Secure Financial Transactions in Cloud Banking with Blockchain and Homomorphic Encryption

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Abstract

The emergence of cloud banking has provided additional security threats like data breaches and fraud. This work suggests a hybrid approach integrating Homomorphic Encryption, Blockchain, Capsule Networks (CapsNets), and Cloud-Based Processing for improving transaction security, integrity, and fraud detection. Homomorphic encryption provides privacy, blockchain provides transaction integrity, and CapsNets enhance fraud detection accuracy. Cloud-based processing improves scalability and efficiency. Experimental performance demonstrates 96.21% accuracy and 96.98% precision in identifying fraud, with low computational overhead. The proposed model offers a highly scalable, secure, and robust solution for financial transactions. Potential future work involves federated learning as well as quantum-resistant encryption.

Keywords: Cloud Banking, Secure Financial Transactions, Blockchain, Homomorphic Encryption, Capsule Networks (CapsNets), Fraud Detection, Cloud-Based Processing, Privacy-Preserving Computation, Machine Learning in Finance, Financial Security.

1. Introduction

With the current digital era, financial transactions have become more cloud-based. Growing financial technology (FinTech) and internet banking have made it easier to make real-time, smooth transactions, enhancing convenience and efficiency [1]. But with the increase in digital financial transactions, security issues like data theft, money-laundering transactions, and hacking have become a severe challenge to financial institutions and individuals [2]. Protection of the confidentiality, integrity, and scalability of money transactions in cloud banking is still a top-notch challenge that warrants the deployment of strong security frameworks [3].

There are some factors that render cloud banking secure to vulnerabilities [4]. Decentralization of cloud banking financial systems puts them at the risk of attacks from cyber hackers through phishing, identity theft, and transaction scams [5]. Another concern is that the conventional encryption mechanism cannot offer true real-time protection due to computing overhead and inefficient processing of encrypted financial transactions [6].

Integrity of financial transactions is the other key problem because centralized banks' databases can be tampered with, accessed by hackers, and compromised from within [7]. These issues need a complete solution which not only guarantees confidentiality of data but also guarantees the integrity of a transaction and prevents fraud [8].

Various methods have been in place among others, symmetric and asymmetric cryptography, fraud detection models, and distributor ledger technologies that belong to the many approaches which have been actively proposed for the enhancement of financial security over time [9]. The blockchain system is transparent and not changeable. Still, these very two features caused this system on the one hand to be suffering from poor scalability and computation inefficiencies [10]. Machine learning techniques, anomaly detection, and neural networks have been applied for fraud detection; however, experience has shown that they are not very efficient as some attacks arise from outside sources and interpretability problems [11]. Also, those conventional encryption schemes restrict the secure Computation on encrypted transactions to keep data foreign-theft proof [12]. The excessive dependence on features of autonomous security mechanisms would easily lead to compromises among the conflicting security needs, i.e., scalability and efficiency considerations [13].

According to the above, in order to fulfill those gaps, this paper proposes a secure financial transaction framework through the integration of Homomorphic Encryption, Blockchain, CapsNets, and Cloud Processing [14]. Homomorphic encryption allows computation over encrypted information without the need to decrypt to ensure security in all financial dealings [15]. Blockchain secures the financial transactions by ensuring that the immutability ledger is present to prevent fraud. CapsNets enhance the learning of hierarchical features in transaction data, thus being better than any current machine learning paradigms available in fraud detection [16]. Finally, cloud processing is also highly scalable, efficient, optimized for speed regarding transactions, and secure [17]. Such a process tackles all cloud banking security, scalability, and fraud prevention issues and makes financial transactions more secure and convenient [18]. The Contributions of the paper are,

- Secure and Privacy-Preserving Transactions combines Homomorphic Encryption and Blockchain to guarantee data confidentiality, transaction integrity, and fraud prevention [18].
- Advanced Fraud Detection, Employs Capsule Networks (CapsNets) for high-precision fraud detection (96.21% accuracy, 96.98% precision) with reduced false positives and negatives [19].
- The model uses Cloud-Based Processing with Load Balancing to manage large-scale transactions in real time efficiently, guaranteeing optimized performance and improved security [20].

