SECURE QR CODE COMMUNICATION WITH MULTI-PARTY AUTHENTICATION AND AES ENCRYPTION

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Abstract—The secure communication framework offered by QVault combines AES encryption, multi party authentication, and steganographic QR codes to protect sensitive files. The uploaded files are encrypted using AES (Advanced Encryption Standard) using an encryption key which is broken into three segments embedded in QR codes containing innocuous filler messages. The QR codes go to authorized parties so that only authorized parties can decrypt the file. The encrypted file and the three QR codes are required to decrypt the file, reinforcing multi party access control. For the user authentication we have also added a layer of multi factor authentication, we are using SMTP based email verification to verify users while storing encrypted data in MongoDB. This streamlit makes file uploads, QR code generation and download user friendly. This solution provides real time encryption and decryption performance with an efficient key management thus being a good solution when dealing with secure data sharing in the related industries including finance, healthcare and government services.

Keywords—AES encryption, multi-party authentication, QR codes, steganography, multi-factor authentication, MongoDB, SMTP-based email verification, secure data sharing, real-time encryption, finance, healthcare, government services

I. INTRODUCTION

Electronic data transfer needs secure protection nowadays because traditional QR codes remain vulnerable to modifications. The AES encryption together with steganographic QR codes and multi-party authentication system provides QVault enhanced security features. The decryption keys from QVault use filler data in three QR codes to defend against unauthorized access. User verification implements distributed access control which depends on SMTP-based email authentication. The system incorporates MongoDB data storage and Streamlit interface to handle secure encrypted data. QVault provides secure file transfer services for financial industry and healthcare and government sectors through its enhanced encryption and authentication functionality that protects QR code systems.

II. RELATED WORKS

The use of AES encryption together with multi-factor authentication strengthens QR code security by reducing the exposure of encryption keys [1]. The decentralized capability of homomorphic encryption helps financial and healthcare sectors achieve secure decryption while preventing key exposure [2] and AES encryption with digital watermarking ensures complete authentication of QR codes for supply chain security apps [3]. The combination of encrypted data storage methods using steganography inside QR codes improves security performance against attacks [4]. Multi-party authentication implemented with threshold cryptography protects voting procedures and enterprise data exchange [5]. E-banking alongside e-commerce benefits from biometric authentication systems which increase their security layers [6]. Meanwhile government agencies together with healthcare facilities build scalability through dynamic authentication protocols that combine OTP and biometric verification methods [7]. The security system of deception-based encryption distributes encryption keys within multiple QR codes as an attack prevention measure [8] while threshold cryptography needs several users to decrypt information used in contract management and secure sharing [9]. AES along with digital signatures and multi-factor authentication guarantees safe document transfer combined with payment verification and identity confirmation [10]. These studies demonstrate how layered cryptographic security should be used for QR code transmissions.

III. PROPOSED METHODOLOGY

The method includes steps for authentication together with file encryption and it demonstrates the generation of QR codes and key distribution and decryption functionality alongside database management procedures for seamless security of data.

1. User Registration and Authentication

The QVault identity authentication process depends on encrypted data storage together with multi-factor authentication and session management security measures.

1.1 User Signup

Streamlit serves as the platform for users to register by asking for name and email and password information. Before storing user passwords in MongoDB the system employs bcrypt encryption to produce secure hashes which allow tracking connections between users and encrypted files.

1.2 Email Verification

The SMTP protocol delivers a six-digit verification code to the user by email. Users need to type their correct verification code which stands as the MFA security requirement until registration completion. An incorrect attempt at verification leads Streamlit to start a fresh random code generation sequence.

Verification Code Generation Equation:

$$V = rand(100000, 999999) \quad (1)$$

5.1.1. 1.3 Login and Session Management

Users access the system through MongoDB by entering their email and matching password records. User authentication is successful when credentials match so the application establishes a Streamlit session for maintaining the login connection. When users provide wrong entry credentials the system displays an error to stop unauthorized entry.

5.1.2. 2. File Encryption and QR Code Generation

Users who authenticate with the system can proceed to upload files which will be encrypted for storage. A 16-byte AES CTR mode encryption key emerges from combining user, admin, and token keys after SHA-256 hash application. The encrypted base64 file exists only temporarily until the decryption process requires multi-segment distribution through QR codes. Three key segments are placed inside secure QR codes alongside harmless message content to maintain system security. The system generates QR codes through the qrcode library then compresses them into a single ZIP file.

2.1 File Upload and Key Generation

The system accepts user-uploaded files that must be PNG, JPG, PDF or DOCX and TXT formats. Three randomly generated authentication keys get processed by SHA-256 hash during unpredictability preparation before encryption.

