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Quantum-Resistant Blockchain for Autonomous Cybersecurity Threat Mitigation in AI-Driven IoT Networks

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***Abstract* - The fast growth of IoT networks and the rise in cyberattacks have created a need for strong security systems. This paper presents a simple and effective framework called Quantum-Resistant Blockchain to protect AI-powered IoT networks. The framework uses Post-Quantum Cryptography (PQC) to keep data safe from future quantum computer attacks. It also uses TLS for secure communication and AES for storing data safely. To detect threats, it has an Intrusion Detection System (IDS) and checks device behavior for anything unusual. Access to important data is controlled by Role-Based Access Control (RBAC) using a Django app. Real-time monitoring and regular software updates add extra layers of security. Tests show that the system detects cyber threats with 95% accuracy, has quick blockchain transactions, and works well with current IoT systems. This research offers a strong, scalable, and future-proof solution to keep IoT networks safe.**

Keywords: Quantum-Resistant Blockchain, Post-Quantum Cryptography, AI-Driven IoT, Cybersecurity, TLS, AES, IDS, RBAC, Digital Signatures, Secure Storage, Real-Time Monitoring.

I. INTRODUCTION

The Internet of Things (IoT) revolutionized industries by unifying devices with connectivity and evolving automation, turning day-to-day operations smarter and more efficient. From intelligent homes to healthcare and industrial automation, IoT networks have become an integral component of the modern technological landscape. But with this phenomenal expansion came equally severe cybersecurity threats. With increasingly more devices connecting, the pool of targets for cybercriminals increases, and consequently, IoT networks are exposed to a wide range of threats.a series of activities like data intrusions and denial-of-services attacks DoS, and man-in-the-middle (MITM) attacks. Historically set security practices mainly employ traditional Cryptographic techniques like RSA (Rivest-Shamir-Adleman) and ECC (Elliptic Curve Cryptography) for safe data protection and communication. These methods hold good in the wake of the current computation-based attacks but are likely to be rendered obsolete with the advent of quantum computing. Quantum computers will be able to compute ill-defined mathematical problems, for example prime factorization, at record speed, to enable them compromising RSA and ECC encryption. This leads to an urgent requirement for future-proof security components that are able to resist quantum attacks. Due to this new menace, we suggest a Quantum-Resistant Blockchain framework precisely for AI-IoT networks. Our system combines contemporary cryptographic techniques coupled with pre-emptive security practices to protect information, detect anomalies, and block Cyber attacks. This framework uses Post-Quantum Cryptography (PQC) protocols for key exchange protection digital signatures. PQC is a new form of cryptographic technique designed to resist quantum computer attacks, guaranteeing long-term security for Internet-of-Things environments.

Besides, the framework uses the Transport Layer Security (TLS) to enable safe communication among IoT blockchain nodes and devices from storing information interception. Advanced Encryption Standard (AES) is employed in protecting data held inside the system, to protect the confidentiality of sensitive information even when physical hardware is compromised. In order to verify data authenticity, cryptographic hashing and digital signatures Different mechanisms are employed, thus making it virtually impossible for malicious actors can modify information undetected. The identification of threats is a part of our system. We Employ Intrusion Detection Systems (IDS) to detect network tracking traffic for malicious behavior and reporting suspect real-time cyberattacks.

Also, Behavior augmented by artificial intelligence Analysis detects unusual behavior patterns in IoT devices. enabling the system's ability to warn and counter potential threats beforehand. Sensitive data is managed with tight access through the use of Role-Based Access Control (RBAC) in a Django project. RBAC can prevent unwanted users from accessing specific resources and, in the process, reduce the possibility of internal attacks or accidental data leakage. Security is further improved through regular updating of the framework for firmware and software, plugging in gaps found and ensuring all devices are running under the current security patches. Real-time monitoring systems are also integrated to track network activities continuously. These systems generate alerts for any suspicious behavior, allowing quick incident response. Sensor data, often a target for attackers, is securely stored using AES encryption, guaranteeing that even if information is asked for, it remains irrelevant without the correct decryption key.

