AI Chatbot Based on RSA and AES Encryption Process

Computer Security and Data Security Final Project Report

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Abstract

This project presents a secure communication framework for AI chatbots by embedding end-to-end encryption (E2EE) into a chatbot system operating over the QQ messaging platform. Motivated by the increasing deployment of plaintext-based chatbots and the absence of cryptographic safeguards in mainstream AI-driven communication, our work addresses the pressing need for privacy-preserving interaction in open messaging environments. We designed and implemented a hybrid encryption architecture that leverages RSA for public-key key exchange and AES-GCM for authenticated symmetric message encryption, achieving a balance between cryptographic strength and computational efficiency.

The system is constructed as a four-layer modular pipeline, comprising a user-facing GUI for cryptographic interaction, a Python-based encryption engine implementing RSA-OAEP and AES-GCM routines, a chatbot backend integrated with the Napcat middleware to interface with QQ, and a secure communication transmission module that serializes messages into Base64-encoded JSON envelopes. This architecture supports multi-round encrypted dialogues, on-demand AES key rotation, and auxiliary functions such as image file encryption—all under the same security framework. Experimental validation demonstrates the system ' s ability to execute secure key exchange, preserve message confidentiality, and enforce integrity in an asynchronous, third-party messaging environment. The interface abstracts all cryptographic operations behind intuitive user actions, ensuring that encryption remains seamless and transparent to end users. Functional testing confirms compatibility across typical QQ message flows, even under network delays and concurrent message streams.

Overall, this project provides a practical and extensible blueprint for secure-by-design chatbot systems. It highlights the feasibility of embedding modern hybrid encryption schemes into AI-driven communication pipelines, paving the way for more robust and privacy-conscious chatbot deployments in real-world applications.

Code Repository: `https://github.com/Le1zyCatt/encrypt_ncatbot.git`

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1 Introduction

In today's digitally interconnected world, the integrity and confidentiality of personal communication are more crucial than ever. AI-powered chatbots are increasingly embedded into daily services—ranging from customer support to educational Q&A—but they often rely on insecure plaintext transmission, especially when integrated with third-party messaging platforms like QQ. As shown in recent systematic reviews, most chatbot deployments lack basic cryptographic safeguards, exposing users to threats such as data leakage and unauthorized access [10, 11].

In response to these vulnerabilities, end-to-end encryption (E2EE) has become standard in mainstream messaging platforms. The Signal Protocol, incorporating AES-256 symmetric encryption and elliptic-curve Diffie–Hellman (X25519) key exchange, now secures over a billion WhatsApp users daily. Despite these advances, E2EE remains largely absent in the design of AI chatbot systems—particularly those operating over untrusted channels or third-party messaging APIs.

Parallel research efforts have explored secure chatbot communication. Kumar et al. (2024) implement a chatbot with E2EE, leveraging RSA for key exchange and AES for message encryption, demonstrating the feasibility of secure chatbot interaction in private domains [7]. Another study systematically surveys chatbot vulnerabilities and emphasizes E2EE as a primary defense mechanism [10].

Motivated by these findings, our project aims to embed a hybrid encryption layer—combining RSA and AES—into an AI chatbot communication system deployed on QQ. The RSA algorithm handles asymmetric key exchange and identity verification, while AES-GCM provides efficient and authenticated symmetric encryption. This hybrid model balances the computational efficiency of symmetric encryption with the secure key distribution of asymmetric schemes, a method well-supported in cryptographic best practices [4, 9]. To our knowledge, this project is among the first to implement hybrid encryption within a chatbot integrated into the QQ messaging platform—an environment where secure-by-design communication remains underexplored.

Crucially, embedding this encryption into an AI-chatbot pipeline poses unique challenges: it must preserve normal chatbot functionality (e.g., message interpretation and response generation) while ensuring message confidentiality over potentially insecure channels. Drawing inspiration from real-world encryption frameworks and adapting them to AI-driven messaging, we demonstrate that secure AI chatbots can be both practical and user-friendly. A visual frontend ensures that all cryptographic operations are transparent to end users.

2 Problems Addressed and Project Goals

In contemporary AI-assisted communication platforms such as `QQ`, users frequently engage with chatbot systems to access services, exchange information, or automate daily tasks. However, a critical shortcoming persists: nearly all communication between users and chatbots occurs in plaintext. These unencrypted transmissions pose substantial privacy and security risks, including unauthorized interception, manipulation, or surveillance during transit across networks, servers, or client devices.

This project aims to address the lack of **privacy protection** and **message encryption mechanisms** in such interactions. To that end, we have designed and implemented an **end-to-end encrypted communication system**, in which all encryption and decryption processes are transparently embedded within the user-facing interface and the chatbot's backend logic. This architecture ensures that users can complete secure conversations without requiring any knowledge of cryptographic principles or configuration.

Our system directly tackles three core problems:

- **Lack of secure transmission:** Messages are traditionally sent in plaintext, making them vulnerable to interception and tampering.
- **No encryption in chatbot pipelines:** Neither the user interface nor the chatbot backend implements encryption by default.
- **Usability barrier for secure tools:** Most encryption-enabled communication systems are not user-friendly and require specialized setup.

To overcome these limitations, the system is designed around the following goals:

1. **Construct a complete encrypted communication logic:** Integrate RSA and AES hybrid encryption to support secure messaging.

2. **Embed decryption/encryption capabilities on both ends:** The frontend handles public-private key generation and AES decryption, while the chatbot backend securely parses ciphertext and issues encrypted replies.

3. **Support multi-round secure conversations:** Each communication round uses freshly generated AES session keys, allowing multiple encrypted exchanges within a single session.

4. **Ensure seamless ciphertext transmission:** Ciphertext is encoded in Base64 and wrapped in structured formats to facilitate transmission over the QQ messaging API.

At a high level, the communication workflow is composed of two sequential phases:

Phase I: Session Setup

Upon initiating communication, the frontend generates an RSA key pair and shares the public key with the chatbot. The chatbot generates an AES session key, encrypts it using the user's public key, and transmits it back to the user for local decryption. This establishes a shared symmetric key for the session.

Phase II: Secure Chat

Using the established AES session key, both the user and chatbot exchange encrypted messages. Each message is encrypted with AES in GCM mode to ensure both confidentiality and integrity. The system supports multiple encrypted turns, with automatic session key updates as needed.

Through this architecture, the project delivers a secure, low-friction AI chatbot interaction mechanism that preserves user privacy while maintaining conversational usability. It demonstrates that end-to-end security can be achieved without sacrificing accessibility or performance.

3 System Architecture and Modules

3.1 System Overview

The architecture of our secure AI chatbot communication system is designed in accordance with modern principles of cryptographic messaging, integrating hybrid encryption schemes, authenticated symmetric cipher modes, and secure session key negotiation. The primary goal is to construct a secure, efficient, and transparent communication pipeline between users and a chatbot hosted on a third-party platform —specifically QQ—without relying on the platform's inherent trustworthiness.

