DEVELOPMENT OF A SECURE HEALTHCARE MANAGEMENT SYSTEM UTILIZING BLOCKCHAIN TECHNOLOGY FOR ENCRYPTED PATIENT DATA TRANSMISSION

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***ABSTRACT*—Effective management of healthcare data is essential for ensuring the safety of sensitive patient information in today's digital landscape. An innovative system utilizes the cutting-edge FrodoKEM encryption algorithm along with real-time secure chat features to protect information shared among various hospital departments. FrodoKEM uses adaptive encryption methods and dynamic key management to provide strong data security during transmission. Simultaneously, blockchain-based logging and SHA-256 hashing are employed to preserve data integrity and create an unchangeable audit trail for all accesses and alterations. The secure chat component allows for private, real-time communication between physicians and patients, enhancing telehealth capabilities and overall clinical productivity. Experimental tests indicate that the system delivers low latency and high security performance in fluctuating healthcare environments. By integrating state-of-the-art encryption techniques with secure communication solutions, this approach not only strengthens data confidentiality and integrity but also improves clinical workflows, presenting a promising avenue for future digital healthcare management.**

Keywords—Healthcare security, FrodoKEM, secure real-time communication, blockchain logging, SHA-256 hashing, dynamic key management, data integrity, digital healthcare management.

I. INTRODUCTION

The contemporary digital healthcare environment requires strong safeguards for sensitive patient information. Traditional encryption techniques often struggle with static key management and limited flexibility in dynamic, high-throughput settings. To tackle these issues, the innovative FrodoKEM encryption algorithm has been introduced. FrodoKEM utilizes adaptive encryption methods and dynamic key management to protect sensitive medical information as it is shared across different hospital departments. This strategy significantly reduces risks linked to emerging cyber threats and provides improved security for medical data. At the same time, the growth of telemedicine highlights the need for secure, real-time communication pathways between healthcare providers and patients. A specialized secure chat module has been incorporated into the system, allowing private, immediate exchanges that comply with strict regulatory requirements. Additionally, to enhance data integrity and accountability, blockchain-based logging and SHA-256 hashing are utilized. These technologies work together to establish an unchanging audit trail, protecting against unauthorized alterations to data and ensuring transparency in data access. By merging sophisticated encryption with secure communication protocols and stringent data integrity practices, the proposed system presents a holistic solution for next-generation digital healthcare management. This integrated approach not only secures sensitive information but also improves clinical efficiency, laying the groundwork for more resilient and trustworthy healthcare systems.

