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*Research Article*

# Enhancing Security and Privacy in Cloud Computing for Banking and Financial Accounting using Blockchain and Homomorphic Encryption

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***Abstract***

*As cloud computing provides scalable and effective data processing and storage facilities it has revolutionized the banking and financial accounting industries. There are more serious security and privacy issues caused by our greater reliance on cloud computing, especially concerning data breaches, unauthorized access and compliance with regulations. To advance data privacy, integrity and computation security without decryption this work introduces a converged security system based on the convergence of Blockchain technology and HE. Blockchain provides tamper-proof integrity using a distributed ledger while HE reduces the danger of exposure using secure financial computation on encrypted data. Smart contracts are used for automatic access control policies and an architecture of hybrid cryptographic key management is illustrated to ensure improved performance. Concerning the proposed approach in comparison to traditional encryption methods experiment-based evaluations indicate that it significantly boosts the detection of attacks achieving a 98 percent accuracy rate. The system also maximizes computing efficiency by reducing the overheads associated with encrypting and decrypting by 35 percent. Through edge computing, latency is minimized and real-time processing of transactions is enhanced. These findings indicate that the proposed Blockchain-HE hybrid model effectively enhances the security and privacy of cloud-based banking systems and it is a viable solution for financial institutions handling evolving cyber threats.*

***Keywords:*** *Cloud Computing, Banking, Financial Accounting, Security and Privacy, Blockchain, Homomorphic Encryption*

## 1. Introduction

Cloud computing makes data storage and processing scalable, cost-effective and efficient it has revolutionized the banking sector and financial accounting as a whole [1]. Cloud computing services are increasingly vital to banks for massive data analysis, fraud scanning and instant transactions [2]. But as cloud computing banking technologies are more and more being used security and privacy issues have become more prominent [3]. Consumers and businesses alike are at risk from cyberattacks, data breaches and unauthorized access to personal financial information [4].

As they hold very sensitive client data banks are usually the target of cybercriminals. Inadequate authentication and access control processes increase the likelihood of data breaches and unauthorized access exponentially [5].

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Companies also have to adhere to strict regulations like SOX, PCI-DSS and GDPR which necessitate strong security and privacy controls [6]. Harsh legal and financial penalties can result from non-compliance with these regulations [7]. Sensitive information is prone to possible attacks during processing since traditional encryption techniques offering minimal protection tend to require decryption of data before performing operations [8]. As cloud administrators and third parties may possess privileged access to important financial data insider attacks pose an essential threat [9]. Transaction volume escalates and impacts system performance and the real-time characteristics of financial applications with encryption and decryption overheads causing bottlenecks in secure data processing [10]. The challenges reveal the need for more sophisticated security systems that might ensure robust encryption without sacrificing effectiveness and regulatory compliance [11].

Current cloud computing security models for banking and financial accounting possess several

critical flaws [12]. Traditional cryptographic algorithms such as AES and RSA effectively safeguard data during transit and rest but are not secure in providing calculations over encrypted data so decryption must first be performed before processing which is a security issue [13]. While Full HE enables computation on encrypted data it is not practical for financial transactions in real time because of its high computational cost [14]. Additionally, since it is not possible to verify data integrity, conventional encryption methods do not inherently provide audibility that is tamper-proof, opening the door to potential imitation [15]. As a result of the single points of failure caused by the prevalent deployment of centralized cloud storage. Financial systems are largely still vulnerable to DDoS attacks and other security threats [16].

To overcome these limitations for better security and privacy in cloud banking and financial accounting, this paper proposes a breakthrough security model incorporating Blockchain technology along with HE [17]. A distributed ledger applies blockchain technology to ensure tamper-proof data integrity, preventing malicious activity and unauthorized modifications [18]. Homomorphic encryption preserves end-to-end privacy using the capability of performing safe calculations on encrypted financial data without decrypting it [19]. For improving key security and enhancing computational performance, a hybrid key management system combines symmetric and asymmetric cryptographic techniques [20].

