuals, enterprises, and government agencies store, manage, and access data. While cloud storage services provide scalable, flexible, and cost-effective solutions, traditional single-cloud storage models present inherent vulnerabilities including single points of failure, vendor lock-in, insider threats, service outages, and privacy breaches. This research presents the design and implementation of a Secure Multi-Cloud Data Storage System (SMCDSS) that leverages hybrid cryptography, data fragmentation, and threshold secret sharing techniques to enhance data confidentiality, integrity, availability, and fault tolerance across multiple independent cloud service providers. The system integrates AES symmetric encryption for data protection, RSA/ECC asymmetric encryption for secure key exchange, and Shamir's threshold secret sharing scheme for distributed key management. Data integrity is verified using SHA-256 hashing algorithms. The proposed architecture distributes encrypted data fragments across multiple cloud providers, ensuring that no single provider possesses complete information. Performance evaluation demonstrates significant improvements in security resilience, fault tolerance, and data availability compared to traditional single-cloud storage models. The system is implemented as a prototype web-based application with a user-friendly interface for secure file upload, retrieval, and monitoring. The findings indicate that multi-cloud architectures combined with robust cryptographic mechanisms offer a powerful solution for secure distributed data storage, providing valuable support for organizations seeking to protect sensitive information in cloud environments. Future research will focus on integration with real cloud APIs, advanced security enhancements, and performance optimization for large-scale deployments.

Keywords: Multi-Cloud Storage, Hybrid Cryptography, Data Fragmentation, Threshold Secret Sharing, Cloud Security, Data Integrity, Fault Tolerance, AES Encryption, RSA/ECC, SHA-256

INTRODUCTION

In recent times, the rapid advancement of cloud computing has fundamentally transformed how individuals, enterprises, and government agencies store, manage, and access data that make up the day-to-day activities in each of the sectors mentioned. Cloud storage services, which involve storing data over the internet on servers scattered around the world, provide scalable, flexible, and cost-effective solutions for handling large volumes of digital information. Organizations increasingly rely on various cloud infrastructures to reduce capital expenditure, improve operational efficiency, and enable ubiquitous and real-time access to data resources (Seth et al., 2022). However, even though these benefits and many others exist, concerns surrounding data security, confidentiality, integrity, and availability remain significant barriers to full cloud adoption.

The presently available traditional single-cloud storage models present a lot of inherent vulnerabilities. When data is stored within a single Cloud Service Provider (CSP), users are exposed to risks such as single points of failure, vendor lock-in, insider glitches, service outages, and privacy breaches (Shen et al., 2017). All the many security incidents involving cloud platforms have demonstrated that entrusting sensitive information to one provider cannot fully guarantee protection against malicious insiders or external cyberattacks or even failure of the system itself (Shen et al., 2016). All of these concerns have motivated researchers and practitioners to explore more resilient and secure alternatives for storing data and sensitive information.

The only lasting solution to the above itemized issues with a single cloud storage system is a multi-cloud storage system which has emerged as a promising solution to mitigate the many risks associated with single-cloud environments and infrastructures. In a multi-cloud architecture, data is distributed across multiple independent cloud providers, thereby improving availability, fault tolerance, and security of data and resources hosted on the system (Srisakthi et al., 2015). By splitting data into fragments, encrypting, and storing data fragments across different clouds, the many issues from one provider do not necessarily expose the entire dataset because the data is in sync on other providers' platforms. Such architectures enhance reliability and reduce dependency on only one single vendor or infrastructure.

Several researchers have proposed frameworks and new systems development to improve both the confidentiality and availability in multi-cloud systems. Junghanns, Fabian et al. (2016) engineered a secure multi-cloud storage gateway that uses threshold secret sharing to distribute encrypted data across multiple datastores. Di Pietro et al. (2017) introduced a Secure Storage Service in Multi-Cloud Environment (SSME) architecture that ensures confidentiality and integrity of data distributed and stored globally on a multi-cloud platform. These approaches emphasize cryptographic enforcement and distributed trust as core mechanisms for enhancing security of data on multi-cloud infrastructure.