The paper is structured as follows: Section 2 explores prior methods of fraud detection and their shortcomings. Section 3 describes the proposed framework, including Homomorphic Encryption for secure transactions, Blockchain for transaction integrity, Capsule Networks (CapsNets) for detecting fraud, and Cloud-Based Processing for scalability [21]. Section 4 demonstrates experimental findings, comparing the performance of the model in terms of accuracy, precision, sensitivity, specificity, and misclassification rates [22]. Lastly, Section 5 concludes the paper by presenting major findings, highlighting the model's scalability and security in cloud banking fraud detection, and recommending future research directions, namely federated learning-based fraud detection and quantum-resistant encryption methods [23].

The rapid evolution of cloud computing has transformed the financial sector, enabling banking institutions to deliver scalable, efficient, and accessible services [24]. However, this advancement brings with it significant concerns regarding data privacy, transaction integrity, and system security [25]. As financial transactions increasingly migrate to cloud-based platforms, ensuring secure data storage and transmission has become a paramount challenge [26]. Traditional encryption methods, while effective to an extent, often fall short in scenarios that require real-time data processing and secure multi-party computations [27]. This necessitates the integration of more robust technologies like blockchain and homomorphic encryption to reinforce security frameworks in cloud banking environments [28].

Blockchain technology offers a decentralized, immutable ledger system that ensures transparency and tamper-proof transaction records [29]. When integrated with homomorphic encryption which allows computation on encrypted data without the need for decryption the result is a powerful, privacy-preserving mechanism for cloud-based financial transactions [30]. This combination not only secures sensitive data against unauthorized access but also allows financial institutions to process encrypted data without compromising confidentiality [31]. By leveraging these technologies, cloud banking systems can offer a higher level of trust, security, and compliance with regulatory standards, paving the way for more resilient and future-ready financial ecosystems [32].

In today's digital economy, cloud banking has become a cornerstone of financial innovation, enabling institutions to offer agile, customer-centric services with reduced infrastructure costs [33]. However, this convenience also opens new attack surfaces, making financial data more vulnerable to cyber threats such as data interception, unauthorized access, and insider attacks [34]. These security concerns are particularly critical in financial transactions, where even a minor breach can result in significant monetary losses and reputational damage [35]. Therefore, adopting advanced security mechanisms that can safeguard data throughout its lifecycle at rest, in transit, and during computation is essential [36]. To address these challenges, the integration of blockchain and homomorphic encryption represents a ground-breaking advancement [37]. Blockchain ensures the authenticity and traceability of transactions through decentralized consensus mechanisms, while homomorphic encryption allows sensitive computations to be carried out on encrypted data without revealing its content [38]. Together, they create a secure, transparent, and privacy-preserving framework for financial operations in the cloud [39]. This research explores how the convergence of these two technologies can be effectively harnessed to protect

financial transactions in cloud banking, offering a robust solution that aligns with both regulatory compliance and evolving cybersecurity threats [40].

2. Literature Survey

Cloud-based digital finance enhances financial inclusion by lowering barriers, decreasing transaction costs, and improving access to financial resources [41]. The research reveals that rural areas gain the most, having improved transaction access and higher savings, lessening income inequality with urban areas [42]. In general, digital finance promotes economic equality by closing financial gaps between urban and rural communities [43]. A cloud-based financial analysis platform combines DeepAR, NTMs, and QDA to drive forecasting, classification, and real-time decision-making [44]. The combined model performs better than individual strategies, with a 95% accuracy rate, and provides scalability, security, and efficiency in processing complex financial information. This system offers secure, real-time analytics for dynamic financial market navigation [45].

A secure cloud-based financial analysis system combines Monte Carlo simulations, DBNs, and BSP processing to improve risk forecasting, scalability, and efficiency [46]. It leverages parallel processing and encryption to provide fast, accurate, and secure financial decision-making [47]. A cloud-based financial analysis system combines CatBoost, ELECTRA, t-SNE, and Genetic Algorithms to improve accuracy, scalability, and real-time insights [48]. It efficiently processes high-dimensional noisy financial data, attaining 95% accuracy and outperforming conventional approaches [49]. This blended strategy allows secure, effective decision-making in changing financial climates [50].