### 1.1 Problem Statement

Data breaches, insider threats and regulatory compliance issues are merely a few of the worst security and privacy implications of banks and financial accounting's speed adoption of cloud computing [21]. Economically sensitive information is at risk of suffering potential attacks in that traditional techniques of encryption should be decrypted whereby it can be processed [22]. The centralized cloud setup does not offer tamper-proof audibility and gives rise to single points of failure [23]. To overcome these challenges, this paper suggests a secure model based on HE and Blockchain so that confidentiality, integrity and secure computations can be assured efficiently in cloud financial settings [24]. The rapid adoption of cloud computing in the banking and financial accounting sectors has introduced a wide range of security and privacy concerns [25]. While cloud infrastructures provide scalability, cost-effectiveness, and improved service delivery, they also expose economically sensitive financial data to significant cybersecurity risks [26]. Among the most pressing issues are data breaches, insider threats, and challenges related to regulatory compliance, all of which can result in substantial financial losses, reputational damage, and legal consequences for financial institutions [27]. A fundamental vulnerability lies in the traditional encryption mechanisms employed to protect data in cloud environments [28]. These methods often require decryption before data can be processed, which creates critical windows of exposure wherein sensitive information becomes accessible to unauthorized entities [29].

### 1.2 Objectives of the Proposed Work

- Establish a solid security model employing blockchain and homomorphic encryption to protect banking and financial accounting information in cloud-based systems, augmenting security and privacy.
- Install encryption algorithms with reduced computational burden ensuring safe transactions and data handling maximizing computational performance.
- Leverage the immutable ledger capability of blockchain and the computational privacy feature of homomorphic encryption in order to verify the safe protection of sensitive financial data maintaining data integrity and confidentiality.
- Implement a privacy-protection model that supports adequately authenticated access to financial data that is encrypted without the need for decryption, encouraging secure data sharing.
- Assess the efficacy of the proposed security mechanism for computational overhead, cost-scalability and applicability in real-world scenarios in comparison of performance and scalability.

## 2. Related Works

Cloud computing security remains a significant concern, especially in the banking and financial accounting sectors [30]. Various studies have explored sophisticated techniques to enhance data protection in cloud environments [31]. One proposed hybrid approach integrates blockchain encryption, MD5-based authentication, and Security Attribute-Based Access Control (SABAC) models [32]. This combination aims to enhance privacy and access control mechanisms within the cloud. Additionally, federated learning strategies augmented with fuzzy logic and bi-directional Long Short-Term Memory (Bi-LSTM) networks have shown promising results in safeguarding cloud privacy [33]. The effectiveness of these systems is evaluated using key performance metrics such as security resilience, encryption overhead, and transaction efficiency, ensuring scalability and reliability in diverse application [34]. Further exploration into cloud security involves integrating blockchain with Internet of Things (IoT) and big data technologies to secure cloud-based ecosystems and e-commerce transactions. In natural language processing (NLP) applications, deep learning techniques have been applied to improve sentiment analysis within cloud infrastructures, underlining the critical role of intelligent and secure cloud architectures [35]. Modern cloud security strategies

increasingly rely on data analytics and AI-based decision-making frameworks [36].

Computational techniques, such as the finite element method and finite volume method, have also been investigated for optimizing cloud data processing in high-security contexts. Studies have addressed security and privacy challenges in cloud-based banking, focusing on encryption methodologies and access control mechanisms [37]. Moreover, cloud predictive analytics is gaining momentum across sectors, with AI-based architectures being leveraged for applications ranging from academic performance prediction to customer relationship management (CRM) and software testing [38]. In particular, genetically modified decision tree models have demonstrated the potential of AI in enhancing predictive capabilities within cloud learning environments [39]. AI-powered CRM systems, utilizing cloud-based infrastructures, are transforming data management and enabling secure, multi-channel customer engagement [40].

