

# Enhanced Rail Fence Cipher (ERFC): A Modern Approach to Secure Emoji-Based Encryption

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**Abstract**—The safeguarding of sensitive data in the modern digital environment has been considered increasingly vital. Although traditional encryption methods are successful, they usually pose challenges in usability for the average user. This paper introduces the Enhanced Rail Fence Cipher, a novel encryption method that utilizes emojis to secure alphanumeric information. In this scheme, a specific emoji is assigned to each character, and the encrypted text is arranged within a randomized grid structure, making ERFC successfully merge security with user-friendly features. This paper explores ERFC's design, operational mechanisms, security benefits, and possible applications.

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## I. INTRODUCTION

Digital communication encryption is the key that maintains the confidentiality and integrity of information while in transmission. Classical methods such as the *Caesar* and *Vigenère* ciphers have formed the backbone of cryptography, but as digital communication progresses, the need for **security** and even **compatibility** of encryption with the modern user is highly essential. This paper introduces an innovative method in the form of the **Enhanced Rail Fence Cipher** that applies emojis to encrypt alphanumeric data. Emojis are a common feature of contemporary digital communication. The ERFC is much better than the standard Rail Fence Cipher since it uses **substitution mapping** and presents the encrypted text in a grid, thereby making it extremely user-friendly and secure.

## II. BACKGROUND

The Rail Fence Cipher is an elementary example of a *transposition cipher*, arranging the characters of the plaintext in a zigzag pattern across several “rails” or rows and then extracting them in sequence from each row to obtain the ciphertext. Relatively easy to carry out, it is prone to methods like **frequency analysis**; hence, it is inadequate for the protection of sensitive information in contemporary contexts.

Modern encryption algorithms such as **AES** and **RSA** provide high-level security but tend to be heavy-duty for a common user to understand. A wide variety of emojis are used while communicating through any digital medium; hence, their usage in constructing an encryption technique that is simultaneously secure and familiar to the common user is promising.

## III. MOTIVATION

The Enhanced Rail Fence Cipher (ERFC) was developed with several key motivations:

- **Improved Security:** Expansion of the simple Rail Fence Cipher with substitution techniques and arranging the encrypted text in a grid layout.
- **User Involvement:** Use of emojis to make the encryption process more engaging and accessible.
- **Relevance Today:** Alignment of encryption techniques with modern online communication trends in which emojis play a significant role.
- **Flexibility and Customization:** Ability to customize the encryption technique through key-based mapping and different grid sizes.

These motivations underscore the need for an encryption technique that is **secure** while at the same time aligning with contemporary communication practices, thus facilitating greater adoption and user-friendliness.

#### IV. ERFC ARCHITECTURE

ERFC is an improvement of the basic Rail Fence Cipher with **substitution mapping**, matrix-based structuring, salt generation, and integrity hashing. The design has four major components:

##### A. Substitution Mapping

**Goal:** Create a one-to-one mapping between alphabetic characters ( $A-Z$ ,  $a-z$ ,  $0-9$ ) and 62 unique emojis.

**Mechanism:**

1. **Character Set:** The cipher uses 62 characters: 26 uppercase letters, 26 lowercase letters, and 10 digits.
2. **Emoji List:** A pre-defined list of 62 unique emojis is used for substitution.
3. **Shuffling Based on Key:**
  - The secret key  $K$  is hashed using **SHA-256** to generate a consistent seed.
  - This seed is used to shuffle the emoji list, ensuring the mapping is unique for each key.
4. **Mapping:**
  - Each character is assigned an emoji from the shuffled list.
  - A reverse mapping is maintained for decryption.

**Security Implications:**

- **Dependency on the Secret Key:** The substitution mapping relies on the secret key, preventing unauthorized access.
- **Uniqueness:** Each character maps to a unique emoji, eliminating decryption ambiguities.

**Mathematical Representation:**

Let:

- $C$  be the set of alphanumeric characters:  $C = \{A, B, \dots, Z, a, b, \dots, z, 0, 1, \dots, 9\}$ .
- $E$  be the set of emojis:  $E = \{e_1, e_2, \dots, e_{62}\}$ .

The substitution mapping  $M$  is defined as:

$$M : C \rightarrow E$$

$$M(c_i) = e_j \quad \text{for each } c_i \in C \text{ and } e_j \in E$$

The reverse mapping  $M^{-1}$  is:

$$M^{-1} : E \rightarrow C$$

$$M^{-1}(e_j) = c_i \quad \text{for each } e_j \in E \text{ and } c_i \in C$$

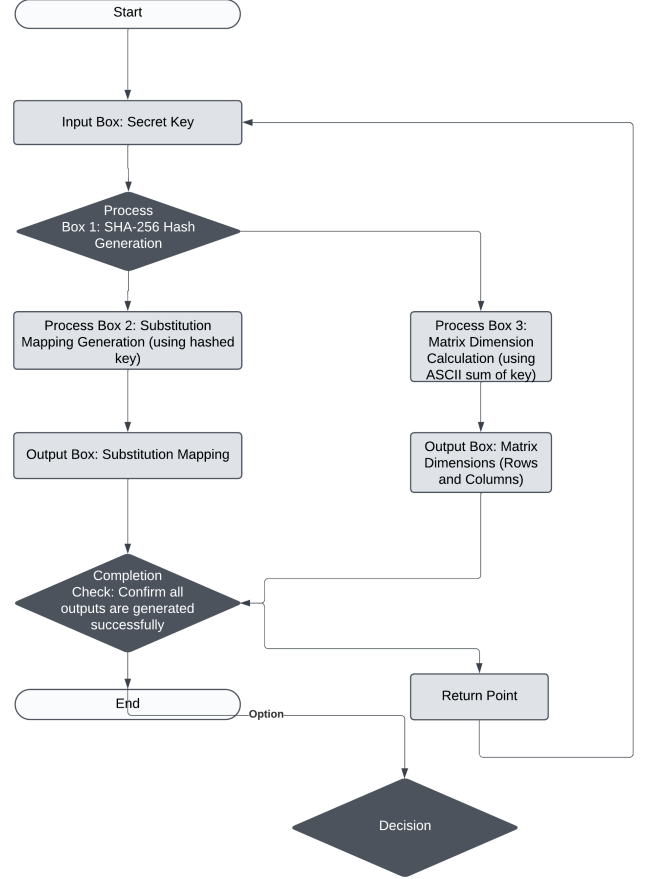


Fig. 1: Substitution Mapping Diagram

##### B. Matrix Construction

**Objective:** Organize the substituted emojis within a grid to obscure the plaintext's structure and enhance security.

**Mechanism:**

###### 1. Matrix Dimensions Calculation:

- **Expansion Factor ( $\alpha$ ):** Determines the grid size relative to the plaintext length. An expansion factor of 5 is used.
- **Rows ( $R$ ) and Columns ( $C$ ):** Calculated based on the key's ASCII sum to introduce variability.

###### 2. Random Placement:

- Substituted emojis are placed randomly within the grid.
- Remaining cells are filled with random filler emojis to mask the actual message.

###### 3. Serialization:

- The grid is read row by row to create the cipher body.

**Security Implications:**

- **Obfuscation:** Random placement within a large grid makes it difficult to identify the actual message.
- **Key Dependence:** Placement randomness is controlled by the key, ensuring unpredictability.

**Mathematical Representation:**

Let:

- $L$  be the length of the plaintext.
- $\alpha$  be the expansion factor (e.g., 5).
- $R$  be the number of rows.
- $C$  be the number of columns.

Calculate:

$$R = (\text{ASCII sum of } K) \bmod 10 + 3$$

$$C = \left\lceil \frac{\alpha \times L}{R} \right\rceil$$

Ensure:

$$R \times C \geq \alpha \times L.$$

### C. Salt Generation and Length Encryption

**Objective:** Include the encrypted plaintext length in the salt of the ciphertext to avoid information leakage and facilitate decryption.

**Steps:**

- **Plaintext Length Encoding:**
  - The plaintext length  $L$  is expressed as a 4-digit string (e.g., “0001” for length 1).
- **Encryption of Length:**
  - The 4-digit string is XORed with the first 4 bytes of the key’s **SHA-256** hash.
  - The result is hex-encoded into an 8-character string.
- **Salt Composition:**
  - The encrypted length is combined with 12 random alphanumeric characters to form a 20-character salt.

**Security Implications:**

- **Non-Disclosure:** Encrypting the plaintext length conceals the message’s size from attackers.
- **Integrity:** Including the encrypted length helps verify the structure during decryption.

**Mathematical Representation:**

Given:

- $SL$  = 4-digit string of plaintext length.
- $H(K)$  = SHA-256 hash of key  $K$ .
- $H(K)[4]$  = first 4 bytes of the hash.

Encrypt:

$$EL = SL \oplus H(K)[4]$$

Hex-encode:

$$HL = \text{Hex}(EL)$$

Generate random salt  $S_r$  of 12 characters. Final salt:

$$S = HL \parallel S_r.$$

### D. Hashing for Integrity

**Objective:** Ensure the ciphertext’s integrity and detect any tampering during transmission.

**Mechanism:**

#### 1. Hash Components:

- **Key ( $K$ ):** Secret key used for encryption/decryption.
- **Salt ( $S$ ):** Contains the encrypted length and random characters.