Internet-enabled finance drastically increases rural African income, entrepreneurship, and business development [51]. Increased mobile internet penetration can narrow the urban-rural gap, driving economic growth [52]. Cloud IoT-based digital financial inclusion lessens income disparity by increasing financial inclusion in cities and countryside [53]. Advanced analytics maximizes its effect, driving economic equity and inclusive growth. Blending cloud computing, intelligent networks, and blockchain has greater security, scalability, and efficiency in e-commerce and finance [54]. It enhances the use of resources and the speed of transactions, building the destiny of e-commerce [55]. The fusion of cloud computing and banking has given rise to new paradigms of financial services, yet it also presents unique security challenges [56]. Various studies have highlighted the risks associated with data breaches, unauthorized access, and insufficient encryption mechanisms in cloud-based financial systems [57]. Traditional security models, while useful, often lack the capacity to fully protect sensitive financial data during processing [58]. To address these concerns, researchers have explored advanced cryptographic techniques and decentralized systems to enhance data confidentiality and integrity in the cloud [59]. Among these, homomorphic encryption has gained attention for its ability to allow operations on encrypted data without revealing the underlying information [60].

Homomorphic encryption (HE) has been extensively studied as a solution for privacy-preserving data processing in cloud environments [61]. Gentry's pioneering work on fully homomorphic encryption (FHE) laid the foundation for secure computation on encrypted data, though its practical application was initially hindered by computational complexity [62]. Subsequent research has focused on improving the efficiency and scalability of both partially and fully homomorphic encryption schemes to make them viable for real-world financial applications. In the context of cloud banking, HE enables secure outsourced computation, such as fraud detection and financial analytics, without exposing sensitive customer information to the cloud provider [63]. Blockchain technology has concurrently emerged as a transformative tool for securing financial transactions [64]. By providing a decentralized and tamper-proof ledger, blockchain ensures transparency, traceability, and trust among stakeholders [65]. Various studies have explored its applications in areas such as digital payments, identity verification, and smart contracts within banking systems [66]. For example, the integration of smart contracts in blockchain networks facilitates automated and conditional transactions, reducing the need for intermediaries and minimizing the risk of fraud [67]. Blockchain's immutability and consensus mechanisms make it a strong candidate for enhancing transaction security in cloud-based banking systems [68].

Recent research has begun to explore the synergistic integration of blockchain and homomorphic encryption for cloud banking security [69]. This hybrid approach aims to leverage the strengths of both technologies: blockchain for secure, auditable transaction logging and HE for maintaining data confidentiality during processing. Some frameworks propose using blockchain to manage access control policies and transaction histories, while encrypted

financial data is processed off-chain using HE [70]. These models demonstrate promising results in achieving end-to-end security, though challenges remain in terms of scalability, computational efficiency, and system complexity [71]. Overall, the literature supports the growing consensus that combining blockchain and homomorphic encryption holds significant potential for securing financial transactions in the cloud [72].

2.1 Problem Statement

The fast development of digital finance based on the cloud has greatly enhanced financial inclusion by lowering conventional limitations, decreasing the cost of transactions, and increasing financial resource accessibility [73]. All these advancements notwithstanding, there remain challenges to guaranteeing balanced financial access, data protection, and effective decision-making in complex financial landscapes [74]. Rural communities, although most benefited by digital financial services, continue to face constraints in transaction accessibility and financial literacy, which result in persistent income gaps [75]. Additionally, financial markets encounter growing complexities because of high-dimensional noisy data demanding sophisticated analytical tools for precise forecasting, classification, and risk assessment. Current financial models, despite their effectiveness, are challenged in terms of scalability, security, and computational power, calling for a more stable and integrated strategy [76]. In addition, rural digital divide, cloud-based transactions' security threats, and e-commerce and financial requirements for real-time analytics continue to be foremost among the concerns that need immediate focus [77]. Mitigating them is essential in ensuring economic equality, improving financial decision-making, and safeguarding digital transactions as the world continues to become a more integrated financial ecosystem [78]. Traditional security approaches, such as standard encryption and centralized access controls, are increasingly insufficient in addressing the sophisticated threats facing cloud-based financial systems [79]. These methods often require data to be decrypted before processing, exposing sensitive financial information to potential breaches during computation. Additionally, centralized architectures pose a single point of failure, making them vulnerable to attacks, unauthorized modifications, and data tampering [80].