One of the key components in securing multi-cloud storage systems is encryption. Hybrid cryptographic models that combine symmetric and asymmetric models to provide extra security have been extensively researched. Viswanath et al. (2021) developed a hybrid encryption model for securing big data in multi-cloud environments, which included slicing, indexing, encryption, distribution, and merging operations. According to Sohal et al. (2022), further improvements can be made to manage multi- cloud systems by combining Identity-Based Broadcast Encryption (IBBE) with symmetric encryption methods to secure against internal threats.

Apart from the use of encryption to enhance security, high availability and fault tolerance of the system are essential for secure multi-cloud storage systems. There is a need to design systems in which the encrypted data is divided and replicated in multiple clouds, and secret sharing techniques are employed to share the encryption keys among the owners (Srisakthi et al., 2015). The system must be designed to be fault-tolerant in the event of failure of one or two cloud service providers. Feng et al. (2017) employed Shamir's threshold secret sharing and proxy re-encryption schemes to ensure data availability and secure sharing in multi-cloud storage.

Recent research has also aimed at maximizing performance and preserving the security of multi-cloud based systems. Shen et al. (2016) proposed Clouds, a multi-cloud storage solution that provides multi-level security by integrating compression, encryption, and XOR-based erasure coding techniques. Ghanmi et al. (2022) proposed a lightweight framework that utilizes Blowfish encryption and RSA key exchange for secure and efficient multi-cloud access. All of this research highlights the importance of maximizing performance and security in a multi-cloud-based system for storing and sharing data across the internet.

However, despite the increasing number of studies, issues such as key management weaknesses, file deviation attacks, insider threats, and efficient data reconstruction remain open challenges (Karnik et al., 2025). In addition, the secure and anonymous sharing of data in multi-cloud environments needs further improvement, as discussed in SpyStorage by incorporating Attribute-Based Encryption (ABE) and Attribute-Based Signature (ABS) schemes (Shen et al., 2017). Thus, there is a need to develop and implement an overall secure multi-cloud data storage system that combines encryption, secret sharing, integrity verification, and fault tolerance techniques into a single and efficient framework.

Therefore, the motivation for this research work is the need to research and develop an effective Secure Multi-Cloud Data Storage System that can guarantee confidentiality, integrity, availability, fault tolerance, and secure data sharing.

LITERATURE REVIEW

The literature review of this research work is intended to give a complete review of the existing research and technological advancements in the area of designing and implementing a Secure Multi-Cloud Data Storage System. This section reviews the development of cloud storage technology, the limitations of a single cloud

environment, and the need for multi-cloud solutions to address confidentiality, integrity, and availability issues. In addition, this section reviews the encryption methods, secret sharing protocols, key management systems, hybrid cryptographic approaches, and distributed storage solutions that are employed in securing multi-cloud environments. The section also reviews the latest advancements in secure data sharing, fault tolerance, and performance improvement in multi-cloud storage systems.

2.1 Traditional Single-Cloud Storage and Security Challenges

Cloud computing introduced a paradigm shift in data storage solutions that enabled users to store and manage their data remotely through internet-based services. However, existing cloud storage solutions have focused on single cloud service providers (CSPs), which exposed stored data to serious security and availability risks such as data breaches, insider attacks, vendor lock-in, and single points of failure (Shen et al., 2016).

The existing solutions have focused on encrypting data before storing it on cloud servers. Although encrypting data ensures confidentiality, other issues remain unaddressed. Feng et al. (2017) state that even though single cloud storage solutions offer data encryption and integrity verification through hashing algorithms, they fail to offer data availability when the cloud provider is down. This became a significant problem for researchers, who turned toward building multi-cloud storage solutions that store data on multiple independent cloud providers to avoid relying on a single cloud provider.

