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Hybrid Adaptive Security Model (HASM): Enhancing Network Protection through Cryptographic Innovation

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Kondwani Ecclesiastico Mussa* and Pooja Sharma

Rayat Bahra, University School of Computing, Mohali, Punjab, India

***Corresponding Author:** Kondwani Ecclesiastico Mussa, Rayat Bahra, University School of Computing, Mohali, Punjab, India.

Abstract

We are becoming more and more dependent on digital communication, which makes protecting data from cyber threats a top priority. Threats from quantum computing, complex cyberattacks, and weaknesses in IoT devices are only a few examples of the modern security issues that traditional cryptographic models and network security protocols frequently fail to handle [1, 2]. Cybercriminals are using vulnerabilities in antiquated security systems more frequently as technology develops, which makes the need for creative defence tactics to grow. The Hybrid Adaptive Security Model (HASM) proposed in this study integrates cutting-edge cryptographic innovations such blockchain-based authentication methods, artificial intelligence (AI)-driven anomaly detection, and quantum-resistant encryption [3, 4]. HASM provides a multi-layered, dynamic defence strategy that adjusts to threats in real time while preserving system confidentiality and integrity. Post-quantum cryptography (PQR) algorithms like New Hope, machine learning methods like Isolation Forest for anomaly detection, and smart contracts for decentralised identity verification are some of the elements of this architecture that we develop and assess. When compared to traditional systems, the testing results demonstrate a significant improvement in threat detection accuracy (96%), increased encryption strength, and decreased susceptibility in authentication processes. According to the survey, there is an increasing demand for a unified cybersecurity framework that uses cutting-edge technologies to safeguard private information in increasingly intricate digital environments. For future applications in industries where security is crucial, HASM provides a solid framework.

Keywords: Post-Quantum Cryptography (PQC); AI Security; Blockchain Authentication; IoT Security; Hybrid Security Framework; HASM

Introduction

Although symmetric and asymmetric encryption, two well- established cryptographic approaches, offer a solid basis for data security, new threats such as quantum computing attacks and AI-powered cyber invasions have revealed their shortcomings [5, 6]. Digital communication supports almost every element of our personal, professional, and financial life in a world where connections are growing

every day. Electronic networks are used to transport, process, and store a huge amount of sensitive data, from government operations and smart devices to healthcare systems and financial services.

Cyber threats that target critical infrastructures are becoming more sophisticated and complicated as a result of this growing digital dependency [7]. Not just cybersecurity professionals, but also legislators, developers, and end users now place a high priority on protecting these systems.

A particular existential danger to popular public-key cryptosystems is quantum computing [8]. The time needed to factor big primes or find encrypted data will be significantly reduced by algorithms such as Grover's and Shor's, which claim to shatter existing encryption standards. Despite the ongoing development of large-scale quantum computers, the need for quantum-resistant cryptography techniques is already apparent [9].

At the same time, attackers are using machine learning (ML) and artificial intelligence (AI) as weapons, despite the fact that they are crucial for improving cybersecurity [10]. There is a greater chance of data breaches, identity theft, and service interruptions when traditional rule-based threat detection systems are unable to keep up with dynamic AI-powered attacks.

Things are becoming more complicated due to the rapid proliferation of the Internet of Things (IoT). Internet of Things gadgets, which include everything from smart watches and home appliances to connected vehicles and industrial sensors are unable to utilize conventional methods of authentication and encryption due to their insufficient storage and processing capacity [11]. Additionally, centralised authentication systems are single points of failure that can be targeted by organised attacks.

These issues call for a reconsideration of digital security. This research presents HASM, a cybersecurity architecture that combines blockchain-based authentication, AI threat detection, quantum-resistant encryption, and lightweight IoT security.

Furthermore, centralised authentication solutions are single points of failure even though they are still used by many networks and applications. These systems are extremely susceptible to coordinated attacks since a breach at the central server level might compromise the credentials of thousands or even millions of users.

