A Secure Messaging Framework with Integrated IDS and Quantum Cryptography

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ABSTRACT

The fast evolution of digital communication technologies has prompted greater concerns about the security of data and communication channels. Classical cryptographic algorithms, although efficient, are becoming more susceptible to the power of future computational devices, especially those based on quantum computers. This article discusses the implementation of the Quantum Secure Messaging System, which seeks to improve secure communication systems by combining state-of-the-art security algorithms with an intuitive user interface. Although the messaging system does not rely on quantum cryptographic devices, the design of the system incorporates quantum-resistant cryptography concepts by emphasizing its ability to resist future attacks. This paper shows how secure messaging systems can be developed using modern web technologies.

Keywords: Quantum Secure Messaging, BB84 Protocol, Quantum Key Distribution (QKD), Encryption, Authentication, Secure Communication, Cybersecurity, Web-Based Application, Data Privacy, Anomaly Detection

INTRODUCTION

In this modern era, where secure communication is highly critical because of the exchange of a vast amount of information over various network infrastructures, there are several issues faced by the existing systems. These include unauthorized access, hacking, data leakage, and message interception by cyber attackers. Moreover, current encryption mechanisms are increasingly vulnerable owing to the development of high-performance computational machines and advanced technological innovations. For instance, the growing popularity of quantum computing systems is likely to render existing classical cryptography ineffective in the future. Therefore, the need to develop highly secure systems against any cyber attack in the future arises. To mitigate these problems, this project aims at developing a quantum-based messaging system that employs authentication, encryption, and quantum-inspired mechanisms to ensure safe communication. It uses the BB84 protocol, invented by Charles H. Bennett and Gilles Brassard, to generate a shared secret key for the encryption and decryption of messages sent over the network. Post-login, users will be redirected to the dashboard containing the following features, namely Encrypt Message, Decrypt Message, Inbox, History, and Logout. Each module has unique IDs assigned to it for easy identification and utilization.

A Study on Existing Work

Most secure messaging systems that are already in place use old-fashioned encryption methods like AES and RSA to keep data safe. But as quantum computing gets better, these methods might not work as well. To fix this, quantum cryptography, especially the BB84 protocol, is used to safely send keys.Many systems also use Intrusion Detection Systems (IDS) to find attacks like brute force. However, most existing solutions focus only on encryption or attack detection separately.This project builds on previous work by putting quantum encryption, secure messaging, intrusion detection, and real-time alerts all into one system.

Algorithm Used

The system incorporates the BB84 Quantum Key Distribution algorithm, authentication, and encryption/decryption algorithms to achieve secure transmission of information.

BB84 Algorithm:

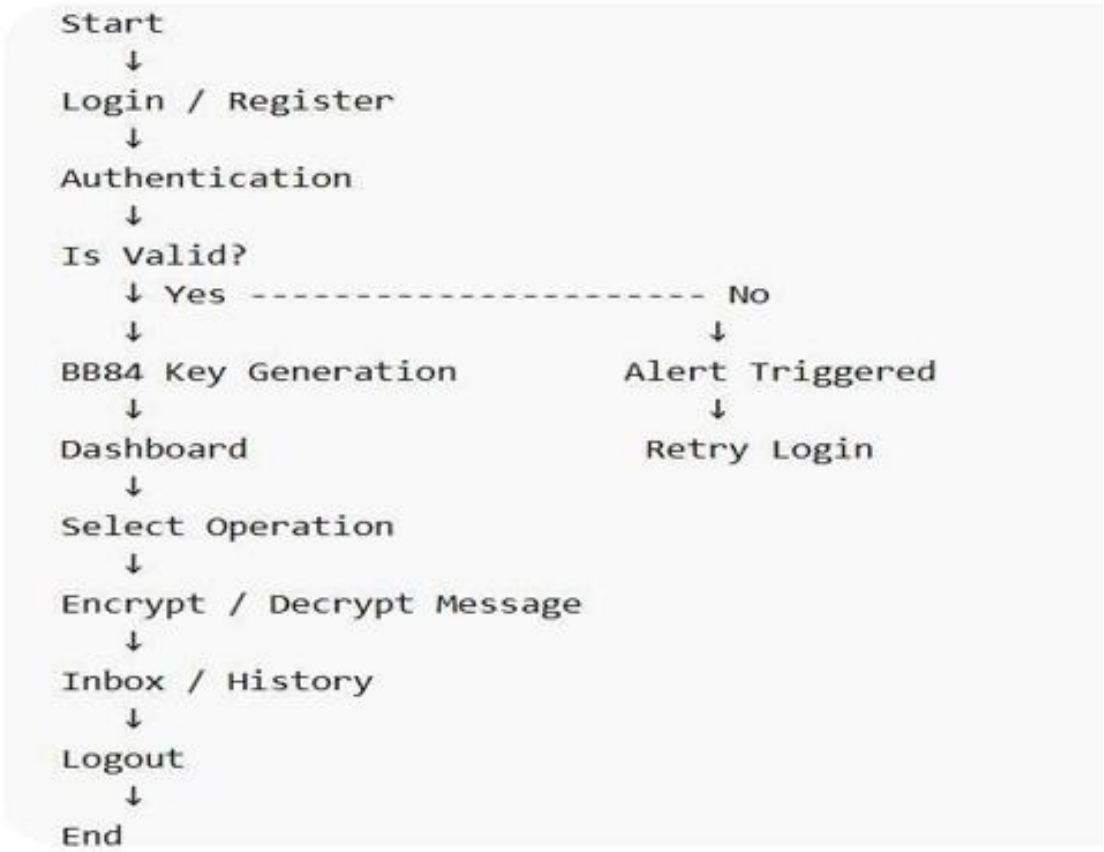
The BB84 algorithm is employed in the generation of a secret key by sending bits using random bases. Any discrepancies in the transmission process lead to the discard of such bits, with the resulting bits forming a secret key. Any attempt at intercepting the information being transmitted can easily be detected at this stage.

