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QUANTUM RESISTANT SECURE CHAT APPLICATION

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Abstract - **This research presents a Quantum resistant secure chat application. While most chat applications use end to end encryption, this method can be vulnerable to the advanced computational power of quantum computers, which can be potentially break these encryptions. By implementing PQ3 algorithm for message encryption, this application can able to resist cyber-attacks from quantum-powered super computers, ensuring enhanced encryption for user communications.**

Keywords— Quantum computers, Post quantum cryptography, end to end encryption, Secure chat application, Cyber-attack.

I. INTRODUCTION

In recent years, with the advent of many means of discipleship, the issue of safety and security has come to the forefront. The appearance of quantum computers makes it clear that enciphering techniques would need to be changed, as the existing ones will be prone to attacks. The Quantum-Resistant Secure Chat Application aims to resolve these issues by combining secure, private communication between users with quantum-resistant algorithms.

Over the years, abstractions have changed in such a way that any safety provided with the use of traditional systems like RSA, ECC, etc., would have little meaning today given the rise of quantum computing performance. The Project seeks to avert this possibility by employing likewise protocols that are meant for quantum warfare infrastructure resistant cryptosystems so that no user data is compromised. Within the application, restrictions on user communication are being implemented due to the expectation of employing post-quantum connector algorithms within the application's communication channels.

To conclude, the Quantum-Resistant Secure Chat Application is aimed at providing solutions for existing security issues but is also designed with the threats of quantum technology. The blending of modern cryptographic technology and user-friendly approach gives a hope for the development of this application in the area of secure communication.

II. LITERATURE SURVEY

"The Hope for Postquantum Security" by van Dijk, M., et al. (2020), published in IEEE Security & Privacy. [1] This paper highlights lattice-based cryptography as a promising solution to secure communications against potential quantum computing threats, which could compromise traditional cryptographic systems.

Quantum Safe Cryptography and Security: An Introduction, Benefits, Enablers and Challenges by Matthew Campagna and Chen (2015):

It discusses the concept of quantum secure communications which is the prevention of any digital communications from the threats of quantum computing [3]. The paper elaborates on the weaknesses of existing cryptographic solutions, most notably their public key infrastructure, heightening in relation to the development of quantum computers which threatens to make most encryption techniques useless.

NIST's Post-Quantum Cryptography (2019)

It [2] is intended that the new public-key cryptography standards will specify one or more additional unclassified, publicly disclosed digital signature, public-key encryption, and key-establishment algorithms that are available worldwide, and are capable of protecting sensitive government information well into the foreseeable future, including after the advent of quantum computers

III. METHODOLOGY

1. Overview of the methodology

This chat application is aimed at users who place a premium on secure and fast communication with real-time updates. Digital communication being the order of the day, this app also seeks to provide an enjoyable experience to users without excluding the various security measures demanded by the app's nature. The platform incorporates sophisticated encryption policies like Post quantum cryptography to prevent any unauthorized access to users' information and messages.

2. Front-End Development with React.js

The main front-end technology for this project is React.js, which provides users with dynamic user-friendly interfaces thanks to its component-based structure. This kind of approach allows the development team to create separate, interchangeable components, which helps in unifying and simplifying the user experience. The User Interface consists of the following core parts: Message List, Message Input Box, User authentication pages, and Profile Management. Modern CSS Layout techniques such as Flexbox and Grid Layout are used to create a user-friendly and aesthetical interface layout compatible with various screen dimensions.

3. Real-Time Communication with WebSocket/Socket.io

The usage of WebSocket technology enables the application both to send and receive data without any restrictions and thus communicating to the web server in real time. The persistent connection feature of WebSocket allows transferring data with any repeated connection requests which makes it inferior to the strategic positioning approach that is used mostly in non – real time applications. Most messaging applications using the traditional Hyper Text Transfer Protocol implement the frequent polling technique. However, WebSocket is different in that it allows the user to open one connection and work with this connection until the user terminates the session eliminating the cost of repeated opening and closing of connections. There is an additional socket.io library feature designed to tackle specific actions like messaging, updating user status, as well as joining and leaving action notifications.