The system is structured into four tightly-coupled functional layers:

- **Front-End User Interface**: Handles user interaction, message input/output, and cryptographic operations;
- **Encryption Algorithm Engine**: Implements core RSA/AES encryption and decryption routines;
- **Chatbot Server Agent**: Deployed via Napcat, responsible for receiving messages, interpreting them, generating responses, and securely returning replies;
- **Communication Transmission Module**: Serializes, encodes, and routes messages in compliance with our custom secure protocol over the QQ platform.

These components work together under a clearly defined two-phase operation model:

Session Setup Phase The client frontend generates an RSA public-private key pair and sends the public key to the chatbot. The chatbot generates an AES session key, encrypts it with the public key, and returns it. The frontend then decrypts this key using the private key.

Secure Chat Phase Both parties use the established AES key to encrypt and decrypt subsequent messages using AES-GCM. Each message includes a ciphertext, a GCM authentication tag, and a unique nonce (IV). This guarantees both confidentiality and authenticity.

This hybrid encryption approach balances computational performance with cryptographic robustness, a model that has been widely adopted in end-to-end secure communication frameworks such as Signal, WhatsApp, and modern TLS versions [3, 8, 1]. Under the assumption of secure RSA padding and nonce uniqueness, this architecture achieves semantic security and ciphertext integrity [5].An overview of the system workflow is shown in Figure 1.

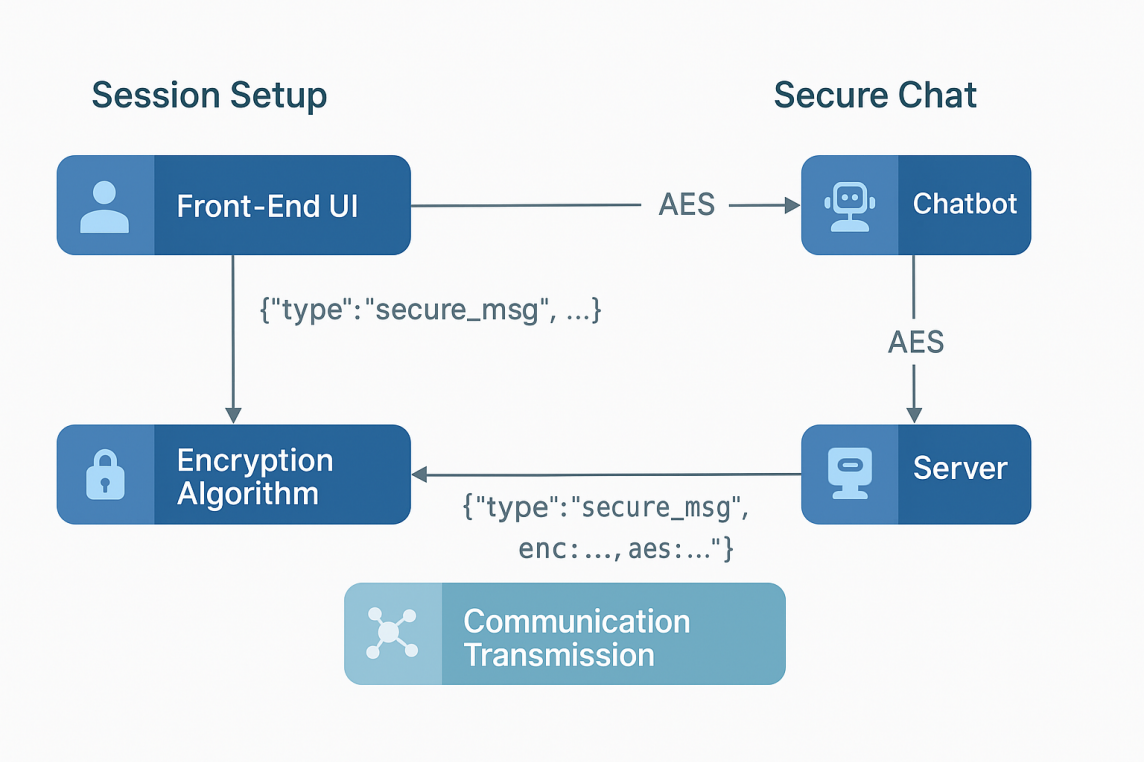

Figure 1: System Architecture and Secure Communication Workflow: The system operates in two phases —Session Setup and Secure Chat—across the four main modules. Encryption is handled at both ends to ensure end-to-end security.

3.2 Session Setup and the Role of Hybrid Encryption

To establish a secure communication session, we adopt a hybrid encryption architecture combining RSA and AES. RSA provides asymmetric key exchange, while AES ensures efficient symmetric encryption. This design mitigates common threats such as eavesdropping and man-in-the-middle (MITM) attacks, aligning with standard security models like Dolev-Yao [1].

The session begins with the user' s frontend generating an RSA key pair (pk_U, sk_U):

$$pk_U = (n, e), \quad sk_U = (n, d), \quad \text{where } n = pq$$

The chatbot generates a fresh AES session key K_{AES} and encrypts it with the user' s public key using RSA:

$$C_K = K_{AES}^e \bmod n$$

This ciphertext C_K is returned to the user as part of the handshake. To protect against chosen plaintext attacks, the RSA encryption employs the PKCS#1 v1.5 padding scheme, which adds structured entropy to the message [2].

The user then recovers the AES key by:

$$K_{AES} = C_K^d \bmod n$$

This completes the asymmetric key encapsulation step. Since no long-term symmetric key is reused across sessions, this process ensures forward secrecy within each individual communication round.

Formalized Flow. The handshake procedure is summarized below:

Algorithm 1: SessionSetup(): RSA-based Key Exchange

Input: None
Output: Shared AES session key K_{AES}

$(pk_U, sk_U) \leftarrow$ RSA.GenerateKeyPair() ; // User side
Send pk_U to chatbot $K_{AES} \leftarrow$ AES.GenerateKey() ; // Chatbot side
$C_K \leftarrow$ RSA.Encrypt(K_{AES}, pk_U) Send C_K to user $K_{AES} \leftarrow$ RSA.Decrypt(C_K, sk_U) ; // User side
return K_{AES}

Once established, K_{AES} is retained locally by both parties for use in subsequent encrypted message exchanges.

3.3 Authenticated Encryption with AES-GCM

Following session setup, all messages are encrypted using AES in Galois/Counter Mode (GCM). This encryption mode offers both confidentiality and integrity, combining high throughput with authenticated encryption—a critical requirement in adversarial environments. AES-GCM is standardized by NIST and widely used in secure protocols like TLS 1.3 [5].

Let M denote the plaintext message, A denote optional associated authenticated data (such as timestamps or metadata), and IV be a 96-bit random nonce. The encryption routine proceeds as follows:

$$(C, T) = \text{AES-GCM}_{K_{AES}}(IV, M, A)$$

where: - C is the ciphertext - T is the 128-bit authentication tag

Decryption is only attempted after T is verified against the input, ensuring resistance to tampering or replay attacks.