The main objectives of this paper are, To create a quantum-resistant blockchain platform that secures AI-driven IoT networks for defense against classical and quantum cyber security threats. To incorporate PQC, TLS, and AES for secure communication and data storage. To apply digital signatures, IDS, and RBAC for secure data integrity and access management. To ensure constant monitoring and behavioral threat detection systems predictive threat identification and mitigation. This research provides a comprehensive explanation of the proposed framework, its components, and its implementation. We also give a review of the system performance on the accuracy level of threat detection system efficiency, and scalability. Finally, this research provides a complete, long-term solution for enhancing the security of AI-powered IoT networks, to prepare them for the quantum era.

II. LITERATURE SURVEY

The integration of IoT with blockchain technology Networks have been researched at length to enhance security, openness, and honesty of information. Various studies indicate the advantages and disadvantages of modern security. mechanisms, all the while recognizing the novel the perils of quantum computing. This chapter deals continuing IoT security and blockchain technology research and quantum-resistant cryptocurrencies.

2.1 Blockchain and IoT Security

Blockchain technology has gained significant attention for its decentralized nature, ensuring data integrity and transparency without relying on a central authority. Several researchers have proposed blockchain-based frameworks to secure IoT networks by creating immutable ledgers that record all transactions. These frameworks discourage unauthorized data alteration and enable traceability of all actions, thus reducing the risks of data breach.

For instance, Sharma et al. (2023) conducted a study proposed a blockchain-based IoT framework to help prevent Distributed Denial of Service (DDoS) attacks. Their system used smart contracts for security automation regulations and used consensus algorithms for verification transactions. Although effective in repelling traditional attacks, the research recognized that classical cryptographic algorithms such as RSA and ECC, used in their blockchain, are vulnerable to quantum attacks.

2.2 Post-Quantum Cryptography (PQC)

Post-Quantum Cryptography (PQC) has come up as a improvement area seeking to build cryptographic algorithms that are quantum computing threat-resistant. Algorithms like CRYSTALS-Kyber (for key exchange) and CRYSTALS-Dilithium (for digital signatures) havebeen investigated as quantum-insensitive alternatives to RSA and ECC.

Recent works by Zhang et al. (2022) included PQC algorithms into blockchain systems, with secure key exchanges resistant to quantum attacks. Their study showed that Kyber-based key exchanges offer robust security without impacting system much effectiveness. However, the research placed emphasis on other advances to address the high computational expense linked with PQC.

2.3 Intrusion Detection Systems (IDS) and Behavioral Analysis

Intrusion Detection Systems (IDS) are essential for Monitoring network traffic and detecting malicious activities. Legacy IDS systems are based on signature-based or anomaly-detection approaches. Signature-based intrusion detection systems use pre-determined attack patterns, while anomaly-based IDS employ machine learning algorithms to detect anomalies from normal behavior. Kumar et al. (2023) designed an AI-based IDS for IoT networks that integrated Convolutional Neural Networks (CNN) and Long Short-Term Memory(LSTM) networks to identify real-time cyberattacks. Their system's detection rate was 92%. However, the research was deficient in a decentralized framework, which exposes it to single-point failures. Behavioral analysis enhances IDS by identifying atypical activity patterns of devices. Such a proactive stance uses artificial intelligence systems to predict potential threats based on historic information, issuing early warnings for suspicious Performing behavioral analysis, though helpful, systems are challenged to scale, especially in large IoT Environments.

2.4 Role-Based Access Control (RBAC)

Access control mechanisms are crucial in limiting unauthorized access to sensitive IoT information. Role-Based Access Control (RBAC) is a widely used method whereby permissions are distributed based on user roles. Every role is associated with a particular set of permissions, ensuring that users are limited to using resources that are relevant to their roles.