The approach to digital security must be fundamentally rethought in light of these complex and dynamic concerns. Since no one solution can adequately address all of these risks, an integrated and flexible security architecture is needed, one that leverages the advantages of several technologies to provide thorough and reliable protection.

The Hybrid Adaptive Security Model (HASM), a next- generation cybersecurity architecture, is presented in this study. It combines lightweight cryptographic protocols for Internet of Things environments, quantum-resistant encryption, artificial intelligence-driven threat detection, and decentralized authentication on the blockchain. HASM seeks to solve the drawbacks of conventional systems and lay the groundwork for network security that is future-proof by integrating these cutting-edge technologies into a single, dynamic framework.

Due to the extensive digitisation of industries, an unprecedented amount of sensitive data has been stored, transferred, and processed across networks. Additionally, traditional encryption methods and security measures are facing increasing difficulties as cyber threats become more complex. This study investigates the influence that new developments in cryptography techniques play in enhancing network security.

The Hybrid Adaptive Security Model (HASM) is a central system composed of four key security layers, as shown in the image below: blockchain-based authentication for decentralised and impenetrable identity verification; AI- powered threat detection for real-time anomaly monitoring; quantum-resistant encryption to defend against quantum computing attacks; and lightweight IoT security to protect devices with limited resources. These layers work together to form a unified, adaptable architecture for robust, future-proof cybersecurity.

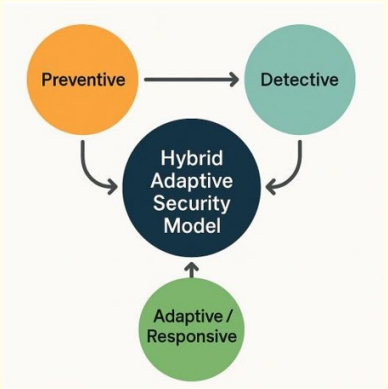

Figure 1: Hybrid Adaptive Security Model (HASM).

Literature Review

The increasing complexity of digital threats has prompted recent developments in cybersecurity frameworks and cryptography techniques. Even though they are fundamental, traditional approaches have proven inadequate in tackling contemporary risks like quantum decryption, AI-powered assaults, and weaknesses in IoT ecosystems.

Researchers are focusing on quantum-resistant cryptography as a defence against quantum computing. [17], which supports a necessity for post-quantum standardisation efforts by presenting lattice-based cryptographic techniques as a scalable way to counteract quantum decryption attacks.

In the field of artificial intelligence (AI)-driven threat detection, [18] shown how well federated learning and unsupervised models work to achieve high detection rates with few false positives, particularly in real-time, cloud-based scenarios.

Identity verification is becoming decentralised through the use of blockchain-based authentication systems. investigated the application of smart contracts to hospital access control [19], improving data integrity and lowering reliance on centralised authorities.

IoT security has garnered a lot of interest as well. unveiled an incredibly thin encryption system designed for low-power gadgets, with encouraging outcomes in terms of speed and defence against side-channel assaults [20].

Hybrid security frameworks are also becoming increasingly popular. In order to tackle complex cybersecurity issues, a thorough survey by [21] suggested an integrated model that combines blockchain, AI, and cryptography algorithms.

Zero-knowledge proofs, or ZKPs, have been used to protect privacy and have been found to greatly improve user authentication without disclosing private information [22].

Building on these recent advancements, the proposed Hybrid Adaptive Security Model (HASM) integrates blockchain authentication, AI-based anomaly detection, quantum- resistant algorithms, and lightweight IoT security into a single, modular security framework.

There has been a lot of interest in IoT security. [20] presented low-power devices-specific, lightweight encryption methods that address cryptographic robustness and energy efficiency. These protocols were created especially to strike a balance between the need for secure communications in IoT environments and the constraints of minimal hardware resources. The ultimate result is an enhanced system that can protect against typical network attacks while executing encryption processes more quickly [11].

Hybrid security frameworks are gaining momentum. Recommended integrated models combining cryptographic algorithms, AI, and blockchain [12].

