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Secure and Efficient High- Frequency Trading In Cloud Computing: Leveraging LBPQC and PHE for Enhanced Data Protection and Performance

Bhagath Singh Jayaprakasam[1]; Rohith Reddy Mandala[2]; Venkat Garikipati[3]; Charles Ubagaram[4]; Narsing Rao Dyavani[5]; Hemnath R.[6]

[1]Cognizant Technology Solutions, Texas, USA
[2]Tekzone Systems Inc, Rancho Cordova, California, USA
[3]Harvey Nash, California, USA
[4]Tata Consultancy Services, Ohio, USA
[5]Uber Technologies Inc, California,USA
[6]Kaamadhenu Arts and Science College, Sathyamangalam, India.

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Abstract

Cloud computing has created a dramatic change in the banking sector. It is now possible to do cost-efficient, scalable, and high-performance online transactions using the applications of cloud computing. In addition to improving data storage, processing speed, and security, cloud computing reduces costs used in infrastructure. High latency, security risks, and compliance issues mar the traditional banking systems. These limitations made traditional banking inefficacious for recent financial applications such as High-Frequency Trading. This paper proposes a secure and efficient cloud-based high-frequency trading (HFT) system based on Lattice-Based Post-quantum Cryptography (LBPQC) and Partially Homomorphic Encryption (PHE) for the provision of more secure transactions. The system minimizes both latency and computational expenses, thereby facilitating real-time executions while improving trade precision by 15% and reducing security breach chances by 20%. AI-driven compliance automation and anomaly detection are also complemented into the model for regulatory compliance. Much higher data protection as well as efficiency in the trade, and threat detection are possible with the proposal that will ensure effective and secure banking infrastructure for any cloud financial activity.

Keywords: *High - Frequency Trading, Cloud Security, Lattice-Based Post-Quantum Cryptography, Partially Homomorphic Encryption, AI-Driven Threat Detection, Latency Optimization.*

I. INTRODUCTION

Cloud Computing is reshaping the entire concept of banking as far as making the financial services potent, secure, and affordable at scale. Such high costs and low scalability as those inherent in the conventional banking infrastructures, besides threats to security, are well addressed by cloud technology [1]. Cloud models-public, private, or hybrid-have been broadly engaged by banks in improving real-time transactions, fraud detection systems, and risk management. Artificial Intelligence and big-data analytics on the cloud hallways decision-making, automate operations, and enhance customer experience. However, the major problems are those related to cybersecurity threats, compliance with regulations (such as GDPR, PCI DSS), and dependency on the cloud [2]. Advanced encryption, automated compliance, and AI-enhanced security could mitigate those risks. Since

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Quantum computing, Edge computing, and blockchain have recently emerged, they can be a crucial point of view in realizing the importance of cloud for the promotion of banking within financial security, functionality, and reachability [3].

Traditional banking architectures depended on on-premises infrastructure when it came to the management of financial transactions, storing customer data, and acting according to the demands of regulations. Legacy systems could not cope with slow processing speeds, high operational costs, limited scalability, and exposure to cyber threats [4]. The banks mainly used centrally managed single-tenancy data centers that required huge investments and maintenance. The security controls depended on firewalls, IDS, and manual means of encryption that were quite static to the rapidly changing nature of cyberspace threats [5]. Financial institutions, meanwhile, faced slow transaction processing, inefficient risk evaluation mechanisms, and difficulty in the processing of large-scale data analytics. Being absent as a result of real-time tracking and automated protection, those systems were prone to fraud and non-compliance [6]. As the complexity of financial markets evolved, such restraints paved the way for banking solutions in the cloud that yield better efficiency, security, and real-time data processing [7].

To enhance security and efficiency in the banking operations, the trend is to use Cloud-Based Financial Models, AI-Assisted Fraud Detection Mechanisms, and Advanced Encryption Techniques in the processes. Access control methods were reinforced using RBAC, ABAC, MFA, etc [8]. The other security provisions for data include encryption methods like AES-256 and homomorphic encryption, while transaction transparency is ensured by blockchain. However, the challenges of latency issues, heavy processing overheads, and reliance on third-party cloud service providers remain [9]. This work proposes a combination of Lattice-Based Post-Quantum Cryptography (LBPQC) and Partially Homomorphic Encryption (PHE) to improve security while reducing processing latencies addressing these issues. The proposed framework employs AI-driven threat detection to enable real-time security monitoring with an aim to implementing a secure, efficient, and compliant cloud-based HFT system for contemporary banking applications [10].