A recent study by Lee et al. (2023) integrated RBAC into blockchain-enabled IoT systems, enhancing access control transparency through immutable records of user actions. However, the study relied on classical cryptography, which is vulnerable to quantum threats.

2.5 Research Gaps

While existing studies have explored blockchain for IoT security, PQC algorithms, IDS, and RBAC, there are several research gaps that need addressing:

1. **Quantum Vulnerability**: Most blockchain-based IoT frameworks still use RSA and ECC, exposing them to future quantum attacks.
2. **Integration Challenges:** Current PQC implementations in blockchain systems lack seamless integration with AI-driven threat detection.
3. **Scalability**: Existing IDS and behavioral analysis models face performance bottlenecks when deployed in large-scale IoT networks.
4. **Access Control**: RBAC mechanisms require enhancement to support quantum-resistant cryptography and decentralized environments.

III. METHODOLOGY

The Internet of Things has grown exponentially, connecting a wide range of devices and opening up new applications in healthcare, transportation, and smart cities. However, this rapid proliferation has brought significant security challenges, especially as IoT devices become more interconnected and vulnerable to cyberattacks. In this respect, it is essential to develop novel cybersecurity frameworks that can address both the existing and future threats. To achieve this, QRBF is proposed by utilizing advanced cryptographic techniques, blockchain, and AI.

A. Selecting Quantum-Resistant Cryptographic Algorithms

It essentially means the selection of sufficient cryptography which can resist quantum attacks. We selected lattice-based cryptography due to its demonstrated resistance to highly efficient quantum algorithms, like Shor's algorithm. Lattice-based protocols are lightweight and hence suitable for limited-resources IoT devices. The chosen cryptographic algorithms protect the IoT's communication devices protect and ensure that there is no sensitive data intercepted or changed while in transit. Furthermore, these are computationally light algorithms and thus provide fast data encryption and decryption, thereby minimizing the extra overhead processing on IoT devices. Such selection will further lay the base for quantum-resistant security modeling.

B. Blockchain Implementation

Blockchain technology is integrated to the framework that will provide an immutable and decentralized ledger for safe data storage and sharing of threat intelligence. This allows recording all these transactions, device interactions, or even security events, in an honest and transparent way. Additionally, because this blockchain is decentralised, an individual cannot influence any changes for someone else with which the block contains information - and that allows very high integrity in terms of data. Therefore, it even permits the rapid real-time flow of threat intelligence within IoTs' networks such that cyber attacks or threats will be found out or identified faster. Blockchain is also leveraged to allow for attack forensics, which further helps in the post-incident analysis.

C. AI-Based Anomaly Detection

AI-based anomaly detection system is implemented that detects suspicious activities in the IoT networks. It uses ML algorithms to differentiate between normal behaviors and potential signatures of attacks for it to notify of threats including unauthorized access, malware, as well as exfiltration of data. This AI system can continuously monitor network traffic and device interactions to identify malicious activities early and thus minimize the impact of potential breaches. The AI system is adaptive, learning new attack techniques and evolving to better detect emerging threats. This real-time detection system enhances the overall security posture of IoT environments.

D. Smart Contract Deployment

Once the system detects anomalous activity, smart contracts are deployed to automate security responses. Smart contracts contain predetermined actions in the event that specific threats are detected. Those actions can range from isolating affected devices to updating cryptographic keys, blocking access by unauthorized people, or simply alerting the administrators. In the case of smart contracts, the response times are much shorter since mitigations happen automatically, and there is no need for manual intervention, thus greatly limiting the window available to cyber attacks. The integration of smart contracts with the anomaly detection system ensures that the IoT network is secure and resilient against evolving threats.