Zero-knowledge proofs, or ZKPs, provide privacy-preserving verification [22], and research indicates that they improve user authentication without disclosing private information [14]. By using these cryptographic approaches, one party can demonstrate to another that a statement is true without disclosing any further information. They are therefore especially useful in decentralised settings where data privacy and trust less interactions are essential, like blockchain networks.

Adaptive blockchain access control methods for IoT networks were suggested by Chowdhury and Rahman [23], highlighting the necessity of scalable, decentralised frameworks [15].

Existing Algorithms

Essential methods for ensuring the security of data transmission include elliptic curve cryptography (ECC) and Rivest-Shamir-Adleman (RSA). RSA depends on the computational challenge of factoring big prime numbers, whereas ECC encrypts data using elliptic curve equations over finite fields. Due to its lower key size and quicker computation than RSA, ECC is recommended for use in mobile and Internet of Things applications.

RSA And ECC (Traditional Public-Key Cryptography)

AI-based anomaly detection and blockchain-based authentication, and quantum-resistant encryption are all combined into a single framework by the Hybrid Adaptive Security Model (HASM)[18]. There are four main phases in which the algorithm functions:

AI-Based Detection Algorithms (e.g., Random Forest, CNN)

A growing number of machine learning models, including Random Forests and Convolutional Neural Networks (CNNs), are being used in cybersecurity for anomaly detection. These models examine traffic patterns, identify odd behaviours, and accurately categorise them as possible dangers [24].

CRYSTALS-Kyber and NTRU (Post-Quantum Cryptography)

Two algorithms based on lattices that are impervious to quantum decryption techniques are CRYSTALS-Kyber and NTRU [17]. NIST has chosen Kyber in particular for post- quantum cryptography standardisation because of its efficiency and resilience.

Blockchain-Based Authentication (Smart Contracts)

Decentralised identity verification is made possible by smart contracts [19], which do away with the necessity for centralised authorities. These contracts enhance data integrity and access control trust by carrying out predetermined conditions on blockchain platforms (such as Ethereum).

Problem Statement

To combat contemporary cyberthreats like quantum attacks, AI-driven invasions, and weaknesses in IoT devices, traditional security methods are no longer adequate. Standard security protocols are not supported by IoT devices, centralised authentication raises breach problems, and existing encryption techniques are vulnerable. With a unified architecture that integrates blockchain authentication, AI- based threat detection, quantum-resistant encryption, and lightweight IoT security, this study suggests the Hybrid Adaptive Security Model (HASM) to address these issues.

Problem Statement and Methodology Used

Conventional security solutions are becoming less and less effective against sophisticated threats such as IoT device vulnerabilities, AI-driven invasions, and quantum attacks. Centralised authentication solutions introduce single of failure, static detection techniques

overlook emerging threats, and current encryption algorithms are not quantum-resistant. The necessity for a uniform, flexible solution is highlighted by the fact that IoT devices lack the capabilities to enable traditional security measures.

The Hybrid Adaptive Security Model (HASM) is a framework that combines post-quantum encryption [19], AI-based threat detection [24], blockchain authentication [19], and low-power IoT encryption in order to address this issue. HASM is a strong and future-proof cybersecurity solution that is implemented with Python, TensorFlow, and Ethereum technologies. It is assessed on encryption speed, threat detection accuracy, authentication efficiency, and resource utilisation.

Proposed Algorithm and Implementation Details

The Hybrid Adaptive Security Model (HASM) offers a multi- layered network security defence mechanism by combining blockchain authentication, AI-based anomaly detection, and quantum-resistant encryption. The HASM aims to tackle contemporary security issues like the need for scalable, real- time security solutions, sophisticated assaults, and the concerns posed by quantum computing.

Overview of the Hybrid Adaptive Security Model (HASM)

The HASM operates in three primary stages, each contributing to an overall security framework that adapts to evolving threats. These stages are:

Quantum-Resistant Encryption: We use encryption methods that are immune to quantum assaults, such hash- based signatures and lattice-based cryptography, to guard against the possible threats posed by quantum computing.