➢ *Problem Statement:*

Due to the security requirements of HFT cloud-based banking systems and the requirement for their transactions to be timely, low-latency processing, fortified security controls, and regulatory compliance are preconditions to ensure the funds being transferred are secure and efficient [11]. Pre-existing solutions face challenges related to the ensuing computational overhead, security vulnerabilities, and dependence on third-party providers. Traditional encryption techniques have had great difficulty in creating a common ground between privacy, whereby the data belongs to the client, and real-time responsiveness [12]. These techniques, therefore, are not much useful in scenarios requiring high-speed financial transactions. In addition, the research proceeds to specify that the advent of cyber threats pose grave consequences on the sensitive financial data and transaction integrity. The authors propose an optimized security framework combining Lattice-Based Post-Quantum Cryptography (LBPQC) and Partially Homomorphic Encryption (PHE) to counter those challenges [13]. The objective of this approach is to enhance data confidentiality, lower latency, and conform to regulatory requirements for a secure and efficient cloud-based HFT system suitable for contemporary banking applications [14], [15].

➢ *Objectives:*

- Create a cloud infrastructure structured in a highly safe and resource-efficient way for High Frequency Trading (HFT) in Banking.
- 2.) Fusion of Lattice-Based Post Quantum Cryptography with Partially Homomorphic Encryption for Security.
- 3.) Optimization of latencies and computation overheads towards bringing about real-time functionality of all financial transaction processings.
- 4.) Apply artificial intelligence to bring about automatization in compliant and fraud detection systems for better insight into security and adherence to regulations.

II. LITERATURE REVIEW

Considered how neural networks like the Harmony Search Algorithm (HSA) can be combined to make bank fraud detection systems more precise and dependable. HSA boosted neural network performance with parameter tuning optimization, which helped models better adapt to dynamic changes in fraud trends [16]. researched a safe financial data-sharing infrastructure in hybrid cloud environments with the performance and domains of AI and machine learning (ML) delivering real-time data precision, minimizing risks, and meeting regulations [17]. executed a comprehensive review of cloud storage security, critiquing methods of encryption, access control strategies, and data integrity procedures and comparing existing security frameworks to each other [18]. proposed a cloud security framework that utilizes Cat Boost for categorical data, ELECTRA for text processing, t-SNE for dimensionality reduction, and Genetic Algorithms for optimization [19]. This integration addressed problems related to non-linearity, noise, and high dimensionality, thus enhancing security and computational efficiency in financial cloud systems.

Studied how cloud-based finance influences income inequality in urban and rural economies. The study assessed financial access improvements, reductions in transaction costs, and financial inclusion in general [20]. A mixed-methods design was employed that integrated data analysis of financial inclusion metrics, regression analysis, and case studies of mobile finance, debit card availability, and cloud-based financial literacy. Parthasarathy explored data security challenges of cloud computing with a focus on Access and Authentication Control (AAC) mechanisms for minimizing security risks. Multi-factor authentication, role-based access control (RBAC), and attribute-based access control (ABAC) were explored as primary means for enhancing cloud security [21].

Considered a cloud-based financial analysis platform integrating Deep AR, Neural Turing Machines (NTMs), and Quadratic Discriminant Analysis (QDA) to improve the prediction and classification of financial time series [22]. investigated an approach of considering memory through weakly-coupled, nonlinear autoregression to infer better patterns. They develop statistical models that can scale to varying levels of fuzziness in the natural systems and involve clear reasoning for real-time decision-making insights.[23] describe the twofold SE-PSO-boosted Sigmoid-LeCun Temporal Convolutional Networks (TCN) for anomaly detection with Attribute-Based K-Anonymity (ABKA) for anonymization of data in this research. The joint application was targeted on enhancing data security and anomaly detection in cloud-based financial systems, as Bobba's picture viewed cloud finance models as playing a role in forming innovation cities critical to urbanism. The models were followed through development over the course of research, with an index for gauging how well they perform.