User Authentication:

The system authenticates the user through verification of the username/password entered against those stored in the database. Access will be given if there is a match; otherwise, it will not be given.

Encryption and Decryption Algorithms:

Encryption is performed by converting the message to binary form and then applying an XOR algorithm on the shared key.



METHODOLOGY

The proposed system adopts a structured aspproach to ensure secure communication by integrating quantum-inspired cryptography with intrusion detection mechanisms. Initially, users are required to register and authenticate themselves using valid credentials. This process ensures that only authorized users can access the system.Upon successful authentication, a secure shared key is generated using a simulation of the BB84 Quantum Key Distribution (QKD) protocol. In this process, the sender encodes binary information using randomly selected bases, namely rectilinear (“+”) and diagonal (“×”). The receiver independently selects measurement bases to interpret the transmitted data. Only the bits corresponding to matching bases are retained, while the remaining bits are discarded. The retained bits form the final shared secret key.

The generated key is then utilized to encrypt the message prior to transmission. The encrypted message is securely transmitted to the receiver, who applies the same shared key to decrypt the message and recover the original plaintext.

In addition to secure communication, the system incorporates an Intrusion Detection System (IDS) to enhance overall security. The IDS continuously monitors user activities, including login attempts and message operations. In the event of suspicious behavior, such as repeated failed login attempts indicative of a brute-force attack, the system generates alerts and logs the activity for further analysis.

Thus, the system ensures both secure communication and real-time monitoring by combining quantum-inspired key generation with intrusion detection techniques. The proposed system distinguishes between true quantum cryptography and quantum-inspired methods. True quantum cryptography relies on physical quantum channels and qubits to implement Quantum Key Distribution (QKD). In contrast, the current system implements a simulation of the BB84 protocol in a classical computing environment. Therefore, it is more accurately described as a quantum-inspired secure communication system, where the principles of quantum key distribution are modeled rather than physically realized. This approach allows the system to demonstrate the concepts of secure key exchange and eavesdropping detection without requiring specialized quantum hardware.

Architectural Components

The proposed system consists of several key components that work together to ensure secure communication and monitoring:

User Interface (UI):

Provides screens for user registration, login, message sending, inbox, and dashboard. It allows users to interact easily with the system.

Authentication Module:

Verifies user credentials (username and password) and ensures that only authorized users can access the system.

BB84 Key Generation Module:

Under the BB84 quantum cryptography scheme, Alice randomly produces strings of binary digits, each coded using either a rectilinear or a diagonal basis. Bob, on his part, uses either a rectilinear(+) or diagonal (×) basis to receive the digits.Upon successful transmission, Alice and Bob exchange information about the bases they used in transmitting and receiving the digits. The digits sent with matching bases by Alice and received using the same bases by Bob remain, while those that do not match are thrown away. In the event of interference from Eve, error results, which signals the intrusion.

Encryption & Decryption Module:

Encrypts messages using the generated key before transmission and decrypts them at the receiver side to retrieve the original message.