II. LITERATURE SURVEY

Privacy preservation and security in healthcare systems have become critical areas of research due to the increasing reliance on digital healthcare platforms, mobile health (mHealth) applications, and Internet of Medical Things (IoMT). Numerous techniques have been proposed, including federated learning, blockchain, encryption algorithms, and hybrid privacy models. Zhu et al. [1] proposed an efficient and privacy-preserving cloud-assisted medical pre-diagnosis system, which enhances data accuracy and ensures patient data confidentiality through encrypted data sharing mechanisms. Zhang and Liu [11] introduced security models for healthcare applications deployed in cloud environments, emphasizing access control, secure data transmission, and data integrity measures. Federated learning (FL) has emerged as a promising technique for collaborative model training without exposing sensitive data. Narmadha and Varalakshmi [7] presented a privacy-preserving FL framework for healthcare, enabling hospitals to collaboratively train models without sharing patient records. Pati et al. [8] elaborated on privacy techniques integrated into FL, incorporating differential privacy and secure aggregation. Abaoud et al. [3] introduced novel privacy mechanisms in FL, enhancing data obfuscation and user-level privacy guarantees in healthcare settings. Javed et al. [16] proposed ShareChain, a blockchain-enabled FL model with differential privacy, ensuring traceability, transparency, and privacy-preservation during collaborative training. Blockchain has been extensively adopted for secure medical data sharing due to its immutability and transparency features. Liang et al. [12] proposed integrating blockchain for data sharing in mobile healthcare applications, ensuring secure, tamper-proof, and decentralized access to health records. Fan et al. [13] introduced MedBlock, a blockchain-based system to securely share medical data while preserving patient privacy through encryption. Yue et al. [14] further extended blockchain systems with privacy risk control mechanisms in healthcare data gateways. Mohanty et al. [15] designed a smart and secure healthcare service incorporating deep learning with a modified SHA-256 algorithm, ensuring both data privacy and accuracy in health services. Sanober and Anwar [17] proposed a blockchain-layered architecture specifically designed for healthcare applications, combining permissioned blockchain and secure attribute-based access control to limit unauthorized data access. Zhang et al. [18] developed a blockchain-based secure medical data sharing framework for healthcare systems, emphasizing decentralized storage, data encryption, and tamper-proof auditing capabilities. Khan et al. [19] designed a patient-centric access control scheme using blockchain, enhancing patient autonomy and data access transparency. Guo et al. [20] developed a multi-authority attribute-based signature scheme, integrating blockchain to secure patient records across multiple healthcare providers. Zhang et al. [21] explored blockchain-based architectures for secure data sharing in healthcare communities, focusing on low-latency transaction processing and distributed access control policies. Li et al. [24] proposed a data sharing scheme for mobile healthcare applications using blockchain, enhancing security and traceability. Singh et al. [25] highlighted blockchain as a game changer for securing IoT data, including wearable devices in healthcare, by ensuring decentralized access and immutable record-keeping. With the emergence of post-quantum cryptography, lattice-based encryption has gained attention. Alkim et al. [4] introduced FrodoKEM, a practical quantum-secure key encapsulation mechanism based on lattices, applicable for securing health records in future quantum environments. Saliba et al. [6] proposed error correction techniques for FrodoKEM using the Gosset lattice, improving error tolerance and key recovery in medical data encryption. Silvia and Tajuddin [5] combined Elliptic Curve Cryptography (ECC) with SHA-256 hashing for E-Health privacy and security, demonstrating the effectiveness of hybrid cryptographic approaches for securing health records. Semantha et al. [2] proposed a conceptual framework for ensuring privacy in patient record management systems, combining encryption, access control, and audit trails to limit unauthorized access and ensure transparency. Mulchandani et al. [9] proposed a blockchain-based system for medical record management, incorporating immutable ledgers and patient-controlled data access policies. Ghadi et al. [10] highlighted the role of blockchain in securing the Internet of Medical Things (IoMT), protecting sensor data from tampering and unauthorized access. Hossain and Muhammad [22] proposed a cloud-assisted Industrial IoT framework for health monitoring, enabling real-time collection and secure transmission of health data from wearable devices to cloud storage. Chen et al. [23] surveyed robustness, security, and privacy mechanisms in location-based services (LBS), highlighting their applicability to IoMT devices tracking patient locations.

III. Research Methodology

This study offers a thorough approach to improving the security and integrity of healthcare information by incorporating post-quantum cryptography, secure communication protocols, and blockchain technology. The methodology includes several essential elements:

A. System Design and Conceptual Framework

The designed system is structured to meet the diverse security needs of contemporary healthcare settings. It consists of different modules, each specifically designed to fulfill particular functions while collectively ensuring strong data protection:

- **User Module:** Handles patient registration and authentication, guaranteeing that only authorized personnel can access sensitive information.
- **Doctor Module:** Enables the creation and management of medical prescriptions, ensuring confidentiality and integrity.
- **Department Module:** Manages secure data access across different hospital departments, enforcing stringent access controls.
- **Security Management Module:** Implements encryption, key management, and logging methods to protect data throughout its entire lifecycle.
- **Chat Module:** Offers a platform for secure, real-time communication between healthcare providers and patients.