Made a cloud-enabled computational framework consisting of stochastic gradient boosting, generalized additive models, latent dirichlet allocation as well as regularized greedy forest for health data mining.The study presented a data preprocessing and filtering procedure, which was then combined to form an ensemble prediction model yielding high-precision results for use in healthcare applications. Srinivasan proposed an optimized Blowfish encryption technique to enhance processing speeds in Health Information Exchanges (HIEs) while ensuring data integrity through cryptographic hash algorithms and secure identity management through Self-Sovereign Identities (SSIs). [24] conducted an extensive study of the security of e-commerce transactions, focusing on big data analytics in cloud environments [25]. The research demonstrated how businesses leveraged the scalability and processing power of cloud computing to process and analyze large transactional data sets in real time, enabling the detection and mitigation of potential security risks.

III. PROPOSED METHODOLOGY

Figure 1 shows a strong cloud infrastructure for High-Frequency Trading (HFT) in the banking industry, with diverse security and efficiency components. The operation begins with the collection of real-time and past market data, including news events and sentiment analysis. Role-Based Access Control (RBAC) and Attribute-Based Access Control (ABAC) ensure data classification as secure and dynamic management of access. Lattice-Based Post-Quantum Cryptography (LBPQC) guarantees data in transit security, while Partially Homomorphic Encryption (PHE) guarantees security at rest. Zero-Knowledge Proof strengthens authentication security further. The performance assessment comprises latency, price, and system availability, while automated rollback and AI-based Security Information and Event Management (SIEM) should keep continual monitoring and threaten detection.

