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Secured E-Banking using Multi-Identity based Fully Homomorphic Encryption

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Abstract

In today's digital landscape, ensuring the security of e-banking platforms is crucial for preventing unauthorized access and safeguarding sensitive financial information. This project employs Fully Homomorphic Encryption (FHE), a significant advancement in cryptography that enables the processing of encrypted data without the need for decryption, thereby preserving privacy throughout the transaction. A pivotal aspect of the system is its encrypted authentication mechanism, which protects login credentials, including usernames and passwords. Additionally, the platform introduces a multi-identity authentication model, allowing users to engage with the system under various secure roles. By integrating FHE with a multi-identity framework, the system provides robust protection against cyber threats.

Keywords: Fully Homomorphic Encryption, Cyber Security, Data privacy, Access Control, Multi-identity, Encrypted processing, Digital Banking.

1. Introduction

The accelerated proliferation of digital banking has greatly enhanced financial convenience and access but also put banking systems under advanced cyber-attacks. With sensitive information and financial data under perennial threats, conventional encryption techniques albeit secure for protecting data in transit or at rest—are lacking in security during the processing of data because they need to be decrypted for calculation. Such exposure offers a tremendous vulnerability that intruders can take advantage. In order to tackle this challenge, this project envisions the use of Fully Homomorphic Encryption (FHE) in e-banking systems. FHE is a cryptographic science breakthrough that can do direct calculations on encrypted data

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without decrypting it. This provides constant confidentiality and integrity of data even at processing time, thus bridging a big security loophole in traditional systems.

Additionally, contemporary banking systems commonly include multiple user profiles—customers, administrators, auditors each having different access requirements. Conventional authentication mechanisms usually do not have the flexibility to support this complexity securely. In order to address this shortcoming, the system proposed here puts forward a multi-identity authentication model so that users can work under different, secure identities depending on their roles. This role-based access model not only exercises tighter control but also thwarts internal and external attacks by restricting user privileges to necessary operations.

By integrating the revolutionary potential of Fully Homomorphic Encryption with a strong multi-identity authentication system, the offered platform is a new-generation solution for secure e-banking guaranteeing data privacy, role-aware access control, and immunity to sophisticated cyber-attacks.

2. Related work

Fully Homomorphic Encryption (FHE) has emerged as an important cryptographic tool for computation over encrypted data. It does not require decryption, providing end-to-end privacy in sensitive data operations. The scheme in [1] presents a compact and efficient multi-identity FHE system where multiple users can encrypt under various identities and be able to perform operations on their ciphertexts without conversion, with optimal communication overhead and system scalability. Improvements to privacy-protecting comparison are addressed in [2], where authors describe techniques to minimize computational overhead and latency in secure comparison, with strong implications for real-time applications. The approach in [3] targets floating-point computation in FHE and presents an overflow-detectable method, essential for numerical computations with sensitive scientific or financial data. With regard to hardware acceleration, the research in [4] describes an FPGA implementation of FHE that is compatible with real-time data encryption and decryption, rendering it more practical for cloud computing systems. The framework structure of leveled identity-based FHE schemes proposed in [5] introduces flexibility for access control within hierarchical organizations without the necessity of intricate key exchanges.

Previous works such as [6] and [7] offer more general introductions to FHE schemes, describing performance trade-offs and structural distinctions between partially, somewhat, and fully homomorphic systems. Such surveys highlight bootstrapping efficiency and noise management, which are still current issues in FHE deployment. The work in [8] also delves further into practical limitations and uses, particularly in secure multiparty computations and outsourced data processing. Deeper theory is provided in [9], explaining FHE from the perspective of finite fields, providing improved versions of schemes like BGV and BFV to enhance their cryptographic security and operational performance. This is supplemented by comparative analysis in [10], which provides real-world implementations and compares encryption throughput, key size, and computational latency, thereby providing practical metrics. Taken together, these papers reflect the fast-tracked coming of age of FHE as a theoretically robust but computationally onerous framework into a more optimized, application-focused cryptographic tool. Ongoing advances in software architecture, hardware design, and mathematical framework are making FHE ever more feasible for uptake in secure cloud computing, privacy-preserving machine learning, and encrypted database systems.