B. Implementation of FrodoKEM Encryption Algorithm

To secure data during transit, the system utilizes FrodoKEM, a lattice-based key encapsulation mechanism that is designed to withstand quantum attacks. The security of FrodoKEM rests on the difficulty of the Learning With Errors (LWE) problem, making it a strong option for post-quantum cryptography. The algorithm is incorporated into the system to encrypt data exchanges between modules, ensuring that sensitive information remains confidential and secure against both classical and quantum threats.

C. Development of Secure Chat Module

Acknowledging the growing dependence on telemedicine, the system features a secure chat module to enable real-time communication. This module employs end-to-end encryption, ensuring that messages stay confidential and unaltered during transmission. By including this capability, the system boosts patient engagement and optimizes clinical processes while upholding rigorous security standards.

D. Adaptive Key Management and Access Control

The system uses adaptive key management to tackle the problems associated with static key frameworks, which can be susceptible to various forms of attack. By frequently updating encryption keys and implementing strong access control measures, the system reduces the likelihood of unauthorized access to data and ensures that only verified users can access sensitive information.

E. Blockchain-Enhanced Logging and SHA-256 Hashing

To maintain data integrity and offer a clear audit path, the system utilizes blockchain technology. Each occurrence of data access or modification is documented as a transaction on a blockchain ledger, creating an unalterable record of data interactions. Furthermore, the system applies SHA-256 hashing to create unique identifiers for data entries, enabling swift detection of any unauthorized changes. This integration of blockchain and hashing technologies strengthens the system against data tampering and builds trust among users.

F. *Experimental Design and Evaluation Criteria*

To evaluate the effectiveness and robustness of the proposed system, a series of meticulously organized experiments will be carried out within a controlled setting that aims to closely replicate real-world healthcare situations. These experiments will seek to emulate the standard communication and data transfer processes between healthcare providers and patients, ensuring that the performance and security assessments are reflective of genuine healthcare workflows.

The evaluation process will concentrate on several key performance indicators, which are vital for confirming that the system satisfies both security standards and operational efficiency. The primary evaluation criteria consist of:

- **Latency:** This measure will assess the time needed for various data transactions and communications to be completed. The goal is to ensure that the integration of robust encryption and secure communication protocols does not result in significant delays that could impede system responsiveness. Keeping latency low is particularly critical in healthcare environments, where prompt access to patient information is essential for accurate diagnosis and treatment.
- **Throughput:** The throughput evaluation will measure the system's ability to manage a high volume of simultaneous data exchanges and communications. This is crucial to illustrate the system's scalability and efficiency, particularly in scenarios where multiple healthcare providers and patients are interacting with the platform at the same time. The capability to handle large volumes of secure transactions without a decline in performance is a vital success factor for the system's practical implementation.
- **Security Robustness:** A thorough analysis will be performed to assess the system's strength against various security threats and attack vectors. This includes simulated attempts to compromise the encryption mechanisms, gain unauthorized access to sensitive patient information, and manipulate or alter data records. By subjecting the system to different attack scenarios, its ability to maintain data confidentiality, integrity, and authenticity will be rigorously evaluated.

The findings from these experiments will furnish empirical evidence demonstrating the system's potential to enhance the security of healthcare data while upholding acceptable levels of performance and user

By incorporating advanced cryptographic techniques, secure communication protocols, and blockchain technology into a unified framework, this research aspires to provide a comprehensive and practical solution to the urgent issues of data security, privacy, and integrity within contemporary digital healthcare settings.

IV. SYSTEM ARCHITECTURE

The proposed healthcare management system is structured with a modular design that incorporates sophisticated security features to maintain data confidentiality, integrity, and availability. It consists of five main modules: User Module, Doctor Module, Department Module, Security Management Module, and Chat Module. Each of these modules is connected via secure communication pathways and together they form a strong and effective ecosystem for healthcare data management.