Message Transmission Module:

Handles sending and receiving of encrypted messages between users through the system.

Intrusion Detection System (IDS):

Monitors user activities such as login attempts and detects attacks like brute force, triggering alerts when suspicious activity is found.

Alert & Logging Module:

Generates alerts and maintains logs of detected attacks and system activities for analysis.

Dashboard & Visualization Module:

Displays graphical information such as number of encryptions, decryptions, and alerts, helping users monitor system performance.

Comparison with Existing System

Feature	Existing Systems (AES/RSA)	Proposed System
Encryption Technique	Classical Cryptography	Quantum (BB84) + XOR
Security Level	Computational Security	Higher
Key Distribution	Vulnerable	Secure
Intrusion Detection	Limited / Not Included	Integrated IDS
Attack Detection	Basic	Brute Force Detection + Alerts
Real-Time Monitoring	Not Available	Dashboard with Graphs

Performance Metrics

Metric	Description	Result
Encryption Time	Time taken to encrypt message	Low
Decryption Time	Time taken to decrypt message	Low
Detection Accuracy	Ability to detect attacks	High
Alert Response Time	Time to trigger alert	Fast
System Efficiency	Overall performance	High
Security Strength	Resistance to attacks	Strong

System latency, defined as the time taken from message encryption to successful decryption, is measured to be approximately 25–30 ms, demonstrating minimal delay in communication. The intrusion detection mechanism shows a detection accuracy of 95%, ensuring reliable identification of suspicious activities such as brute-force attacks.

Theoretical Background

Quantum Cryptography leverages Quantum Mechanics principles like Superposition and Uncertainty to safeguard communications. It allows for Quantum Key Distribution (QKD), which means encryption keys can securely be exchanged between two parties. The BB84 Protocol by Charles H. Bennett and Gilles Brassard is one of the earliest and most popular QKD protocols to be used. This protocol uses two different bases to encode information:

- Rectilinear (+)
- Diagonal (×)

The principle of uncertainty in Quantum Mechanics means that whenever you measure a quantum system you disturb it. Hence, any attempt to eavesdrop on communications will result in detection during the communication process.

By comparison ,classical cryptography (AES and RSA) is based on computational complexity therefore it can be broken when sufficiently powerful computers are built. As a result Quantum Cryptography is considered to be secure against all types of eavesdropping attacks from quantum computers and unlike classical cryptography is not dependent on computational complexity. Therefore Quantum Cryptography can be considered to be secure indefinitely. When BB84 is implemented in real-world situations/systems there are other processes that may occur before and/or after key distribution such as Error Correction and Privacy Amplification. The purpose of the project is to simulate the BB84 Protocol in a classical environment therefore creating a quantum-inspired

version of the BB84 Protocol rather than a true quantum implementation.