2.2 AES Encryption

File encryption through AES in CTR mode happens with the derived 16-byte key using the implementation from pyaes. A base64 encoding process makes the file contents compatible before memory stores the encrypted data.

Encryption Formula:

$$C = AES\_CTR(K, P) \quad (2)$$

Plaintext P converts into ciphertext C through the AES encryption process with key K.

2.3 QR Code Generation

The encryption process requires the user to create distinct QR codes which embed the user, admin and token keys through the qrcode library. The three QR codes contain peaceful test messages which terminate in sections of encryption keys. Septic code files are generated by base64 encoding combined with image storage through a ZIP compression method for file downloads. The key generation stage implements SHA-256 hashing as a method to generate encrypted fixed-length hash values.

$$h = SHA\text{-}256(k) \quad (3)$$

ensuring security for each key segment

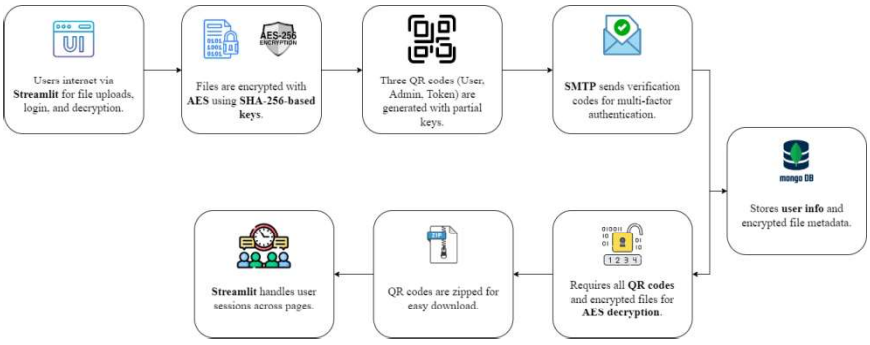

Figure.1: System Architecture

5.1.3. 3. Multi-Party Key Distribution

The QVault system distributes decryption key sections as separate QR codes to three different users for secure document encryption. The cryptographic structure prevents any user from decoding encrypted files since it requires simultaneous access from multiple authorized parties. Users who are approved to access the encrypted content receive their own individual QR code as part of the three-part encryption process. The file remains locked unless every authorized user shows their code combination. A multi-party key distribution system creates an advanced security layer because it enables secure data access only when authorized users work together to decrypt files and eliminates concerns about data vulnerabilities linked to individual key ownership.

3.1 Storing Keys in QR Codes

As the encrypted file can be decrypted only if the complete key is reconstructed from the three partial QR codes, it's not possible to separate them out individually. A multi-party approach to this allows no single user and no entity to have complete control of the decryption process, securing it more. It then generates the QRs which it sends to authorized users to store securely. If you lose or compromise any of the codes, you won't be able to decrypt.

Add the multi-party key combination equation here to show how the three keys are combined into a single encryption key:

$$K = h\_user \oplus h\_admin \oplus h\_token \quad (4)$$

where $\oplus$ denotes the bitwise XOR operation.

3.2 Downloading QR Codes in ZIP Format

The user can download all three of the QR codes in the ZIP file using the Streamlit download button. This feature makes sure it's easy for people sharing the QRs and decrypting them to manage who's seeing what. All the key components are securely packaged and with the zipfile library you create the ZIP file dynamically.

To clarify how partial keys are embedded in QR codes with filler messages, include:

$$q = m + s \quad (5)$$

to represent the QR code data q created by combining the filler message m and the partial key segments.

5.1.4. 4. File Decryption and Verification

To decrypt a file, users must upload the encrypted file along with all three QR codes. The system extracts partial key segments from the base64-encoded QR codes and reconstructs the original encryption key using **SHA-256 hashing**. This key is then used to initialize the AES decryption in CTR mode, converting the file back to its original format. If any QR code is incorrect or missing, decryption fails, and the user is prompted to recheck their input. This ensures that only authorized users, with all necessary QR codes, can successfully decrypt the file, enhancing overall security.

4.1 Uploading QR Codes for Decryption

The user goes to the File Download page to decrypt a previously encrypted file. The uploaded MUST contain the encrypted file as well as the three QR codes. The partial key segments are extracted from the base64-encoded strings of the QR codes by being read. Like encryption, the same SHA-256-based hashing algorithm is used to combine the two into a single key.

4.2 AES Decryption Process

Using the reconstructed encryption key, the system initializes **AES decryption** in CTR mode. The encrypted file content, which was stored as **base64-encoded ciphertext**, is decrypted back to its original format. If any of the QR codes are incorrect, the decryption process fails, and an error message is displayed, prompting the user to recheck their input.