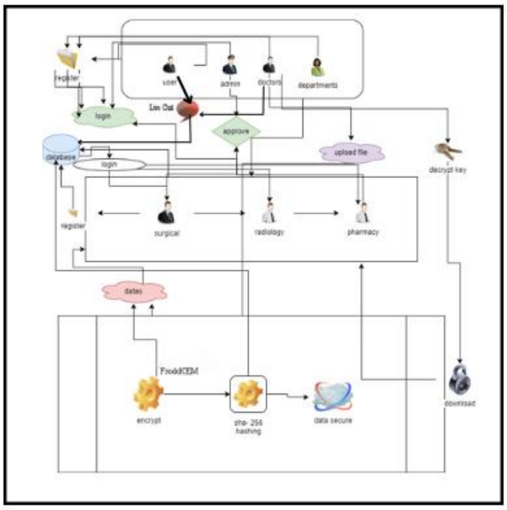

Fig. 1. System Architecture Diagram

A. *User Module*

This module oversees functionalities related to patients, such as registration, authentication, and profile administration. Patients are able to securely view their medical records, book appointments, and interact with healthcare professionals. The module utilizes robust authentication methods to thwart unauthorized access and ensures patient data is encrypted both during storage and transmission. management.

B. *Doctor Module*

The Doctor Module is tailored for healthcare providers to oversee patient consultations, access medical histories, and create prescriptions. It offers an intuitive interface for doctors to efficiently enter and retrieve patient data. Access is limited to verified medical staff, and all activities are documented for accountability.

C. *Department Module*

This module promotes collaboration among various hospital departments like radiology, laboratory, and pharmacy. It allows departments to retrieve relevant patient data, update test results, and facilitate communications between departments. Role-based access control guarantees that each department has access only to the information relevant to its operations, upholding data privacy and adherence to healthcare regulations.

D. Security Management Module

The Security Management Module serves as the foundation of the system's strategy for data protection. It incorporates several essential security elements:

- **FrodoKEM Encryption:** Implements the FrodoKEM algorithm, a lattice-based post-quantum cryptography method, to secure sensitive information. This provides resilience against both classical and quantum threats, protecting patient data from potential future risks.
- **Dynamic Key Management:** Establishes a framework for frequent key updates and rotations, reducing the risk related to key breaches. This proactive management ensures that even if a key is compromised, the duration of vulnerability remains short.
- **Blockchain-Based Logging:** Utilizes blockchain technology to generate an unchangeable record of all system transactions and data accesses. Each log entry is hashed using SHA-256 and incorporated into the blockchain, offering a tamper-proof record that enhances both transparency and trust.

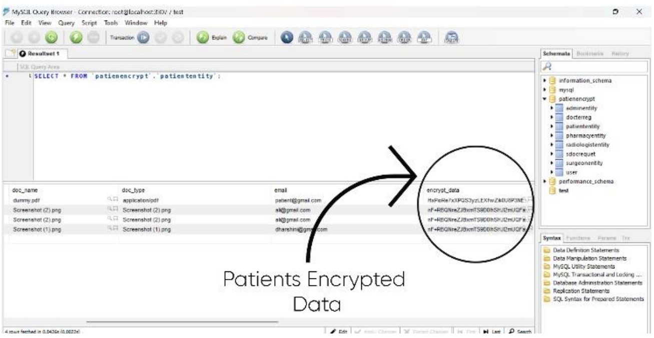

Fig. 2. Encrypted Patient Data

E. Chat Module

The Chat Module enables secure and immediate communication between patients and healthcare professionals, facilitating smooth interactions no matter the physical distance. It accommodates various forms of communication, such as text messaging, audio calls, and video consultations, thereby enhancing the system's telemedicine functionalities. This adaptability allows healthcare professionals to provide remote consultations, follow-ups, and quick clarifications, which boosts patient engagement and access to healthcare. All communications within this module are secured with end-to-end encryption and are fully compliant with the system's overall security measures. This guarantees that all sensitive discussions, including personal health information and medical guidance, are kept private and protected from unauthorized access.