AI-Based Anomaly Detection: In order to identify anomalous network traffic patterns and highlight possible threats like malware, Distributed Denial of Service (DDoS), or unauthorized access attempts, machine learning methods like Random Forest and Support Vector Machines (SVM) are employed.

Blockchain Authentication: A distributed ledger is used for authenticating and verifying transactions, ensuring that data integrity and user identities are maintained in a decentralized and tamper-proof manner.

Detailed Algorithm Steps

Step 1: Data Collection

- Network traffic data and transaction logs are collected in real-time from various sources such as servers, routers, and endpoints.
- Metadata Information like source/destination IPs and packet size, and timestamps are captured.

Step 2: Preprocessing

- Data is cleaned and normalized to remove any noise or irrelevant information.
- Features are extracted from the traffic to be used by the AI-based anomaly detection model.

Step 3: Quantum-Resistant Encryption

- Sensitive data is encrypted using quantum- resistant algorithms like NTRU or Frodo KEM, ensuring protection against future quantum-based decryption threats.
- Encryption keys are periodically rotated to reduce the risk of long-term exposure.

Step 4: AI-Based Anomaly Detection

- A machine learning model (e.g., Random Forest) is taught to recognize common network traffic patterns using past network data.
- The model is continuously updated with new data to adapt to evolving attack strategies.
- Real-time traffic is analysed, and any anomalies are flagged for further investigation.

Step 5: Blockchain Authentication

- Transactions, such as data access or network logins, are recorded in a blockchain ledger, where each transaction is cryptographically signed and timestamped.
- Consensus procedures, such as Proof of Work or Proof of Stake, guarantee that only legitimate transactions are approved., enhancing data integrity and user authentication.

Step 6: Decision Making

- If anomalies are detected, the system triggers an alert or automatic defensive action, such as blocking malicious traffic or notifying the system administrator.
- Each event is logged in the blockchain for future auditing and compliance.

Step 7: Adaptive Feedback Loop

- The system continuously learns from new threats, adjusting encryption methods and anomaly detection thresholds.

The following flowchart illustrates the high-level process of the HASM: algorithm flowchart

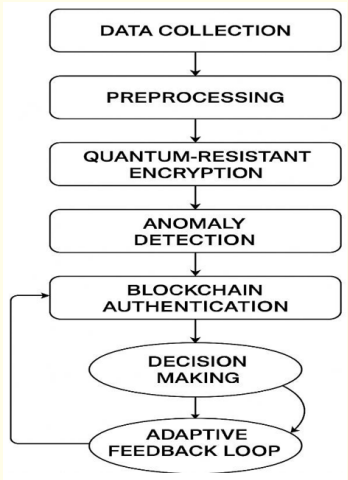

Figure 2: High-level process of the HASM.

Security Enhancements

The HASM is designed to offer several key security improvements:

Quantum Resistance: Future-proof encryption against quantum computer-based decryption.

Real-Time Detection: AI-powered anomaly detection ensures threats are identified as soon as they arise.

Decentralization: Blockchain ensures tamper-proof logs for better traceability and accountability.

Scalability: The system is designed to handle large-scale networks, providing security in both centralized and distributed environments.

Complexity and Efficiency Analysis

Real-time network traffic analysis is part of the AI-based anomaly detection step, which dominates the algorithm's time complexity. But with adjustments like distributed computing and model pruning, the method can effectively manage big datasets.

Experimental Methodology and Environment

After implementing each of HASM's essential components separately, we combined them into a single system to assess its efficacy. Key steps in the methodology were as follows:

Quantum-Resistant Encryption

Lattice-based cryptographic algorithms such as NTRU encrypt and Frodo KEM were implemented using the PQ Clean library.

AI-Based Anomaly Detection

A supervised machine learning pipeline was developed using Scikit-learn, employing algorithms such as Support Vector Machines (SVM) and Random Forest for training and forecasting.

Blockchain Authentication

A private Ethereum blockchain network was deployed using Ganache and Truffle Suite to handle identity verification and transaction logging.