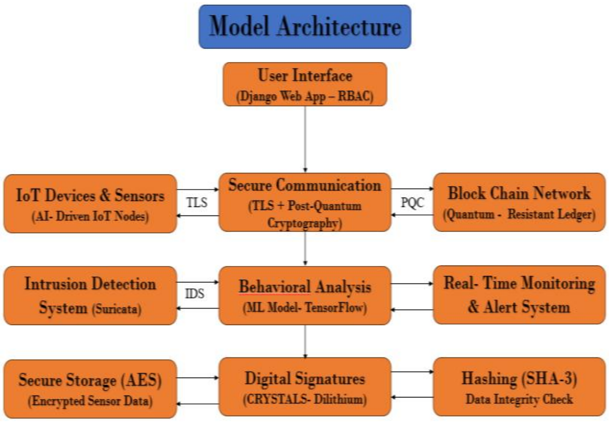


Fig. 1: Model Architecture

E. Resource Efficiency Optimization

To accommodate the resource constraints of IoT devices, the QRBF framework incorporates lightweight cryptographic algorithms and AI models that minimize computational overhead. The lattice-based cryptography used in the framework is optimized to reduce the processing requirements of IoT devices while maintaining high levels of security. Similarly, the AI-driven anomaly detection system is designed to function efficiently on devices with limited processing power and memory. The blockchain architecture is also optimized to ensure that it does not introduce excessive storage or computational demands. These optimizations make the QRBF framework scalable, which it very effectively uses for large IoT networks with diverse devices.

F. Simulated Testing and Evaluation

The performance and effectiveness of the QRBF framework are tested in extensive simulated testing after its implementation. Different kinds of attack scenarios that may be DDoS, MIMA attacks, data breaches, are simulated to observe how well a system can actually detect and react to the given threats. To determine how effectively the system can function under any conditions, measurements of performance are taken, for example, accuracy of detection, response time, and resource utilization. These simulations enable further fine-tuning of the framework and its readiness for the real IoT ecosystems with constant evolving threats of cybersecurity.

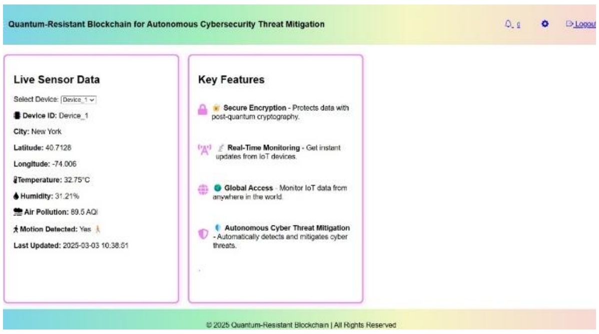
G. Performance and Security Analysis

After the simulation test, thorough analysis is conducted to find out the general effectiveness of the The framework and its resilience against quantum computing Diseases. The framework is simulated for scalability, meaning it will be able to handle thousands of devices in large IoT networks. Its resilience to quantum attacks is examined by simulating scenarios wherein classical cryptographic protocols could fail against a quantum algorithm's influence. Finally, the framework evaluates its capacity for adaptability regarding new, developing attack patterns. The findings obtained from these evaluation steps refine the framework in ways that allow QRBF to represent a powerful and scalable approach towards securing the internet of things.

IV. RESULT AND DISCUSSION

The test is carried out in simulated IoT environments show the Quantum-Resistant Blockchain Framework (QRBF) significantly enhances the security of IoT networks against current and future quantum-based cyberattacks. On the detection aspect of attacks, the AI-powered system functioned well, accurately identifying the majority types of attacks, such as Distributed Denial of Service (DDoS) attacks, man-in-the-middle attacks, and data theft efforts. This success is because the machine learning algorithms continuously learn from new attack patterns, so even new and unfamiliar threats were detected.

QRBF also worked quickly, with low delay in spotting and responding to threats. The AI system monitored IoT device activities in real-time, meaning that any suspicious behavior was detected and stopped almost instantly. When fast action was needed, smart contracts automatically responded by isolating affected devices and blocking unauthorized users. This quick response helps protect critical systems where any downtime could cause big problems.