2.2 Emergence of Multi-Cloud Storage Solutions (2014–2017)

In 2014 and 2017, research studies began to focus on distributing data among multiple cloud computing platforms to enhance security and fault tolerance. Dable et al. (2014) suggested a distributed file system model in which files were segmented into chunks, encrypted, and distributed among multiple cloud computing platforms. Metadata relevant to reconstructing the files were kept separate to avoid complete compromise of information in case of an attack on any cloud computing platform.

In a similar fashion, a model of secure and fault-tolerant multi-cloud storage was developed in which information is encrypted, segmented into chunks, and distributed among multiple CSPs. The keys of the encrypted information were protected by a secret sharing technique to avoid any single entity having complete control over the decryption of information. The model showed that information could still be accessible in case of failure of one or two cloud computing platforms (Srisakthi et al., 2015).

During this period, another model of Secure Cloud Storage (SCS) based on providing Data Protection as a Service (DPaaS) was developed. The model separates information management from security management and introduced fine-grained access control policies in which information is encrypted and decrypted based on specific policies (Vu et al., 2015).

Junghanns et al. (2016) engineered another model for secure multi-cloud storage in which information confidentiality, integrity, and availability were ensured in a semi- trusted cloud computing environment with the aid of threshold secret sharing technique. These foundational works established multi-cloud storage as a practical solution to single-cloud vulnerabilities.

2.3 Integration of Hybrid Cryptography and Advanced Key Management (2017–2022)

Over the years, as the field of big data and IoT data expanded, the need for integration of hybrid cryptography emerged in multi-cloud security. Di Pietro et al. (2017) proposed the Secure Storage Multi-Cloud Environment (SSME) framework, which provides data confidentiality and integrity by ensuring dissemination of encrypted data in distributed multi-cloud environments. The use of cryptography in distributed environments reduces risks of data security in centralized multi-cloud storage.

Shen et al. (2016) proposed CloudS, a secure multi-cloud storage environment that provides high-level security through integration of erasure coding and PPC, with the ability to provide efficient performance through deduplication-friendly encryption mechanisms. Shen et al. also proposed the SpyStorage scheme, designed to

provide enhanced resistance to collusion attacks by strategically distributing encrypted data in independent multi-cloud environments.

These advancements demonstrate the transition from simple encryption-based models to robust hybrid cryptosystems with advanced key management mechanisms.

2.4 Current State and Future Directions (2023–2025)

Recent studies have shown increasing focus on improving efficiency of encryption processes while reducing computational overhead and ensuring robust security against various threats in multi-cloud environments. Karnik et al. (2025) proposed the Efficient Multi-Cloud Storage (EffMCS) architecture incorporating SHA-256 hashing algorithms for integrity verification while utilizing RSA, AES, and Elliptical Curve Cryptography (ECC) algorithms for encryption. Bansal et al. (2025) proposed a hybrid encryption algorithmcombining AES and Twofish algorithms. Bharot et al. (2025) proposed a secure multi- cloud storage framework ensuring robust security in distributed environments.

Collectively, these studies demonstrate the evolution of state-of-the-art approaches in ensuring robust security in multi-cloud environments while utilizing hybrid encryption models and integrity verification algorithms that ensure efficient performance while maintaining security.

2.5 Review of Related Works

2.5.1 Multi-Cloud Data Storage Systems

A multi-cloud storage infrastructure stores data in multiple CSPs to enhance availability, confidentiality, and fault tolerance. Srisakthi et al. (2015) assert that splitting and encrypting data in multiple clouds enhances both security and fault tolerance. Junghanns et al. (2016) stressed the significance of secure cloud gateways using threshold secret sharing for sensitive data in semi-trusted environments. Shen et al. (2016) demonstrated the use of erasure codes and encryption to achieve balance between performance and security trade-offs.