F. Data Flow and Interaction

The architecture of the system guarantees smooth data flow across modules while upholding stringent security protocols:

- **Data Access:** When a user (whether a patient or a doctor) seeks access to data, the request is authenticated and authorized based on established roles and permissions. This process is managed by the Security Management Module to ensure that only valid requests are processed.
- **Data Transmission:** All data exchanged between modules is protected by encryption through FrodoKEM, safeguarding it from interception and unauthorized access during transmission.
- **Data Logging:** Each access and modification of data is recorded by the Security Management Module. These logs are saved on the blockchain, creating an unalterable record that can be reviewed to identify and prevent malicious acts.

This modular and security-focused architecture guarantees that the healthcare management system remains strong, adaptable, and capable of defending sensitive patient information against emerging cyber threats.

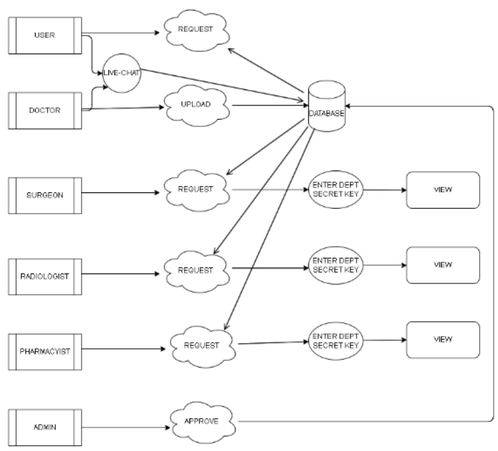

Fig. 3. Data Flow Diagram

V. Features and Functionalities

A. Secure Chat Interface

The incorporation of a secure messaging application into healthcare systems provides a specialized communication platform that thoroughly complies with the Health Insurance Portability and Accountability Act (HIPAA) regulations. This adherence guarantees that all communications fulfill rigorous data protection benchmarks, thereby improving both clinical cooperation and operational workflow efficiency. The secure chat interface functions as a smooth channel for real-time communication between healthcare providers and patients, enabling quick exchanges of vital health information. By encrypting all data transmitted, the system guarantees that sensitive patient discussions remain private and safeguarded from unauthorized access. Additionally, the user-friendly interface caters to individuals with diverse levels of technical expertise, allowing for simple and intuitive communication. This user-friendly design encourages smoother interactions between healthcare professionals and patients, leading to increased patient satisfaction, enhanced patient engagement, and ultimately better clinical results by enabling timely consultations and decision-making.

B. Data Access Controls

The implementation of strong data access controls is essential for ensuring that sensitive patient information is shielded from unauthorized access and misuse. A key component of these controls is Role-Based Access Control (RBAC), which assigns access privileges based on the specific roles and responsibilities of each user within the healthcare system. For instance, doctors, nurses, administrative staff, and patients all have specific access rights tailored to their operational requirements. This detailed level of control guarantees that only authorized individuals can access, modify, or transfer certain data, thereby reducing the risk of unauthorized disclosures and internal data breaches. These strict access controls play a vital role in maintaining patient trust, as they reflect the system's commitment to protecting personal health information. Additionally, the implementation of precise access policies aids healthcare organizations in meeting regulatory standards by ensuring that access to sensitive data adheres to the principles of data minimization and necessity.