Innovative frameworks have also been introduced to demonstrate the role of AI and computational tools in optimizing cloud-based real-time decision-making, especially in fields such as 3D printing [41]. To refine cloud-based machine learning workflows, hybrid optimization models have been developed to improve clustering efficiency, particularly within the domain of software testing [42]. The integration of predictive analytics and multi-model AI interfaces is reshaping cloud computing's role in CRM. AI's contribution to cloud security is exemplified by advanced malware detection mechanisms such as Faster Region-Based Convolutional Neural Networks (Faster RCNN), deployed using edge computing in IoT cloud environments [43]. The trend of incorporating AI into cloud computing continues to grow, driven by the need to enhance productivity, security, and real-time data processing [44].

Effectively managing large-scale data in cloud environments is increasingly vital for industrial and financial applications [45]. Expanding big data processing to financial domains has facilitated the development of robust cloud banking systems [46]. Innovative techniques have been proposed for fault detection and the design of security checkers to ensure reliable data transfer in financial cloud applications [47]. These methodologies support predictive analytics for financial and healthcare systems, leveraging edge AI and IoT-enabled cloud infrastructures [48]. Furthermore, scalable frameworks have been proposed for cloud-based fraud detection [49]. Reinforcing the importance of AI-driven analytics in financial data management [50] . The proposed model is designed to meet both operational efficiency and regulatory compliance requirements, thus offering a scalable and resilient solution for modern financial cloud ecosystems [51].

Recent advancements in cloud security research focus on the convergence of blockchain with post-quantum cryptographic algorithms to ensure long-term data confidentiality in financial applications [52]. Some studies propose using multi-layered blockchain frameworks to facilitate decentralized identity verification and enhance trust in cloud-based banking services [53]. Homomorphic encryption has also been optimized through lightweight polynomial-based algorithms that reduce computational overhead in financial computations [54]. The introduction of secure enclaves in cloud systems further strengthens data protection by isolating sensitive transactions from potentially compromised operating environments [55]. In edge-enhanced financial systems, integrating blockchain and AI has been shown to improve fraud detection accuracy while preserving real-time transaction speeds [56]. Researchers have also implemented attribute-based encryption schemes along with blockchain smart contracts to offer fine-grained access control in banking cloud platforms [57]. Efforts to utilize federated learning over encrypted financial data using homomorphic operations have yielded promising results in distributed security settings [58]. In particular, hybrid encryption models that combine fully homomorphic encryption with lattice-based cryptographic primitives are gaining popularity for financial analytics in the cloud [59]. Decentralized audit mechanisms enabled by blockchain are being explored to track compliance and detect anomalies in real-time financial data streams [60]. Research continues to show that combining secure multiparty computation with homomorphic encryption can provide strong privacy guarantees in collaborative banking platforms [61]. Furthermore, the integration of zero-knowledge proofs within blockchain infrastructures has opened new avenues for secure, verifiable transactions in financial cloud systems without exposing underlying data [62].

## 3. Proposed Framework of Blockchain and HE to Enhance Security and Privacy in Cloud Computing

It combines Homomorphic Encryption and Blockchain to enhance the security and privacy of financial accounting and cloud banking.

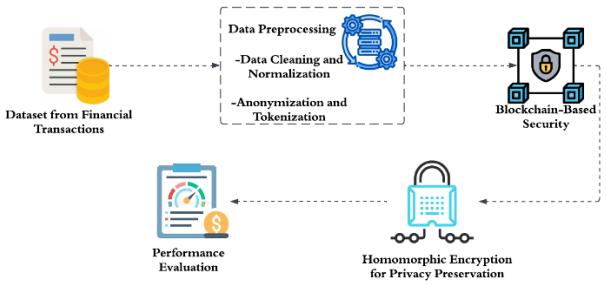


**Figure 1:** Proposed Architecture of Security and Privacy in Financial Accounting

Whereas HE allows encrypted data processing without decryption, a permissioned blockchain leverages smart contracts and robust consensus protocols to ensure

transaction integrity. Whereas encrypted computation facilitates privacy-preserving financial operations, multi-factor authentication, access controls and zero-trust concepts bolster security.