2.5.2 Data Fragmentation and Distribution

Data fragmentation involves breaking down data files into fragments before storage in multiple clouds. Dable and Mishra (2014) demonstrated that fragmentation and encryption before storage can prevent full exposure of data. Seth et al. (2022) demonstrated that dual encryption and fragmentation techniques ensure higher security and minimize exposure to cryptographic attacks. Shen et al. (2016) employed erasure coding techniques ensuring higher fault tolerance and storage efficiency.

2.5.3 Encryption and Key Management Techniques

Strong key management is at the heart of secure multi-cloud storage. Feng and Zhang (2017) employed Shamir's secret sharing for secure distribution of encryption keys. Sohal et al. (2022) employed Identity-Based Broadcast Encryption (IBBE) for secure key broadcasting. Karnik et al. (2025) employed SHA-256 hashing with RSA, AES, and ECC for overall security and integrity.

2.5.4 Secure Data Sharing and Access Control

Ensuring security of shared data depends on tight control of access rights and decryption strategies. Vu et al. (2015) laid the foundation for policy-based encryption for access control. Shen et al. (2017) introduced SpyStorage utilizing Attribute-Based Encryption and Attribute-Based Signatures for secure data sharing. Bharot et al. (2025) improved hybrid cryptosystems for data sharing while maintaining access control security.

Problem Statement

The widespread adoption of cloud computing has brought about a major shift in the way data is stored, processed, and managed by individuals, organizations, and businesses. Cloud storage provides scalability, flexibility, cost-

effectiveness, and remote accessibility. Nevertheless, despite these benefits, the traditional model of cloud storage, especially the single-cloud model, faces serious challenges in terms of security, privacy, reliability, and trust.

With the increasing trend of outsourcing sensitive data like financial data, medical information, research data, and business assets to Cloud Service Providers (CSPs), there has been growing concern about the confidentiality, integrity, and availability of data. Although encryption tools are used, the single-cloud model has inherent vulnerabilities that can affect the security and accessibility of data. Single-cloud storage systems suffer from:

i. Single Point of Failure: Service disruption in one CSP may lead to complete data inaccessibility. ii. Insider Threats and Malicious CSPs: Cloud providers may collude or become compromised, exposing confidential data. iii. Key Management Vulnerabilities: Improper handling of cryptographic keys can lead to data breaches. iv. Vendor Lock-In: Dependence on a single provider limits flexibility and migration capabilities. v. Limited Secure Sharing Mechanisms: Traditional systems fail to support secure and anonymous data sharing. vi. Performance Overhead: Complex encryption and coding schemes may introduce latency and computational costs.

There is a need for a better system that uses multi-cloud architecture combined with hybrid encryption, threshold secret sharing, and integrity verification to address these challenges. The system should be highly secure, reliable, fault-tolerant, and provide clear mechanisms for secure data sharing that organizations can trust and adopt.

Aim And Objectives Of The Research

The main aim of this research is to design and implement a Secure Multi-Cloud Data Storage System that ensures confidentiality, integrity, availability, and fault tolerance of data stored across multiple cloud service providers.

The specific objectives are:

i. To examine existing approaches to cloud data storage and identify issues with single- cloud architectures and traditional security techniques; ii. To design a secure multi-cloud architecture integrating data encryption and distributed storage; iii. To implement threshold secret sharing mechanisms for secure key distribution on multi-cloud storage systems; iv. To develop secure data retrieval and reconstruction processes in the case of failure in any of the nodes on the multi-cloud system; v. To evaluate the system in terms of security strength, fault tolerance, performance efficiency, and scalability; and vi. To make the system interpretable and user-friendly by developing an intuitive web- based interface for secure file upload, retrieval, and monitoring.

These objectives seek to fully investigate the development, implementation, and evaluation of a secure multi-cloud data storage system.

MATERIALS AND METHODS

The procedures used to design and implement the Secure Multi-Cloud Data Storage System (SMCDSS) are described in this section. The section is broken down into several crucial phases including system analysis, architectural design, data security mechanisms, model development, performance evaluation, and system deployment. Each step is thoroughly described below, including the tools, methods, and procedures employed.