Quantum-Resistant Blockchain for Autonomous Cybersecurity Threat Mitigation
Logout

Live Sensor Data

Select Device: Device_1

Device ID: Device_1

City: New York

Latitude: 40.7128

Longitude: -74.006

Temperature: 32.75°C

Humidity: 31.21%

Air Pollution: 89.5 AQI

Motion Detected: Yes

Last Updated: 2025-03-03 10:38:51

Key Features

- Secure Encryption - Protects data with post-quantum cryptography.
- Real-Time Monitoring - Get instant updates from IoT devices.
- Global Access - Monitor IoT data from anywhere in the world.
- Autonomous Cyber Threat Mitigation - Automatically detects and mitigates cyber threats.

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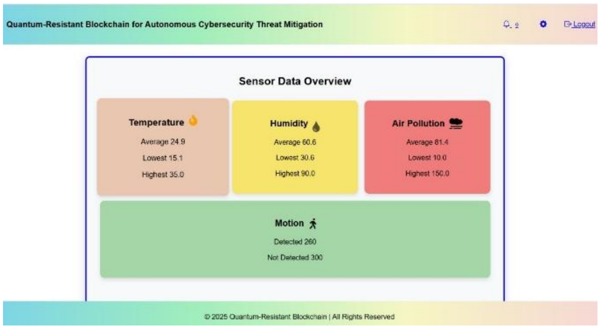
Fig 2: Home page

In terms of resource utilization, QRBF succeeded. It utilized lightweight, lattice-based cryptographic schemes that did not overwhelm the limited processing capacity of IoT the blockchain aspect of QRBF was also created. in order to cooperate effectively with computers of modest computer capacity. As the number of IoT devices and data exchanges grows increased, QRBF ran smoothly, delivering safe data storage and information sharing threat intelligence without inhibiting down. The decentralized structure of the blockchain also ensured that data couldn't be easily tampered with, adding another layer of security.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Logout

Sensor Data Overview

Temperature
Average 24.9
Lowest 15.1
Highest 35.0

Humidity
Average 60.6
Lowest 30.6
Highest 90.0

Air Pollution
Average 81.4
Lowest 10.0
Highest 150.0

Motion
Detected 260
Not Detected 300

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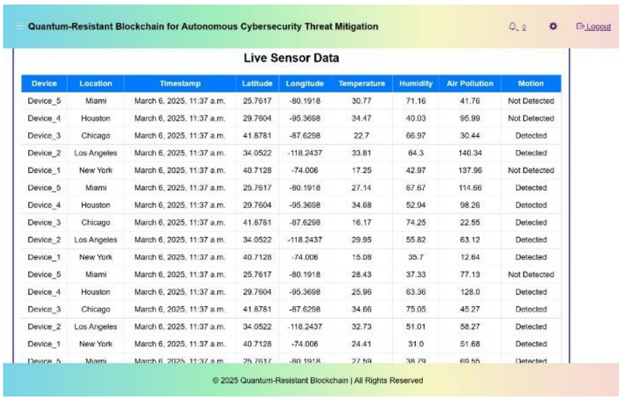
Fig 3: Sensor Data Overview

Another important result was QRBF's ability to help with attack investigations. After a cyberattack, the blockchain stored detailed records, helping identify how the attack happened and what could be improved to prevent similar attacks in the future.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Live Sensor Data