3. Security Consideration and Threat Model

This study employs a multi-layered security system that goes beyond the primary application of Fully Homomorphic Encryption (FHE) to address extensively typical internal and external threats of e-banking systems. To begin with, FHE permits computations to be executed directly on encrypted data without exposing it during computation, which is a severe weakness in traditional systems that need to decrypt data for computation. Second, unauthorized access is blocked by employing multi-identity and multi-factor authentication mechanisms, which drastically minimize the probability of credential stealing or brute-force attacks. Third, replay and injection attacks are prevented by employing session tokens and time-stamped transaction requests such that any attempt to reuse or inject unauthorized data within a session is rendered useless. Fourth, integrity of the data is maintained with the use of cryptographic hash functions that can identify and avert unauthorized changes during storage or transit. Lastly, the system also deals with internal threats with role-based access control, which limits the rights of internal users, reducing chances of administrative abuse or accidental exposure of data. This multi-layered defense model enhances the entire robustness and reliability of the e-banking infrastructure.

3.1 Security Evaluation Parameters

The performance of the suggested security measures was tested against some of the most important performance parameters. The accuracy of authentication was measured by FAR and FRR in the multi-identity authentication module, which guaranteed valid users were properly identified without allowing unauthorized ones. Encryption overhead was examined by taking a measurement of encryption, decryption, and homomorphic processing times and comparing them against conventional encryption techniques like AES and RSA to compare performance efficiency. Access control strength was tested by testing a variety of unauthorized accesses like privilege escalation and credential spoofing to assess the strength of access controls in hostile environments. Data confidentiality score monitored the percentage of operations performed without decrypting sensitive information, which was a direct measurement of the implementation quality of Fully Homomorphic Encryption (FHE) to maintain data privacy. Finally, scalability testing was conducted by emulating user loads of between 10 and 500 concurrent users, all the while keeping the security controls functioning effectively and never compromising system performance under heavy loads.

4. Proposed Work

The proposed e-banking platform introduces a next-generation security framework by incorporating Multi-Identity Based Fully Homomorphic Encryption (FHE) a cutting-edge cryptographic approach that guarantees data privacy, even during computation. Traditional security models, while effective at protecting data in transit or at rest, require decryption during processing, exposing critical data to potential exploitation. This project eliminates that vulnerability by performing operations directly on encrypted data, thereby preserving privacy throughout the transaction lifecycle.

At the core of the system's architecture lies a multi-layered design that blends robust encryption, flexible identity management, and comprehensive user access control. The platform is structured into four essential layers, each contributing to the system's overall security, scalability, and performance.

The User Interface (UI) Layer acts as the primary communication point between end-users and the system. It manages actions such as account creation, login, transaction initiation, and status monitoring. Designed with user experience in mind, this layer ensures that

individuals whether customers, administrators, or auditors can navigate the system efficiently while being assured of secure interactions. Accessibility is paired with authentication, ensuring every user action is verified before being processed.

The Encryption and Computation Layer is where the real innovation lies. This component houses the Fully Homomorphic Encryption engine, enabling the execution of mathematical and logical operations on encrypted data. This means that financial computations, balance checks, fund transfers, and updates are all carried out without revealing any raw information to the backend or system operators. Even in the unlikely case of a breach, data remains indecipherable, thereby eliminating the threat posed by insider attacks or external intrusions.

A key innovation in the proposed framework is the Multi-Identity Authentication Module. This module introduces role-specific identities for users, allowing them to switch between secure roles based on their responsibilities. The Database Layer serves as the secured storage hub for all sensitive data, including login credentials, user profiles, encrypted transaction records, and activity logs. Every data item stored in this layer is encrypted using advanced schemes, ensuring that even if the database is compromised, the data remains inaccessible without the appropriate decryption keys.

Ultimately, this project not only enhances the security of online banking systems but also sets a precedent for future banking technologies by delivering a privacy-first, role-aware, and tamper-resistant financial environment. The proposed solution paves the way for secure, transparent, and efficient e-banking systems, ensuring that users can manage their finances without compromising on data protection or user experience.