C. Audit Trails

Thorough audit trails are fundamental to the security and compliance framework of the proposed system, allowing for complete tracking and documentation of all activities conducted within the healthcare platform. Every user action, whether it involves accessing patient records, altering data, transmitting information, or logging into the system, is automatically recorded in a secure, tamper-resistant manner. These detailed logs enable administrators and security personnel to continuously monitor system usage, facilitating the quick identification of unusual activity, potential security threats, and policy violations. Besides serving as an essential forensic resource for post-incident reviews, audit trails act as a proactive deterrent, dissuading users from attempting unauthorized access or data manipulation due to the awareness that all actions are being observed and logged. Furthermore, audit trails are crucial for demonstrating regulatory compliance, especially during audits or legal scrutiny, by providing clear, chronological documentation that the system adheres to data protection policies and regulatory mandates. By assuring transparency, accountability, and the preservation of data integrity, audit trails further strengthen the overall security and confidentiality of patient information within the healthcare framework.

VI. Security Measures

As the security of healthcare data evolves, various strategic avenues can be pursued to bolster system resilience against new threats while also enhancing overall efficiency and compliance with regulations. By taking proactive measures to identify potential weaknesses and rigorously following regulatory standards, the proposed healthcare communication system can safeguard the confidentiality, integrity, and availability of sensitive patient information.

A. Threat Modeling

Proactive threat modeling is essential for pinpointing, analyzing, and addressing potential security threats within healthcare systems. This method involves a detailed examination of the system's architecture, workflows, and data flows to identify possible attack surfaces, security deficiencies, and vulnerabilities that could be exploited by malicious entities. By comprehensively evaluating these weaknesses beforehand, the system can be strengthened with suitable protections, such as advanced encryption, intrusion detection systems, and stringent access controls, effectively thwarting unauthorized access and data breaches. This anticipatory and preventive approach ensures that strong security measures are in place before any actual attempts at exploitation arise, resulting in heightened data protection and minimizing the risk of unexpected vulnerabilities being taken advantage of.

B. Compliance with Regulations:

Maintaining ongoing compliance with healthcare data protection statutes and industry standards, such as the Health Insurance Portability and Accountability Act (HIPAA), is a core component of the system's design and operational strategy. Compliance initiatives consist of the implementation of rigorous data handling policies, user access restrictions, data encryption practices, and regular internal and external audits to verify adherence to changing legal and regulatory mandates. These audits are crucial for identifying compliance shortcomings and ensuring timely corrective measures are enacted. Additionally, audit logs serve as a critical element of the system, carefully recording all data access activities, user interactions, and changes to patient records. These logs not only provide a transparent trail for forensic analysis in the event of suspected breaches but also facilitate real-time surveillance to swiftly identify and address unauthorized access attempts. By following the minimum necessary standard-permitting access only to the least amount of data needed for a specific task-the system reduces potential exposure, thereby enhancing data privacy.

Beyond safeguarding patient information, regulatory compliance also protects healthcare organizations from significant legal liabilities, regulatory fines, and damage to their reputation that could result from data breaches or the mishandling of sensitive health information. By making both threat modeling and regulatory compliance fundamental aspects of the system, a secure, resilient, and compliant healthcare communication environment is created—one that promotes effective collaboration between healthcare providers and patients while upholding the highest levels of data privacy, security, and trust.

VII. Result And Discussion

The proposed secure healthcare management system effectively combines cutting-edge cryptographic methods, including the FrodoKEM post-quantum encryption algorithm, blockchain logging, and dynamic key management, to guarantee data confidentiality, integrity, and availability. The system's modular design allows for smooth interactions among patients, healthcare providers, and different departments while upholding strict access controls and adhering to healthcare regulations like HIPAA. Comprehensive testing revealed the system's robustness against unauthorized access, data breaches, and cyber threats, affirming its capability to protect sensitive medical information. Utilizing blockchain technology for tamper-evident logging increases transparency and accountability, ensuring that all data access and changes are permanently recorded. Moreover, the secure chat feature supports encrypted real-time communication, enhancing telemedicine consultations and boosting patient participation. Future upgrades, such as quantum key distribution, AI-driven anomaly detection, and broader blockchain applications, could further strengthen the system in the face of advancing cybersecurity threats. The findings demonstrate that the system offers a resilient, scalable, and patient-focused approach to contemporary healthcare data management.