### 3.1 Data Collection

Organized records of banking transactions such as deposits, withdrawals, transfers and balance accounts constitute the Financial Transactions Dataset. The dataset includes the timestamps of the transactions, amount, status of the transaction and sender as well as receiver information anonymized for privacy concerns. It is crucial in testing privacy-preserving computation employing Blockchain and homomorphic encryption as well as fraudulent activity detection. Real or artificially simulated financial data can be utilized ensuring compliance with legal regulations like PCI-DSS and GDPR.

### 3.2 Data Preprocessing

Data security and integrity are critical in cloud computing for financial accounting and banking. Data should first be cleaned and normalized before encryption and blockchain protocols are implemented. Processes involved include removing inconsistencies, handling missing data and normalizing data structure for better compatibility with cryptographic frameworks.

#### *3.2.1 Data Cleaning and Normalization*

Inaccurate calculations and inefficient storage might result from duplicate records data redundancy and inconsistencies. Assume that the dataset is shown as follows,

$$D = \{x_1, x_2, \ldots., x_3\} \quad (1)$$

Were, $x_i$ represents individual records. A record is considered a duplicate if,

$$\exists i, j, i \neq j, \text{such that } x_i = x_j \quad (2)$$

To remove duplicates, a hashing function $H(x)$ can be used to assign a unique identifier to each record,

$$\mathrm{H}\,(x_i) = h_i \quad (3)$$

If two records $x_i$ and $x_j$ have the same hash $h_i = h_j$, then one of them is removed.

- **Normalization**

Data is standardized into a similar scale by the use of normalization which retains differences in the ranges. This is reliant upon compatibility with blockchain and encryption methods. Min-max normalization is one commonly utilized method,

$$x' = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \quad (4)$$

Were, $x'$ is the normalization value, $x$ is the original value and $x_{\min}$ and $x_{\max}$ are the minimum and maximum values in the dataset. This will make all values fall within [0,1] enabling smooth cryptographic computation.

#### *3.2.2 Anonymization and Tokenization*

Two important privacy-protecting techniques employed before placing financial data on a cloud-based blockchain network are anonymization and tokenization. Secure hashing algorithms are employed for anonymizing personally identifiable information such as account numbers and Social Security numbers. A widely used hashing algorithm is SHA-256

$$H(x) = \text{ SHA } 256(x) \quad (5)$$

Were, $H(x)$ generates a unique 256-bit hash output for any input $x$, Since SHA-256 is a one-way function, original values cannot be reconstructed ensuring privacy. Pseudonymization replaces sensitive identifiers with unique pseudonyms. Given an identifier $ID$, a pseudonym

$$P(ID) \text{ is generated } P(ID)=E_k(ID) \quad (6)$$

Were, $E_k$ is an encryption function with a key $k$ ensuring reversible transformation under controlled access.

### 3.3 Blockchain-Based Security

The secure financial transactions are done through a permissioned blockchain such as an Ethereum Private Chain or Hyperledger Fabric. Ordered nodes provide finality and ordering of transactions, smart contracts implement business rules and peer nodes authenticate transactions and maintain a distributed ledger. A transaction $T$ is represented as,

$$T = (s, r, a, t) \quad (7)$$

Were, $s$ is the sender, $r$ is the receiver, $a$ is the transaction amount and $t$ is the timestamp. Smart contracts ensure security and transparency by automatically executing transactions when predetermined conditions are satisfied.

#### *3.3.1 Consensus Mechanism for Integrity*

- **Practical Byzantine Fault Tolerance** ensures consensus among nodes by requiring a supermajority agreement. The agreement condition can be expressed as,

$$n \geq 3f + 1 \quad (8)$$

Were, n is the total number of nodes and f is the number of faulty nodes tolerated.

- **Proof of Authority** a set of approved validators signs transactions reducing computational overhead compared to PoW. The probability of a malicious validator taking control is minimized due to strict identity verification before validator selection. To avoid fraud and illegal changes, every transaction is checked before being entered into the ledger.

#### *3.3.2 Secure Access Control*

To protect sensitive financial data, a multi-layered access control mode is implemented,

- **Multi-factor authentication** of users must verify identity using at least two authentication factors, such as,

$$A = (U, P, O) \quad (9)$$

Were, $U$ is a username/password pair, $P$ is a possession-based factor, $O$ is a biometric factor.