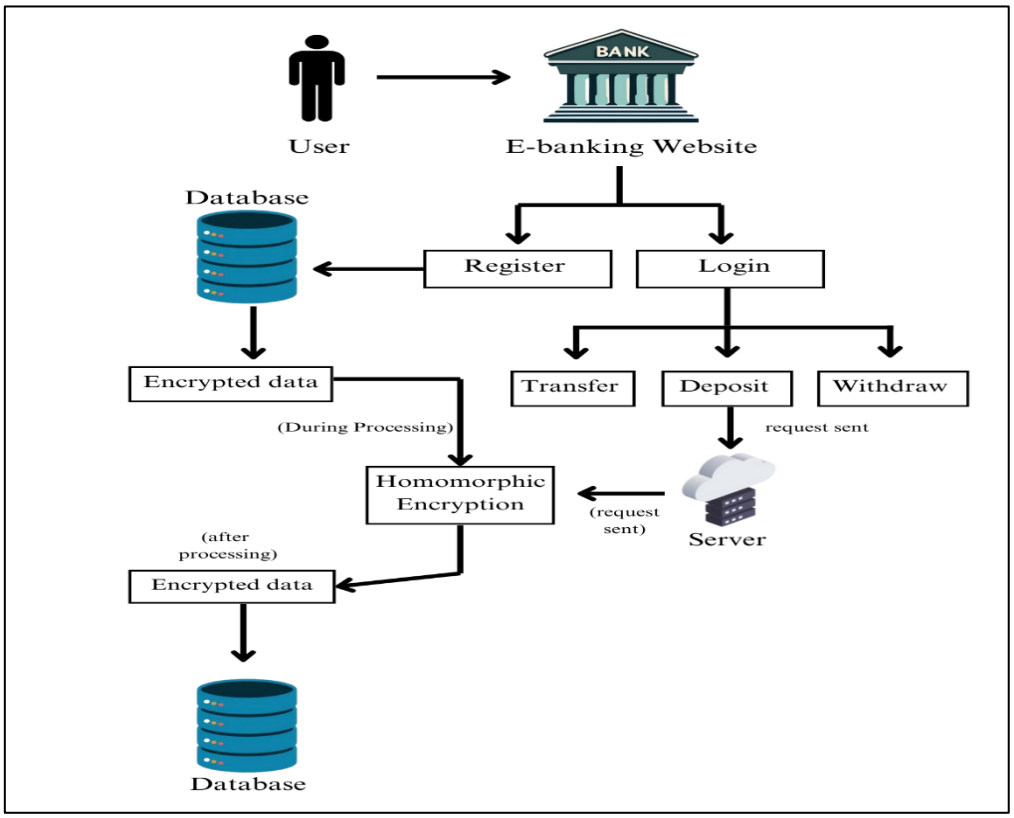

Figure 1. Architecture Diagram

5. Results and Discussion

The project culminated in the successful implementation of a Multi-Identity Based Fully Homomorphic Encryption (FHE) framework tailored specifically for secure e-banking operations. The core focus was on building a system that ensures both data confidentiality and role-specific access control throughout the transaction process.

At the heart of the implementation is the development of advanced encryption algorithms under the FHE paradigm, allowing operations to be performed directly on encrypted data. This eliminates the need for decryption during computation, thereby maintaining privacy even while processing sensitive financial information. Such an approach is critical in banking systems where data integrity and confidentiality are non-negotiable.

Additionally, a comprehensive quantitative analysis was conducted to benchmark the performance of the proposed system. The encryption time for Fully Homomorphic Encryption (FHE) was compared against traditional methods (AES and RSA) using datasets ranging from 10KB to 1MB, revealing the latency introduced by advanced encryption. Resource utilization

metrics including CPU load, memory consumption, and disk I/O were monitored during encrypted transactions to assess system efficiency. To evaluate scalability, the system was stress-tested under simulated multi-user environments, scaling from 10 to 500 concurrent sessions, and was found to maintain consistent performance under load. Furthermore, security resilience was tested through simulated brute-force and replay attacks, allowing assessment of the system's detection speed and its ability to maintain integrity during active threat scenarios.

A key advancement was the integration of a multi-identity authentication mechanism, where users are assigned unique roles and identities based on their function within the system. This model enhances access control by restricting functionalities to authorized users only. Role-specific privileges were rigorously tested to validate the system's ability to prevent unauthorized access and misuse of administrative capabilities.

The performance of the proposed FHE system was evaluated using a variety of operational metrics. Encryption, decryption, and homomorphic computation times were measured to assess the overhead introduced by FHE. Although the encryption model naturally introduces higher latency compared to conventional methods, the use of optimization techniques such as parallel processing and efficient key management significantly improved response times, making it feasible for real-time banking applications.