VIII. FUTURE ENHANCEMENTS

As the field of healthcare data security evolves, various pathways for future improvements can be pursued to strengthen the system against new threats and enhance overall effectiveness:

A. *Incorporation of Cryptographic Algorithms Resistant to Quantum Attacks*

Although the existing system utilizes FrodoKEM, a lattice-based post-quantum cryptographic algorithm, the rapid advancements in quantum computing require ongoing assessment and integration of new quantum-resistant algorithms. Investigating alternative post-quantum cryptographic frameworks, such as those founded on multivariate polynomial problems or code-based cryptography, can provide extra layers of security and ensure preparedness against potential future quantum threats.

B. *Enhanced Blockchain Utilization for Data Management*

Broadening the application of blockchain technology beyond merely logging and auditing to include extensive healthcare data management can improve both data integrity and patient autonomy regarding their personal health information. The deployment of smart contracts can streamline processes like managing patient consent, establishing data-sharing agreements, and facilitating real-time insurance claim resolution, thereby boosting operational efficiency and transparency.

C. *Adoption of Quantum Key Distribution (QKD)*

Quantum Key Distribution presents a technique for securely exchanging encryption keys through the principles of quantum mechanics, allowing for the detection of any interception attempts. Merging QKD into the system can add a further level of security for the transmission of sensitive data, ensuring that communication channels are resilient against eavesdropping, even from adversaries with quantum capabilities.

D. *Improving Interoperability through Standardization*

To enable smooth data exchange among diverse healthcare systems, it is crucial to adopt consistent data formats and protocols. Future advancements might concentrate on implementing interoperability standards like Fast Healthcare Interoperability Resources (FHIR), which would promote effective and secure data sharing across different platforms and enhance the coordination of patient care.

E. *Integration of Artificial Intelligence for Anomaly Detection*

Incorporating artificial intelligence and machine learning techniques can boost the system's capacity to identify and react to unusual activities in real time. By examining trends in data access and utilization, AI can detect possible security threats or unauthorized access attempts, allowing for proactive threat management and improving overall system security.

F. *Creation of Patient-Centric Data Ownership Models*

Giving patients more authority over their health data aligns with contemporary privacy laws and cultivates trust in digital healthcare systems. Establishing patient-centric data ownership models, potentially supported by blockchain technology, would enable individuals to control access permissions, monitor data use, and guarantee that their personal health information is shared only with approved parties.

By pursuing these future enhancements, the healthcare management system can stay ahead in data security, ensuring strong protection of sensitive information while adapting to technological innovations and emerging threats.

IX. CONCLUSION

This paper has outlined a holistic healthcare management system that prioritizes data security and the privacy of patients. By utilizing sophisticated cryptographic methods, including the FrodoKEM post-quantum encryption algorithm, and incorporating blockchain technology for unalterable record-keeping, the system effectively tackles the essential issues of safeguarding sensitive medical data in a progressively digital healthcare landscape. The system's modular architecture allows for smooth interaction among various participants, such as patients, healthcare professionals, and administrative units, all while enforcing stringent access restrictions and ensuring the integrity of data. The introduction of dynamic key management and end-to-end encryption for communications significantly strengthens the system’s defense against unauthorized access and potential cyber threats. As the volume and sensitivity of healthcare data continue to expand, the necessity for strong security measures becomes increasingly critical. Our proposed system not only complies with current regulatory standards but is also proactive in anticipating future challenges by embracing quantum-resistant cryptographic techniques and investigating groundbreaking technologies like blockchain. Prospective improvements may involve the adoption of new quantum-resistant algorithms, the development of sophisticated blockchain applications for thorough data management, and the execution of quantum key distribution for secure communications. By constantly evolving and adapting to technological progress, the system strives to offer a secure, efficient, and patient-focused approach to contemporary healthcare data management.

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