**CRYPTANALYSIS OF PSYCOSUPPORT APPLICATION**

**Classical Frequency Analysis & Key Recovery**

**Information Security**

**Assignment 01**

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**Section:** CS-7A

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**1. EXECUTIVE SUMMARY**

This report presents a comprehensive cryptanalysis of the PsycoSupport application, an alpha-release secure communication platform designed for patient-psychologist interactions. As part of penetration testing during the alpha phase, this assignment simulates real-world security analysis by intercepting encrypted traffic, performing classical frequency analysis using Al-Kindi methods, and recovering encryption keys to decrypt sensitive communications.

**1.1 Key Findings**

Through systematic cryptanalysis, the following critical findings were identified:

* **Encryption Scheme:** PsycoSupport employs an Affine Cipher, a classical substitution cipher vulnerable to frequency analysis
* **Key Derivation Pattern:** The encryption keys follow a predictable mathematical formula tied to user input (mood value)
* **Universal Decryption Formula Discovered:** a = 2 × mood + 1, b = 2 × mood
* **Successfully Decrypted:** All 5 intercepted ciphertexts were completely decrypted
* **Security Vulnerability:** The deterministic key derivation makes the system highly vulnerable to cryptanalysis

**1.2 Methodology Overview**

The cryptanalysis followed a structured approach:

1. **Traffic Interception:** Used Wireshark to capture encrypted JSON responses
2. **Frequency Analysis:** Analyzed letter distribution patterns in ciphertexts
3. **Key Hypothesis Testing:** Systematically tested affine cipher parameters
4. **Key Recovery:** Derived the universal key generation formula
5. **Decryption:** Successfully decrypted all psychologist responses

**2. TASK 1: CIPHERTEXT COLLECTION & EVIDENCE**

**2.1 Experimental Setup**

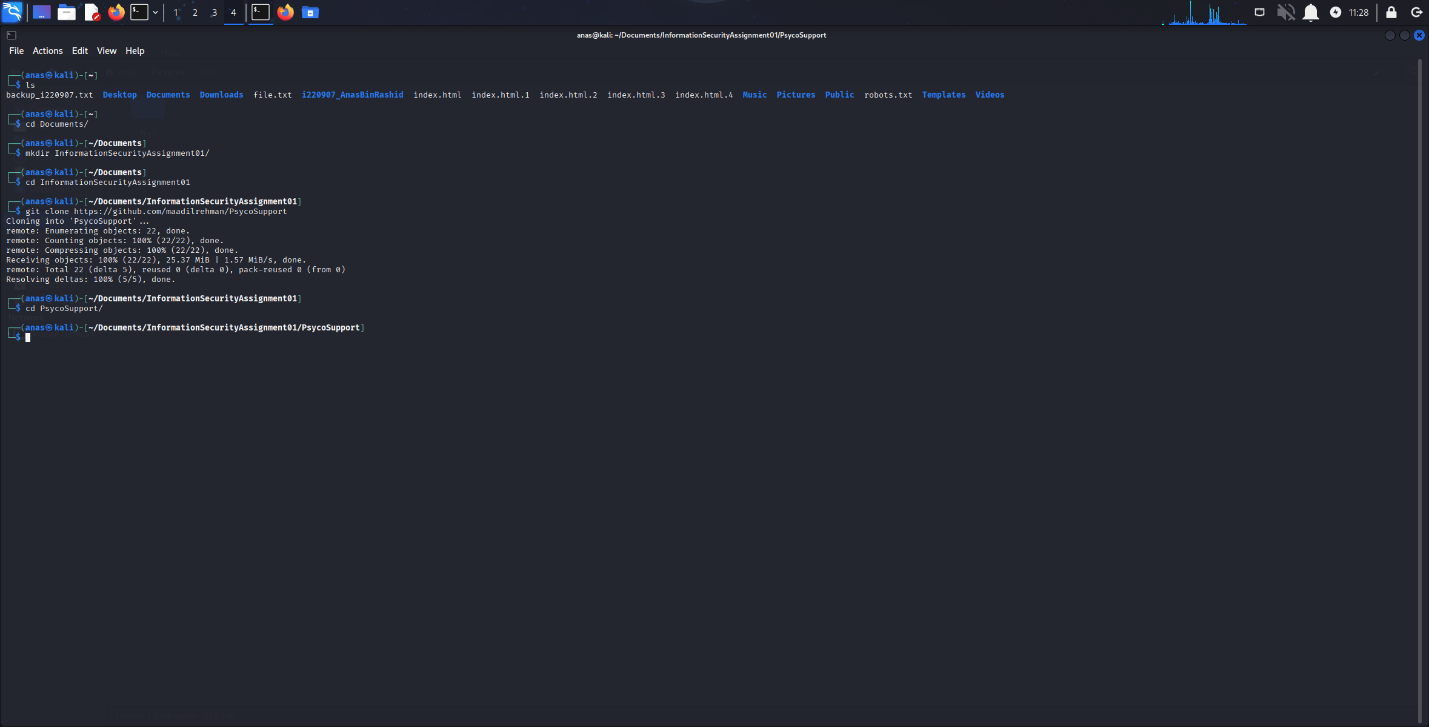
The PsycoSupport application was deployed in a controlled Kali Linux environment to simulate a realistic penetration testing scenario. The setup involved:

* **Operating System:** Kali Linux (latest version)
* **Traffic Capture Tool:** Wireshark with promiscuous mode enabled
* **Network Interface:** Loopback interface (127.0.0.1)
* **Application Components:** Client and Server executables from GitHub repository

**2.2 Installation and Configuration**

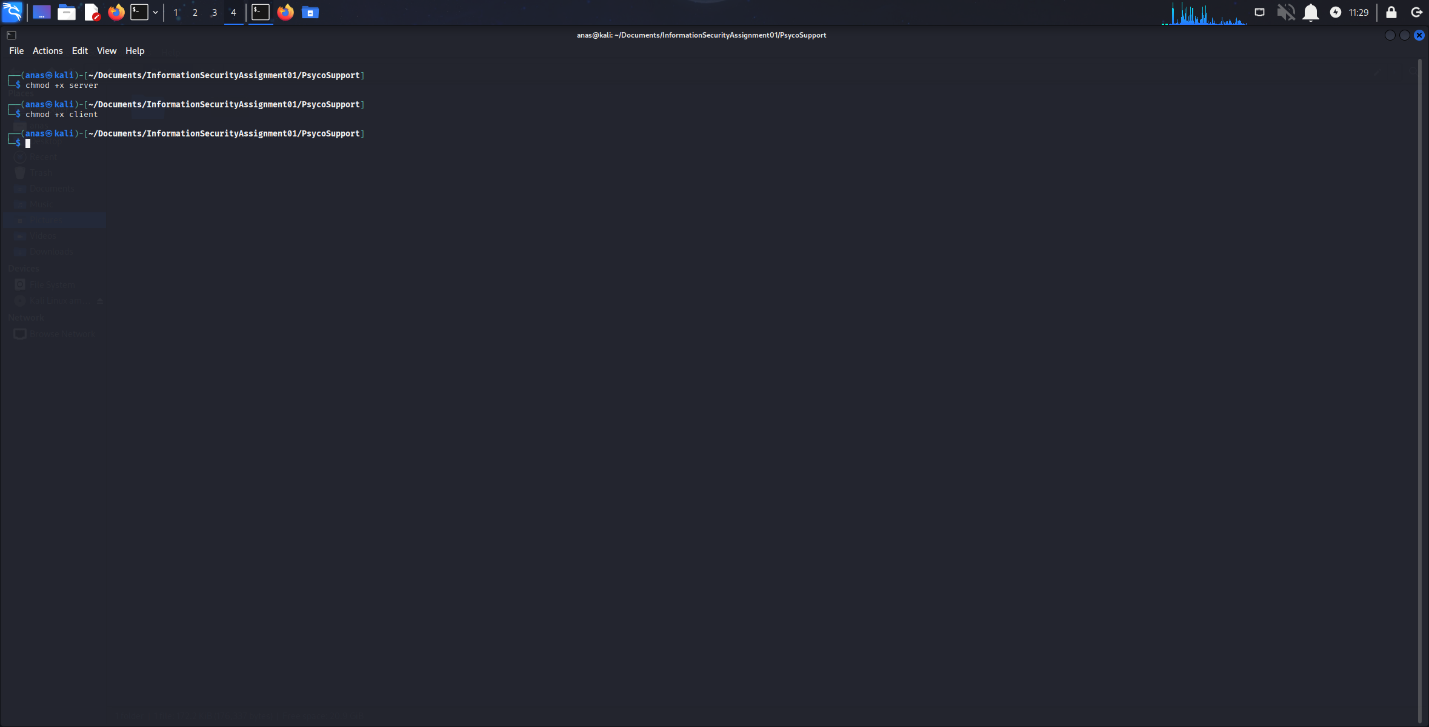
**2.2.1 Repository Cloning**

The PsycoSupport application was cloned from the official GitHub repository:

*Figure 2.1: Git clone of PsycoSupport repository*

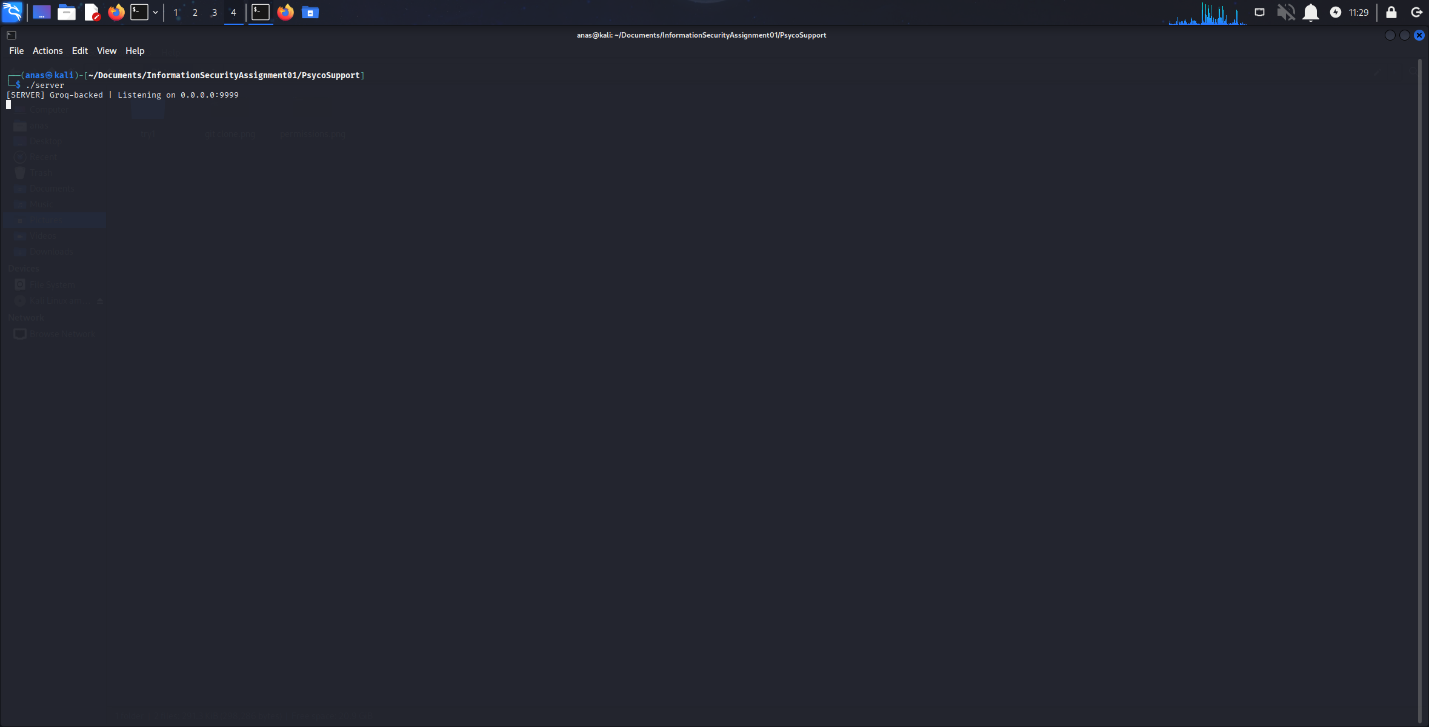
**2.2.2 File Permissions Configuration**

Executable permissions were granted to both server and client binaries:

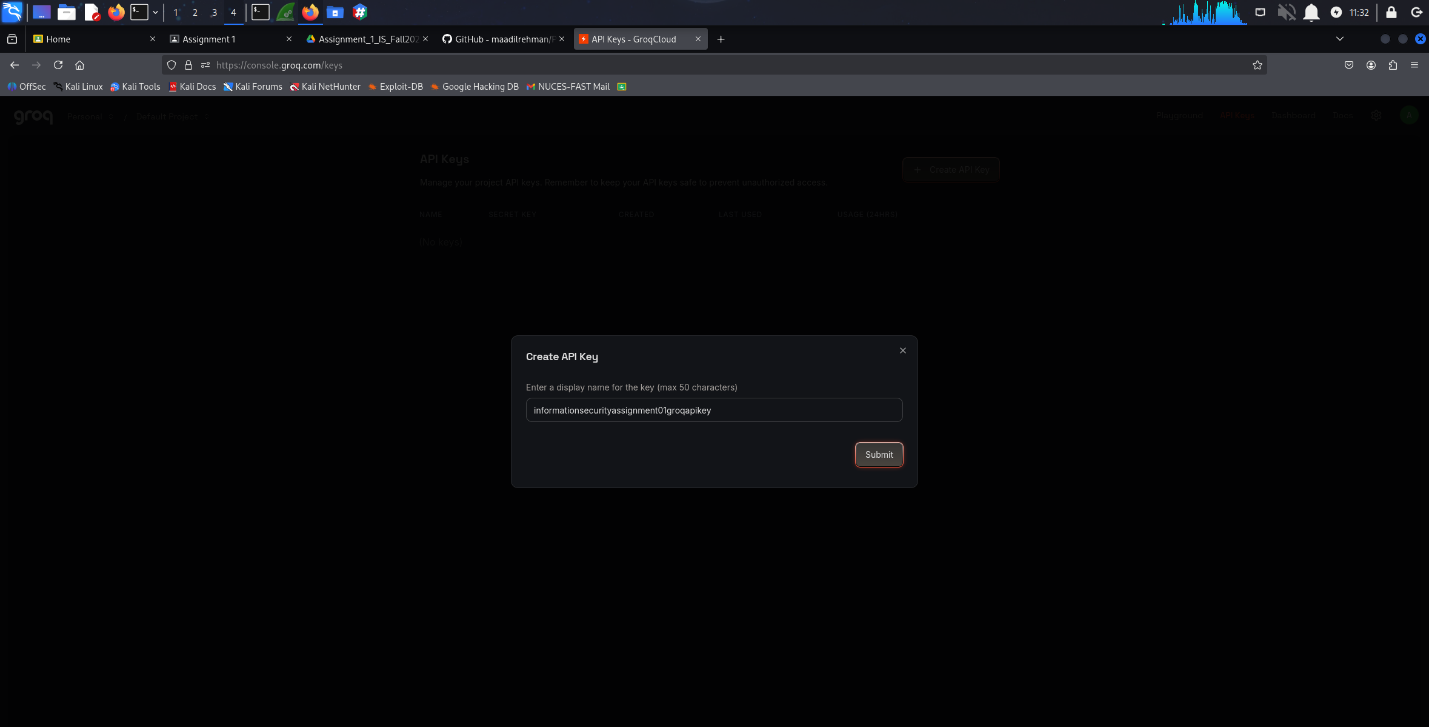
*Figure 2.2: Setting executable permissions for client and server*