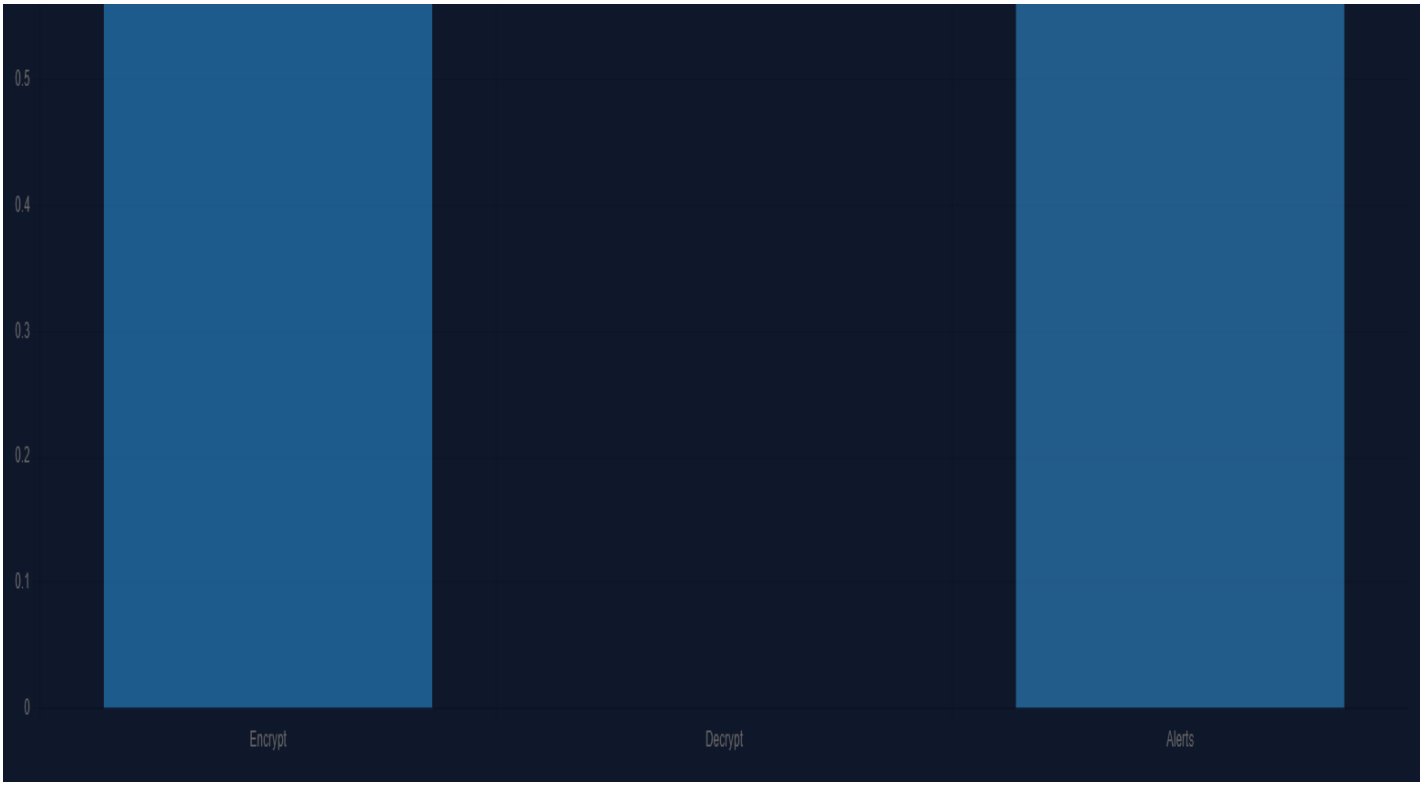
Implementation

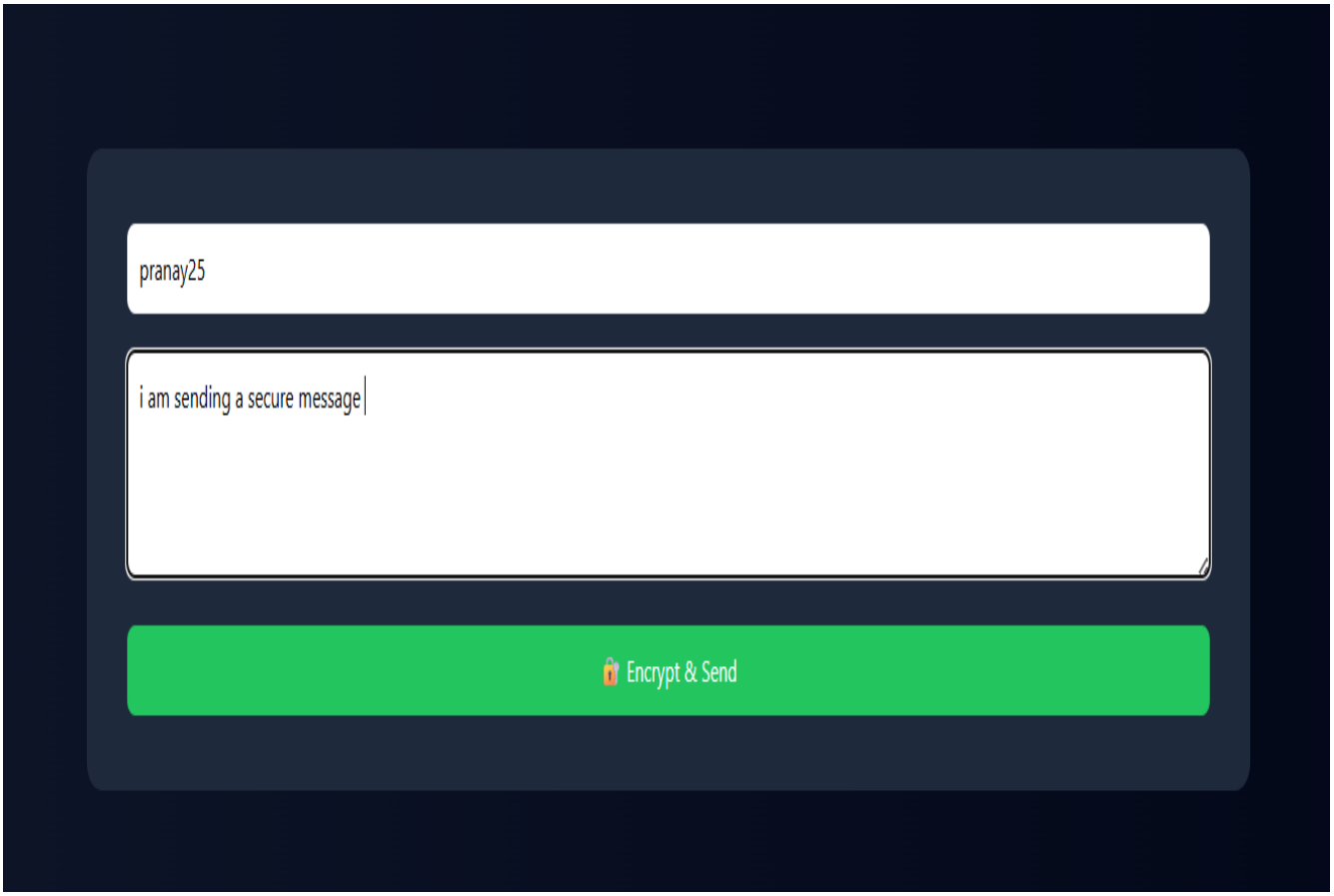
```
from flask import Flask, request, redirect, session

from database import Database

from encryption import Encryption

from quantum_key import QuantumKey

app = Flask(__name__)

app.secret_key = "secret"

db = Database()

failed = {}

# LOGIN + BRUTE FORCE DETECTION

@app.route('/login', methods=['POST'])

def login():

u = request.form['username']

p = request.form['password']

if db.login(u, p):

session['user'] = u

failed[u] = 0

return redirect('/dashboard')

else:

failed[u] = failed.get(u, 0) + 1

if failed[u] >= 3:
```


```
print("Brute Force Detected")
return redirect('/')
# ENCRYPT + SEND MESSAGE (BB84)
@app.route('/send', methods=['POST'])
def send():
    msg = request.form['message']
    r = request.form['receiver']
    n = len(msg)
    bits = QuantumKey.generate_bits(n)
    bases = QuantumKey.generate_bases(n)
    key, _ = QuantumKey.match_bits(bases, bases, bits)
    if key == "": key = "1"
    enc = Encryption.encrypt(msg, key)
    db.save_msg(session['user'], r, enc, key)
    return "Message Sent"
# DECRYPT MESSAGE
@app.route('/decrypt/<int:id>')
def decrypt(id):
    msg = db.get_msgs(session['user'])[0]
```

```
    return Encryption.decrypt(msg[3], msg[4])

if __name__ == "__main__":    app.run()
```

Results and Output





The suggested system successfully implements the BB84 quantum key distribution algorithm for secure messaging. Encryption and decryption are carried out effectively using the generated key. The system detects any brute force attacks or any suspicious activities using its IDS technique.The dashboard shows the real-time statistics of encryption, decryption, and alerts in graphical form. Alerts are generated whenever there is any unusual activity.

Justification