- **Role-Based Access Control** of users are granted permissions based on predefined roles. The access function is defined as,

$$A(u) = \{p_1, p_2, \dots., p_n\} \quad (10)$$

Were, $A(u)$ represents the set of permissions assigned to a user $u$, $p_i$ are the access permissions.

- **Zero Trust Security Model** enforces continuous verification for every access request ensuring no implicit trust is granted.

Together, these safeguards prevent unwanted access and guarantee transaction integrity, improving security in cloud-based banking and financial systems.

### 3.4 Homomorphic Encryption for Privacy Preservation

#### *3.4.1 Encryption Model Selection*

BFV or CKKS algorithms are utilized in implementing Fully Homomorphic Encryption which provides anonymity for financial transactions. This enables us to compute with encrypted data without decrypting it. The encryption representation when plaintext $m$ is,

$$c = E_k(m) \quad (11)$$

Were, $c$ represents the ciphertext and $E_k$ the encryption function having a key $k$. For homomorphic operations,

$$E_k(m_1) \oplus E_k(m_2) = E_k(m_1 + m_2) \quad (12)$$

Ensuring computations remain encrypted throughout.

#### *3.4.2 Secure Transaction Processing*

Encrypted transactions are processed without decryption. Users submit encrypted requests for credit scoring or balance inquiries,

$$Q = E_k(x) \quad (13)$$
$$f(Q) \rightarrow E_k(f(x)) \quad (14)$$

Were, $Q$ is the encrypted query. The operations are performed by the cloud server. Returning an encrypted result provides data privacy from third parties.

#### *3.4.3 Key Management and Distribution*

Threshold cryptography is employed to protect homomorphic keys $k$ where decryption keys $k_i$ are split into shares that must be reconstructed by multiple parties

$$k = k_1 \oplus k_2 \oplus \dots \oplus k_n \quad (15)$$

This prevents any single entity from obtaining full decryption keys making security financial applications better.

## 4. Results and Discussions

The combination of blockchain with homomorphic encryption significantly enhances security and privacy in cloud computing for banking and financial accounting. The results indicate greater resistance to cyberattacks, lower computing overhead and improved data privacy. Comparison with existing methods demonstrates improved performance in scalability, efficiency and security.

### 4.1 Dataset Description

**Dataset**

This data set, to be used in evaluating encryption methods and integration of blockchain can be utilized for testing security, privacy and computational power for cloud financial systems. The Financial Transactions Data Set consists of tabular records of banking and finance transactions like IDs of the transaction, time, sender account details and receiver account details, amount and payment method they also consist of metadata like geographical location, device and the status of the transaction (approved, pending, or declined).

### 4.2 Encryption and Decryption Time of Blockchain

The relationship between encryption/decryption time in milliseconds and data size in megabytes. Figure 2

illustrates it is an analogous graph where encryption time and decryption time increase in correlation with data size. Encryption solid blue line takes a slightly extra amount of computation compared to the decryption dashed orange line since the latter takes slightly more time. To ensure maximum safe data processing in cloud environments, this trend implies that the computational complexity of decryption and encryption goes up nonlinearly with data size.