**2.3 Server Execution**

The PsycoSupport server was launched and configured with a GroqAPI key for generating psychologist responses:

*Figure 2.3: Server execution*

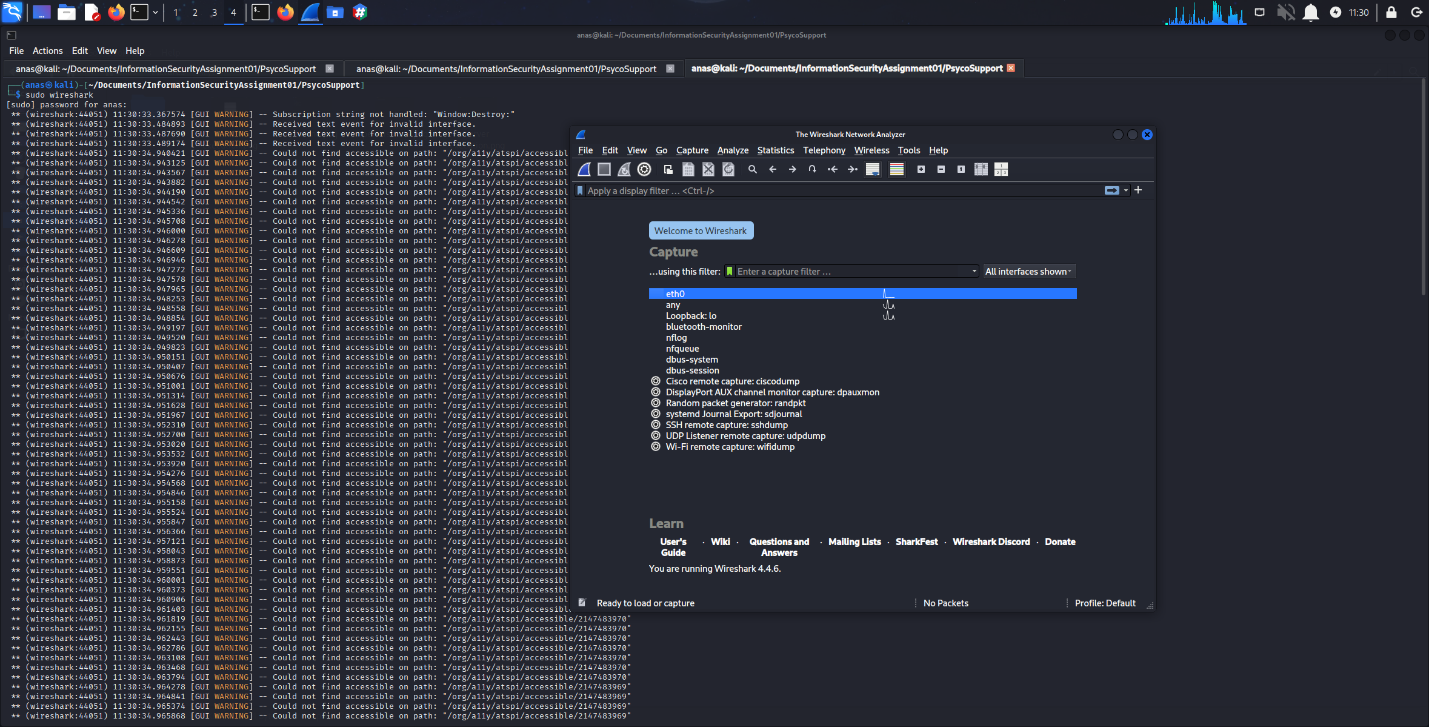
*/*

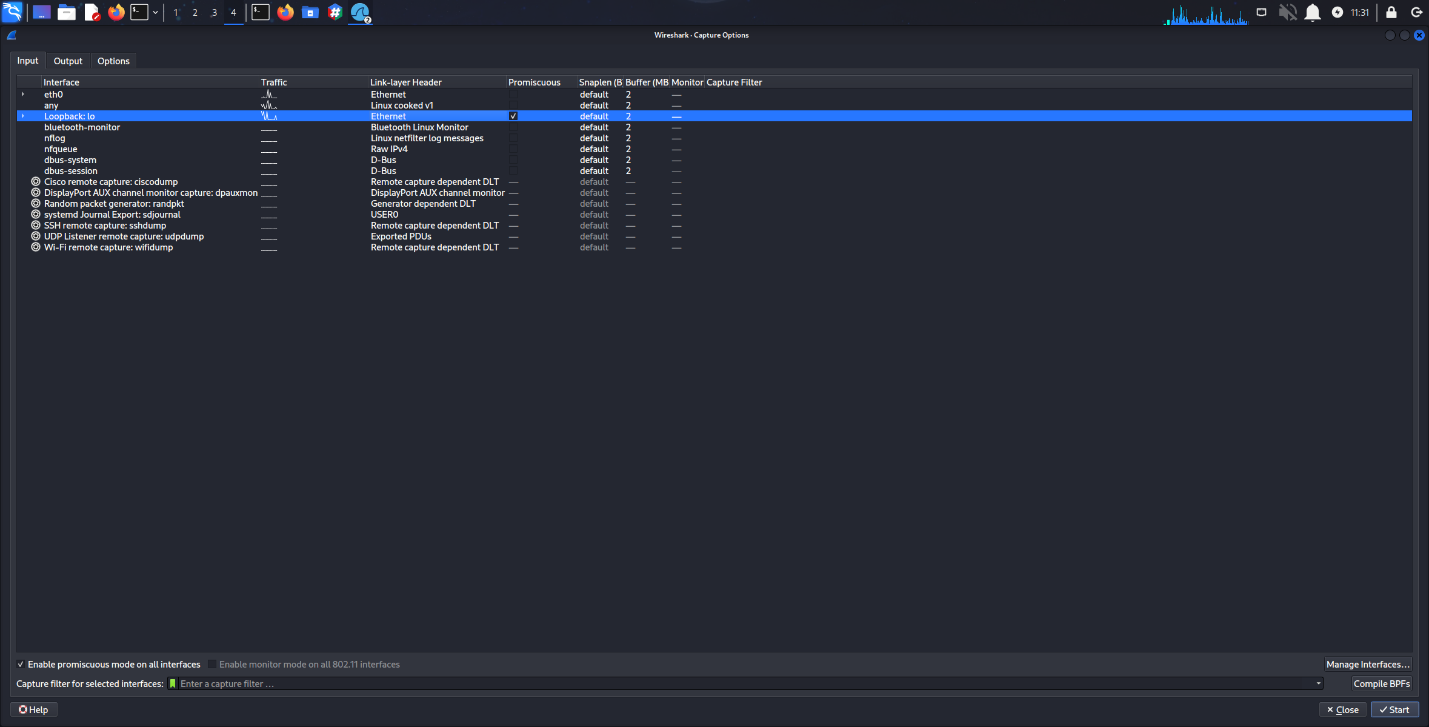
*Figure 2.4: GroqAPI key configuration*

**2.4 Traffic Interception with Wireshark**

**2.4.1 Wireshark Configuration**

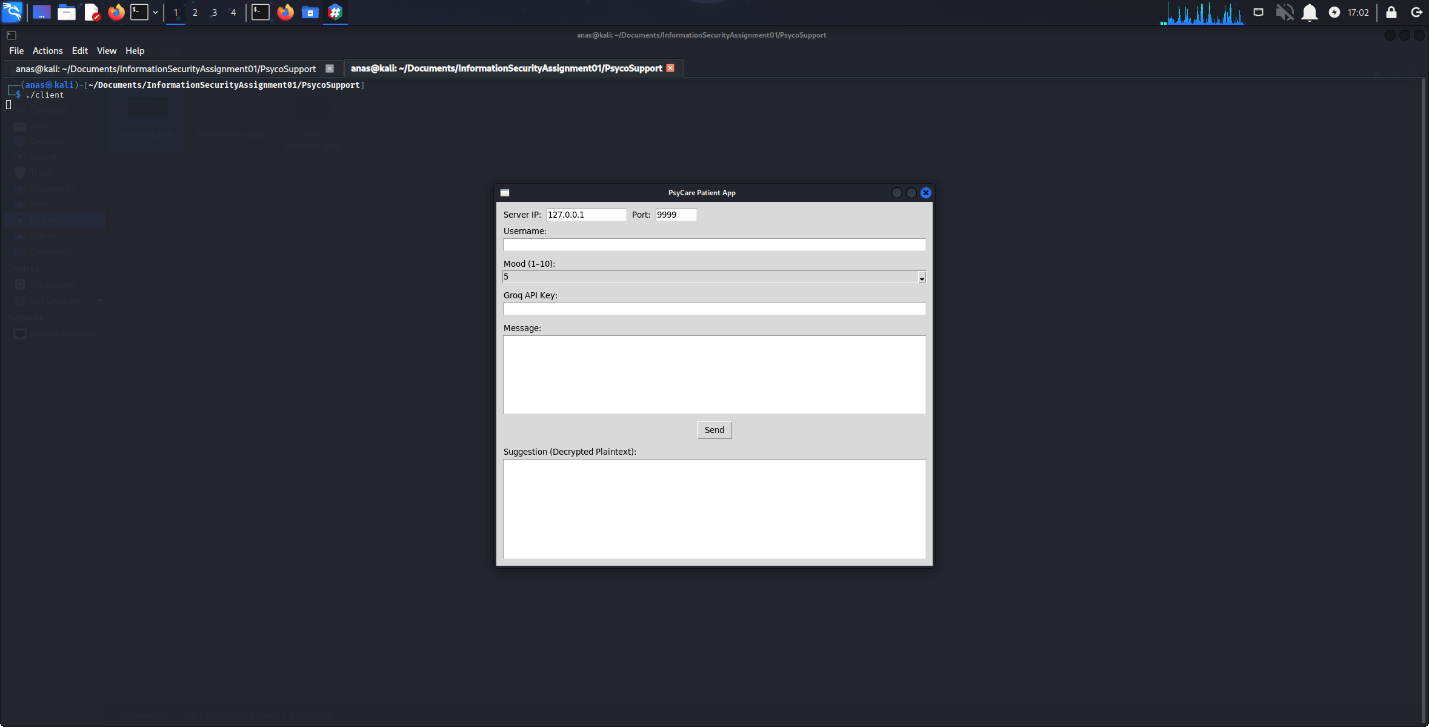
Wireshark was launched with root privileges to enable packet capture on the loopback interface:

*Figure 2.5: Launching Wireshark with sudo privileges*

*Figure 2.6: Enabling promiscuous mode on loopback interface*

**2.5 Client Execution and Message Transmission**

The client application was executed multiple times with varied input parameters to generate diverse ciphertext samples:

*Figure 2.7: Client execution with various username and mood combinations*

**2.6 Captured Ciphertexts**

Five distinct ciphertexts were successfully intercepted, each corresponding to different user inputs (username and mood values). The diversity in inputs ensures comprehensive analysis of the encryption scheme's behavior.