Algorithmic Flow. The message encryption and decryption logic is defined as:

Algorithm 2: SecureChatTurn(): AES-GCM Encryption

Input: Plaintext message M, AES key K_{AES}
Output: Encrypted payload (C, T, IV)

$IV \leftarrow$ Random(96-bit) $A \leftarrow$ AssociatedData() ; // Optional metadata
$(C, T) \leftarrow$ AES-GCM.Encrypt(K_{AES}, IV, M, A) **return** (C, T, IV)

Algorithm 3: DecryptReceivedMessage()

Input: Ciphertext C, tag T, IV, AES key K_{AES}
Output: Plaintext M or error

if *VerifyTag*$(C, T, IV) = false$ **then**
  return *Reject: Invalid ciphertext*
$M \leftarrow$ AES-GCM.Decrypt(K_{AES}, IV, C) **return** M

To further reduce key exposure, the system supports session key rotation: the AES key may be refreshed after a fixed number of messages (N) or after a timeout period (T minutes), by invoking a new RSA handshake. This strategy is inspired by forward secrecy designs from TLS and Signal' s Double Ratchet algorithm [1].

By combining formal cryptographic routines with transparent application-layer integration, this design ensures that user conversations remain confidential, tamper-resistant, and efficient—even across insecure messaging infrastructures like QQ.

3.4 Integration Across System Modules

Each system component plays a distinct yet interdependent role in maintaining secure communication. As shown in Figure 1, modules are organized into a layered pipeline spanning the user interface, cryptographic services, transmission control, and chatbot logic.

The **front-end interface module** manages user interactions, local key lifecycle, and cryptographic invocation. It performs Base64 encoding of ciphertexts, uses cryptographically secure pseudo-random number generators (CSPRNGs) for key generation, and caches session metadata such as message counters and timeouts. To end-users, encryption remains invisible—facilitated through a minimal GUI with message input, logs, and real-time encryption status indicators.

The **chatbot server module** is integrated into the QQ platform via Napcat as a stateless handler. It parses JSON-formatted messages, extracts and decrypts AES keys using the stored RSA public key, and verifies integrity tags. Based on decrypted payloads, it responds either via rule-based logic or LLM backends (e.g., GPT), before re-encrypting the reply with a fresh AES key.

The **encryption algorithm module**, written in Python using PyCryptodome, handles RSA encapsulation, AES-GCM operations, padding schemes, tag verification, and re-keying logic. All cryptographic parameters—RSA key length (2048-bit), AES key size (256-bit), nonce format, tag length (128-bit)—adhere to NIST standards [6].

The **communication transmission module** formats all secure messages into structured JSON envelopes:

```
{
  "type": "secure_msg",
  "payload": {
    "ciphertext": "<Base64>",
    "tag": "<Base64>",
    "iv": "<Base64>",
    "aes_key": "<RSA-encapsulated key>"
  }
}
```

Modules operate as a unified pipeline: the frontend encrypts via the crypto layer, transmits through the communication handler, and receives parsed replies from the chatbot. This layered separation enhances maintainability, extensibility, and testability across the entire system.

3.5 Theoretical Significance and Security Assurance

The hybrid encryption architecture aligns with modern cryptographic constructions. The system adopts the KEM-DEM paradigm: RSA acts as the Key Encapsulation Mechanism (KEM), while AES-GCM provides the Data Encryption Mechanism (DEM) for authenticated encryption. This design ensures IND-CCA2 and INT-CTXT security under standard assumptions [1]. AES-GCM enables AEAD (Authenticated Encryption with Associated Data), offering semantic security and integrity verification. Per-session AES keys, combined with fresh nonces and GCM tags, enforce strong confidentiality and replay protection. Padding schemes such as PKCS#1 v1.5 prevent structural attacks during RSA encapsulation [2]. From a threat model perspective, the system defends against passive observation, message tampering, chosen-plaintext and replay attacks. Session isolation via ephemeral AES keys further limits exposure. Collectively, this achieves cryptographic robustness while preserving usability—a necessary balance in real-world secure chatbot deployments.

4 Implementation and Key Technologies

This section elaborates on the technical implementation of the hybrid encryption system described earlier. We detail the generation, serialization, and application of RSA and AES keys, the construction of ciphertext envelopes, and the integration of cryptographic operations with the chatbot communication pipeline. Key implementations are developed in Python using a combination of custom number-theoretic logic and established cryptographic libraries.

The codebase is organized into four principal Python modules:

- `RSA_Tool.py`: Provides a command-line interface for generating RSA key pairs, exporting/importing in PEM and DER formats, and inspecting internal parameters such as d_P, d_Q, and $q^{-1} \bmod p$.
- `RSA_Encrypt.py`: Implements the core hybrid encryption and decryption procedures, including RSA-OAEP encapsulation and AES-GCM symmetric encryption.

- `GUI.py`: A PyQt5-based graphical interface for end-users to manage key generation, encryption/decryption, and message log viewing.
- `main.py`: Serves as the backend listener and controller, continuously monitoring messages from Napcat, recognizing encrypted payloads, and invoking decryption or encryption routines as needed.

These modules are loosely coupled through structured JSON-based message exchange and file-based RSA key sharing, facilitating modular development and testing.

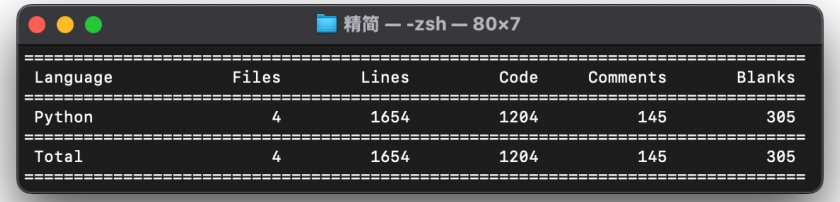

Figure 2: Total code constitution and workload chart

4.1 Technology Stack

The hybrid encryption system utilizes the following technology stack:

- **Python 3.10+**: Core development language and runtime environment.
- `cryptography`: Provides core cryptographic primitives including RSA-OAEP key encapsulation, AES-GCM authenticated encryption, ASN.1 key parsing, and symmetric/asymmetric key serialization.
- `gmpy2`: Used for generating large safe primes and performing modular arithmetic in RSA key construction.
- `pyasn1`: Enables ASN.1 DER encoding of private key components for standardized PEM output.
- `tkinter`: Built-in GUI framework used to construct the interactive encryption/decryption interface, including tabs for RSA, AES, image encryption, and secure messaging.
- `Napcat SDK`: Middleware layer responsible for intercepting and relaying QQ chat messages, integrated with the chatbot backend for secure communication.