4. Back-End Development with Node.js and Express.js

The chat application's server is constructed using Node.js, which implements an event-driven, non-blocking I/O architecture, which is suitable for managing real-time multiple user sessions. It employs Express.js, a minimal and open-source web application framework designed for Node.js, for the purpose of handling API requests so that RESTful APIs can be implemented for the data interchange between the client and server. Express.js middleware is also used for purposes like user authentication, logging and error management. This sectioning makes it easier to maintain the application and enhances the security by reducing the chances of interdependence. The application implements JSON Web Tokens to manage the users' sessions, therefore messaging features are protected and accessible only to the logged in users. In order to avoid the possibility of unsecured data being stored as such, PQ3 is used to protect the content of messages that are to be kept in a database.

5. Data Management with MongoDB

The choice of MongoDB as the database is attributed to the fact that it's a document-oriented storage which accommodates data in a more flexible way in form of a Json structure. This helps in effective accommodating of the user profile and chat message data which have different structures. Two collections are designed in the database for Users and Messages, whereby a Message contains sender, receiver, date, time and content fields. Such indexing is done for the most queried fields like user id and time for the purpose of speeding up the data retrieval processes and enhancing the performance the database. PQ3 algorithm is used for encrypting the message prior to saving for privacy reasons. In addition, there are as well Monitoring tools in place to aid in observing database usage and combating security threats.

6. Security and Privacy Considerations

Security is a core focus of the application, and multiple measures are implemented to protect data privacy and integrity. In addition to PQ3 encryption, the application employs multi-factor authentication to add an extra layer of protection. Role-based access control is used to restrict access based on user permissions, ensuring that sensitive actions are limited to authorized users. Secure coding practices are enforced to prevent vulnerabilities such as SQL and NoSQL injection attacks. Input validation and query parameterization help reduce the risk of malicious code injection. Endpoint security strategies, such as rate limiting and API protection, safeguard sensitive areas of the application and prevent abuse.

7. Testing and Deployment

Thorough testing is conducted to ensure reliable communication between the client and server. Integration testing verifies that data flows as expected, with testing frameworks simulating user interactions to confirm the proper functionality of real-time messaging. Load and performance testing assess the application's response under high traffic, identifying potential performance bottlenecks. The application is deployed on Render.com, which integrates with GitHub to enable continuous deployment whenever changes are pushed to the main branch. Environment variables are securely managed to handle sensitive data, and the Render.com platform provides monitoring and logging tools that allow the development team to track application performance and quickly resolve issues as they arise.

8. Ongoing Maintenance and Updates

Ongoing maintenance is a critical aspect of the application, ensuring that it remains secure and responsive to user needs. Monitoring tools track performance metrics, enabling proactive identification of potential issues. User feedback is actively collected to guide future improvements, and the development team follows an agile methodology to implement updates and new features. This iterative process helps the application evolve based on user needs, keeping the platform relevant and reliable over time.

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IV. PROPOSED METHODOLOGY

1. Design and architecture of the application

The frontend of the chat application is constructed using React.js, a popular JavaScript library for building dynamic and responsive user interfaces. React component-based architecture facilitates the creation of modular and reusable UI elements, making it easier to maintain the chat window, message feed, and user authentication modules. With React, each of these components operates independently, enhancing scalability and simplifying updates. The application also uses modern CSS to deliver a visually appealing experience, integrating CSS frameworks and preprocessors to simplify styling. This approach ensures that the layout is responsive, with features like animations, adaptive sizing, and cross-browser compatibility, all while maintaining high accessibility standards. CSS was carefully crafted to make the application usable for individuals of all technical backgrounds.

The backend of the chat application is built with Node.js and Express.js to handle real-time communication and data management efficiently. Node.js provides a non-blocking, event-driven runtime environment ideal for high concurrency, enabling the application to handle multiple user requests simultaneously. Express.js is employed for routing and API management, structuring the server-side logic for handling HTTP requests and managing data flow between the server and client. The backend handles user authentication through hashed passwords and JSON Web Tokens, ensuring that sensitive user data is protected during login and session management. This approach provides a strong foundation for security, helping to prevent unauthorized access to user accounts.

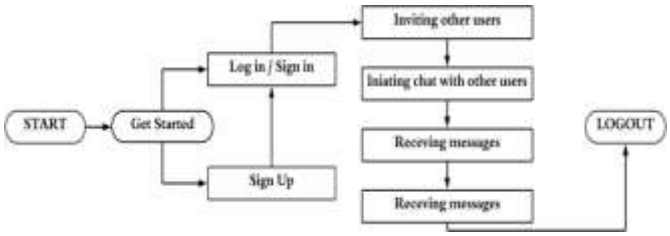

Figure 1.1 Work Flow of the chat application

2. Real-time communication with web socket and socket.io

To support real-time messaging, the application relies on WebSocket technology, [6] which allows for persistent, two-way communication between the client and server. Unlike traditional HTTP, WebSocket maintains an open connection, enabling instant message transmission without requiring repeated requests. This setup ensures that users can see each other's messages in real-time, providing a smooth, responsive chat experience. Socket.io, a WebSocket library, is integrated to simplify the process and manage event-driven communication. With Socket.io, users experience seamless message updates, seeing each message immediately without needing to refresh the page, making the chat interaction more engaging and efficient.