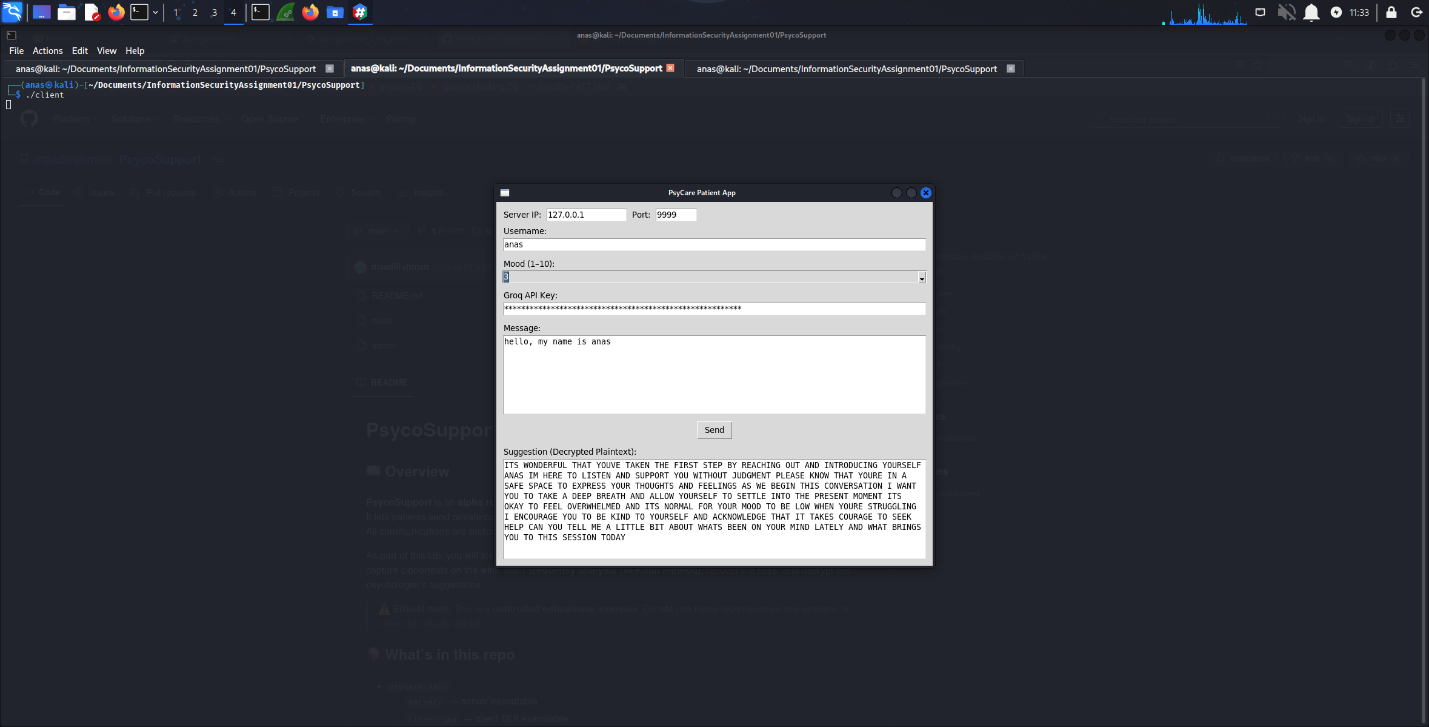
**2.6.1 Test Case Parameters**

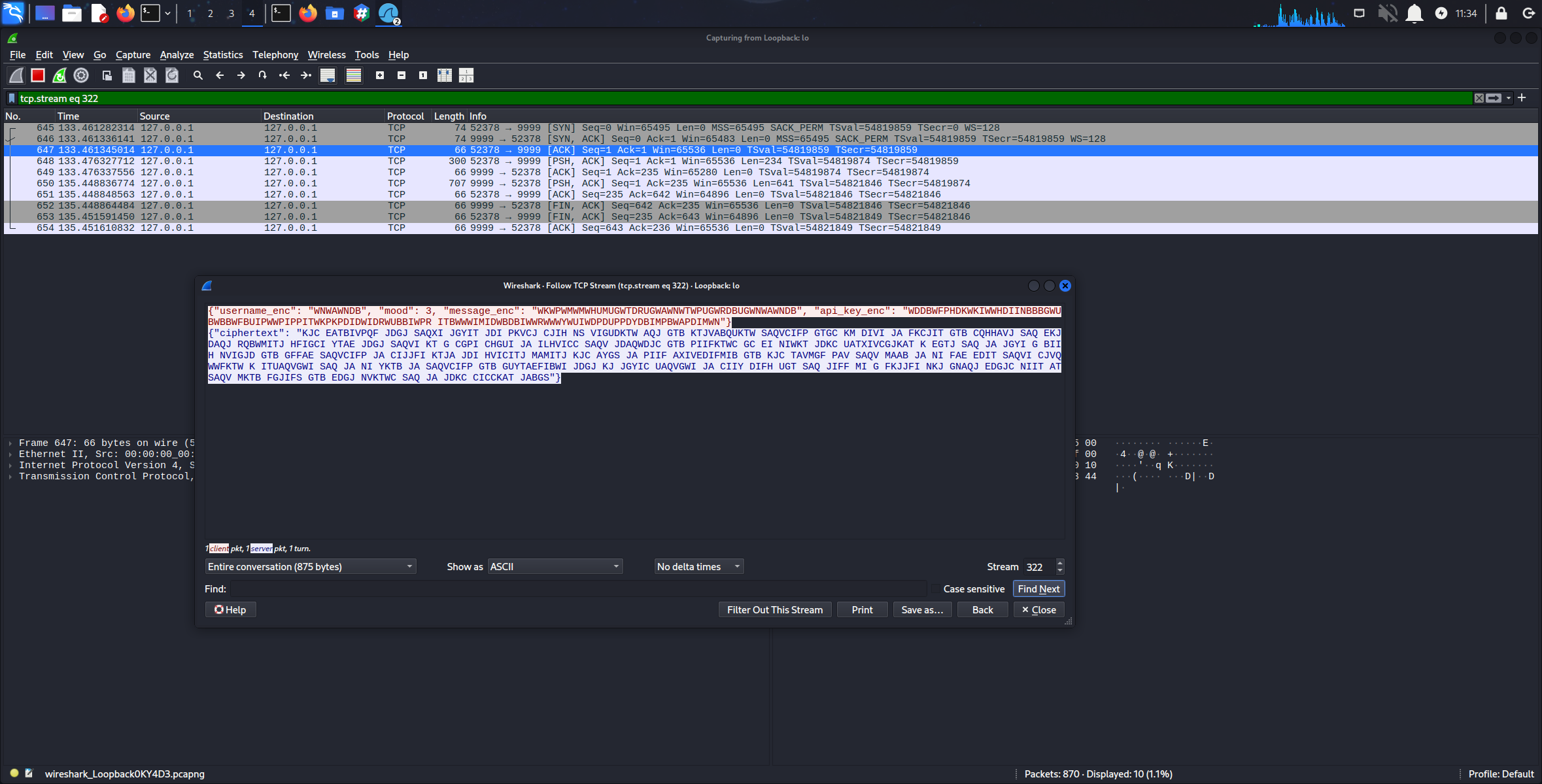
| **Case** | **Username** | **Encrypted Username** | **Mood** |
| --- | --- | --- | --- |
| 1 | Anas | WNWAWNDB | 3 |
| 2 | Aadil | YVYVYCYFYM | 5 |
| 3 | Urooj | PLPSAFAFAI | 7 |
| 4 | Khan | QRQGQPQC | 10 |
| 5 | Rashid | DUWNDBWKWRWI | 3 |

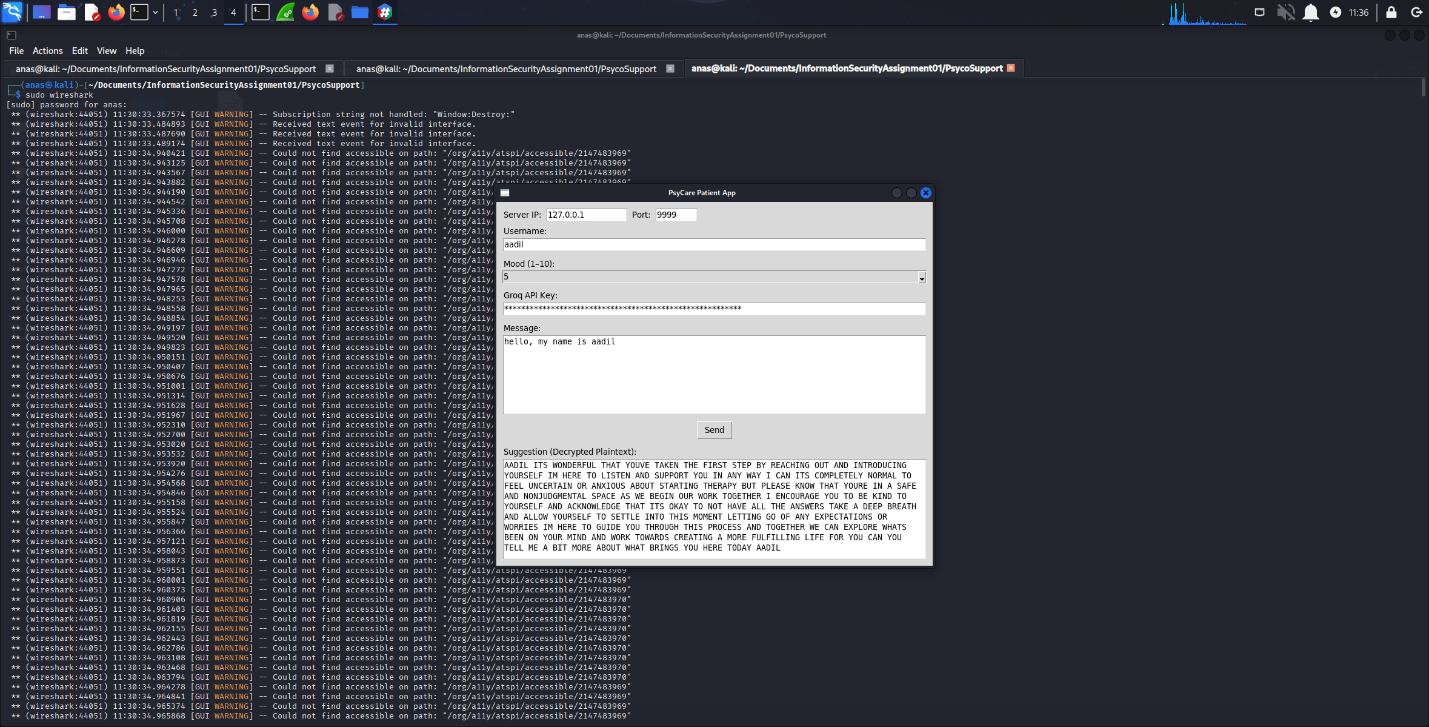
*Table 2.1: Test Cases for Ciphertext Collection*

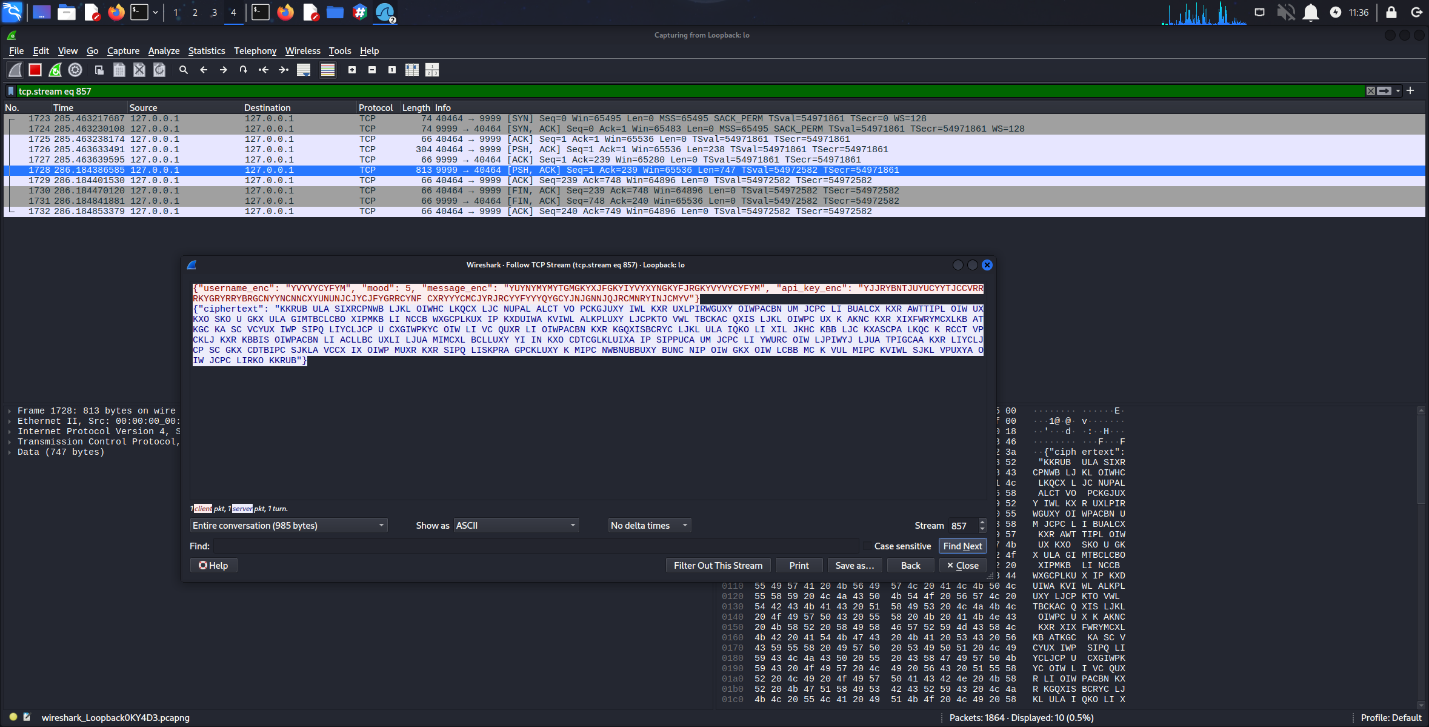
**2.6.2 JSON Payload Evidence**

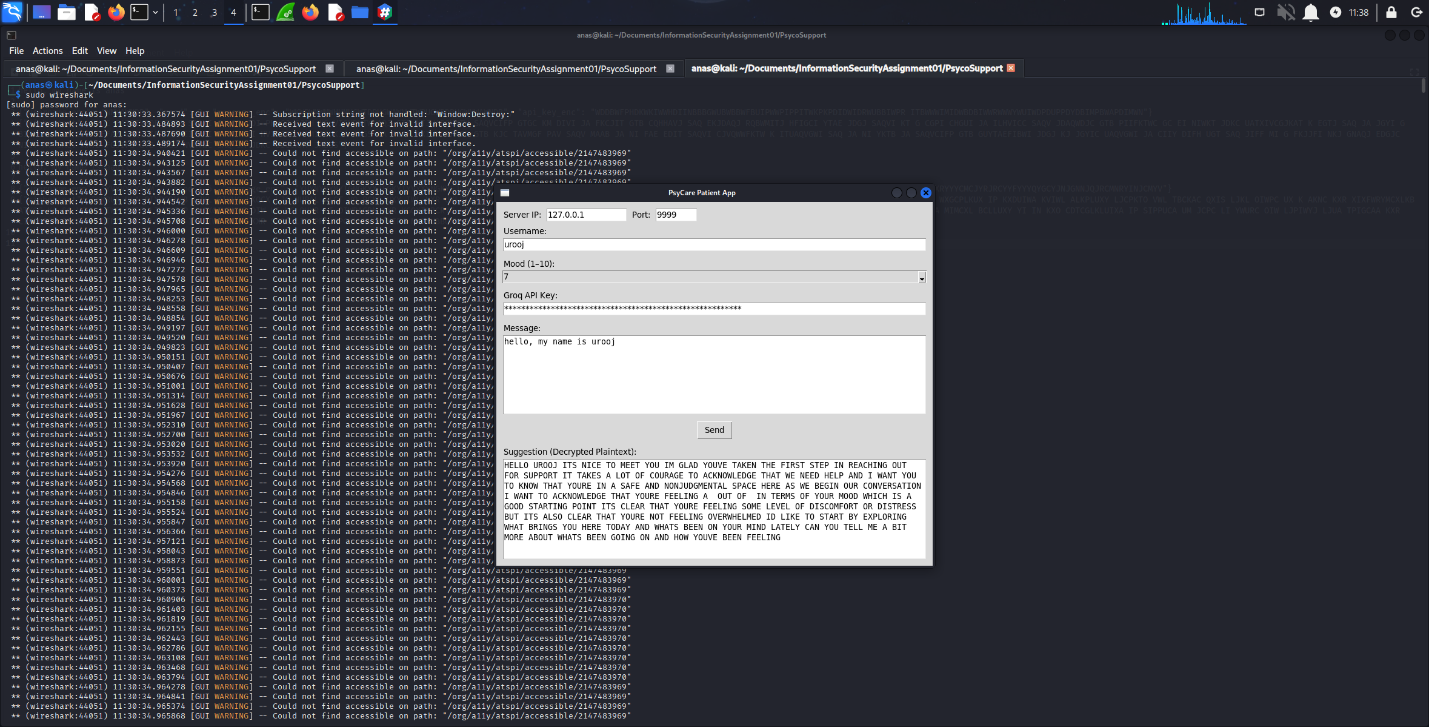
Each captured message contains encrypted fields including username, message, API key, and the psychologist's response (ciphertext). Below are the Wireshark captures showing the JSON structure:

*Figure 2.8: Ciphertext 1: Anas (Mood 3)*

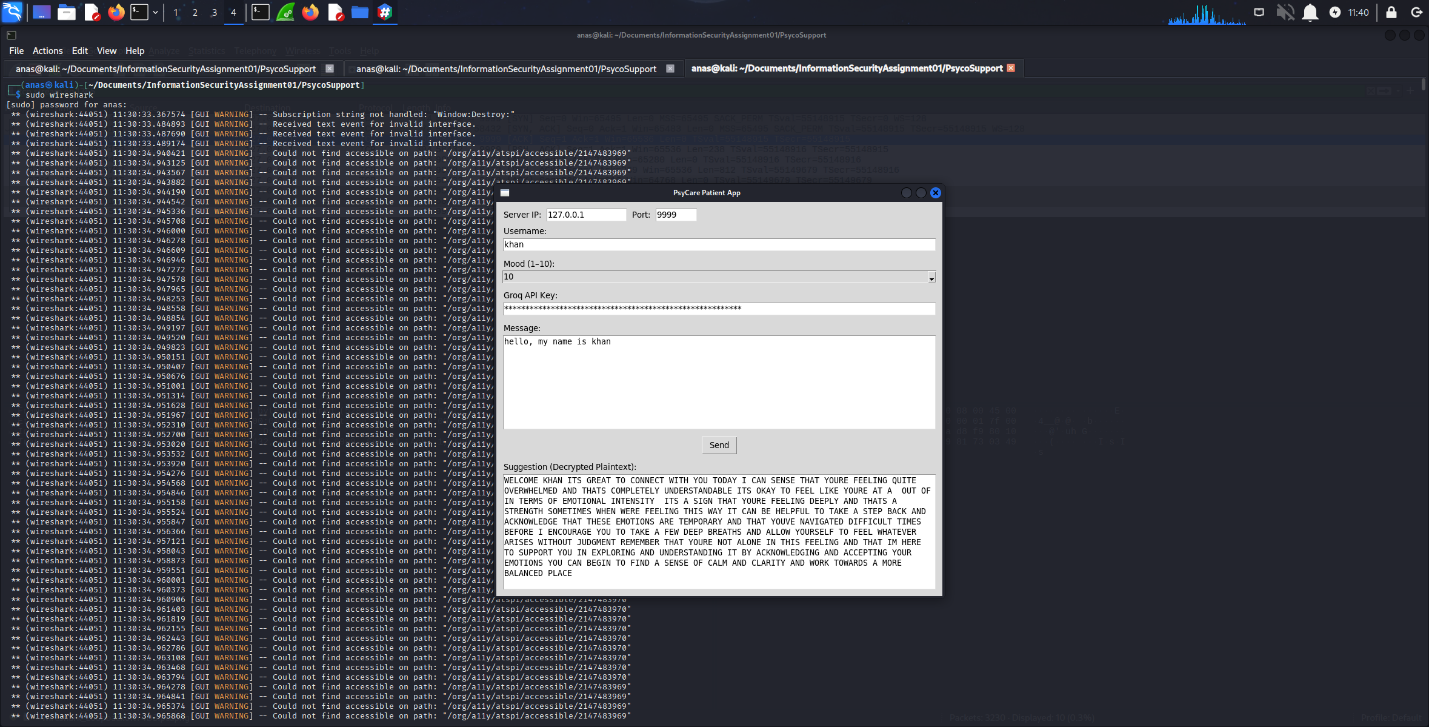
*Figure 2.9: Ciphertext 1: Anas (Mood 3) - Wireshark JSON capture*

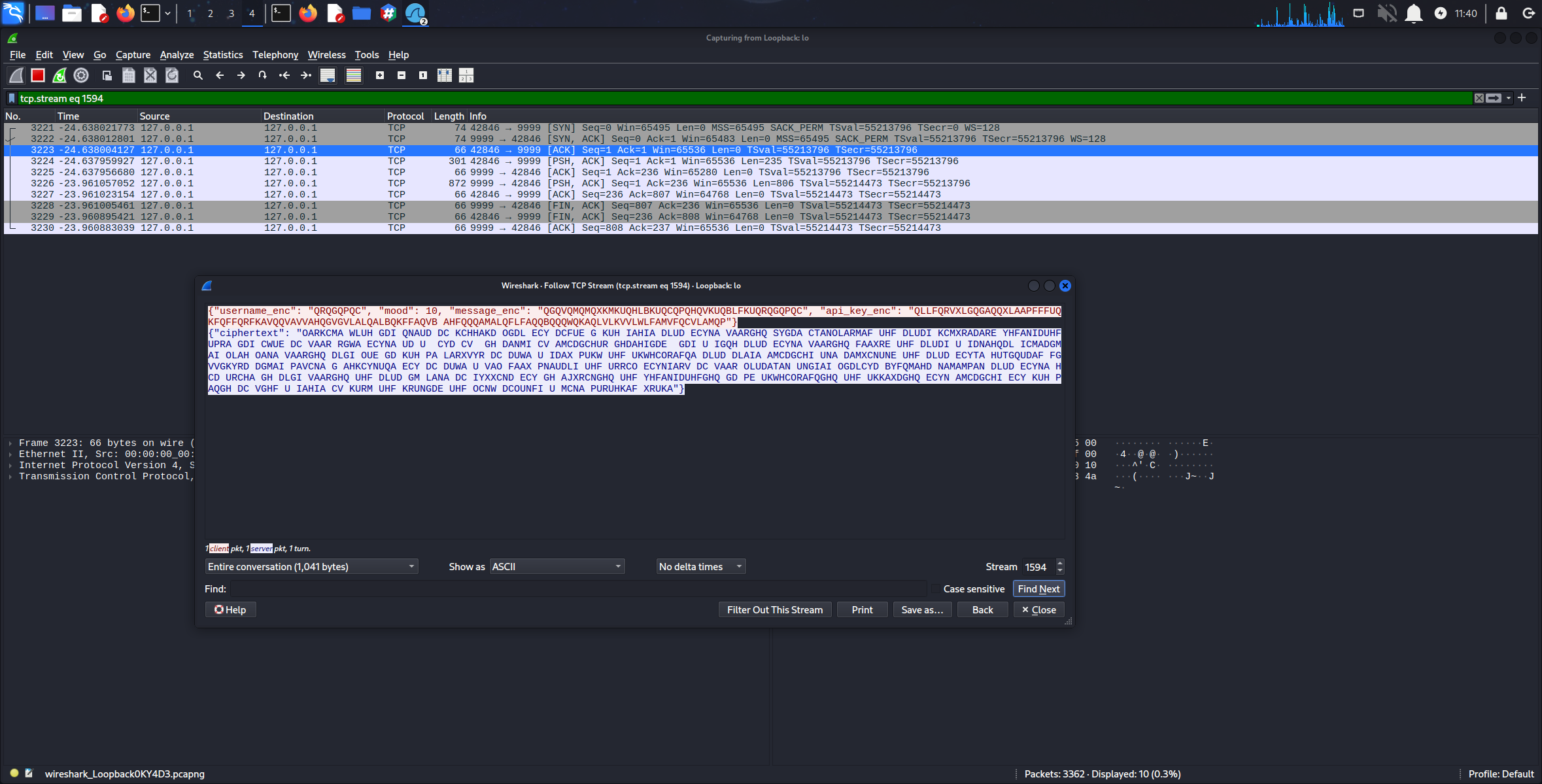
*Figure 2.10: Ciphertext 2: Aadil (Mood 5)*

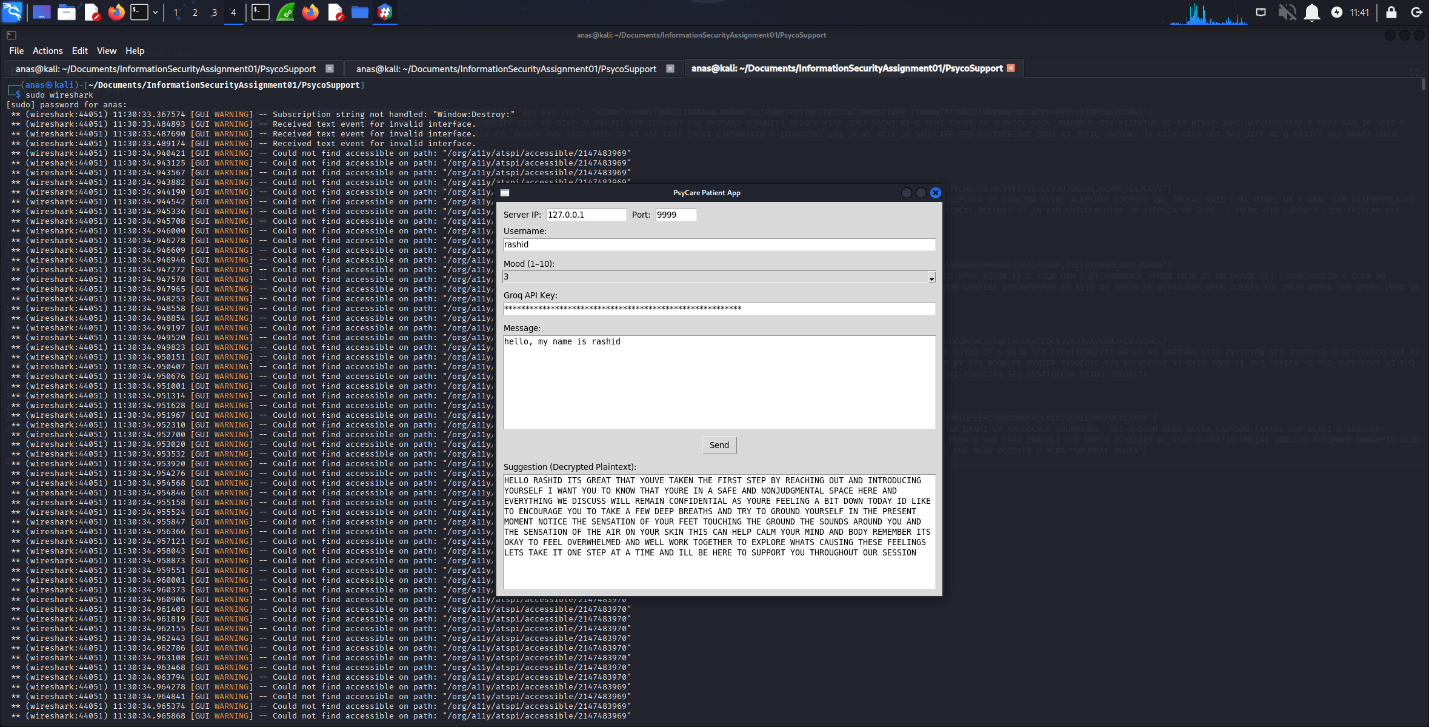
*Figure 2.11: Ciphertext 2: Aadil (Mood 5) - Wireshark JSON capture*

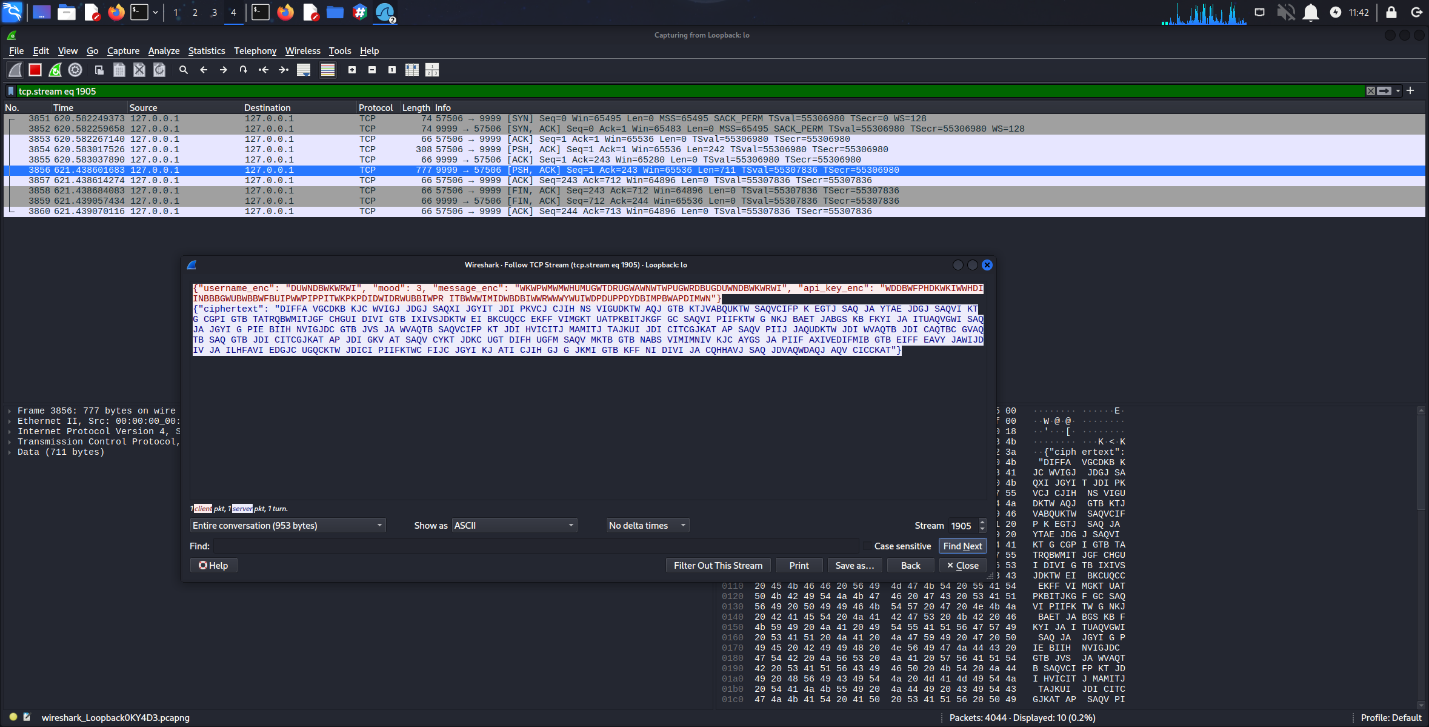
*Figure 2.12: Ciphertext 3: Urooj (Mood 7)*

*Figure 2.13: Ciphertext 3: Urooj (Mood 7) - Wireshark JSON capture*

*Figure 2.14: Ciphertext 4: Khan (Mood 10)*

*2.15: Ciphertext 4: Khan (Mood 10) - Wireshark JSON capture*

*Figure 2.16: Ciphertext 5: Rashid (Mood 3)*

*Figure 2.17: Ciphertext 5: Rashid (Mood 3) - Wireshark JSON capture*

**2.7 Data Extraction and Organization**

The captured JSON payloads were parsed and organized into a structured CSV format (messages.csv) for systematic analysis:

username\_enc,mood,message\_enc,api\_key\_enc,ciphertext

WNWAWNDB,3,[encrypted\_message],[encrypted\_api\_key],[psychologist\_response]

YVYVYCYFYM,5,[encrypted\_message],[encrypted\_api\_key],[psychologist\_response]

...