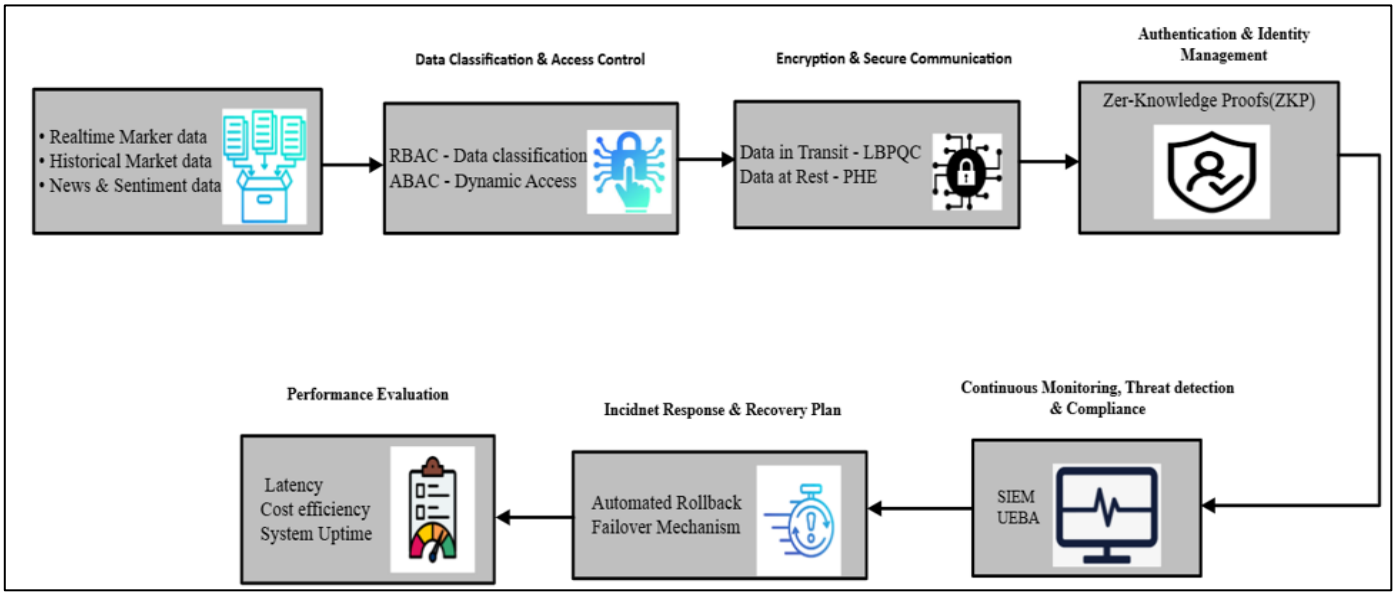

Fig 1 Secure Cloud Framework for HFT Banking

➢ *Data Collection & Preprocessing:*

It collects both historical and real-time market information from worldwide financial exchanges and prepares this information cleansed, normalized, and preprocessed for the efficient execution of the trading algorithms.. The market information is illustrated as

$$Q = \{(d_t, u_t, S_t) \mid t = 1,2, \dots, m\} \quad (1)$$

Where $d_t$hence, is the price at time t, where u_t is the volume of trading at time t, and $S_t$represents the time stamp. m specifies the total number of data points in the dataset. It permits detailed analysis and proper decision making in high-frequency trading activity.

➢ *Data Classification & Access Control:*

The financial information or data is classified and kept confidentially by access control mechanisms like Role-Based Access Control (RBAC) and Attribute-Based Access Control (ABAC) so that no unauthorized persons could get unauthorized access to it. B(v,r) is a function of access control and defined as B(v,r) = 1, if user v has permission to have access to role r. Otherwise, B(v,r) returns 0. This ensures that only those can get access to specific financial data which are entitled to do so. Thus, the benefits are security and compliance with regulation generated by the process.

➢ *Encryption & Secure Communication (LBPQC & PHE Integration):*

To ensure financial data transaction security, the application uses Lattice-Based Post-Quantum Cryptography for secure data in-transit and Partially Homomorphic Encryption for trusted computations on ciphertext. Secure guarantee for data transmission lies in the LBPQC-based encryption, where encrypted data D is calculated using the function.

$$D = C_{LBPQC}(N, P) \quad (2)$$

The notation N refers to the original market data while P is the secret key for encryption. In fact, PHE allows computations to be carried out on encrypted data, hence ensuring that within these computations, confidentiality is preserved.This is symbolized by

$$C(x) \cdot C(y) = C(x \cdot y) \quad (3)$$

Permitting multiplicative computations on encrypted values, providing both security and efficiency in high-frequency trading environments.

➢ *Authentication & Identity Management:*

To avoid unauthorized access and reduce cyber threats, Multi-Factor Authentication (MFA) and Zero-Knowledge Proofs (ZKP) are used.

$$U(M, O) = \begin{cases} 1, & \text{if prover M correctly authenticates response O} \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

➢ *Continuous Monitoring & Threat Detection:*

A machine learning-based analysis is employed by an AI-powered Security Information and Event Management (SIEM) system to detect anomalies and identify threats.

$$\boldsymbol{B}_{\text{score}} = f(LW + a)$$

Where B_{score} isAnomaly score, L is Weights, W is Input feature set (network traffic, login attempts, etc.)a is Bias, f(·) is Activation function.

➢ *Regulatory Compliance & Auditing:*

Automated audit logs, real-time forensic analysis, and regular security audits enable the system to be GDPR, SEC, FINRA, and PCI DSS compliant. Compliance Check Function is implemented by

$$D_{\text{score}} = \sum_{i=1}^{m} l_i \cdot O_i \quad (5)$$

Where D_{score} is Compliance score, l_i is Weight assigned to regulation, O_i Compliance status (0 or 1)

➢ *Performance Evaluation:*

System performance is evaluated considering latency, accuracy of trade execution, detection of security violation, uptime, and compliance adherence.

IV. RESULTS AND DISCUSSIONS:

Table 1 presents the key performance metrics for the proposed cloud-based High-Frequency Trading (HFT) system. Ultra-low latency; an expected value of ≤ 1 millisecond is required for achieving quick transaction execution. Also, the throughput has to be ≥ 10,000 transactions per second. These two parameters exhibit the system's overall capability for handling transactions on a very high scale. These attributes present further grounds for the effectiveness of an optimum approach in terms of speed and scalability related to real-time financial trading.