4.2 RSA Key Generation and Parameter Derivation

The RSA key generation process is implemented in two stages. First, two 1024-bit safe primes p and q are generated using the GMP-based library `gmpy2`. These are used to compute the modulus $n = pq$ and Euler's totient $\varphi(n) = (p-1)(q-1)$. With a fixed public exponent $e = 65537$, the private exponent is calculated via modular inversion:

$$d = e^{-1} \bmod \varphi(n)$$

To support optimized CRT-based decryption, the following parameters are also computed:

$$d_P = d \bmod (p-1), \quad d_Q = d \bmod (q-1), \quad q^{-1} \bmod p$$

The private key is serialized using ASN.1 DER format and exported in PEM format as follows:

Listing 1: PEM Encoding via ASN.1 DER

```
def gen_key():
    p, q = gen_p_q()
    params = {
        '-p': p,
        '-q': q,
        '-o': "private.pem"
    }
    cmd = [sys.executable, "RSA_Tool.py"]
    for key, value in params.items():
        cmd.append(str(key))
        cmd.append(str(value))
    result = subprocess.run(cmd, capture_output=True, text=True)
    if result.stderr:
        print("错误信息:", result.stderr)
    with open("private.pem", "rb") as f:
        private_key = load_pem_private_key(f.read(), password=None)

    public_key = private_key.public_key()
    public_pem = public_key.public_bytes(
        encoding=serialization.Encoding.PEM,
        format=serialization.PublicFormat.SubjectPublicKeyInfo
    )
    public_key_str = public_pem.decode('utf-8')

    private_pem = private_key.private_bytes(
        encoding=serialization.Encoding.PEM,
        format=serialization.PrivateFormat.TraditionalOpenSSL,
        encryption_algorithm=serialization.NoEncryption()
    )
    private_key_str = private_pem.decode('utf-8')

    if os.path.exists("private.pem"):
        os.remove("private.pem")
    if os.path.exists("public.pem"):
        os.remove("public.pem")

    return public_key_str, private_key_str
```

4.3 RSA-Based Session Key Encapsulation

To establish a secure session between two parties, the system utilizes RSA-OAEP encryption with SHA-256 for encapsulating a randomly generated AES key. This hybrid approach guarantees semantic security under adaptive chosen ciphertext attacks (IND-CCA2), as recommended in modern cryptographic protocols.

The encryption process is implemented as follows:

Listing 2: Encrypting a Session Key Using RSA-OAEP

```
def encrypt_text(original_text: str, peer_public_key_str: str) -> str:
    data = original_text.encode('utf-8')

    if not peer_public_key_str.strip().startswith("-----BEGIN␣PUBLIC␣KEY-----"):
        raise ValueError("Invalid␣PEM␣format")
    if not peer_public_key_str.strip().endswith("-----END␣PUBLIC␣KEY-----"):
        raise ValueError("Invalid␣PEM␣format")

    public_key = serialization.load_pem_public_key(
        peer_public_key_str.encode('utf-8')
    )

    cipher_text = public_key.encrypt(
```

```
        data,
        padding.OAEP(
            mgf=padding.MGF1(algorithm=hashes.SHA256()),
            algorithm=hashes.SHA256(),
            label=None
        )
    )

    return base64.b64encode(cipher_text).decode('utf-8')
```

Once the ciphertext is transmitted, the receiver uses their private key to perform the decryption:

Listing 3: Decrypting an RSA-OAEP Encapsulated Key

```
def decrypt_text(encrypted_base64: str, my_private_key_str: str) -> str:
    cipher_text = base64.b64decode(encrypted_base64)

    private_key = serialization.load_pem_private_key(
        my_private_key_str.encode('utf-8'),
        password=None
    )

    plain_bytes = private_key.decrypt(
        cipher_text,
        padding.OAEP(
            mgf=padding.MGF1(algorithm=hashes.SHA256()),
            algorithm=hashes.SHA256(),
            label=None
        )
    )

    return plain_bytes.decode('utf-8')
```

This complete RSA-based key encapsulation mechanism provides a secure channel for transmitting the AES session key before symmetric encryption is used.

4.4 AES-GCM Implementation with `cryptography`

To ensure both confidentiality and integrity, our system applies AES in Galois/Counter Mode (AES-GCM), implemented via the `cryptography` library. Each encryption operation uses a randomly generated 96-bit nonce and outputs a ciphertext along with an authentication tag. All fields are Base64 encoded and concatenated for transmission.

Listing 4: AES-GCM Encryption Function

```
def aes_encrypt(plaintext: str, key: bytes) -> str:
    plaintext_bytes = plaintext.encode('utf-8')

    padder = sympadding.PKCS7(128).padder()
    padded_data = padder.update(plaintext_bytes) + padder.finalize()

    nonce = os.urandom(12)  # 96-bit nonce
    cipher = Cipher(algorithms.AES(key), modes.GCM(nonce), backend=default_backend())
    encryptor = cipher.encryptor()

    ciphertext = encryptor.update(padded_data) + encryptor.finalize()
    tag = encryptor.tag

    encrypted_data = nonce + tag + ciphertext
    return base64.b64encode(encrypted_data).decode('utf-8')
```

Decryption is performed by decoding and splitting the components, followed by authentication and unpadding:

Listing 5: AES-GCM Decryption Function

```python
def aes_decrypt(ciphertext: str, key: bytes) -> str:
    encrypted_data = base64.b64decode(ciphertext)
    nonce = encrypted_data[:12]
    tag = encrypted_data[12:28]
    ciphertext_bytes = encrypted_data[28:]

    cipher = Cipher(algorithms.AES(key), modes.GCM(nonce, tag), backend=default_backend())
    decryptor = cipher.decryptor()
    padded_plaintext = decryptor.update(ciphertext_bytes) + decryptor.finalize()

    unpadder = sympadding.PKCS7(128).unpadder()
    plaintext_bytes = unpadder.update(padded_plaintext) + unpadder.finalize()
    return plaintext_bytes.decode('utf-8')
```

This AES-GCM design ensures both message confidentiality and resistance against tampering.

4.5 Image Encryption via AES-GCM

To demonstrate the flexibility of the hybrid cryptographic system, we implement a dedicated image encryption module that applies AES-GCM to binary image files. This functionality highlights the system's ability to process not only text but also arbitrary binary data, such as photos and graphical content, with confidentiality and integrity guarantees. The encryption workflow involves several key steps:

1. The user selects an image file using a graphical file dialog.
2. The image is read as a byte stream and padded using PKCS7 to ensure block alignment.
3. A random 96-bit nonce is generated.
4. AES-GCM encryption is performed to obtain the ciphertext and authentication tag.
5. The encrypted output is structured as `nonce + tag + ciphertext` and saved as a binary file.