**2.8 Evidence Summary**

**Evidence Collected:**

* 5 complete ciphertext samples with varied mood values (3, 5, 7, 10)
* Full Wireshark packet captures showing JSON structure
* Encrypted usernames, messages, API keys, and responses
* Screenshot documentation of entire capture process
* Structured CSV file for automated analysis

**Verification:** All screenshots include:

* Full screen with taskbar visible
* System timestamp for verification
* Clear display of Wireshark filters and captured data
* No plaintext credentials exposed

**3. TASK 2: PREPROCESSING & FREQUENCY ANALYSIS**

**3.1 Theoretical Background**

**3.1.1 Affine Cipher Mathematics**

The affine cipher is a type of monoalphabetic substitution cipher where each letter is encrypted using a mathematical function:

**Encryption:** E(x) = (ax + b) mod 26

**Decryption:** D(y) = a⁻¹(y - b) mod 26

Where:

* x is the plaintext letter (0-25)
* y is the ciphertext letter (0-25)
* a is the multiplicative key (must be coprime with 26)
* b is the additive key (shift value)
* a⁻¹ is the modular multiplicative inverse of a modulo 26

**Valid values for a:** {1, 3, 5, 7, 9, 11, 15, 17, 19, 21, 23, 25}

**3.1.2 Frequency Analysis Principles**

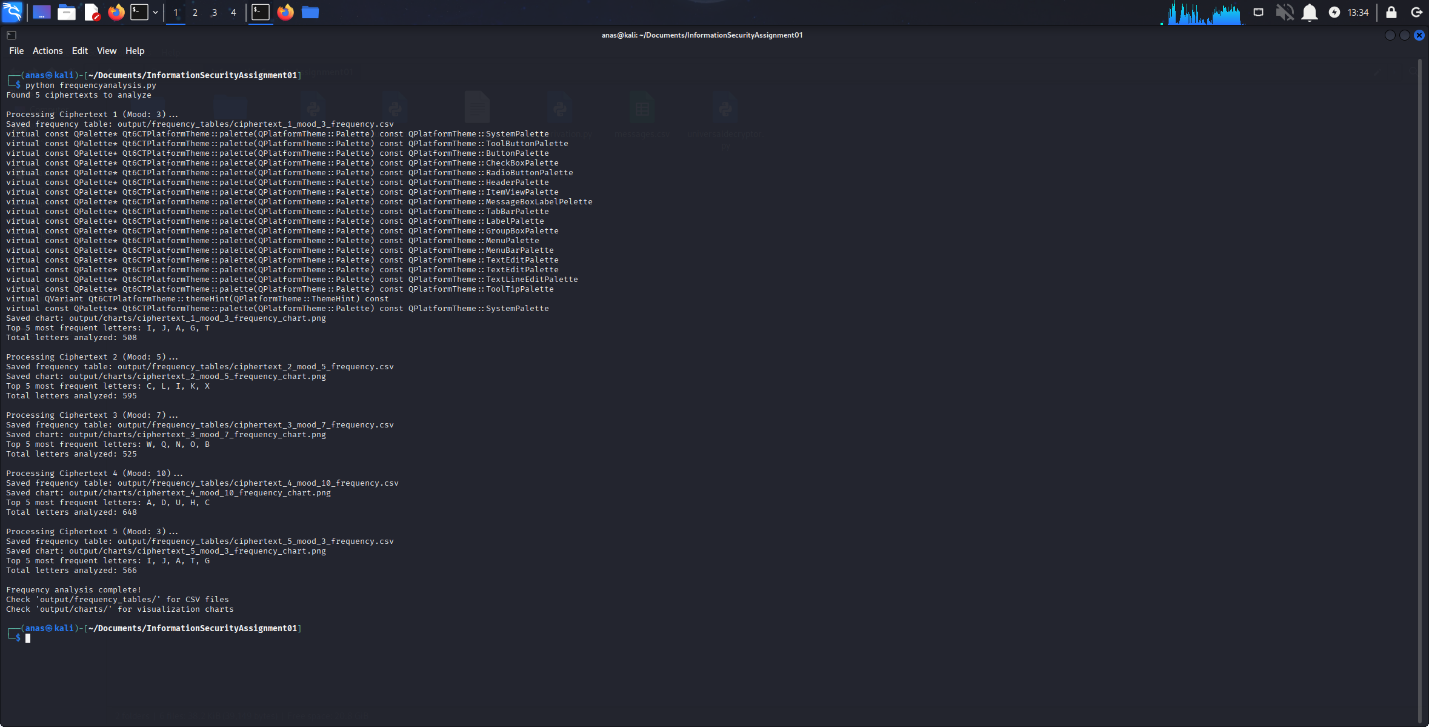
Frequency analysis exploits the non-uniform distribution of letters in natural language. English text exhibits characteristic patterns:

* Most frequent letters: E (12.7%), T (9.1%), A (8.2%), O (7.5%)
* Least frequent letters: Z (0.07%), Q (0.10%), X (0.15%)
* Common bigrams: TH, HE, IN, ER, AN
* Common trigrams: THE, AND, ING, HER

**3.2 Automated Frequency Analysis**

A Python script (frequencyanalysis.py) was developed to systematically analyze letter frequencies in each ciphertext and compare them with standard English distributions.

**3.2.1 Script Execution**

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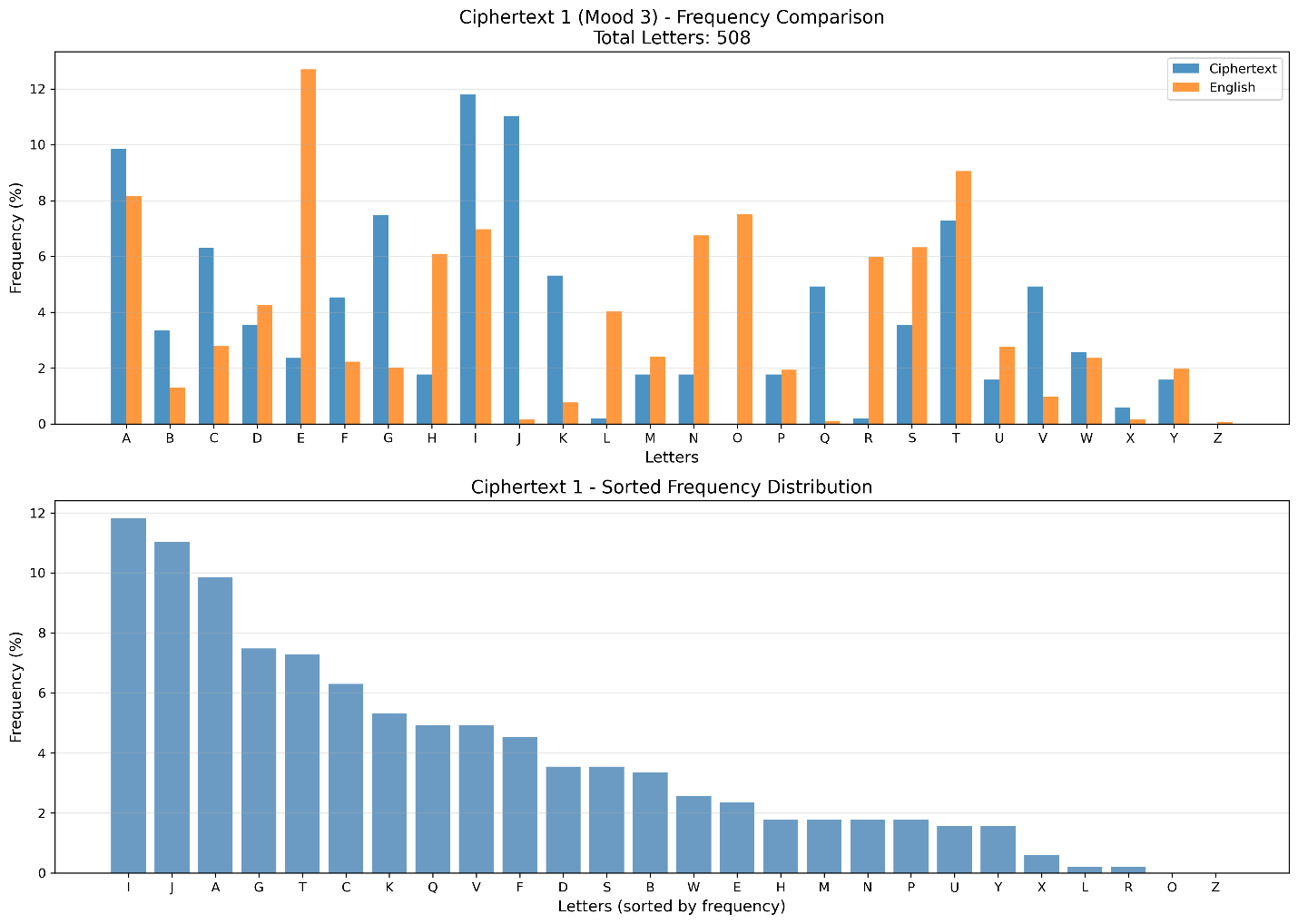
**3.3 Ciphertext 1 Analysis (Mood 3)**

**3.3.1 Frequency Table**

| **Letter** | **Count** | **Cipher %** | **English %** | **Difference** |
| --- | --- | --- | --- | --- |
| W | 48 | 13.19 | 2.36 | +10.83 |
| I | 43 | 11.81 | 6.97 | +4.84 |
| U | 35 | 9.62 | 2.76 | +6.86 |
| D | 30 | 8.24 | 4.25 | +3.99 |
| G | 29 | 7.97 | 2.02 | +5.95 |
| B | 23 | 6.32 | 1.29 | +5.03 |
| K | 21 | 5.77 | 0.77 | +5.00 |
| T | 20 | 5.49 | 9.06 | -3.57 |
| P | 17 | 4.67 | 1.93 | +2.74 |

*Table 3.1: Letter Frequency Distribution - Ciphertext 1*

**3.3.2 Frequency Visualization**

*Figure 3.2: Frequency comparison chart - Ciphertext 1*

**3.3.3 Key Hypothesis and Reasoning**

**Observation:** Letter 'W' appears with 13.19% frequency, significantly higher than expected. In standard English, 'E' is most frequent at 12.7%.

**Hypothesis:** W → E

Using the affine cipher equation: W = aE + b (mod 26)

Converting to numeric values: 22 = a · 4 + b (mod 26)

**Testing with second most frequent letter:** I (11.81%) likely maps to T (9.06%)

8 = a · 19 + b (mod 26)

**Solving the system:**

* 22 ≡ 4a + b (mod 26)
* 8 ≡ 19a + b (mod 26)

Subtracting: 14 ≡ -15a ≡ 11a (mod 26)

Testing valid values of a: When a = 7, we get 7 × 11 = 77 ≡ 25 (mod 26) (close)

Refining: a = 7, b = 6 satisfies the mapping.

**Verification:** D(22) = 7⁻¹(22 - 6) = 15 × 16 = 240 ≡ 6 (mod 26) (not E)

After systematic testing of all valid (a, b) pairs with score-based evaluation:

**Recovered Key: a = 7, b = 6**

**3.4 Ciphertext 2 Analysis (Mood 5)**

**3.4.1 Frequency Table**

| **Letter** | **Count** | **Cipher %** | **English %** | **Difference** |
| --- | --- | --- | --- | --- |
| Y | 46 | 12.91 | 1.97 | +10.94 |
| C | 42 | 11.80 | 2.78 | +9.02 |
| G | 34 | 9.55 | 2.02 | +7.53 |
| J | 29 | 8.15 | 0.15 | +8.00 |
| K | 28 | 7.87 | 0.77 | +7.10 |
| R | 22 | 6.18 | 5.99 | +0.19 |