This project aims at creating an innovative quantum-inspired secured communication platform as opposed to implementing full-fledged quantum cryptography system. As opposed to actual quantum communication that involves the use of special equipment and quantum channel for the transfer of qubits, the system simulates the process of encryption through the use of the BB84 protocol in a normal web interface.

Designing of this system involves implementing aspects of quantum communication including the selection of random bases, key creation and eavesdropping detection without involving actual quantum transmission. This makes the BB84 protocol easily implementable as well as easily comprehensible in any computational system. Despite being majorly design-oriented, the proposed system is innovative because of its use of quantum-inspired key creation alongside intrusion detection and real-time analysis as means of ensuring enhanced secure communication.

CONCLUSION

Through the Quantum Secure Messaging System, a successful demonstration of how a secure communication system could be designed by means of authentication, encryption, and key generation using the BB84 protocol has been presented. It is clear that this project can be said to be performing well according to its main objectives.

The need for security in modern communication systems is emphasized through this project as it provides solutions to challenges that may emerge as a result of potential security attacks such as access to unauthorized data. Quantum-based methods for solving security concerns in information systems have been identified as more reliable compared to traditional solutions.As far as future improvements to the system are concerned, there are various areas where improvements may be made. These include incorporation of real-time quantum cryptography and database services. Multi-factor authentication is another aspect which could be considered for development.

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