Listing 6: Image Encryption Using AES-GCM

```python
def encrypt_image():
    key = base64.b64decode(aes_key_entry.get())
    filepath = filedialog.askopenfilename(...)
    with open(filepath, "rb") as f:
        image_data = f.read()

    nonce = os.urandom(12)
    padder = pad_module.PKCS7(algorithms.AES.block_size).padder()
    padded_data = padder.update(image_data) + padder.finalize()

    cipher = Cipher(algorithms.AES(key), modes.GCM(nonce), backend=default_backend())
    encryptor = cipher.encryptor()
    ciphertext = encryptor.update(padded_data) + encryptor.finalize()
    tag = encryptor.tag

    encrypted_data = nonce + tag + ciphertext
    with open(save_path, "wb") as f:
        f.write(encrypted_data)
```

Decryption is the reverse of the above process. The nonce and tag are extracted from the encrypted file, and AES-GCM is used to verify and decrypt the ciphertext. PKCS7 padding is then removed to retrieve the original image bytes, which are saved to disk.

Listing 7: Image Decryption Using AES-GCM

```python
def decrypt_image():
    key = base64.b64decode(aes_key_entry.get())
    with open(filepath, "rb") as f:
        enc_data = f.read()
```

```
    nonce = enc_data[:12]
    tag = enc_data[12:28]
    ciphertext = enc_data[28:]

    cipher = Cipher(algorithms.AES(key), modes.GCM(nonce, tag), backend=default_backend())
    decryptor = cipher.decryptor()
    padded_plain = decryptor.update(ciphertext) + decryptor.finalize()

    unpadder = pad_module.PKCS7(algorithms.AES.block_size).unpadder()
    plain = unpadder.update(padded_plain) + unpadder.finalize()

    with open(save_path, "wb") as f:
        f.write(plain)
```

This module expands the scope of the encryption system beyond message-based secure communication, allowing users to secure local image files with authenticated encryption. It is particularly useful in scenarios where private visual data needs to be archived or transferred securely.

4.6 Secure GUI Integration for Hybrid Encryption

To enhance user experience and support real-time encrypted communication, our system provides a fully functional graphical interface using `tkinter`. This GUI enables end users to generate RSA key pairs, manage AES keys, perform encryption/decryption operations, and initiate a secure chat session with the bot client.

Session Initialization via GUI The encryption session is initiated by clicking the "Start Secure Session" button, which triggers automatic RSA key generation and dispatches the public key to the chatbot. The backend stores the private key and updates the encryption status:

Listing 8: Secure Session Initialization and Key Dispatch

```
def start_encryption_session():
    rsa_public_key, rsa_private_key_str = gen_key()
    secure_chat_ui["status_label"].config(text="已开启加密通信", fg="green")
    msg = f"加密通信模式on:{rsa_public_key}"
    send_text_message(msg, user_id="2401262719")
```

This process abstracts cryptographic key generation from the user, simplifying session establishment.

AES Session Key Decryption Upon receiving a response from the bot, the interface allows users to paste the Base64-encoded encrypted AES key into the input field. When the "Decrypt and Set AES Key" button is clicked, the system invokes RSA decryption and stores the resulting AES key for use in future communications:

Listing 9: Receiving and Decrypting AES Session Key

```
def receive_and_decrypt_aes_key(aes_enc_b64: str):
    private_key = serialization.load_pem_private_key(rsa_private_key_str.encode(),
    password=None)
    encrypted_key = base64.b64decode(aes_enc_b64)
    aes_key = private_key.decrypt(
        encrypted_key,
        padding.OAEP(
            mgf=padding.MGF1(algorithm=hashes.SHA256()),
            algorithm=hashes.SHA256(),
            label=None
        )
    )
    session_aes_key = aes_key
    aes_key_entry.insert(0, base64.b64encode(aes_key).decode('utf-8'))
```

This mechanism effectively completes the RSA-AES hybrid handshake, establishing a shared symmetric key for ongoing message encryption.

Encrypted Message Composition and Transmission Once the AES key is set, the user can send an encrypted message via the GUI. The plaintext input is encrypted using AES-GCM, then Base64-encoded and wrapped into a structured message. The secure message is dispatched through the bot client API:

Listing 10: Encrypt and Send Secure AES-GCM Message

```
def encrypt_and_send_message_with_aes(plaintext: str, key: bytes):
    encrypted_b64 = aes_gcm_encrypt(plaintext, key)
    secure_json = {
        "type": "secure_msg",
        "enc": encrypted_b64,
        "format": "gcm_base64"
    }
    send_text_message(json.dumps(secure_json), user_id="2401262719")
```

This design separates cryptographic logic from user input/output, ensuring consistent security while minimizing user error.

By tightly coupling user actions with secure cryptographic operations, the GUI transforms complex hybrid encryption workflows into an accessible and intuitive experience. This modular interface is especially useful for security education, protocol testing, and system demonstration purposes.

5 Testing and Demonstration

To validate the effectiveness and correctness of our hybrid RSA-AES encryption framework, we conducted a complete end-to-end test using the developed GUI tool and real QQ message transmission. The process is divided into three major phases: key exchange, secure message sending, and secure reply decoding. Each phase is elaborated with screenshots and step-by-step explanation.

5.1 Phase I: Key Initialization and Exchange (Step 1–4)

This phase establishes a secure communication context by generating RSA keys and exchanging public keys between the GUI and the bot over QQ. It ensures the basis for asymmetric encryption and later AES session key encapsulation.

5.1.1 Step 1: Generate Safe Primes \textitp and \textitq

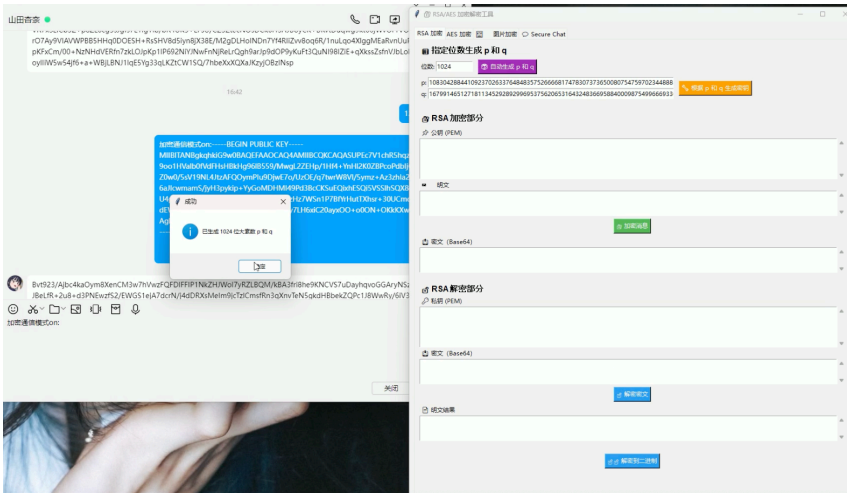

Figure 3: User generates 1024-bit safe primes using the GUI.

In this step, the user initializes the cryptographic system by generating two large prime numbers of 1024 bits each, labeled p and q. Within the RSA module of the GUI, the user specifies the bit length and clicks the `Generate` button. The system internally calls the `gmpy2.next_prime()` function to randomly generate cryptographically secure primes. Upon completion, a pop-up dialog confirms the generation,

and the resulting values are automatically populated into the input fields labeled “p:” and “q:”. These primes serve as the foundation for constructing the RSA keypair.