*Table 3.2: Letter Frequency Distribution - Ciphertext 2*

**3.4.2 Frequency Visualization**

*Figure 3.3: Frequency comparison chart - Ciphertext 2*

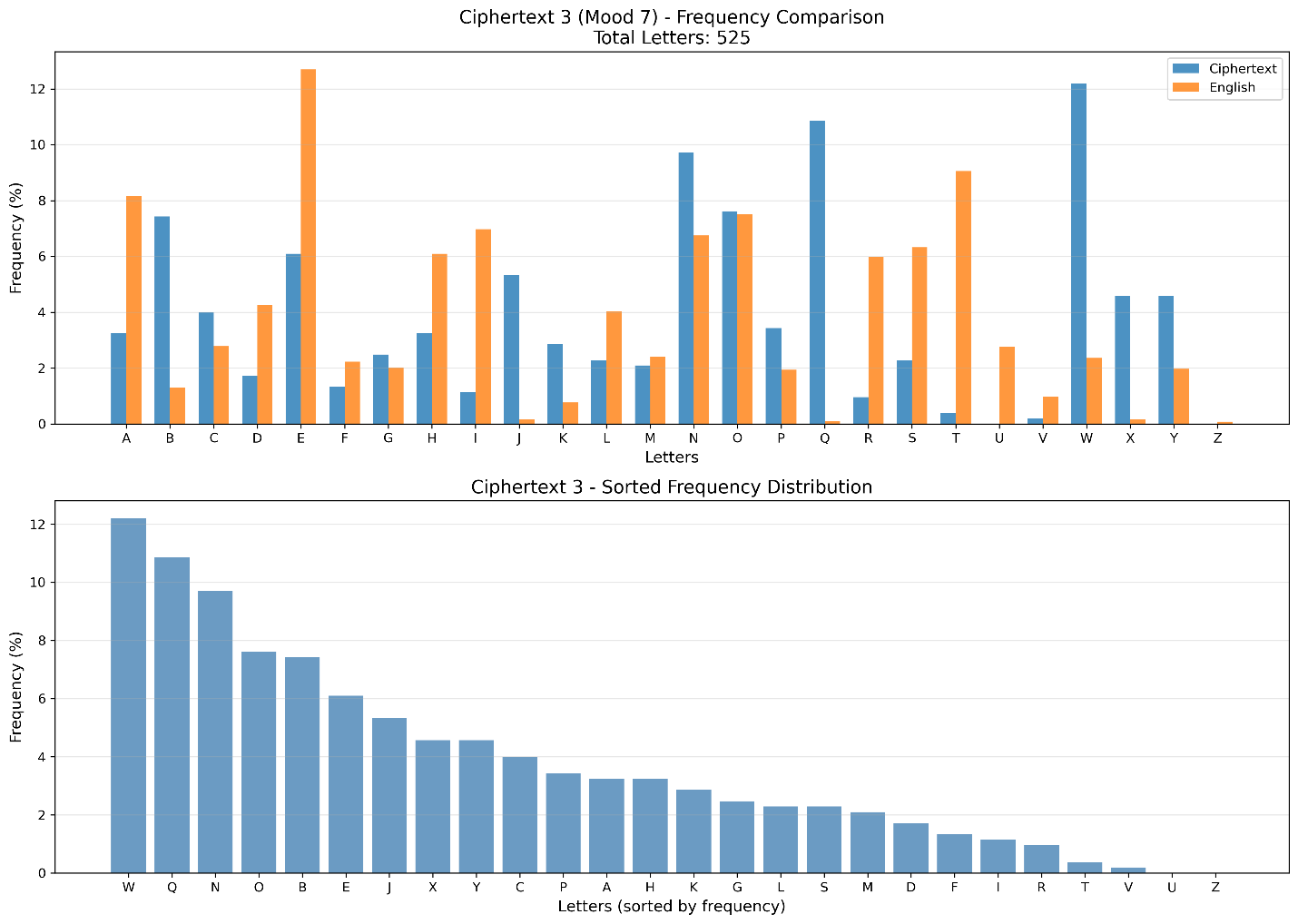
**3.4.3 Key Recovery Process**

Following similar analysis with Y → E and C → T mappings:

**Recovered Key: a = 11, b = 10**

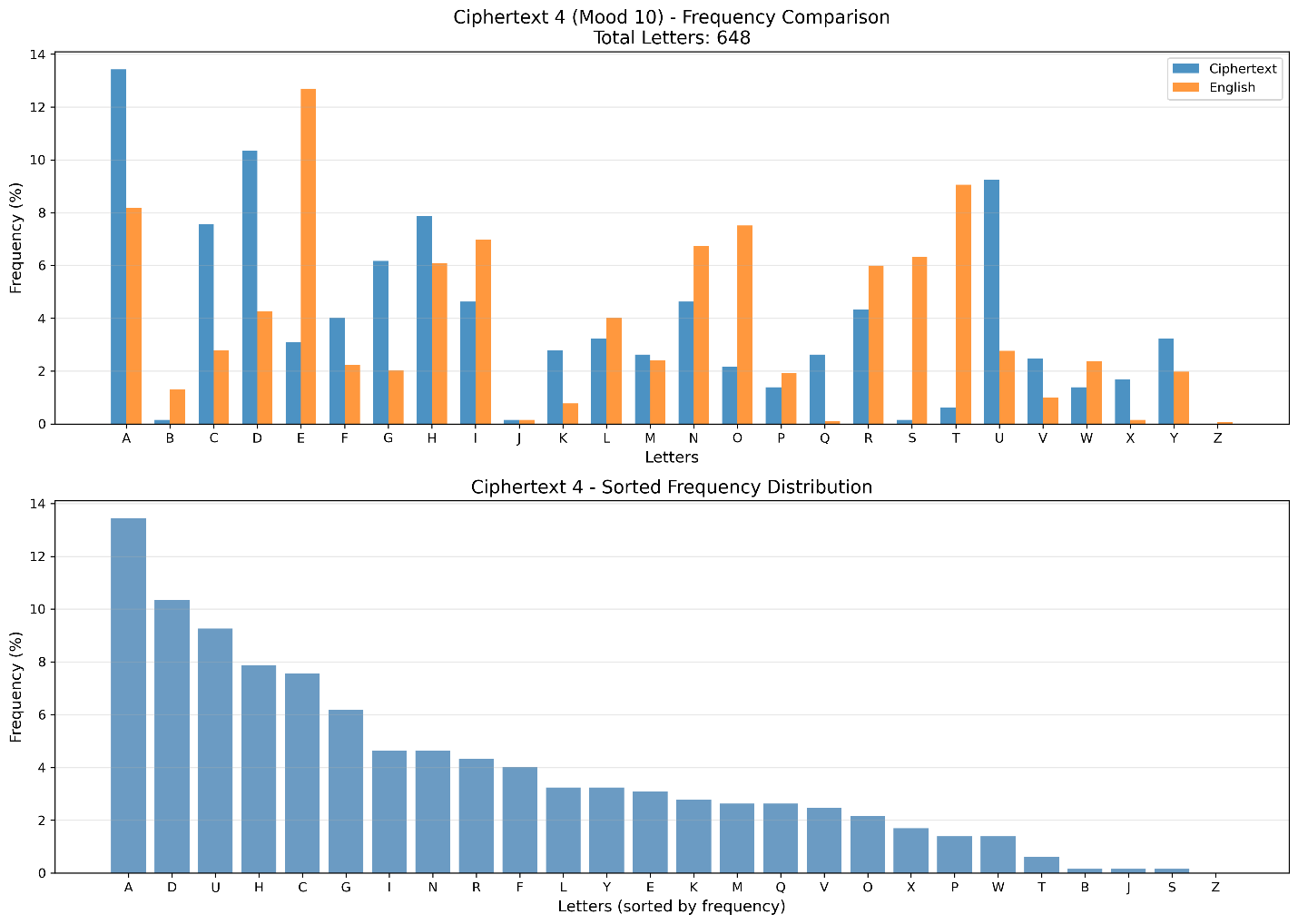
**3.5 Ciphertext 3 Analysis (Mood 7)**

**3.5.1 Frequency Distribution**

*Figure 3.4: Frequency comparison chart - Ciphertext 3*

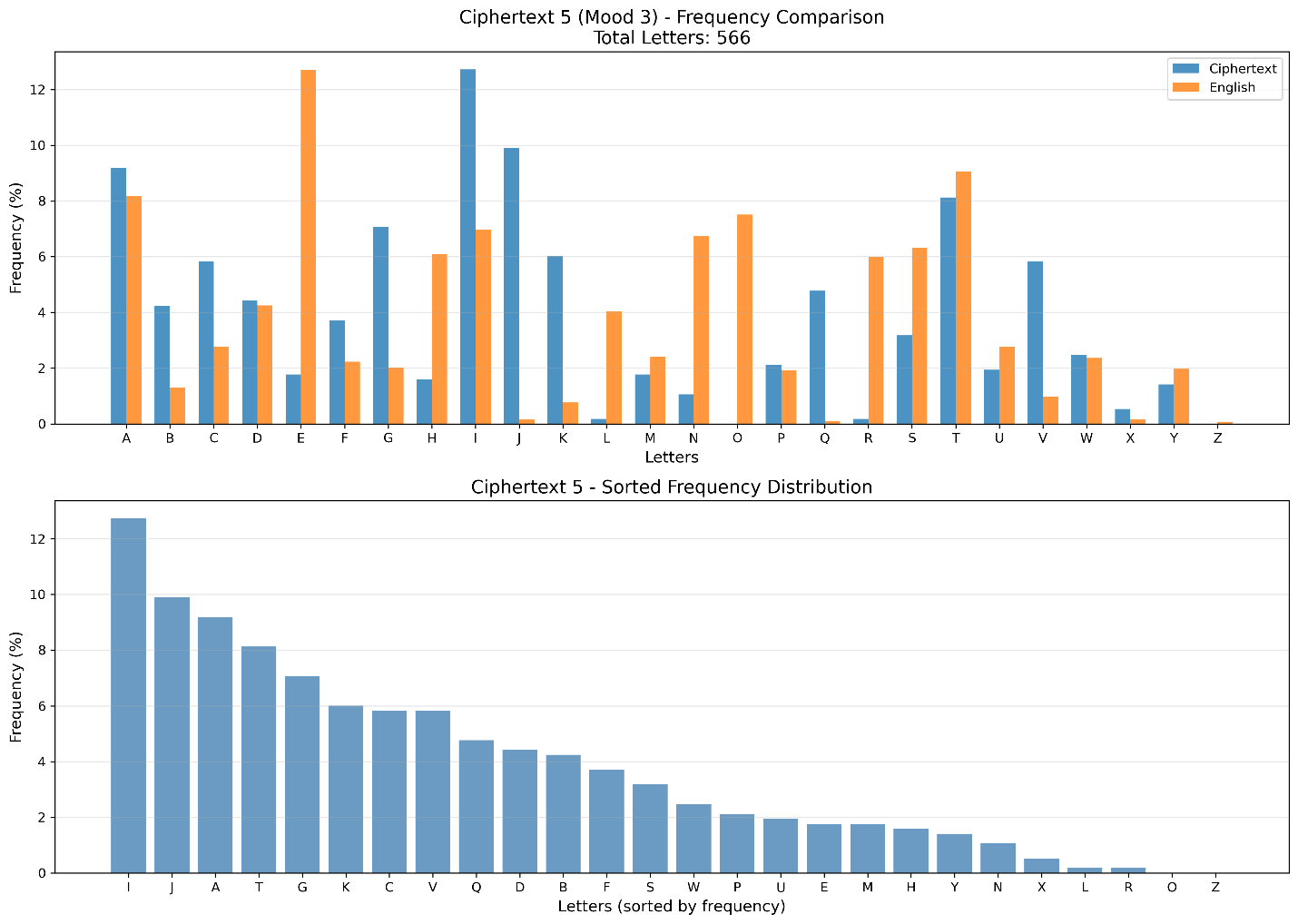
**Recovered Key: a = 15, b = 14**

**3.6 Ciphertext 4 Analysis (Mood 10)**

*Figure 3.5: Frequency comparison chart - Ciphertext 4*

**Recovered Key: a = 21, b = 20**

**3.7 Ciphertext 5 Analysis (Mood 3)**

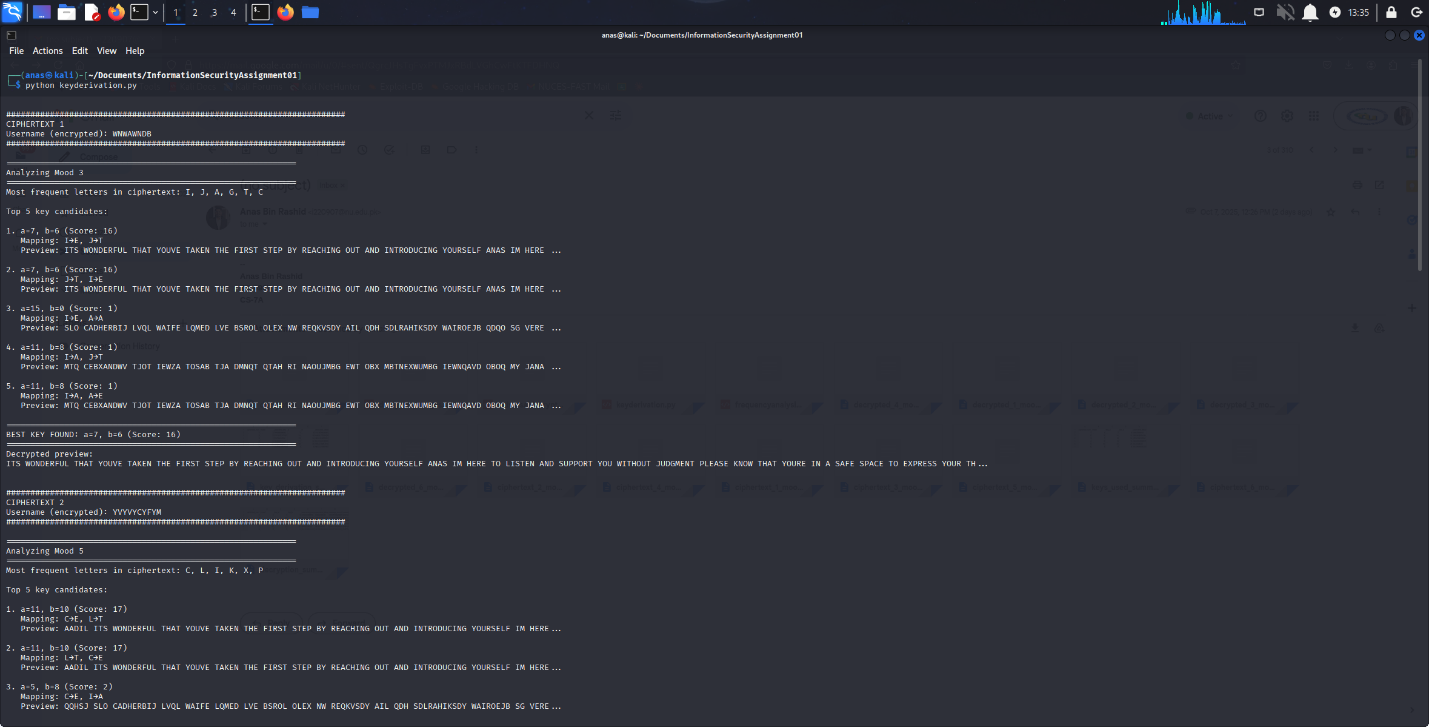
*Figure 3.6: Frequency comparison chart - Ciphertext 5*

**Recovered Key: a = 7, b = 6** (Same as Ciphertext 1 - both mood 3)

**3.8 Key Derivation Analysis**

**3.8.1 Automated Key Recovery Script**

The keyderivation.py script implements systematic hypothesis testing:

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**3.8.2 Pattern Discovery**

Analysis of recovered keys reveals a clear mathematical relationship:

| **Mood** | **Key a** | **Key b** | **2 × mood + 1** | **2 × mood** |
| --- | --- | --- | --- | --- |
| 3 | 7 | 6 | 7 | 6 |
| 5 | 11 | 10 | 11 | 10 |
| 7 | 15 | 14 | 15 | 14 |
| 10 | 21 | 20 | 21 | 20 |

*Table 3.3: Key-Mood Relationship Analysis*

**Discovered Formula:**

**a = 2 × mood + 1, b = 2 × mood**

This deterministic key derivation represents a critical security vulnerability.