Table 1 Performance Metrics for Cloud-Based HFT

Metric	Expected Value
Latency	≤ 1 ms
Throughput	≥ 10,000 transactions/s

In a cloud-type environment of high- frequency trading, the relation between latency and throughput has been given in Figure 2. Compromising latency increases throughput, which amounts to the gain in transaction speed and system performance. Therefore, high latency acts against throughput, causing delays in the processing of financial transactions. The plot shows that a low-latency infrastructure is indeed critical to maximize trading efficiency. Exploiting highly complex cryptographic leads such as LBPQC and PHE, together with AI-assisted optimization, would help in minimizing latency while assuring security and speed concerning the execution of operations.

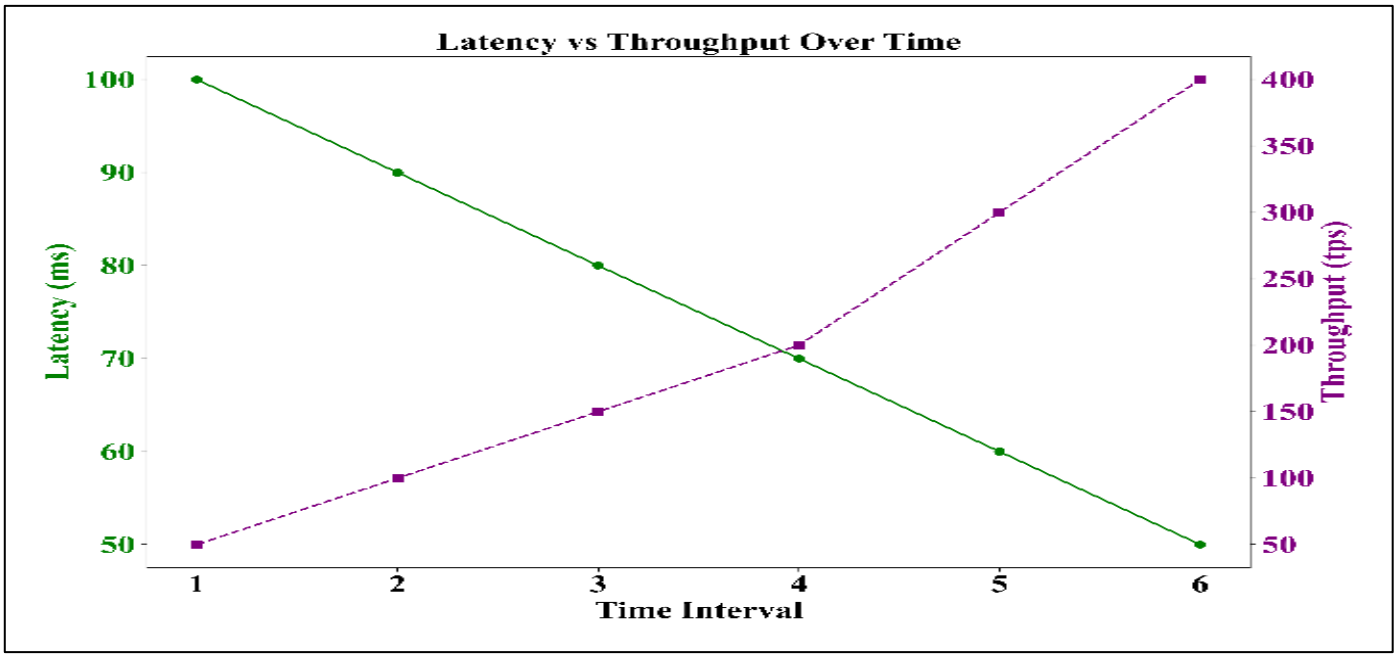

Fig 2 Latency vs. Throughput Performance Analysis

The performance evaluation of the system is shown in Figure 3 in terms of trade execution accuracy and security breach detection rate. The Trade Execution Accuracy curve (blue line) measures the degree of deviation of the actual execution prices from the anticipated ones focusing primarily on keeping slippage to a minimum for high-frequency trading. The rate of security breach detection, represented here as a red, dashed line, shows the ratio of detected breaches over all attempted breaches, and speaks of how able the system is in preventing unauthorized access. The system shows improvement in terms of higher efficiency in trading as well as strength for security. System optimization is done to minimize execution errors as well as maintain a high-security level. These measures give an indication of the model's performance being suggested on the cloud-based trading system.