5.1.2 Step 2: Generate RSA Keypair and Export Public Key

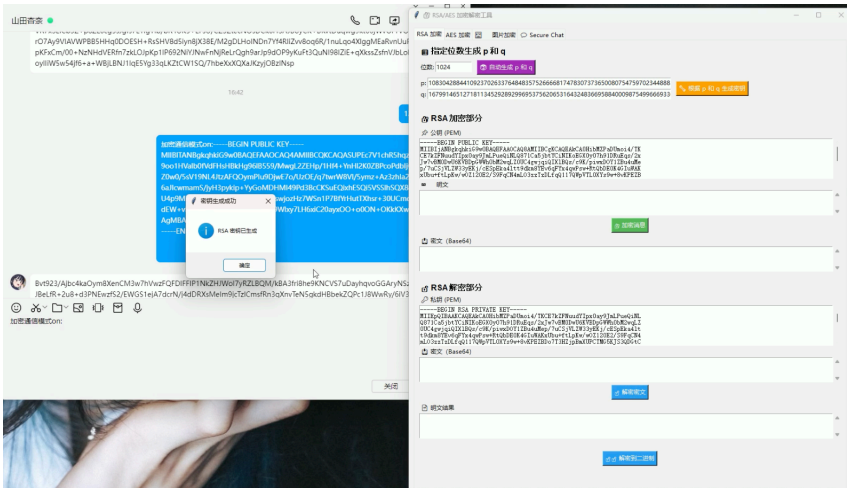

Figure 4: RSA public/private key generated and public key extracted.

The user clicks the button labeled “Generate Keypair” to initiate RSA key generation based on the previously generated primes. The system executes `RSA_Tool.py`, which computes the RSA modulus $n = p \times q$, the Euler totient $\varphi(n) = (p-1)(q-1)$, and the private exponent $d \equiv e^{-1} \mod \varphi(n)$. The keypair is serialized using the `pyasn1` library and encoded in PEM format. The GUI then displays the resulting public and private keys in designated PEM text areas.

5.1.3 Step 3: Send Public Key to Bot via QQ

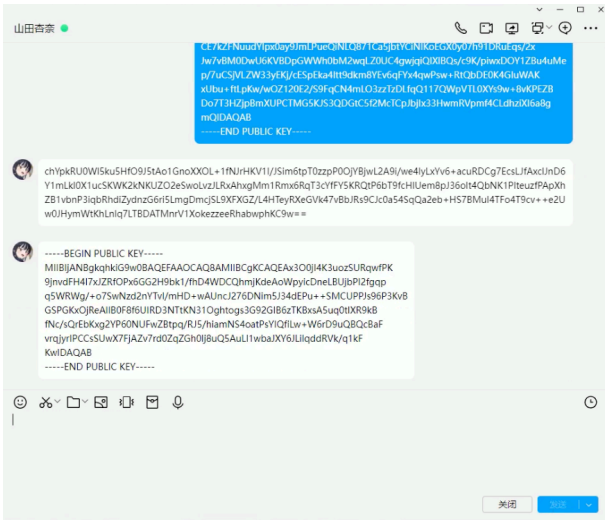

Figure 5: User sends PEM-encoded public key via QQ message.

After generating the RSA public key, the user copies the PEM-encoded string and pastes it into a QQ message. The message is prefixed with the special flag `Encryption Mode On:`, indicating the initiation of secure communication. Once sent, the bot listens for this trigger and extracts the public key from the message body. It parses the PEM string, reconstructs the public key object, and prepares for session key encryption.

5.1.4 Step 4: Bot Replies with RSA-Encrypted AES Key

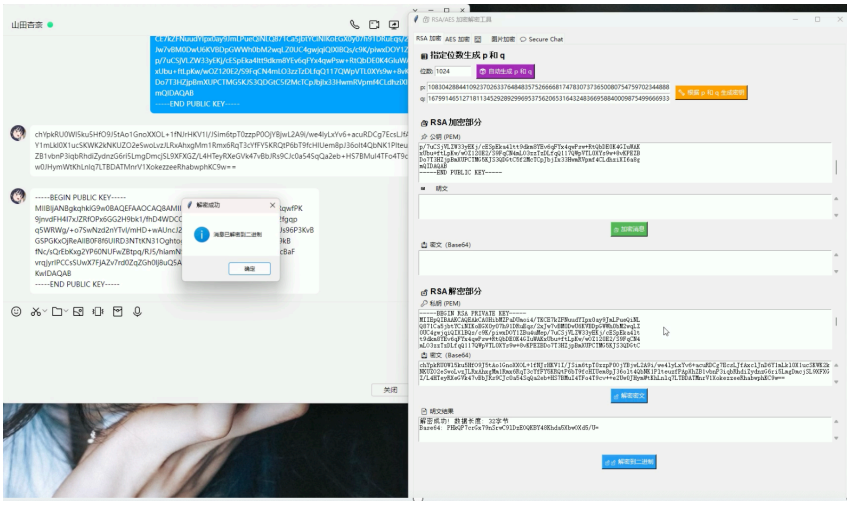

Figure 6: Bot replies with RSA-encrypted AES key (Base64 encoded).

Upon receiving and parsing the public key, the bot generates a random 256-bit AES session key. This key is encrypted using RSA-OAEP with the received public key and then Base64-encoded. The encrypted key is sent back to the user as a QQ message. On the user's side, the GUI automatically detects the incoming encrypted key, decrypts it using the private RSA key, and stores the AES key securely for use in future encrypted communication.

5.2 Phase II: Secure Message Transmission (Step 5–6)

Once the AES session key is successfully established, users can transmit encrypted messages to the bot using symmetric encryption.

5.2.1 Step 5: AES-GCM Encryption of User Message

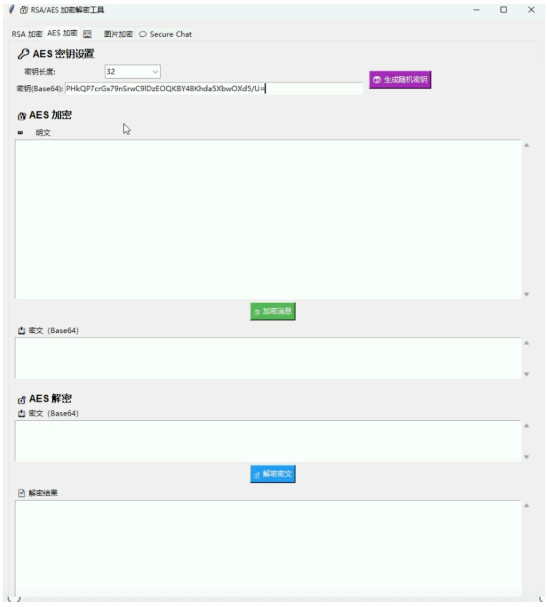

Figure 7: GUI encrypts message using AES-GCM and displays Base64 output.