3. Implementation of quantum-resistant encryption (pq3)

The application prioritizes security by implementing the PQ3 encryption algorithm, a post-quantum cryptographic standard that protects data against quantum computing threats. Traditional encryption methods may become vulnerable to quantum computing, so PQ3 offers a future-proof solution. The PQ3 algorithm encrypts messages with a unique encryption key for each user, ensuring that only the intended recipient can decrypt and read the message. Using public-key cryptography principles adapted for quantum resistance, PQ3 provides robust security for the chat's sensitive data. Performance optimizations are applied to prevent any lag from the encryption process, preserving the real-time functionality of the chat application.

4. Database management and secure data storage with MongoDB

MongoDB [5] was chosen for data storage due to its document-oriented structure, which aligns well with the chat application's data needs, including user profiles and messages. MongoDB's flexibility allows it to store data in JSON-like documents, supporting quick retrieval and easy scalability. Sensitive data, including user information and messages, are encrypted before storage, ensuring confidentiality even if the database is compromised. Hashing and salting techniques further protect user passwords, while encryption keys are stored separately to mitigate single-point vulnerabilities. To manage data securely, role-based access control restricts access to sensitive data, and MongoDB's security features, such as access control and data validation, are employed to prevent unauthorized access.

5. Hosting and deployment using git and render

The application's source code is managed using Git, enabling version control, collaborative development, and tracking of changes. Git's continuous integration (CI) capabilities allow for automated testing and code reviews, identifying issues before they reach production. This helps maintain code quality and reduces the risk of bugs in the live application. For deployment, the application uses Render.com, a hosting service chosen for its compatibility with Node.js applications and support for automatic deployment. Render.com integrates with GitHub repositories [7] to reflect updates immediately after code is pushed, streamlining deployment and simplifying the process. Render's scalable hosting options ensure consistent performance by dynamically allocating resources during high-traffic periods, helping the application scale as the user base grows.

6. Enhanced security measures

The application incorporates multi-factor authentication (MFA) as an added security layer, requiring users to verify their identity with additional verification steps, such as SMS codes or an authenticator app. MFA enhances account protection, making unauthorized access significantly more difficult. To facilitate user adoption, the application guides users through the MFA setup during onboarding, explaining its benefits and providing clear instructions. Role-based access control restricts data access to authorized users, enhancing data privacy and protecting sensitive parts of the application. Session management features, including session timeouts, automatically log users out after extended inactivity, safeguarding users who may forget to log out from unauthorized access.

7. User privacy and data minimization

Data minimization practices are followed to collect only essential information, reducing the amount of sensitive data exposed to potential breaches. This helps preserve user privacy and limits the risk of unauthorized access to non-essential data. Users are informed of the data collection policies, outlining how their data is used and their rights over their information, ensuring transparency and compliance with privacy regulations. For analytical purposes, any non-essential data is anonymized to prevent the identification of individual users. Periodic audits are conducted on stored data to delete or anonymize any non-essential information, supporting a privacy-first approach in handling user data.

V. RESULT AND DISCUSSION

1. Real-time communication performance

The chat application excels in real-time communication performance, utilizing WebSocket and Socket.io technologies to facilitate seamless and instant message delivery between users. Testing has shown that messages are sent and received nearly instantaneously, with an average latency of under 50 milliseconds, depending on network conditions. Additionally, the application demonstrated its ability to handle high traffic efficiently during load testing. Even with numerous concurrent active users, Socket.io event-driven structure enabled optimal resource usage, ensuring that multiple users could communicate without significant performance degradation. This reliability in performance ensures that users experience consistent and effective messaging capabilities.