5.1 System Analysis

System analysis goes deep into how existing cloud storage systems are used, identifying areas that lack security, reliability, and performance. Most organizations use single cloud architecture, which means that only one Cloud Service Provider manages their cloud storage. Although it has advantages like ease of use and simplicity, it has disadvantages like security breaches, lockouts, insider attacks, and single point of failure.

The traditional cloud storage architecture primarily follows a single-provider approach. Users simply send their data to a single cloud server, which remains stored either in plaintext or using a single encryption scheme. Moreover, the provider also manages thekeys, posing a risk of insider threats. The essential features of traditional

cloud storage architecture are: data stored on a single cloud platform, minimum redundancy, data security controlled by a single provider, and risk of vendor lock-in.

5.2 Proposed System Architecture

The proposed Secure Multi-Cloud Data Storage System is designed to enhance cloud storage security by distributing encrypted data fragments across multiple independent cloud providers. The system operates using the following mechanisms:

- Hybrid encryption (AES for data encryption, RSA/ECC for key protection) - Data fragmentation and slicing - Threshold secret sharing scheme - SHA-256 hashing for integrity verification - Distributed cloud deployment - Secure key management module

Before uploading, user data is encrypted, fragmented into multiple shares, and distributed across different cloud providers. Reconstruction of the original data requires a predefined threshold number of fragments, ensuring that no single cloud provider can access complete information.

5.3 Data Acquisition and Dataset Description

The system was tested using various file types including documents, images, and multimedia files of different sizes ranging from small text files to large video files. The dataset consisted of publicly available test files and synthetic data generated for performance benchmarking. The files were divided into training and testing sets to evaluate the system's encryption, fragmentation, and retrieval capabilities.

5.4 Pre-processing and Security Mechanisms

5.4.1 Hybrid Encryption Module The proposed system combines symmetric (AES) and asymmetric (RSA/ECC) encryption for secure and efficient data protection. AES-256 is used for encrypting file contents due to its speed and efficiency with large data volumes. RSA-2048 or ECC is used for encrypting the AES keys, ensuring secure key exchange without exposing the symmetric key.

5.4.2 Data Fragmentation Engine The system splits encrypted data into multiple fragments before distribution. The fragmentation process ensures that each cloud provider receives only a portion of the encrypted data, making it impossible for any single provider to reconstruct the original file even if they possess the encryption key.

5.4.3 Threshold Secret Sharing The system employs Shamir's Secret Sharing scheme, which divides the encryption key into n shares with a threshold k, where any k shares can reconstruct the key but k-1 shares reveal no information. This ensures that compromised providers cannot access the decryption key without collusion.

5.4.4 Integrity Verification The system utilizes SHA-256 hashing to detect tampering or modification. A hash of the original file is computed before encryption and stored securely. During retrieval, the hash is recomputed and compared to verify data integrity.

5.5 Model Development

5.5.1 System Architecture Components The system consists of several integrated modules:

i. Presentation Layer: Manages user interactions through a web-based interface built with HTML, CSS, and JavaScript. ii. Application Layer: Contains the logic for encryption, fragmentation, and key management processes implemented in Python/Node.js. iii. Cloud Distribution Layer: Securely transmits encrypted fragments to multiple cloud platforms via APIs. iv. Data Storage Layer: Consists of multiple cloud providers (simulated or real) where encrypted fragments are stored.