The user enters a plaintext message in the GUI's encryption panel and clicks `Encrypt Message`. The system generates a 96-bit random nonce and applies AES-GCM encryption using the stored AES session

key. The result—consisting of the ciphertext, authentication tag, and nonce—is encoded in Base64 and displayed in the GUI. This encryption provides both confidentiality and integrity.

5.2.2 Step 6: Send Ciphertext via QQ

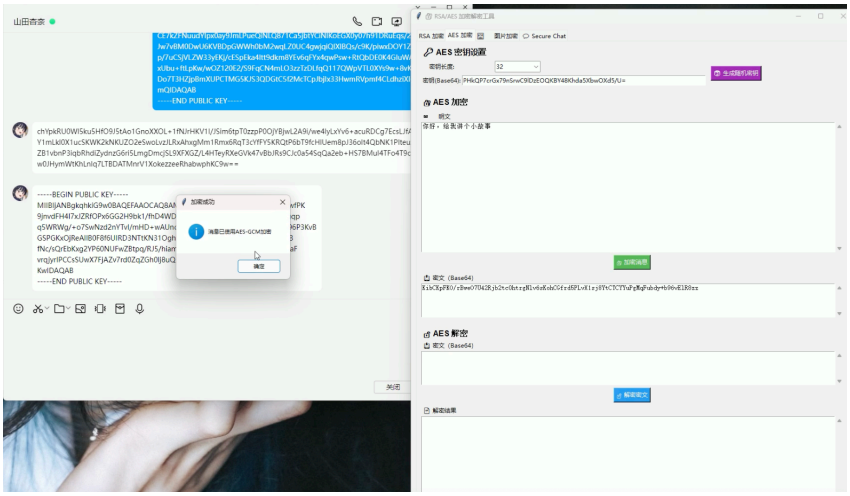

Figure 8: Encrypted Base64 ciphertext is sent via QQ.

The Base64-encoded ciphertext is copied from the GUI and pasted into the QQ chat. The bot continuously monitors incoming messages and, upon detecting a valid AES-GCM encrypted payload, extracts the relevant fields (nonce, ciphertext, and tag) and performs decryption using the current AES session key.

5.3 Phase III: Bot Response and Message Decoding (Step 7–9)

This phase covers the full round-trip communication: bot-generated reply encryption, message delivery, and user-side decryption.

5.3.1 Step 7: Bot Replies with AES-GCM Encrypted Answer

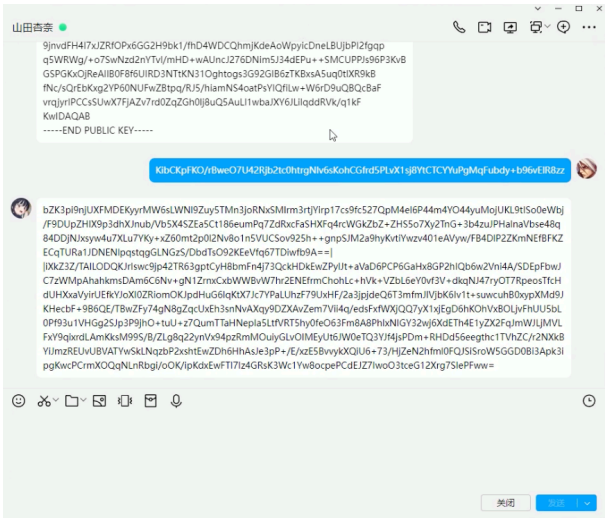

Figure 9: Bot sends AES-encrypted Base64 reply message.

The bot uses the AES session key to encrypt a GPT-generated response via AES-GCM. The encrypted result is encoded in Base64 and sent back to the user through QQ. This ensures the response is both confidential and authenticated.

5.3.2 Step 8: User Pastes Ciphertext for Decryption

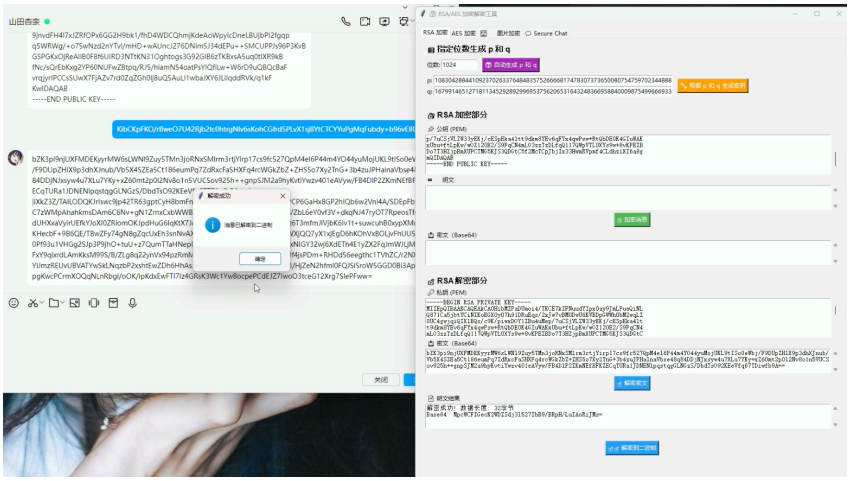

Figure 10: User pastes AES-GCM ciphertext into GUI decryption box.

Upon receiving the encrypted reply from the bot, the user copies the ciphertext and pastes it into the decryption input field in the GUI. The user then clicks the `Decrypt Message` button to proceed.

5.3.3 Step 9: GUI Decodes Message and Displays Plaintext

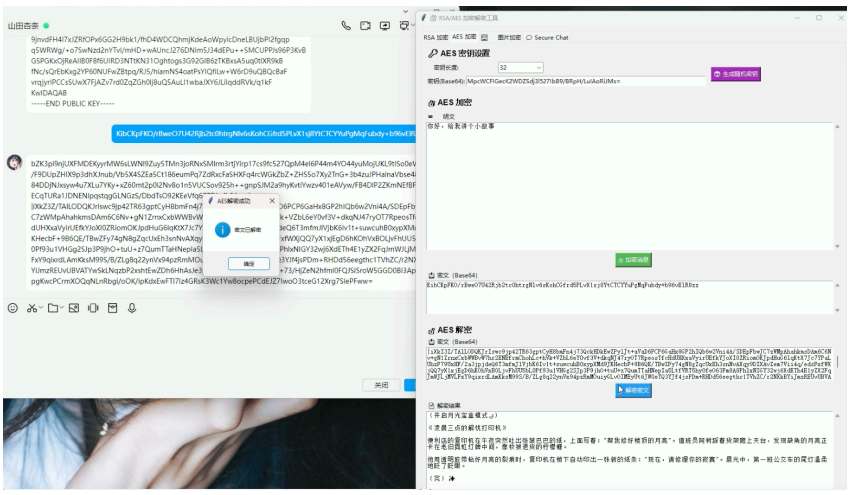

Figure 11: GUI successfully decrypts and displays the bot's plaintext reply.