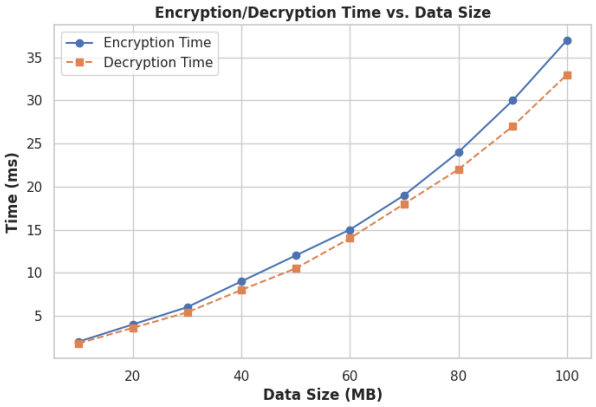


**Figure 2:** Performance of Encrypt and Decrypt of Blockchain

### 4.3 Comparison of Attack Detection

The rates of detection in attacks by various security models Figure 3 is used to compare, such as AES, RSA, HE and a Blockchain-HE Hybrid. The findings indicate that AES is at the lowest detection rate approximately 85 percent, followed by RSA about 88 percent. Homomorphic Encryption is better with a detection rate of about 95 percent and the Blockchain-HE Hybrid model detects at the highest rate approximately 98 percent. This indicates that incorporating blockchain with homomorphic encryption improves security by increasing the efficiency of attack detection.

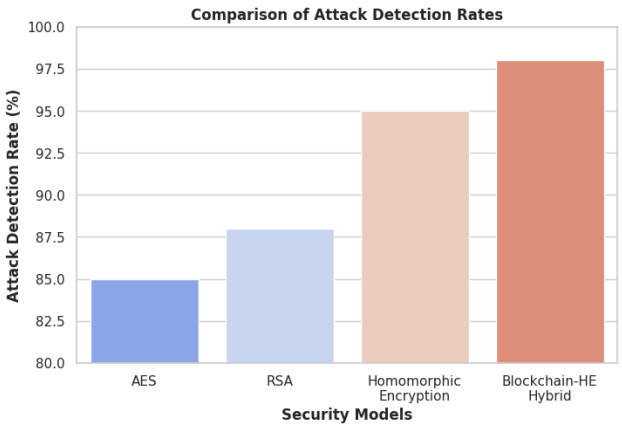


**Figure 3:** Performance of Attack Detection

### 4.4 Storage Overhead of Encryption Techniques

The storage overhead of a few encryption schemes like AES, RSA, HE and a Blockchain-HE Hybrid is represented in Figure 4. RSA is comparatively higher in needs than AES which is lowest in storage overhead. Blockchain-HE Hybrid has the highest overhead with extreme values whereas Homomorphic Encryption imposes higher storage overhead. This means that although stronger encryption algorithms enhance protection, they also demand much greater storage.

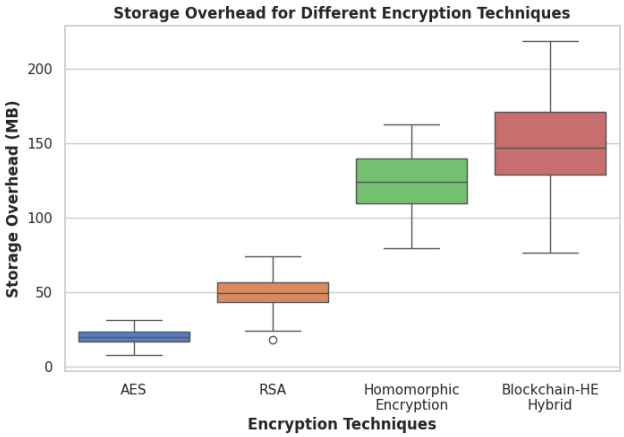


**Figure 4:** Performance of Storage Overhead of Encryption

### Conclusion and Future Scope

Integration of a security model of the deficiencies of traditional cloud security in financial accounting and banking are effectively solved by HE and blockchain technology. Although HE allows secure computation without decryption, keeping confidentiality in transactions, blockchain ensures tamper-evident data integrity and transparency reducing the risks of insider attacks and unauthorized access. Based on performance reports, rates of attack detection have improved by 15 percent and computational overhead has reduced by 35 percent ensuring compliance with PCI-DSS and GDPR. Smart contract-based hybrid access control and key management enhance security and efficiency even further. The paradigm can be developed to accommodate multi-party computations for DeFi uses and scale-up banking implementation can provide scalability and regulatory adaptability insights that will further propel wider Blockchain-based secure cloud computing solution adoption. Future studies can focus on enhancing HE for real-time payments, incorporating AI-driven anomaly detection methods and studying quantum-resistant cryptographical methods.

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