2. Quantum-resistant encryption (pq3) implementation

The integration of PQ3 post-quantum level-3 encryption has significantly bolstered the application's security measures. Testing confirmed that the encryption effectively protects against both traditional cyber threats and potential quantum computing attacks. The PQ3 algorithm ensures that only authorized users can decrypt messages, maintaining data integrity and confidentiality throughout communication. The encryption and decryption processes have been optimized to facilitate efficient real-time communication, ensuring that users experience minimal delays when sending or receiving messages. This high standard of security reinforces the application's commitment to protecting user data.

3. User authentication and access control

The implementation of multi-factor authentication (MFA) within the application has successfully enhanced security, reducing the risks associated with unauthorized access. Feedback from user testing indicates that MFA is user-friendly, particularly for those utilizing smartphone-based authenticators. [9] Additionally, the application employs role-based access control (RBAC), which effectively limits access to administrative functions and sensitive data based on user roles. This measure not only protects against insider threats but also minimizes the risk of accidental data exposure. Together, these security features create a robust authentication and access control system that reinforces the overall security posture of the application.

4. Database security and privacy compliance

To ensure the security of user data, all sensitive information, including messages, passwords, and personal details, is encrypted before storage in MongoDB. This encryption safeguards data from unauthorized access, maintaining confidentiality even in the event of a data breach. The application adheres to data minimization practices aligned with GDPR and other privacy regulations, collecting only essential user information. Furthermore, users are empowered with control over their personal data management, ensuring compliance with privacy standards. As privacy regulations evolve, continuous updates will be necessary to maintain compliance and build user trust. To enhance data security, regular audits are conducted to verify that sensitive data remains encrypted and essential, while incorporating data anonymization for analytics to uphold user privacy without sacrificing valuable insights.

5. User experience and accessibility

The user interface (UI) of the application, designed using React.js, provides a smooth and intuitive user experience, which has been positively received by users. The simplicity, speed, and accessibility features of the interface cater particularly well to visually impaired users. CSS styling contributes to the customizability of the interface, allowing users to choose themes and color schemes that meet their

accessibility needs. Additionally, dynamic components and keyboard navigation options enhance interaction across various devices and platforms. While the current interface is well-received, user feedback indicates a desire for more customization options, such as adjustable font sizes and additional themes. Addressing these requests could further enhance the adaptability and user satisfaction of the application.

6. Deployment and scalability on render.com

Render.com [4] has proven to be an effective hosting solution, successfully utilizing auto-scaling features to adapt resources based on user traffic. Testing during peak usage times demonstrated Render's ability to manage traffic surges without sacrificing performance, aligning with the application's scalability goals. Although Render.com currently meets the project's hosting needs, future growth in the user base may necessitate larger server resources or multi-region deployments to ensure optimal global performance. To enhance resilience further, the application could benefit from sophisticated load balancing across multiple servers, allowing for data redundancy and faster response times, particularly for users located in different geographical regions.

7. Limitations and areas for improvement

The application faces certain limitations and challenges that present opportunities for improvement. One significant issue is the performance costs associated with quantum-resistant encryption. While PQ3 encryption is essential for security, it also imposes computational demands that may slightly affect message processing speed. Additionally, despite prioritizing user privacy, some users have expressed a desire for greater control over their data management, such as the ability to delete message histories. Implementing user-controlled data management features could enhance satisfaction and reinforce the application's privacy-first approach. Furthermore, the real-time nature of communication introduces inherent security risks due to continuous WebSocket connections. Incorporating AI-based threat detection could enhance protection against cyber threats by monitoring unusual activities in real-time, further safeguarding the application from potential vulnerabilities.

VI. CONCLUSION

This secure chat application development provides an in-depth approach to one of the main aims, which is creating a communication platform that users find easy to use, quick, and very safe. The use of React.js made it possible to come up with a modern and easy to use the front end while WebSocket in conjunction with Socket. Io has been used to achieve real time messaging as Node.js and Express.js is the backend services that supports high performance. MongoDB acts as a database and therefore ensures that no user data and communications are lost which upholds the core principle of data protection.

This standard of encryption guarantees that the application will serve a tool for communication that is resistant to quantum computing and assures that such data will be safe within the limits of threats provided by cyber space. Enhanced measures such as multi-factor authentication as well as role-based access control would also ensure user data remains protected while maximizing user confidence on the platform.

The deployment on Render.com was both affordable and elastic hosting. Thanks to Git integration, the system was able to apply version control and deploy the project without delay. Render's auto-scaling technology effectively coped with enhanced or decreased user activity levels which confirmed the ability of the system to support more users in the future increasing its growth potential.

VII. ACKNOWLEDGMENT

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