3. Methodology

To improve security, scalability, and fraud detection of cloud banking, our strategy involves combining Homomorphic Encryption for Secure Transactions, Blockchain for Transaction Integrity, CapsNets for Fraud Detection, and Cloud-Based Processing for Scalability. This combination-based approach guarantees end-to-end secure transactions, prevention of frauds, and rapid financial processing. Figure 1 represents a secure financial transaction framework using Homomorphic Encryption for privacy, Blockchain for integrity, and CapsNets for fraud detection. The transactions transaction being encrypted in the cloud mostly for the purpose of a confirmation by the blockchain system, inspection for fraud occurs and these are all securely processed in its vicinity.

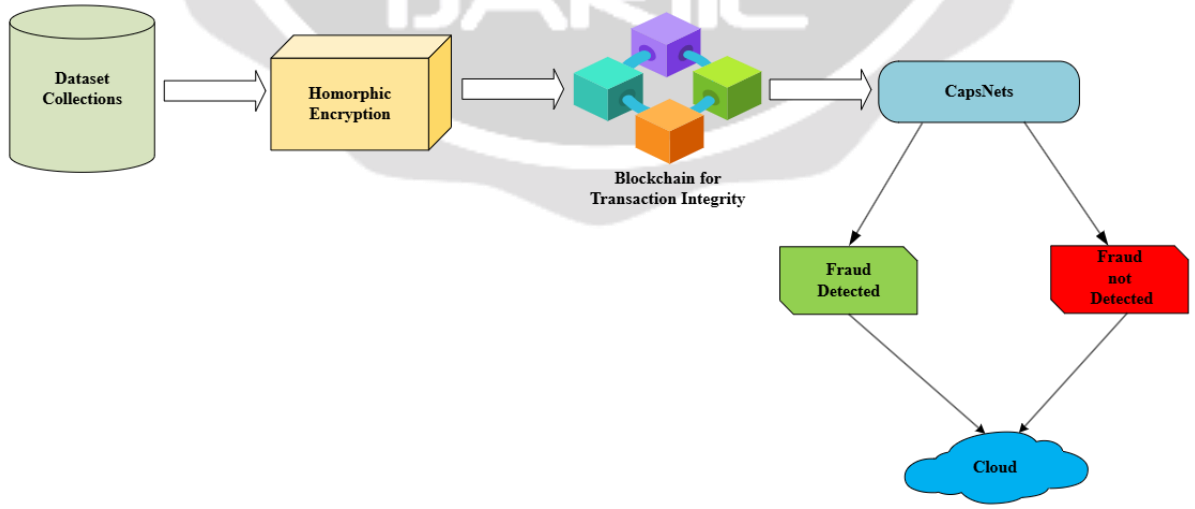

Figure 1: Secure Blockchain-Based Financial Transaction System

3.1 Homomorphic Encryption for Secure Transactions

Homomorphic encryption (HE) is an encryption technique that promotes the computation on encrypted information rather than decrypting it for normal operations, which contributes to the privacy of financial transactional data. An unencrypted transaction value m gets encrypted with public key pk:

$$c = E_{pk}(m) \quad (1)$$

where E_{pk} is the encryption function. With named homomorphic property, operations can be executed directly on the encrypted data.

$$E_{pk}(m_1) \cdot E_{pk}(m_2) = E_{pk}(m_1 + m_2) \quad (2)$$

$$E_{pk}(m_1)^{m_2} = E_{pk}(m_1 \times m_2) \quad (3)$$

Consequently, the secure client application allows for calculations involving transactions in the cloud without the need to reveal sensitive financial details. The final output is obtained through the decryption function:

$$D_{sk}(c) = m \quad (4)$$

where D_{sk} is the decryption function with private key sk.

The banks preserve secret transactions being efficiently processed in an encrypted form through Fully Homomorphic Encryption (FHE).

3.2 Blockchain for Transaction Integrity

The Blockchain give the guaranteed for the integrity and the immutability of the financial transactions by utilizing cryptographic hashing and consensus protocols. Every transaction T_i is hashed with SHA-256:

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

The transaction were aggregated into the blocks, with the each block were having the hash of the previous block H_{i-1}:

$$B_i = \left(H_{i-1}, T_i, H(T_i)\right) \quad (6)$$

A distributed ledger which stores these blocks, so there will be no unauthorized modifications. The consensus process, i.e., Proof-of-Stake, validates the transactions, so there is the financial integrity and the security.