Through this project, a robust and secure e-banking platform was realized, one that processes transactions without compromising user privacy. The encrypted computation model ensures that all sensitive data remains protected throughout its lifecycle, from input to processing and storage.

To validate the effectiveness and reliability of the proposed system, several assessment strategies were employed. User role testing was conducted to ensure that each identity admin, auditor, and customer operated strictly within its assigned privileges, confirming the robustness of role-based access control. Penetration testing was performed using tools such as OWASP ZAP to identify and address vulnerabilities, particularly in the authentication and encryption modules. A comparative study was also undertaken, where the system's performance and privacy metrics were evaluated against conventional encryption frameworks like AES and RSA, highlighting the superior security and data confidentiality achieved through FHE. In addition, comprehensive test case coverage, encompassing both functional and non-functional

scenarios, was implemented to verify consistent and reliable behavior across typical and edge-case usage patterns in real-world e-banking environments.

Despite the promising results, certain limitations remain that present opportunities for future enhancement. One such area is encryption overhead although the system has been optimized, Fully Homomorphic Encryption (FHE) still introduces notable computational latency, which could be further minimized through GPU acceleration or specialized hardware. Additionally, the current scope of user testing is limited; future plans include expanding to broader demographics in terms of age, experience level, and user roles to ensure both accessibility and security for a wider audience. Another potential improvement is the integration of AI-driven real-time security monitoring, which would enhance the system's ability to detect and respond to anomalies proactively. Finally, ongoing feedback from live users after deployment will be essential for refining the user interface and improving overall system functionality based on practical usage insights.

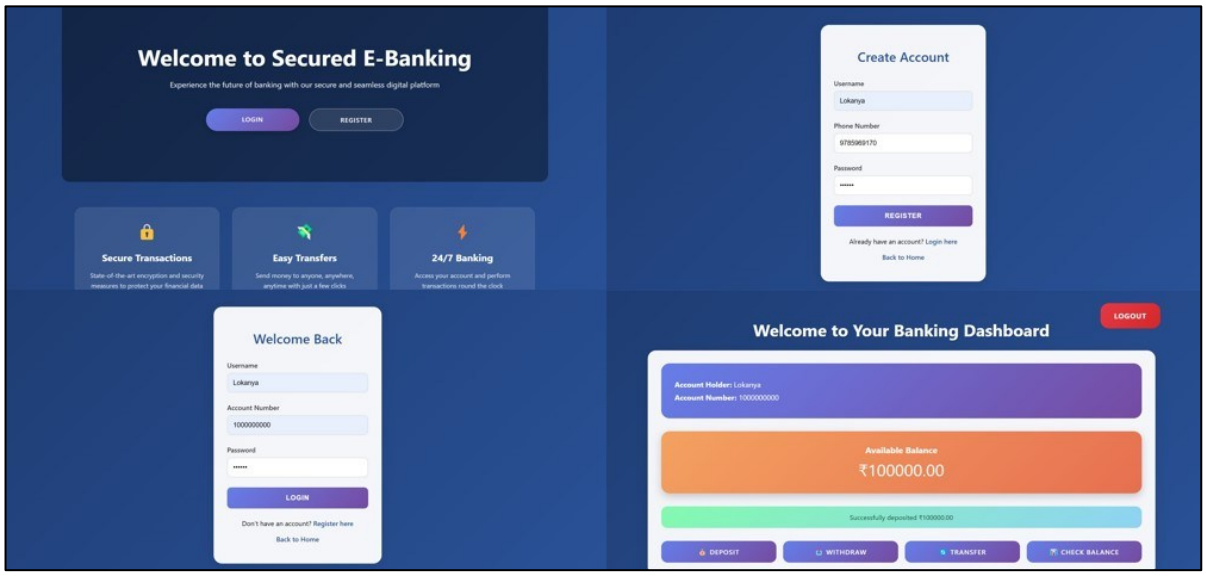

Figure 2. User Interfaces Overview

The main dashboard, which gives quick access to secure banking features, and the login/registration modules are both highlighted in Fig. 2, which gives a visual overview of the application's user interface.