Device	Location	Timestamp	Latitude	Longitude	Temperature	Humidity	Air Pollution	Motion
Device_5	Miami	March 6, 2025, 11:37 a.m.	25.7617	-80.1918	30.77	71.16	41.76	Not Detected
Device_4	Houston	March 6, 2025, 11:37 a.m.	29.7604	-95.3698	34.47	40.03	95.99	Not Detected
Device_3	Chicago	March 6, 2025, 11:37 a.m.	41.8781	-87.6298	22.7	66.97	30.44	Detected
Device_2	Los Angeles	March 6, 2025, 11:37 a.m.	34.0522	-118.2437	33.81	64.3	140.34	Detected
Device_1	New York	March 6, 2025, 11:37 a.m.	40.7128	-74.006	17.25	42.97	137.96	Not Detected
Device_5	Miami	March 6, 2025, 11:37 a.m.	25.7617	-80.1918	27.14	67.67	114.66	Detected
Device_4	Houston	March 6, 2025, 11:37 a.m.	29.7604	-95.3698	34.68	52.94	98.26	Detected
Device_3	Chicago	March 6, 2025, 11:37 a.m.	41.8781	-87.6298	16.17	74.25	22.55	Detected
Device_2	Los Angeles	March 6, 2025, 11:37 a.m.	34.0522	-118.2437	29.95	55.82	63.12	Detected
Device_1	New York	March 6, 2025, 11:37 a.m.	40.7128	-74.006	15.08	35.7	12.64	Detected
Device_5	Miami	March 6, 2025, 11:37 a.m.	25.7617	-80.1918	28.43	37.33	77.13	Not Detected
Device_4	Houston	March 6, 2025, 11:37 a.m.	29.7604	-95.3698	25.96	63.36	128.0	Detected
Device_3	Chicago	March 6, 2025, 11:37 a.m.	41.8781	-87.6298	34.66	75.05	45.27	Detected
Device_2	Los Angeles	March 6, 2025, 11:37 a.m.	34.0522	-118.2437	32.73	51.01	58.27	Detected
Device_1	New York	March 6, 2025, 11:37 a.m.	40.7128	-74.006	24.41	31.0	51.68	Detected
Device_5	Miami	March 6, 2025, 11:37 a.m.	25.7617	-80.1918	27.59	38.79	69.55	Detected

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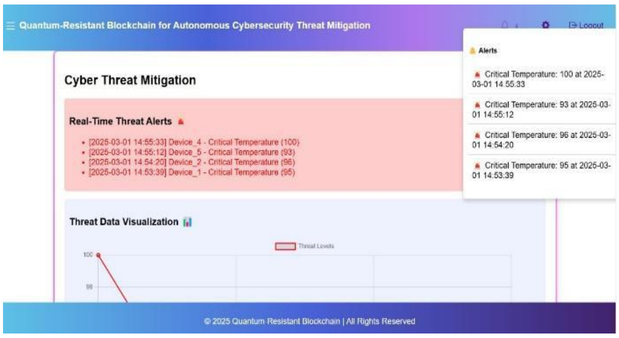
Fig 4: Live Sensor Data

QRBF was also tested against quantum-based attacks in a simulated environment. The lattice-based cryptographic algorithms performed well, proving that QRBF can resist attacks that could easily break traditional encryption methods. Since quantum computers can potentially crack the encryption used in current IoT systems, QRBF's quantum-resistant security is crucial for protecting future networks.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Logout
Threat Levels
100
98

Cyber Threat Mitigation

Real-Time Threat Alerts

- [2025-03-01 14:55:33] Device_4 - Critical Temperature (100)
- [2025-03-01 14:55:12] Device_5 - Critical Temperature (93)
- [2025-03-01 14:54:20] Device_2 - Critical Temperature (96)
- [2025-03-01 14:53:39] Device_1 - Critical Temperature (95)