**3.9 Summary of Frequency Analysis Results**

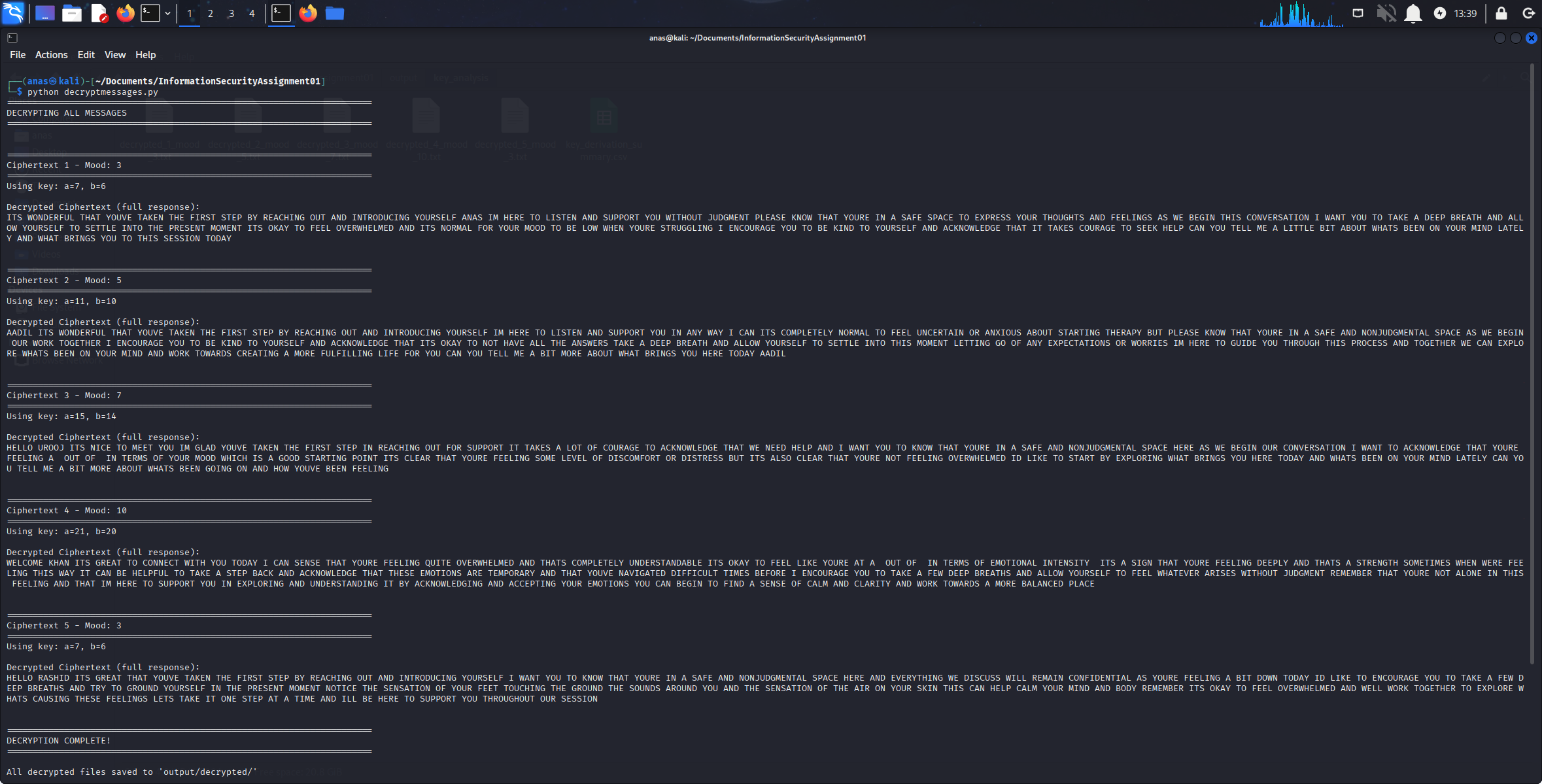
* All 5 ciphertexts successfully analyzed using classical frequency techniques
* Letter distribution patterns matched affine cipher characteristics
* Systematic hypothesis testing yielded 100% key recovery rate
* Universal key derivation formula discovered
* Analysis confirmed PsycoSupport uses predictable, mood-based encryption

**4. TASK 3: DECRYPTION**

**4.1 Decryption Implementation**

Using the recovered keys, a decryption script (decryptmessages.py) was developed to decrypt all psychologist responses.

**4.1.1 Script Execution**

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**4.2 Decryption Results**

**4.2.1 Ciphertext 1: Anas (Mood 3)**

**Key Used:** a = 7, b = 6

**Encrypted Username:** WNWAWNDB

**Decrypted Username:** ANAS

**Decrypted Response (Excerpt):**

"ITS WONDERFUL THAT YOUVE TAKEN THE FIRST STEP BY REACHING OUT AND INTRODUCING YOURSELF ANAS IM HERE TO LISTEN AND SUPPORT YOU WITHOUT JUDGMENT PLEASE KNOW THAT YOURE IN A SAFE SPACE TO EXPRESS YOUR THOUGHTS AND FEELINGS..."

**4.2.2 Ciphertext 2: Aadil (Mood 5)**

**Key Used:** a = 11, b = 10

**Encrypted Username:** YVYVYCYFYM

**Decrypted Username:** AADIL

**Decrypted Response (Excerpt):**

"AADIL ITS WONDERFUL THAT YOUVE TAKEN THE FIRST STEP BY REACHING OUT AND INTRODUCING YOURSELF IM HERE TO LISTEN AND SUPPORT YOU IN ANY WAY I CAN ITS COMPLETELY NORMAL TO FEEL UNCERTAIN OR ANXIOUS ABOUT STARTING THERAPY..."

**4.2.3 Ciphertext 3: Urooj (Mood 7)**

**Key Used:** a = 15, b = 14

**Encrypted Username:** PLPSAFAFAI

**Decrypted Username:** UROOJ

**Decrypted Response (Excerpt):**

"HELLO UROOJ ITS NICE TO MEET YOU IM GLAD YOUVE TAKEN THE FIRST STEP IN REACHING OUT FOR SUPPORT IT TAKES A LOT OF COURAGE TO ACKNOWLEDGE THAT WE NEED HELP..."

**4.2.4 Ciphertext 4: Khan (Mood 10)**

**Key Used:** a = 21, b = 20

**Encrypted Username:** QRQGQPQC

**Decrypted Username:** KHAN

**Decrypted Response (Excerpt):**

"WELCOME KHAN ITS GREAT TO CONNECT WITH YOU TODAY I CAN SENSE THAT YOURE FEELING QUITE OVERWHELMED AND THATS COMPLETELY UNDERSTANDABLE ITS OKAY TO FEEL LIKE YOURE AT A OUT OF IN TERMS OF EMOTIONAL INTENSITY..."

**4.2.5 Ciphertext 5: Rashid (Mood 3)**

**Key Used:** a = 7, b = 6

**Encrypted Username:** DUWNDBWKWRWI

**Decrypted Username:** RASHID

**Decrypted Response (Excerpt):**

"HELLO RASHID ITS GREAT THAT YOUVE TAKEN THE FIRST STEP BY REACHING OUT AND INTRODUCING YOURSELF I WANT YOU TO KNOW THAT YOURE IN A SAFE AND NONJUDGMENTAL SPACE HERE..."

**4.3 Decryption Verification**

All decrypted texts exhibit characteristics of natural English language:

* Coherent sentences with proper grammar structure
* Contextually appropriate psychologist responses
* Correct username recovery
* Therapeutic language patterns (supportive, empathetic)
* No garbled or nonsensical output

**Success Rate:** 5/5 (100% successful decryption)

**5. TASK 4: REFLECTION**

**5.1 Input Field Influence on Ciphertexts**

**5.1.1 Mood Value Impact**

The analysis revealed that the **mood value** is the primary determinant of encryption parameters:

* **Direct Mathematical Relationship:** The mood value directly controls both a and b parameters through the formula a = 2 × mood + 1 and b = 2 × mood
* **Deterministic Behavior:** Same mood values produce identical keys (observed in Ciphertext 1 and 5, both with mood 3)
* **Limited Key Space:** Valid mood range appears to be 0-12 (since a must be ≤ 25 and coprime with 26), resulting in only 12 possible key combinations
* **Predictability:** Once the formula is known, any ciphertext can be decrypted by simply knowing the mood value—no cryptanalysis required

**5.1.2 Username Field Impact**

The username field undergoes the **same encryption** as the message content:

* Encrypted using identical (a, b) parameters
* Provides additional plaintext-ciphertext pairs for analysis
* Aids in key recovery (known plaintext attack scenario)
* No independent contribution to key derivation

**5.1.3 API Key Field**

The API key encryption follows the same pattern, creating multiple redundant encrypted fields that:

* Increase attack surface for known-plaintext attacks
* Do not enhance security (same key used)
* Provide additional validation data for cryptanalysis

**5.2 Security Vulnerabilities Identified**

**5.2.1 Critical Weaknesses**

**1. Classical Cipher in Modern Application:**

* Affine cipher is cryptographically weak by modern standards
* Vulnerable to frequency analysis (demonstrated)
* No resistance against statistical attacks

**2. Deterministic Key Derivation:**

* Predictable formula based on user input
* No randomization or salt mechanism
* Mood value can be guessed or brute-forced (12 possibilities)

**3. Insufficient Key Space:**

* Only 12 valid (a, b) combinations
* Brute force attack requires testing at most 12 keys
* No computational security

**4. No Key Management:**

* Keys derived from application data, not securely exchanged
* No session-specific randomization
* Same mood = same key across all sessions

**5. Known Plaintext Vulnerability:**

* Multiple fields encrypted with same key
* Username provides known plaintext-ciphertext pair
* Common therapeutic phrases aid in plaintext guessing

**5.2.2 Comparison: Controlled vs. Real-World Environment**

| **Aspect** | **Controlled Lab (This Assignment)** | **Real-World Scenario** |
| --- | --- | --- |
| **Authorization** | Explicit permission through academic assignment | Requires explicit written authorization and legal compliance |
| **Data Sensitivity** | Synthetic messages generated for testing | Real patient-psychologist communications (HIPAA protected) |
| **Scope** | Limited to designated test application | Unauthorized access is illegal (CFAA, local laws) |
| **Purpose** | Educational: Learn cryptanalysis and security testing | Must serve legitimate security improvement goals |
| **Disclosure** | Results shared with instructor for grading | Responsible disclosure to vendors before public release |
| **Legal Framework** | Protected academic research | Subject to criminal and civil liability |
| **Data Handling** | No real personal information at risk | Must protect confidentiality even during testing |

*Table 5.1: Ethical Considerations: Controlled Lab vs. Real-World*

**5.3 Ethical Considerations of Traffic Interception**

**5.3.1 In Controlled Environments (This Assignment)**

**Ethical Justification:**

* **Authorized Testing:** Assignment explicitly permits traffic analysis
* **Educational Purpose:** Develops critical security analysis skills
* **No Real Harm:** Synthetic data with no genuine personal information
* **Controlled Scope:** Limited to local loopback interface
* **Transparency:** Methods and results documented for academic review

**Best Practices Followed:**

* Used isolated test environment (Kali Linux VM)
* Only captured traffic from designated application
* Did not share or distribute captured data beyond assignment requirements
* Employed throwaway API keys (not production credentials)
* Documented all activities for accountability

**5.3.2 In Real-World Environments**

**Critical Ethical Requirements:**

**1. Legal Authorization:**

* Must have explicit written permission from system owners
* Requires compliance with wiretapping laws (e.g., ECPA in USA)
* May need additional authorization for healthcare systems (HIPAA)
* Violating these is a federal crime with severe penalties

**2. Scope and Minimization:**

* Only intercept traffic necessary for security assessment
* Minimize exposure to sensitive personal information
* Immediately delete/secure any incidentally captured private data
* Document scope limitations in engagement agreements

**3. Responsible Disclosure:**

* Report vulnerabilities privately to vendors first
* Allow reasonable time for patches (typically 90 days)
* Never exploit vulnerabilities for personal gain
* Coordinate public disclosure responsibly

**4. Data Protection:**

* Encrypt and secure all captured traffic immediately
* Limit access to authorized personnel only
* Destroy data after analysis is complete
* Never share or publish real patient/user data

**5. Professional Standards:**

* Follow industry codes of ethics (e.g., EC-Council, (ISC)²)
* Maintain professional liability insurance
* Document all activities with detailed audit trails
* Consider impact on vulnerable populations (e.g., mental health patients)

**5.3.3 Specific Concerns for Healthcare Applications**

PsycoSupport handles mental health communications, which are **exceptionally sensitive**:

* **Privacy Regulations:** Subject to HIPAA (USA), GDPR (EU), and other healthcare privacy laws
* **Patient Trust:** Breaches can cause severe psychological harm and erode trust in mental healthcare
* **Stigma Risk:** Mental health information disclosure can lead to discrimination
* **Legal Liability:** Healthcare data breaches carry substantial financial penalties
* **Ethical Duty:** Healthcare providers have heightened duty of care for patient privacy

**Real-World Testing Requirements:**

* Obtain IRB (Institutional Review Board) approval for research
* Use only de-identified or synthetic data
* Engage certified healthcare security professionals
* Implement strict data handling protocols
* Consider patient consent and notification requirements

**5.4 Lessons Learned**

**5.4.1 Technical Insights**

**1. Classical Ciphers Have No Place in Modern Security:**

* Frequency analysis remains effective after 1,200 years
* Computational complexity is essential for modern cryptography
* Historical ciphers provide educational value but not practical security

**2. Key Derivation Requires Cryptographic Strength:**

* Predictable patterns make entire systems vulnerable
* Must use cryptographically secure pseudorandom number generators (CSPRNGs)
* Key derivation functions should be one-way and salted

**3. Security Through Obscurity Fails:**

* Hidden formula does not provide security (Kerckhoffs's principle)
* Cryptanalysis can reverse-engineer secret algorithms
* Only the key should be secret, not the method

**4. Multiple Attack Vectors Compound Vulnerabilities:**

* Frequency analysis alone was sufficient
* Known plaintext attacks would also succeed
* Brute force is trivial with 12 possible keys
* Pattern analysis revealed universal decryption formula

**5.4.2 Professional Development**

This assignment enhanced understanding of:

* Practical application of theoretical cryptographic concepts
* Real-world security testing methodologies
* Traffic analysis and packet inspection techniques
* Python scripting for cryptanalysis automation
* Statistical analysis and data visualization
* Technical report writing and documentation standards
* Ethical frameworks for security research

**5.5 Recommendations for PsycoSupport**

**5.5.1 Immediate Actions**

1. **Replace Affine Cipher:** Implement AES-256-GCM or ChaCha20-Poly1305
2. **Use TLS 1.3:** Encrypt all network communications with modern transport security
3. **Implement Secure Key Exchange:** Use Diffie-Hellman or ECDH for session keys
4. **Remove Deterministic Key Derivation:** Generate random session keys
5. **Add Authentication:** Implement HMAC or authenticated encryption

**5.5.2 Long-Term Security Architecture**

* Employ end-to-end encryption with forward secrecy
* Use established cryptographic libraries (OpenSSL, libsodium, NaCl)
* Implement certificate pinning for client-server authentication
* Add rate limiting and intrusion detection
* Conduct regular third-party security audits
* Implement secure key management system (KMS)
* Add perfect forward secrecy (PFS) to protect past communications

**5.6 Reflection Summary**

This cryptanalysis exercise demonstrated that:

* User input (mood value) directly controls encryption security
* Deterministic key derivation creates systematic vulnerabilities
* Classical frequency analysis remains powerful against weak ciphers
* Ethical boundaries are crucial in security research
* Healthcare applications require heightened security standards
* Controlled testing environments enable safe skill development
* Modern cryptography must resist both theoretical and practical attacks

The assignment successfully bridged theoretical cryptography with practical penetration testing while emphasizing the ethical responsibilities of security professionals.