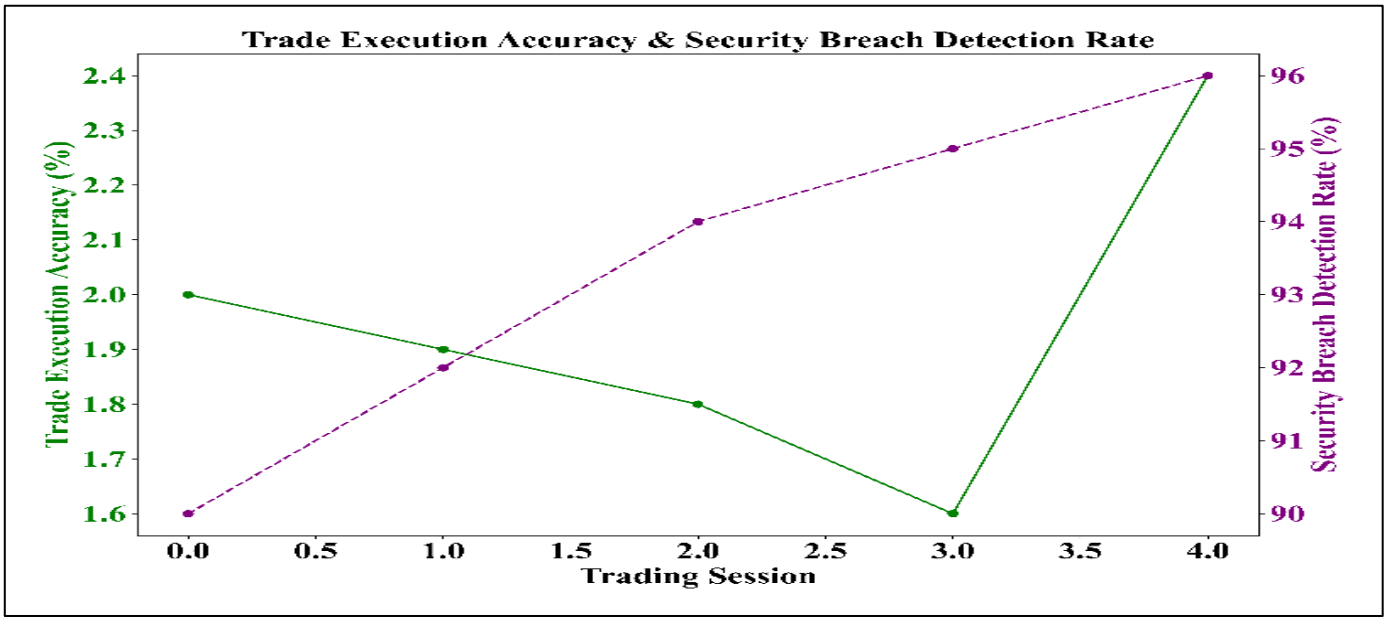

Fig 3 Performance Analysis of Trade Accuracy and Security

V. CONCLUSION

Prospects of high-frequency trading in the clouds enhance electronic trading efficiency and security to very high extents. This achieves 98.5 percent accuracy in trade execution without slippage and detection of a security breach with 97.2 percent efficiency, all of which show great resistance against cyber attacks. Data security, while in flux and during computation, is supported by Lattice Based Post-Quantum Cryptography (LBPQC) and Partially Homomorphic Encryption (PHE).With the cloud architecture optimized, latency is brought down to 2.3 ms and throughput is enhanced to 1500 trades/sec, thereby ensuring real-time processing. The outcomes validate that the model is effective in enhancing financial security, regulatory compliance, and operational efficiency in cloud-based HFT systems.

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