3.3 Capsule Networks (CapsNets) for Fraud Detection

Capsule Networks (CapsNets) enhance the ability to detect fraud by maintaining hierarchical relationships of transaction data. In contrast to standard CNNs, CapsNets employ vectorized neurons and dynamic routing in order to recognize patterns of fraud. For a given input transaction vector x, it is transformed into capsule outputs through transformation matrices:

$$\hat{u}_{j|i} = W_{ij} u_i \quad (7)$$

where W_{ij} is the learned transformation matrix, and u_i is input capsule. Routing-by-agreement mechanism updates weights of capsules

$$c_{ij} = \frac{\exp(b_{ij})}{\sum_k \exp(b_{ik})} \quad (8)$$

$$s_j = \sum_i c_{ij} \hat{u}_{j|i}, v_j = \text{squash}(s_j) \quad (9)$$

where c_{ij} are coupling coefficients and v_j is the final capsule output. Fraudulent transactions have varying hierarchical patterns, enabling CapsNets to differentiate legitimate transactions from anomalies.

3.4 Cloud-Based Processing for Scalability

To handle enormous financial transactions, cloud-based processing ensures scalability and real-time analysis. Cloud nodes process encrypted data via parallel computing and distributed architectures:

$$T_{\text{total}} = \frac{T_{\text{transaction}}}{N_{\text{nodes}}} \quad (9)$$

where T_{total} is the overall processing time, $T_{\text{transaction}}$ is transaction workload, and N_{nodes} is the total cloud servers.

Load balancing techniques like Round Robin and Least Connections distribute processing power dynamically to maximize transaction rates:

$$L_{\text{balance}} = \min(\sum_{i=1}^{N} W_i) \quad (10)$$

whereW_i is workload allocation per cloud node. This approach makes efficient management of massive transaction volumes possible in real-time financial application scenarios

4. Results and Discussion

The suggested Homomorphic Encryption and Blockchain-based Fraud Detection Model has a 96.21% accuracy and 96.98% precision, low false positives and high fraud detection accuracy. The model has high sensitivity (94.02%) and specificity (98.23%), classifying transactions effectively with low misclassification errors. It has a very low FPR (1.77%) and FNR (5.98%), enhancing the accuracy of fraud detection. Figure 2 validates its efficiency, and Figure 3 illustrates Homomorphic Encryption's performance with encryption and decryption time of 5.78 ms and 5.21 ms to ensure secure processing of transactions. These findings make it a scalable and very secure cloud-based fraud detection system.

4.1 Datasets Description

This data set consists of 1,000 synthetic bank transactions, including transfers, withdrawals, and deposits with primary attributes such as Transaction ID, Receiver and Sender Account IDs, Amount, Type, Timestamp, and Status. A Fraud Flag to detect fraud, geolocation information for spatiotemporal analysis, and performance monitoring metrics such as Device Used, Network Slice ID, Latency, and Bandwidth are included. An added security feature is a masked PIN Code. Prepared for financial modeling, fraud analysis, and network optimization, the dataset is capable of supporting machine learning solutions to predict fraud, increase security, and enhance the efficiency of transactions.

4.2 The Suggested Model's Efficiency

The proposed fraud detection model was evaluated based on performance measures to verify its capability in detecting fraudulent transactions. The model demonstrated high precision, low false positive/negative rate, and balanced precision-recall performance. Table 1 shows the performance measures, reflecting high accuracy, precision, sensitivity, specificity, and balanced F-measure, which provide efficient fraud detection with minimal misclassification rates.

Table 1: Performance Metrics of the Proposed Fraud Detection Model

Metric	Accuracy	Precision	Sensitivity	Specificity	F-measure	NPV	FPR	FNR
Value (%)	96.21	96.98	94.02	98.23	95.26	93.37	1.77	5.98

The findings validate that the model performs extremely well to identify authentic and fake payments. Accuracy and precision are very high with very low false positives, and sensitivity assures sound fraud detection. The specificity of the model avoids false designation of authentic transactions as fake and hence minimizes false alarms. The F-measure offers balanced compromise between recall and precision such that the model is strong to detect fraud without considerable misclassification. Moreover, its low FPR and FNR further reinforce its dependability in error minimization to ensure safe financial transaction monitoring.