The GUI extracts the Base64-encoded nonce, tag, and ciphertext, reconstructs the AES-GCM cipher, and performs decryption using the AES key. If the authentication tag is verified, the plaintext is displayed in the output window, confirming secure end-to-end encrypted communication.

Overall, this demonstration proves the system's ability to securely exchange session keys, transmit encrypted messages, and verify message authenticity using a hybrid RSA-AES architecture.

6 Challenges and Reflections

The implementation of a secure AI chatbot communication system posed multiple challenges spanning cryptographic design, platform integration, performance optimization, and user experience. Throughout development, we encountered both theoretical and practical constraints, prompting iterative refinement of our system architecture.

6.1 Cryptographic Key Management

One of the earliest challenges involved securely generating, storing, and rotating cryptographic keys. While RSA key pairs were generated locally per session to enhance forward secrecy, managing these keys in memory without long-term persistence raised issues with session continuity. Moreover, embedding PEM-encoded keys into user-facing components required careful handling of encoding, parsing, and format validation. Our resolution involved adopting ephemeral keys per session and base64-wrapping all transmitted components to ensure safe transport.

6.2 Asymmetric Latency in Message Flow

Due to the distributed nature of the system—where the frontend client and backend chatbot operate asynchronously over a third-party platform—we observed variable delays in message processing. This occasionally led to race conditions during session key handshakes or message decryption. To mitigate this, we introduced retry mechanisms for failed key exchanges and timestamp-based synchronization flags to enforce causal message ordering within a session.

6.3 Napcat Framework Stability and Limitations

Napcat provided a lightweight interface for message relay but lacked support for advanced features such as reliable message acknowledgement, end-to-end encryption hooks, or persistent session state. Additionally, bot events (e.g., `@bot.private_event`) were sometimes lost under high load, especially when multiple encrypted conversations were active in parallel. As a temporary measure, we limited concurrent encrypted sessions to one and added stateful session IDs to ensure consistency.

6.4 Reflections and Takeaways

This project demonstrated the feasibility—and complexity—of retrofitting strong cryptographic guarantees into chatbot infrastructures not originally designed for secure messaging. Our experience revealed that:

- Applied cryptography requires not only algorithmic correctness but also systemic coherence across transport, interface, and protocol layers.
- Frontend-backend synchronization is critical in environments where timing and delivery are nondeterministic.
- Security is a moving target: protecting confidentiality must be matched with integrity, forward secrecy, and usability.

We believe that our work lays the groundwork for future secure chatbot designs that prioritize privacy by default. While the system in its current form is functional and demonstrative, it also highlights opportunities for further improvement in reliability, extensibility, and multi-user session support.

7 Future Work

While our current system successfully demonstrates secure AI chatbot communication using hybrid RSA-AES encryption, it also reveals areas for further development in robustness, user experience, and cryptographic completeness. Based on our implementation experience and evaluation, we propose the following directions for future enhancement.

1. Automated AES Key Reception and Processing At present, the frontend interface requires manual steps to receive and decrypt AES session keys sent by the chatbot. This process interrupts user experience and introduces potential for misoperation. Future versions should implement an automated listener module that detects incoming encrypted AES keys and invokes the corresponding decryption function. This will streamline session establishment and enhance transparency.

2. Session Key Caching and Identity Binding To support multi-user encrypted communication, we plan to introduce a robust key cache mechanism that maps `user_id` to session-specific AES keys. This would allow the system to store, retrieve, and rotate keys on a per-session basis, eliminating the need to reconfigure secure communication with each new message. This improvement ensures seamless support for multiple encrypted conversations in both group and private modes.

3. Enriched Encrypted Protocol Metadata Our current `secure_msg` format lacks descriptors for encryption mode or IV placement, which may cause decryption failures under incompatible assumptions. We propose extending the message envelope with explicit fields such as:

```
{
  "type": "secure_msg",
  "mode": "GCM",
  "iv": "<Base64>",
  "ciphertext": "...",
  "tag": "...",
  "aes_key": "<RSA-encapsulated key>"
}
```

This protocol enhancement will make the system more flexible and interoperable with future cryptographic modes (e.g., CBC, CCM, or even AEAD ChaCha20).

4. Integration with LLM-Based Chat Engines Lastly, while the current response generation logic is either rule-based or based on external API calls (e.g., DeepSeek), future work includes securely integrating local LLMs into the chatbot backend. This would allow encrypted semantic queries, enabling multi-round secure dialogue with context-aware responses—all within a privacy-preserving framework.

5. Enhanced Message Authentication and Anti-Tampering Our current system ensures message confidentiality and integrity using AES-GCM, but additional layers of authentication can be beneficial. We plan to integrate digital signatures (e.g., RSA-SHA256) or HMACs for message origin verification. This would help prevent message spoofing and tampering, especially in group settings or hostile environments.

In summary, while our system establishes the foundation for private chatbot communication, its long-term viability relies on modular upgrades, richer cryptographic protocols, and enhanced user trust through better interfaces and defenses.

8 Conclusion

This project presents a fully functional and theoretically grounded end-to-end encrypted chatbot communication system, specifically tailored for integration with third-party messaging platforms such as `QQ`. By combining RSA-based public key cryptography with AES-GCM authenticated symmetric encryption, the system achieves a hybrid encryption framework that ensures both confidentiality and integrity of user-bot interactions.

Throughout the development process, we have addressed a critical gap in existing chatbot deployments—namely, the lack of secure message transmission mechanisms. Our implementation integrates all cryptographic operations seamlessly into the user interface and chatbot backend, enabling secure, multi-round dialogue without requiring any cryptographic knowledge from the user. The encryption handshake leverages RSA-OAEP for session key encapsulation, followed by AES-GCM for message encryption with per-message nonce and authentication tags, aligning with contemporary security standards.

From a system engineering perspective, the project demonstrates the feasibility of deploying cryptographic protocols in constrained and asynchronous communication environments. Modular design across four key components—front-end GUI, encryption core, chatbot server, and transmission handler—ensures maintainability, extensibility, and testability. The successful GUI-based demonstration confirms the system's capability to perform full-cycle encryption and decryption over real-world channels, validating its security and usability.

Beyond its technical robustness, the project reflects a practical philosophy: security should be transparent, user-friendly, and integral to system architecture—not a post-hoc addition. The challenges we

faced in synchronization, key management, and platform limitations highlight the complexity of real-world secure system design. Nevertheless, the project lays a concrete foundation for privacy-preserving AI applications and suggests a viable path forward for secure chatbot ecosystems.

In summary, this work provides a compelling demonstration that modern cryptographic techniques can be adapted into accessible and operationally efficient chatbot systems. By delivering a hybrid encryption framework embedded within a familiar messaging context, it represents an important step toward making privacy a default feature in AI-driven communication.

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