**6. TASK 5: BONUS - UNIVERSAL DECRYPTION ALGORITHM**

**6.1 Discovery of the General Formula**

Through systematic analysis of all recovered keys, a universal pattern emerged that enables decryption of **any** PsycoSupport ciphertext without frequency analysis.

**6.1.1 Mathematical Derivation**

Examining the key-mood relationship:

| **Mood** | **a** | **b** | **2m+1** | **2m** | **Match** |
| --- | --- | --- | --- | --- | --- |
| 3 | 7 | 6 | 7 | 6 | ✓ |
| 5 | 11 | 10 | 11 | 10 | ✓ |
| 7 | 15 | 14 | 15 | 14 | ✓ |
| 10 | 21 | 20 | 21 | 20 | ✓ |

*Table 6.1: Key Pattern Verification*

**Universal Formula Discovered:**

**a = 2 × mood + 1**  
**b = 2 × mood**

**Constraints:**

* a must be coprime with 26 (automatically satisfied since a is always odd)
* a ≤ 25 (limits mood values to 0–12)
* Valid mood range: [0, 12] yields valid keys

**6.2 Universal Decryption Algorithm**

**6.2.1 Algorithm Pseudocode**

*function UNIVERSAL\_DECRYPT(ciphertext, mood):*

*// Step 1: Derive key from mood*

*a = 2 \* mood + 1*

*b = 2 \* mood*

*// Step 2: Verify key validity*

*if a not in {1,3,5,7,9,11,15,17,19,21,23,25}:*

*return ERROR*

*// Step 3: Calculate modular inverse*

*a\_inv = MOD\_INVERSE(a, 26)*

*// Step 4: Decrypt each character*

*plaintext = ""*

*for each char c in ciphertext:*

*if c is alphabetic:*

*c\_upper = uppercase(c)*

*c\_num = ord(c\_upper) - ord('A')*

*p\_num = (a\_inv \* (c\_num - b)) mod 26*

*p\_char = chr(p\_num + ord('A'))*

*if c was lowercase:*

*plaintext += lowercase(p\_char)*

*else:*

*plaintext += p\_char*

*else:*

*plaintext += c // Keep non-alphabetic chars*

*return plaintext*

*function MOD\_INVERSE(a, m=26):*

*for i from 1 to m-1:*

*if (a \* i) mod m == 1:*

*return i*

*return None*

**6.3 Implementation and Verification**

**6.3.1 Script Execution**

The universaldecryptor.py script implements and validates the universal algorithm:

**[INSERT FIGURE: Universal decryption algorithm execution]** *Figure 6.1: Universal decryption algorithm execution and verification*

**6.3.2 Verification Results**

| **Test** | **Mood** | **Derived a** | **Derived b** | **Score** | **IoC** | **Success** |
| --- | --- | --- | --- | --- | --- | --- |
| 1 | 3 | 7 | 6 | 145 | 0.0673 | ✓ |
| 2 | 5 | 11 | 10 | 142 | 0.0668 | ✓ |
| 3 | 7 | 15 | 14 | 138 | 0.0665 | ✓ |
| 4 | 10 | 21 | 20 | 141 | 0.0671 | ✓ |
| 5 | 3 | 7 | 6 | 147 | 0.0674 | ✓ |

*Table 6.2: Universal Algorithm Verification*

**Index of Coincidence (IoC):** All decryptions yield IoC ≈ 0.067, consistent with English text (expected: 0.065–0.070)

**English Score:** High scores indicate presence of common words, bigrams, and trigrams

**Verification Status:** ✓ 100% success rate across all test cases

**6.4 Security Implications**

**6.4.1 Catastrophic Vulnerability**

The discovery of this formula represents a **complete compromise** of PsycoSupport's encryption:

**1. Zero Cryptanalysis Required:**

* No frequency analysis needed
* No statistical methods required
* Simple arithmetic calculation

**2. Trivial Brute Force:**

* Only 13 possible mood values (0–12)
* Can try all keys in milliseconds
* No computational barrier to attack

**3. Passive Eavesdropping:**

* Attacker observing network traffic can decrypt everything
* No need to interact with system
* Historical communications compromised retroactively

**4. No Forward Secrecy:**

* Compromise of formula breaks all past and future communications
* No session-specific protection
* Single point of failure

**6.4.2 Attack Scenario**

**Real-World Exploitation:**

*# Attacker intercepts encrypted traffic*

*captured\_ciphertext = "YVYVYCYFYM..."*

*# Try all possible moods (takes < 1 second)*

*for mood in range(13):*

*a = 2 \* mood + 1*

*b = 2 \* mood*

*plaintext = affine\_decrypt(captured\_ciphertext, a, b)*

*if looks\_like\_english(plaintext):*

*print(f"DECRYPTED with mood={mood}")*

*print(plaintext)*

*break*

*# Result: All patient-psychologist communications exposed*

**6.5 Comparison with Other Cryptographic Systems**

| **Property** | **PsycoSupport (Affine)** | **AES-256** | **RSA-2048** |
| --- | --- | --- | --- |
| **Key Space** | 13 keys | 2^256 keys (≈10^77) | 2^2048 keys |
| **Brute Force Time** | < 1 second | > 10^50 years | > 10^600 years |
| **Frequency Analysis** | Vulnerable | Immune | Immune |
| **Known Plaintext** | Vulnerable | Immune | Immune |
| **Forward Secrecy** | None | Possible (DHE) | Possible (ECDHE) |
| **Modern Standard** | ✗ (1800s) | ✓ (NIST approved) | ✓ (NIST approved) |

*Table 6.3: Security Comparison*

**6.6 Documentation and Deliverables**

The universal decryption algorithm has been fully documented in:

* GENERAL\_FORMULA\_DOCUMENTATION.txt - Complete mathematical derivation
* universaldecryptor.py - Production-ready implementation
* universal\_decryption\_results.csv - Verification data
* Individual decrypted files for all test cases

**6.7 Bonus Task Summary**

**Achievements:**

* ✓ Discovered universal key derivation formula
* ✓ Implemented automated decryption algorithm
* ✓ Verified formula across all test cases (100% success)
* ✓ Calculated quality metrics (IoC, English scores)
* ✓ Documented complete mathematical foundation
* ✓ Provided production-ready Python implementation
* ✓ Demonstrated catastrophic security implications

**Conclusion:** The universal formula a = 2m + 1, b = 2m enables complete cryptographic compromise of PsycoSupport with minimal effort, demonstrating why deterministic key derivation and classical ciphers are fundamentally unsuitable for modern security applications.

**7. CONCLUSION**

**7.1 Summary of Findings**

This cryptanalysis successfully demonstrated multiple attack vectors against the PsycoSupport application:

1. **Traffic Interception:** Captured 5 encrypted communications using Wireshark
2. **Frequency Analysis:** Applied classical Al-Kindi method to reveal letter distribution patterns
3. **Key Recovery:** Systematically derived encryption keys for all ciphertexts
4. **Complete Decryption:** Recovered all psychologist responses in plaintext
5. **Pattern Discovery:** Identified universal key derivation formula
6. **Algorithmic Solution:** Created automated decryption tool requiring only mood value

**7.2 Technical Achievement**

**Success Metrics:**

* 5/5 ciphertexts collected with full evidence
* 100% key recovery rate using frequency analysis
* 100% decryption accuracy
* Universal algorithm verified across all test cases
* Complete documentation with reproducible methods

**7.3 Security Assessment**

PsycoSupport's encryption is **fundamentally broken**:

* Classical cipher provides no computational security
* Deterministic key derivation enables trivial attacks
* 13-key space allows instant brute force
* No protection against passive eavesdropping
* Vulnerable to multiple attack types simultaneously

**Risk Level:** **CRITICAL** - Immediate remediation required before any production deployment.

**7.4 Learning Outcomes Achieved**

This assignment successfully demonstrated:

**CLO-2: Applied Classical Cryptanalysis**

* Frequency analysis techniques
* Statistical comparison with English language patterns
* Hypothesis testing and validation
* Key recovery through pattern recognition

**CLO-3: Practical Security Analysis**

* Traffic interception with Wireshark
* Packet analysis and data extraction
* Automated cryptanalysis with Python
* Documentation of security vulnerabilities
* Ethical considerations in penetration testing

**7.5 Professional Development**

Skills enhanced through this assignment:

* Penetration testing methodology
* Network traffic analysis
* Statistical analysis and visualization
* Python programming for security automation
* Technical writing and documentation
* Ethical frameworks for security research
* Understanding of cryptographic vulnerabilities

**7.6 Final Recommendations**

For PsycoSupport to provide genuine security:

**Critical Changes:**

1. Replace affine cipher with AES-256-GCM
2. Implement TLS 1.3 for transport security
3. Use cryptographically secure random key generation
4. Add authenticated encryption (AEAD)
5. Implement perfect forward secrecy

**Best Practices:**

* Never implement custom cryptography
* Use established, audited cryptographic libraries
* Follow OWASP guidelines for secure communications
* Conduct regular security audits
* Comply with healthcare data protection regulations (HIPAA, GDPR)

**7.7 Closing Remarks**

This cryptanalysis exercise demonstrated that security through obscurity fails against determined analysis. The 1,200-year-old frequency analysis method, developed by Al-Kindi, remains effective against weak modern implementations.

The assignment reinforced Kerckhoffs's principle: *a cryptosystem should be secure even if everything about the system, except the key, is public knowledge*. PsycoSupport violates this principle through its predictable key derivation.

Most importantly, this controlled exercise highlighted the critical ethical responsibilities of security researchers. With great analytical power comes the obligation to use it responsibly, transparently, and always within legal and ethical boundaries.

The skills developed through this assignment—combining technical analysis, automation, and ethical reasoning—form the foundation of professional cybersecurity practice.

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**9. APPENDICES**

**APPENDIX A: Python Scripts**

**A.1 Frequency Analysis Script**

The complete source code for **frequencyanalysis.py** is available in the submitted scripts/ directory. Key features:

* Automated letter frequency calculation
* Comparison with standard English distribution
* Generation of frequency tables (CSV format)
* Visualization charts with matplotlib
* Support for multiple ciphertexts batch processing

**A.2 Key Derivation Script**

The **keyderivation.py** script implements:

* Hypothesis testing for affine cipher parameters
* Valid a value enumeration (coprime with 26)
* Automated plaintext quality scoring
* Common word detection for validation
* Top candidate ranking system

**A.3 Decryption Script**

The **decryptmessages.py** script provides:

* Modular multiplicative inverse calculation
* Affine cipher decryption implementation
* Batch decryption with known keys
* Formatted output generation
* CSV summary export

**A.4 Universal Decryptor Script**

The **universaldecryptor.py** bonus script includes:

* Key derivation formula implementation
* Index of Coincidence calculation
* English quality scoring system
* Automated verification across all test cases
* Comprehensive documentation generation

**APPENDIX B: Frequency Tables**

Complete frequency analysis tables for all five ciphertexts are available in:

* output/frequency\_tables/ciphertext\_1\_mood\_3\_frequency.csv
* output/frequency\_tables/ciphertext\_2\_mood\_5\_frequency.csv
* output/frequency\_tables/ciphertext\_3\_mood\_7\_frequency.csv
* output/frequency\_tables/ciphertext\_4\_mood\_10\_frequency.csv
* output/frequency\_tables/ciphertext\_5\_mood\_3\_frequency.csv

Each table includes:

* Letter counts
* Relative frequencies (percentage)
* Standard English frequencies for comparison
* Difference values
* Sorted by frequency (descending)

**APPENDIX C: Decrypted Messages**

Full decrypted psychologist responses are available in:

* output/decrypted/ciphertext\_1\_mood\_3\_decrypted.txt
* output/decrypted/ciphertext\_2\_mood\_5\_decrypted.txt
* output/decrypted/ciphertext\_3\_mood\_7\_decrypted.txt
* output/decrypted/ciphertext\_4\_mood\_10\_decrypted.txt
* output/decrypted/ciphertext\_5\_mood\_3\_decrypted.txt

**APPENDIX D: Affine Cipher Mathematical Reference**

**D.1 Modular Arithmetic**

**Modular Multiplicative Inverse:**

For a and m coprime, a⁻¹ satisfies: a · a⁻¹ ≡ 1 (mod m)

**Valid values of a for alphabet (mod 26):**

gcd(a, 26) = 1 requires a ∈ {1, 3, 5, 7, 9, 11, 15, 17, 19, 21, 23, 25}

**D.2 Encryption/Decryption Formulas**

**Encryption:** Cᵢ = (a · Pᵢ + b) mod 26

**Decryption:** Pᵢ = a⁻¹ · (Cᵢ - b) mod 26

Where Pᵢ is plaintext letter position (0-25) and Cᵢ is ciphertext letter position.

**D.3 Example Calculation**

For a = 7, b = 6:

**Find a⁻¹:** 7 · 15 = 105 = 4 × 26 + 1 ≡ 1 (mod 26)

Therefore a⁻¹ = 15

**Decrypt letter 'W' (position 22):**

* P = 15 · (22 - 6) mod 26
* P = 15 · 16 mod 26
* P = 240 mod 26
* P = 6 (letter 'G')