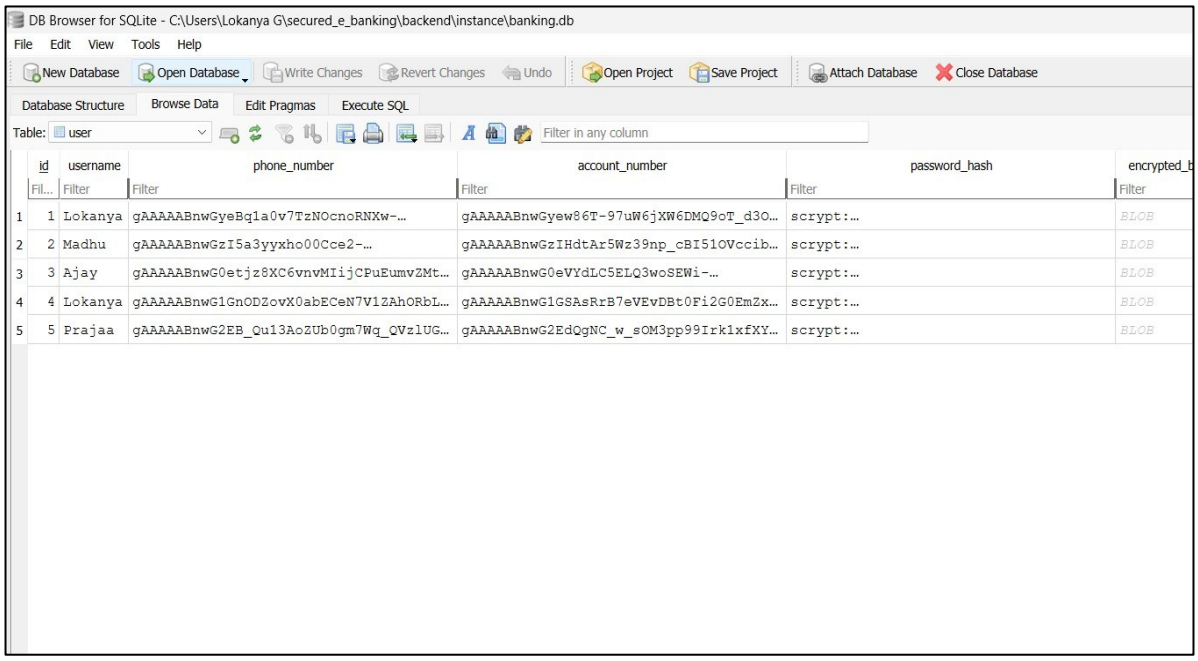

Figure 3. Data Storage using FHE

Fully Homomorphic Encryption (FHE), as shown in Fig. 3, is used to securely store data, guaranteeing that private financial information is encrypted even while it is being calculated.

```
C:\Users\Lokanya G\secured_e_banking\backend>pytest --cov=app test_integration.py
============================================= test session starts =============================================
platform win32 -- Python 3.12.4, pytest-8.3.5, pluggy-1.5.0
rootdir: C:\Users\Lokanya G\secured_e_banking\backend
plugins: cov-6.1.1
collected 3 items

test_integration.py ...                                                                              [100%]

================================================ tests coverage ================================================
_________________________________ coverage: platform win32, python 3.12.4-final-0 _________________________________

Name     Stmts   Miss  Cover
--------------------------
app.py     388    128    67%
--------------------------
TOTAL      388    128    67%
============================================== 3 passed in 7.23s ===============================================
```

Figure 4. Integration Testing Result

With 100% code coverage and all test cases passing, the results of successful integration testing are displayed in Fig. 4, guaranteeing system dependability.

6. Conclusion

The adoption of Multi-Identity Based Fully Homomorphic Encryption (FHE) in e-banking systems represents a significant advancement in fortifying security and safeguarding user privacy. By enabling the processing of encrypted data without necessitating decryption, this system mitigates the risk of exposure to potential breaches during computation, thereby ensuring that confidential financial information remains secure even in vulnerable environments. Furthermore, the implementation of multi-identity authentication enhances user validation by assigning specific roles and access levels, thereby reinforcing a secure and controlled operational framework. Looking ahead, the incorporation of quantum-safe encryption techniques and performance enhancements could further bolster the resilience and trustworthiness of e-banking platforms, establishing new benchmarks for secure online transactions.

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