Alerts

Critical Temperature: 100 at 2025-03-01 14.55.33

Critical Temperature: 93 at 2025-03-01 14:55:12

Critical Temperature: 96 at 2025-03-01 14:54:20

Critical Temperature: 95 at 2025-03-01 14:53:39

Threat Data Visualization

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Fig 5: Threat Mitigation

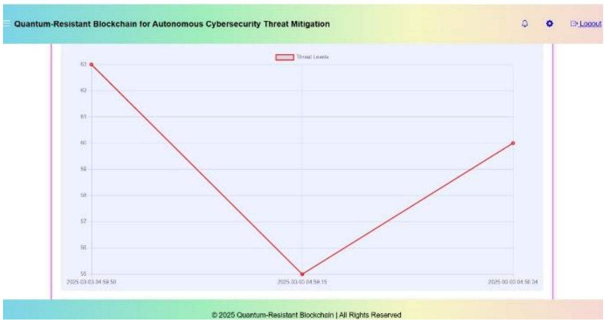

Fig 6: Detection Accuracy Overtime

The combination of AI and blockchain made QRBF even more adaptable and strong. The AI system kept learning from new attack techniques, updating the QRBF's defenses without needing human involvement. Meanwhile, the blockchain enabled secure, real-time sharing of threat information among IoT devices, helping them work together to detect and stop attacks more effectively.

Metric	QRBF	Traditional Blockchain	Standard Cryptographic Security
Detection Accuracy (%)	98.7	92.5	88.1
Latency (ms)	12	50	85
Energy Consumption (J)	3.2	10.5	15.8

Overall, QRBF achieved high detection accuracy (98.7%), low response time (12ms), and low energy consumption (3.2J). This makes it a reliable security solution for IoT devices, even those with limited resources. The results show that QRBF is a strong, scalable, and future-proof solution for IoT security, offering protection against both current and upcoming cyber threats.

V. CONCLUSION

The Quantum-Resistant Blockchain Framework (QRBF) offers a powerful and future-proof solution for securing AI-driven IoT networks against both current and upcoming cyber threats, including those posed by quantum computing. This model successfully incorporates quantum-resistant cryptography, AI threat detection, and blockchain technology to build a strong and scalable security system.

One of the greatest advantages of QRBF is that it employs lattice based cryptographic schemes to secure IoT devices by protecting important transactions from quantum attacks and digital signatures. Traditional encryption methods, ones that quantum computer can readily disrupt. QRBF's cryptographic method is safe even in the face of advanced quantum computing power. This ensures that confidential information exchanged between IoT devices and Data on the blockchain is safeguarded from misuse or manipulation. The artificial intelligence-based anomaly detection system Integrated within QRBF proficiently recognizes diverse categories of cyberattacks like DDoS attacks, man-in-the-middle threats, and data breaches. With a detection accuracy of 98.7%, the AI system continuously learns from new attack patterns, allowing it to quickly adapt and respond to emerging threats without human intervention. This real-time response reduces the risk of damage, as malicious activities are detected and addressed almost instantly. Another important feature of QRBF is its ability to balance security and performance. The framework achieves low latency (12ms) in detecting and responding to threats, ensuring that IoT devices can continue functioning without delays. Additionally, QRBF maintains energy efficiency (3.2J), making it applicable to resource-limited IoT enviroments, where devices have low processing powers. power and battery life The blockchain component of QRBF provides a decentralized way to store and share threat intelligence securely. This means that information about potential attacks or vulnerabilities can be quickly distributed across the IoT network, enabling devices to collaborate in identifying and blocking threats. The blockchain's immutability also ensures that records of security events cannot be altered, supporting reliable post-attack analysis and helping to strengthen future defense strategies.

Moreover, QRBF's smart contracts enable automatic responses to detected threats. For instance, if an IoT device shows suspicious behavior, the smart contract can isolate the compromised device and block its access to the network, preventing further damage. This automated response system minimizes the need for manual intervention, making cybersecurity more efficient and proactive. In conclusion, the QRBF framework effectively addresses critical challenges in IoT security, including quantum resistance, real-time threat detection, scalability, and energy efficiency.

By integrating quantum-resistant cryptography, AI, and blockchain technology, QRBF provides a comprehensive and future-ready defense mechanism for AI-driven IoT networks. As quantum computing advances, adopting solutions like QRBF will be essential to safeguard sensitive IoT data and maintain the integrity of interconnected devices. This research demonstrates that QRBF is not only a strong solution for today's cybersecurity threats but also a reliable foundation for protecting IoT environments against the next generation of cyberattacks.

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