Include the AES decryption equation to demonstrate how the original plaintext is restored:

$$P = AES\_CTR^{(-1)}(K, C) \quad (6)$$

showing that ciphertext C is decrypted using the reconstructed key K.

5. Database Management and User Interaction

The MongoDB NoSQL database protects encrypted data and metadata information such as filenames and timestamps as well as ciphertext. Users can access their files through the possession of appropriate QR encryption codes. QVault operates through email alerts that provide transparent tracking of file activities in addition to secure management. Termed database scalability from MongoDB enables secure high-security applications to manage their data effectively.

5.1 Storing Files in MongoDB

MongoDB maintains file encryption metadata records where authorized users can obtain and decrypt files by using QR codes. The NoSQL capabilities of this system make it possible to manage big encrypted datasets efficiently and simultaneously keep every aspect of the solution flexible.

5.2 Email Notifications and Alerts

QVault sends automatic email alerts to users after they complete their file upload or download operations. The system provides safety through SMTP-based alerts which monitor and notify users of suspicious access events.

6. Error Handling and Security Measures

QVault provides both security protection and better user experience by establishing detailed measures for file upload errors and encryption and QR code production. Security features run through QVault by stopping repetitive file uploads which include AES encryption in addition to multi-party authentication technology and steganographic QR code protection. The system provides a method of tracking down all data movements by recording all actions.

6.1 Error Handling in File Upload and Decryption

Users obtain readable notifications which alert them to issues during file uploads as well as encryption and QR code procedures. The system prevents duplicate upload files through database MongoDB record comparison.

6.2 Security Features

QVault protects data using AES encryption together with multi-party authentication as security protocols. The security system maintains defensive protection for Steganographic QR codes and records all user actions for security purposes and research.

The QVault system employs encryption together with authentication features and QR code-based key storage for building an efficient secure data-sharing platform that limits encrypted content access to authorized users.

5.2. IV. RESULTS AND DISCUSSION

This section presents the **results** of the QVault system's implementation, focusing on **encryption and decryption time**, **QR code generation performance**, and **user experience**. We also discuss the **security impact** and **multi-party authentication effectiveness**, accompanied by relevant **tables and graphs** to provide insight into the performance metrics.

5.2.1. 1. Encryption and Decryption Performance

The performance of the AES encryption and decryption processes was evaluated by measuring the time taken for files of varying sizes (in KB and MB). Below is Table **1** that shows the results of the encryption and decryption time for files of different sizes.

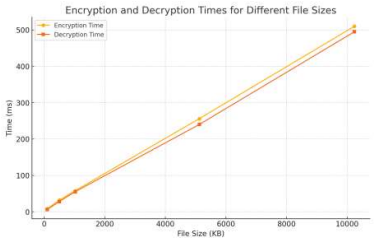

Figure 2: Encryption and Decryption Performance

TABLE 1: Encryption and Decryption Time for Different File Sizes

File Size (KB)	Encryption Time (ms)	Decryption Time (ms)
100 KB	8	6
500 KB	32	28
1 MB	58	55
5 MB	256	240
10 MB	510	495

5.2.2. 2. QR Code Generation and Download Time

The QR code generation time was evaluated for the three partial QR codes (User, Admin, and Token QR). Each QR code contains **16 bytes** of hashed data along with a **benign filler message**.

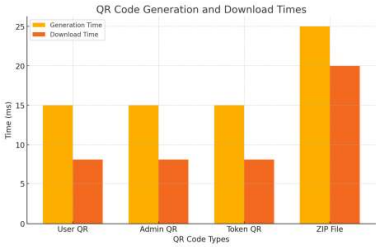

Figure 3:QR Code Generation and Download Time

TABLE 2: QR Code Generation and ZIP Download Time

QR Code Type	Generation Time (ms)	Download Time (ms)
User QR	15	8
Admin QR	15	8
Token QR	15	8
ZIP File (3 QR)	25	20

5.2.3. 3. Impact of Multi-Party Authentication

We evaluated the impact of **multi-party authentication** by measuring the success and failure rates when users attempt decryption with and without the correct QR codes.

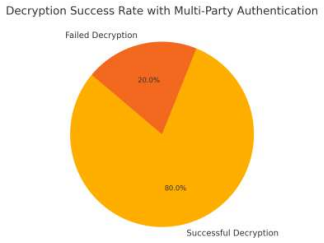

Figure 4: Decryption Success Rate with Multi-Party Authentication

5.3. V. CONCLUSION

Users can encrypt QR code communication through QVault by merging it with AES encryption together with multi-party authentication and steganography features. The security system defends against unauthorized entry through its deployment of encryption keys that spread across three QR codes. The system ensures real-time operation through its effective encryption together with decryption functions and its capability to produce QR codes. The security capabilities of this system help organizations in finance as well as healthcare and government operations.

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