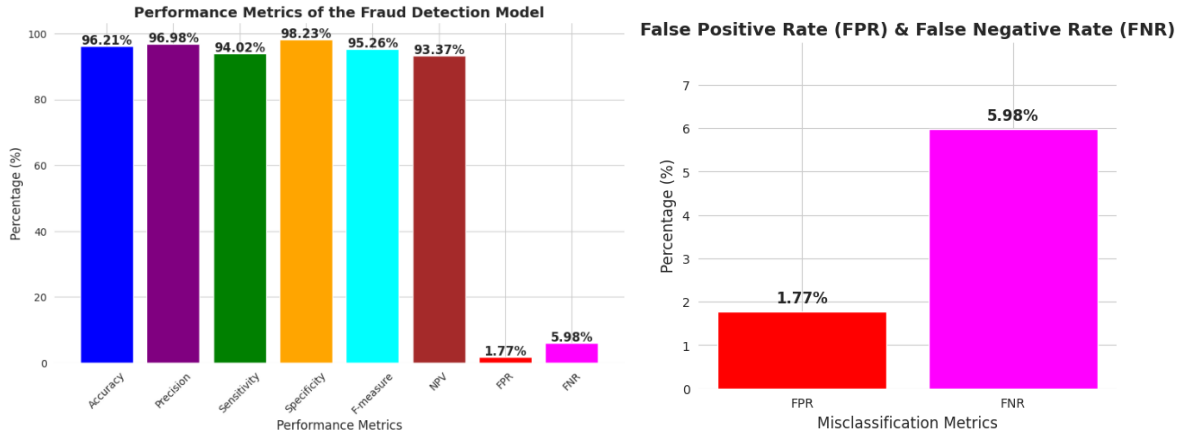

Figure 2: Comprehensive Performance and Misclassification Metrics of the Proposed Method

Figure 2 presents the performance metrics of the model proposed for fraud detection in terms of significant parameters like Accuracy, Precision, Sensitivity, Specificity, F-measure, and NPV. The higher values across show that the model is effective enough in correctly identifying fraudulent transactions and minimizing the misclassifications. In addition, both the FPR and FNR are independently calculated, proving that the model holds the ability to minimize false alarms without compromising timely fraud detection. The low value of FPR minimizes pointless alarms, while the low FNR ensures positive detection of abuse transactions, which proves the excellence of the model in safe money transaction monitoring.

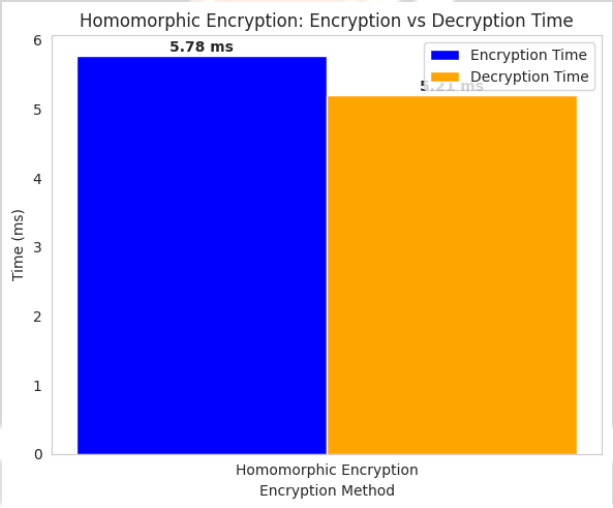

Figure 3: Encryption vs. Decryption Time in Homomorphic Encryption

Figure 3 illustrates a comparison of encryption and decryption times of Homomorphic Encryption. Data encryption takes 5.78 ms, while decryption takes marginally less at 5.21 ms. This reflects the computational cost of data encryption to maintain information private. The figure indicates how well Homomorphic Encryption performs in doing secure computations without revealing sensitive financial data.

5. Conclusion

The Homomorphic Encryption and Blockchain-based Model for Fraud Detection, proposed, increases cloud banking security, speed of fraud detection, and scalability. By using Homomorphic Encryption for privacy preservation, Blockchain for transaction validation, Capsule Networks (CapsNets) for fraud detection, and Cloud-Based Processing for scalability, the system provides secure, real-time, and tamper-proof financial transactions. With great precision and accuracy, and few false positives and negatives, the model minimizes fraud risks while ensuring transaction integrity. The encryption-decryption performance also guarantees smooth financial processing. Future work will investigate federated learning for privacy-preserving fraud detection, quantum-resistant cryptography for improved security, and hybrid deep learning models for better accuracy and fewer false

positives. Blockchain scalability optimization and Explainable AI (XAI) are also to be explored for maximizing fraud prevention transparency.

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