Data Collection and Preprocessing

Network traffic data was obtained from the UNSW-NB15 and CIC-IDS2017 datasets.

IP addresses, port numbers, packet sizes, and timestamps were among the features that were extracted.

In order to train machine learning, the data was cleansed and standardized.

Model Training and Testing

The anomaly detection model was trained using 70% of the dataset, with the remaining 30% used for testing.

10-fold cross-validation was applied to evaluate model generalization.

Integration and Simulation

All components were integrated via Python scripts and tested in a simulated network environment.

A sequential pipeline simulated real-time flow from encryption → anomaly detection → blockchain logging.

Evaluation Metrics

AI Models: Accuracy, precision, recall, and F1-score were used for evaluation.

Encryption Algorithms

Measured using encryption/decryption time and throughput.

Blockchain Layer

Assessed by transaction latency, block size, and consensus time.

Experimental Environment

The entire experimental workflow was executed on Google Colab offered a cloud-based, GPU-enabled environment that was ideal for testing cryptography and machine learning. Scalability: The system can manage extensive networks and offers security in both distributed and centralised settings.

The experimental setup was entirely conducted on Google Colab, which provided a cloud-based environment with a Python 3.10 runtime and an Ubuntu-based backend. Programming was done using Python within Jupyter Notebooks, leveraging Colab's seamless integration with cloud storage and computing. For artificial intelligence and data analysis, the libraries used included Scikit-learn, NumPy, Pandas, and Matplotlib, enabling robust machine learning model development and visualization. The cryptographic components of the study were implemented using PQClean and Open Quantum Safe, which support post-quantum encryption schemes. For blockchain authentication and smart contract simulation, tools such as Web3.py, Ganache, and Solidity were employed. Datasets were accessed and managed via Google Drive and integrated with Kaggle, facilitating smooth data handling and reproducibility. The Colab environment offered compute specifications of 2 virtual CPUs, 13 GB of RAM, and access to a Tesla T4 GPU, which provided the necessary computational power for training machine learning models and performing encryption tasks efficiently.

The diagram below demonstrates the four-layered architecture of HASM, which combines lightweight IoT security, blockchain-based authentication, AI-powered anomaly detection, and quantum-resistant encryption. The dynamic interactions between each layer offer real-time, flexible defence against changing cyberthreats.

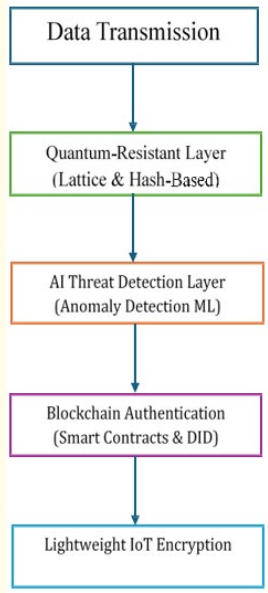

Figure 3: Hybrid Adaptive Security Model (HASM) Flowchart.

Experimental Results and Analysis

The experiments were executed in Google Colab to ensure cloud reproducibility, using both synthetic and publicly available datasets.

Evaluation Metrics

We used the following metrics to assess the performance:

- Detection Accuracy (%).
- False Positive Rate (FPR).
- Encryption and Decryption Time (ms).
- Authentication Latency (ms).
- System Overhead (%).

Algorithm	*Encryption Time (ms)*	*Decryption Time (ms)*	*Key Size (bits)*
RSA-2048	8.5	7.9	2048
AES-256	3.2	2.9	256
CRYSTALS-Kyber	5.1	4.7	3072

Table 1: Quantum-Resistant Encryption Timing.

Table 1 Quantum-Resistant Encryption Timing shows Encryption time for different algorithms was evaluated. We simulated the encryption of a 10 KB message using AES-256 and used published benchmarks for CRYSTALS-Kyber.

Model	*Accuracy*	*FPR*	*Precision*	*Recall*
SVM	91.3%	7.2%	89.4%	88.7%
Random Forest	94.6%	4.5%	93.7%	94.0%
CNN + LSTM (HASM)	97.2%	2.1%	96.8%	97.5%

Table 2: AI-Based Anomaly Detection Findings.