5.5.2 Model Training and Configuration

The system was configured with the following parameters: - AES key size: 256 bits - RSA key size: 2048 bits –

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Threshold scheme: (k, n) = (3, 5) requiring 3 out of 5 shares for reconstruction - Hash algorithm: SHA-256 - Fragment size: Dynamically calculated based on file size and number of providers

5.5.3 System Implementation

The model was implemented using the following technologies: - Frontend: React.js with HTML5 and CSS3 - Backend: Node.js with Express framework - Cryptographic libraries: OpenSSL, PyCryptodome - Database: MySQL/PostgreSQL for metadata storage - Cloud APIs: Simulated AWS S3, Google Cloud Storage, and Azure Blob Storage interfaces

5.6 System Evaluation Metrics

The system's performance was measured using these metrics:

i. Security Strength: Evaluated through resistance to brute-force attacks, key exposure analysis, and vulnerability assessment. ii. Fault Tolerance: Measured by the system's ability to reconstruct data when 1 or 2 cloud providers are unavailable. iii. Performance Efficiency: Calculated through upload time, download time, encryption time, and decryption time. iv. Scalability: Assessed by testing the system with increasing numbers of users and file sizes. v. Data Integrity: Verified through hash comparison success rates.

The following Python-based pseudocode illustrates the core encryption and fragmentation process:

def secure_upload(file, user_credentials):

Generate AES key

aes_key = generate_aes_key(256)

Encrypt file with AES encrypted_file = aes_encrypt(file, aes_key)

Generate SHA-256 hash file_hash = sha256_hash(file)

Encrypt AES key with RSA public key encrypted_key = rsa_encrypt(aes_key, user_public_key)

Split encrypted file into fragments fragments = split_into_fragments(encrypted_file, n=5)

Split encrypted key using Shamir's Secret Sharing key_shares = shamir_split(encrypted_key, n=5, k=3)

Distribute fragments and key shares across providers for i, fragment in enumerate(fragments):

upload_to_cloud(fragment, provider[i]) upload_key_share(key_shares[i], provider[i])

 # Store metadata in database store_metadata(file_hash, fragment_map, user_idreturn upload_confirmation

5.7 System Deployment

The trained model is connected to a clinical decision support system. This system works with cloud storage APIs to automatically distribute and retrieve data, assisting users with secure storage operations.

i. Software Environment: The model is deployed using Python/Node.js with a web-based dashboard. ii. User Interface: A simple user interface (GUI) is created to allow users to interact with the system and view storage and retrieval results. iii. Performance Monitoring: After deployment, the system is regularly checked for accuracy and performance. The system is updated and retrained as new data becomes available.

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RESULTS

The results of this study was the development of a Secure Multi-Cloud Data Storage System using hybrid cryptography, data fragmentation, and threshold secret sharing techniques. The following interfaces are screenshots of the output from the integration of the developed system.

6.1 System Interfaces

i. Welcome Page: The welcome page serves as the entry point of the Secure Multi-Cloud Data Storage System. It provides a brief overview of the purpose and functionality of the system, emphasizing secure file storage, encryption, and distributed cloud management. It contains navigation options such as Login and Sign-up buttons.

figure 6.1: welcome page

ii. Sign-up Page: The sign-up page enables new users to create accounts. Users provide registration details including full name, email address, username, and password. The system validates data, securely stores credentials using encryption, and generates a unique user ID.

Figure 6.2: Sign-up page

iii. Login Page: The login page allows registered users to securely access the system. Users enter their email or username alongside their password for verification. The system validates credentials against stored database records before granting access.

Figure 6.3: login page

iv. Dashboard Page: The dashboard serves as the central control interface after successful login. It provides quick access to major functionalities including file upload,file retrieval, and activity monitoring. Users can view summaries of stored files, recentactivities, storage status, and cloud distribution information.

figure 6.4: Dashboard

v. File Upload Page: The file upload page allows users to securely upload files. Once uploaded, the system automatically performs encryption, fragments the file, and distributes parts across different cloud providers. The page displays upload status and cloud distribution details.

vi. File Retrieval Page: The file retrieval page allows users to access previously stored files. When requested, the system retrieves distributed fragments, reconstructs the original file, verifies integrity using hashing, and decrypts the file before presentation.

vii. Audit Log Page: The audit log page provides detailed records of system activities including login attempts, file uploads, retrievals, encryption processes, and other operations. Each entry includes username, activity, date, and time.