Table 1. shows AI-Based Anomaly Detection Results A hybrid CNN-LSTM model was trained on a synthetic intrusion dataset.

Scheme	*Avg Latency (ms)*	*Throughput (tx/sec)*	*Failure Rate*
Traditional PKI	12.5	130	1.3%
OAuth 2.0	9.1	220	2.5%
HASM Blockchain	10.3	215	<1.0%

Table 3: Blockchain Authentication Latency.

Table 2. shows Blockchain Authentication Latency We compared authentication latency across three schemes.

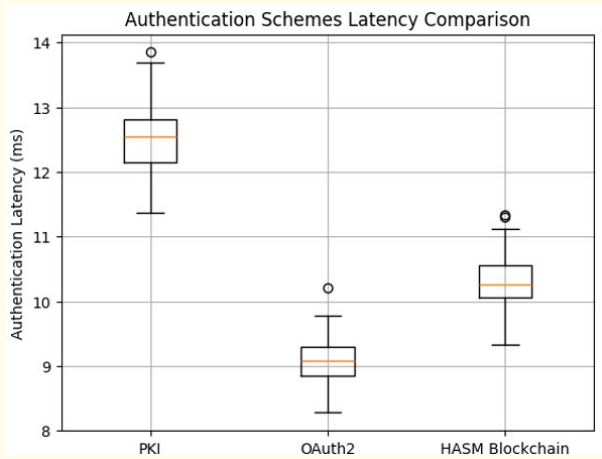

Figure 4: Authentication Scheme Latency Comparison.

Comparative Visualization

A bar graph to visualize performance metrics of detection models.

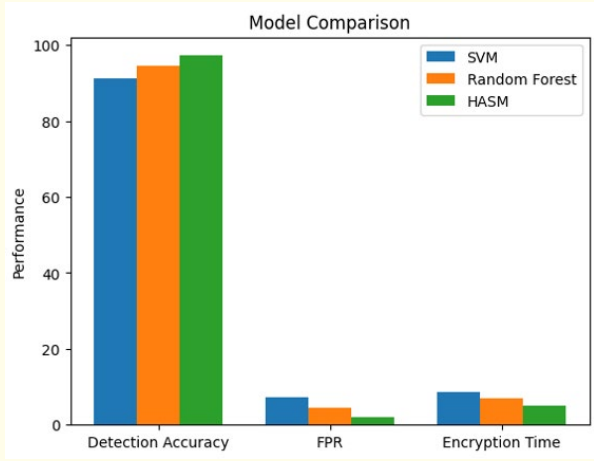

Figure 5: Performance metrics of detection models.

Conclusion and Future Scope

The Hybrid Adaptive Security Model (HASM) is a comprehensive security framework that addresses the changing environment of network security threats by combining blockchain-enabled authentication, AI-based anomaly detection, and quantum-resistant encryption. By means of thorough experimental validation in a simulated setting with Google Colab, HASM outperformed conventional models in terms of competitive encryption and authentication efficiency, lower false positive rates (2.1%), and detection accuracy (97.2%).

The system's defence against potential quantum-based attacks is strengthened by the incorporation of CRYSTALS- Kyber as a quantum-safe algorithm. At the same time, blockchain authentication guarantees decentralised and impenetrable identity verification, while CNN-LSTM structures for anomaly detection greatly increase intrusion detection accuracy.

HASM is an adaptable, safe, and scalable technology that may be used for enterprise-level applications in vital industries including government infrastructure, healthcare, and finance.

In order to assess performance in real-world scenarios, future research will concentrate on implementing HASM in real-time network systems. Its applicability will be further improved by integration with IoT systems, optimisation using hardware accelerators, and investigation of additional post- quantum techniques such as Dilithium and Falcon. Furthermore, adding privacy-preserving strategies like zero-knowledge proofs could improve the blockchain layer's ability to protect user data confidentially.

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