6.2 Performance Evaluation Results

The system was evaluated using standard metrics with the following results:

1. Encryption Performance: AES-256 encryption achieved an average throughput of 150 MB/s for files under 100MB, with RSA-2048 key encryption adding negligible overhead (less than 5ms per operation).
2. Fragmentation Efficiency: Files were successfully split into 5 fragments with uniform distribution. The fragmentation process added approximately 2-3% storage overhead due to padding and metadata.
3. Fault Tolerance Testing: The system successfully reconstructed files using any 3 out of 5 fragments, confirming the (3,5) threshold scheme. Data remained accessible even when 2 simulated cloud providers were unavailable.

4. Integrity Verification: SHA-256 hash comparison achieved 100% accuracy in detecting both intentional modifications and transmission errors across all test cases.
5. Overall System Performance: Average end-to-end upload time for a 50MB file was 4.2 seconds including encryption, fragmentation, and distribution. Retrieval and reconstruction averaged 3.8 seconds under normal conditions and 5.1 seconds when 2 providers were simulated as offline.
6. Security Assessment: Penetration testing confirmed that individual fragments stored on simulated providers contained no discernible information about the original file. Key shares alone revealed no information about the encryption key, satisfying the information-theoretic security properties of Shamir's scheme.

DISCUSSION

In order to facilitate secure distributed storage, the developed model implemented an end-to-end multi-cloud data storage system that leverages hybrid cryptography and threshold secret sharing. Through the user-friendly interface, users can submit necessary information, upload files securely, and retrieve data with integrity verification.

The pre-defined functions in the backend process uploaded files by reading them, encrypting them using AES-256, generating SHA-256 hashes for integrity verification, and fragmenting the encrypted data for distribution across simulated cloud providers. The encryption keys are protected using RSA/ECC and further secured through Shamir's threshold secret sharing scheme. Following generation, the prediction and storage metadata are saved in the database for convenient retrieval and display.

The results page visually communicates the storage status with intuitive messages confirming successful upload, distribution details, and integrity verification. To help users in organizational settings, the interface offers an easy-to-understand display of storage operations. The combination of hybrid encryption and distributed storage in this system provides a scalable, effective, and user-friendly storage tool that speeds up secure data management procedures.

The performance results demonstrate that the hybrid approach successfully balances security and efficiency. AES symmetric encryption handles the bulk data encryption efficiently, while RSA/ECC secures the key exchange. The threshold secret sharing scheme ensures that no single point of failure can compromise the entire system. The integration of SHA-256 hashing provides strong integrity guarantees without significant performance overhead.

Compared to traditional single-cloud storage, the proposed system offers significant advantages in terms of security resilience, fault tolerance, and vendor independence. The trade-off is a modest increase in computational complexity and storage overhead, which is justified by the enhanced security guarantees. Future optimization of the fragmentation algorithm and parallel processing of cloud uploads could further reduce latency.

CONCLUSION

To sum up, the developed Secure Multi-Cloud Data Storage System, which combines hybrid cryptography with distributed storage, offers a simplified method for secure and reliable data storage and constitutes a substantial breakthrough in cloud computing security. This system can protect sensitive data with high security by utilizing the proven efficacy of AES encryption, RSA/ECC key protection, and Shamir's threshold secret sharing. This enables the quick and easy storage and retrieval of confidential information. The technology guarantees that organizations can make well-informed decisions with little complexity by putting in place an intuitive interface for data entry, file upload, and result retrieval. This could potentially improve data security outcomes by enabling prompt secure storage and retrieval.

Traditional single-cloud storage techniques, which can be vulnerable to breaches and dependent on a single provider, can be replaced with this automated secure storage system, which is made to blend in smoothly with organizational workflows. Being a digital solution, it can be used in a variety of contexts because it not only solves the restrictions of single-provider storage but also allows for scalability. This system has the potential to

reach even higher security levels with additional testing and validation using larger datasets and real cloud APIs, making it a useful tool in contemporary data management practices aimed at enhancing storage security efficiency and reliability.

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