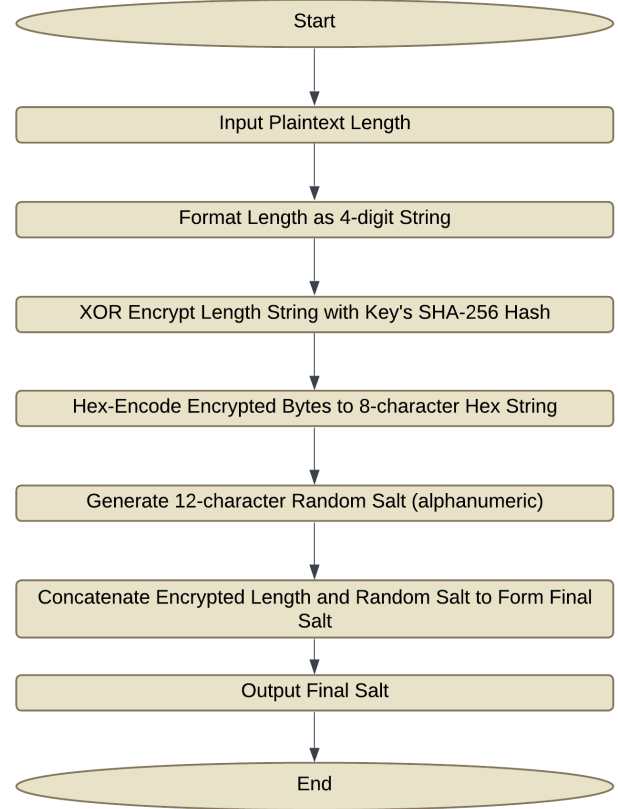


Fig. 2: Salt Generation and Length Encryption Diagram

- **Plaintext ( $P$ ):** The original message.

#### 2. Hash Generation:

- Concatenate the key, salt, and plaintext:

$$C = K \parallel S \parallel P.$$

- Compute the SHA-256 hash of the concatenated string:

$$H = \text{SHA-256}(C).$$

#### 3. Hash Inclusion:

- The hash  $H$  is transmitted alongside the ciphertext for integrity verification during decryption.

**Security Implications:**

- **Integrity Verification:** Detects any changes to the ciphertext or salt.
- **Authentication:** Confirms the message’s origin by verifying possession of the correct key.

## V. OPERATIONAL WORKFLOW

ERFC maintains a clear encryption and decryption procedure to ensure security and integrity.

### A. Encryption Process

#### 1. Plaintext Validation:

- Verify that the plaintext is alphanumeric. If not, reject the input.

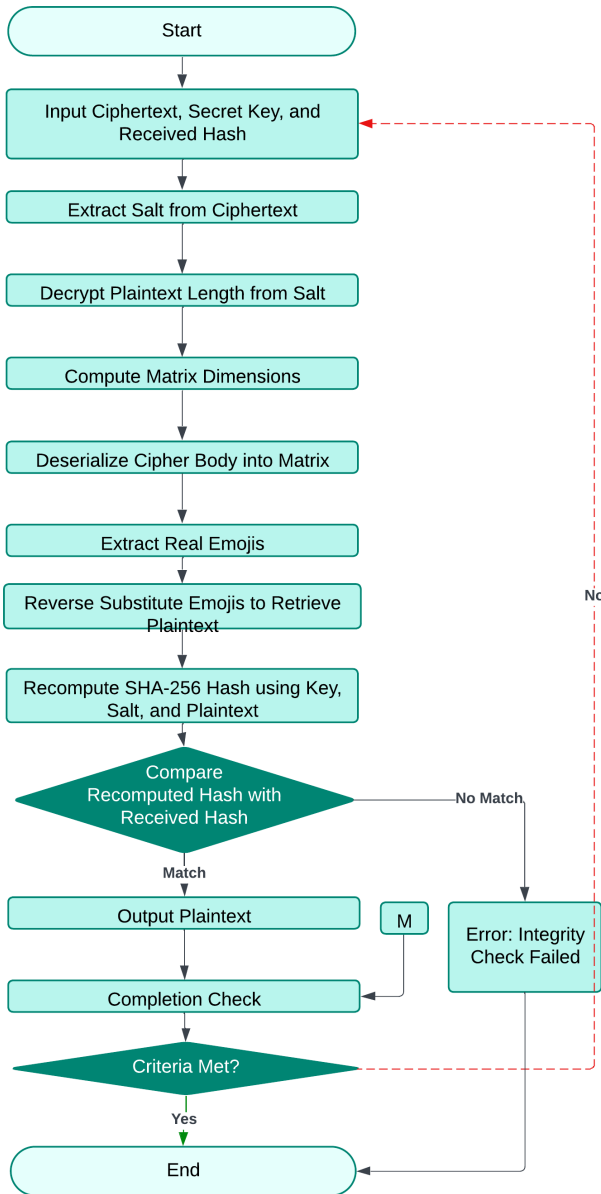


Fig. 3: Hashing for Integrity Diagram

## 2. Substitution Mapping Generation:

- Generate a mapping between characters and emojis based on the secret key.

## 3. Text Substitution:

- Replace each character of the plaintext with its corresponding emoji to form the substituted text.

## 4. Matrix Dimension Calculation:

- Determine the number of rows and columns in the grid using the ASCII sum of the key and the expansion factor.

## 5. Construction of Matrix:

- Distribute the replaced emojis in the grid at random positions.

- Fill the remaining cells with filler emojis at random positions.
- 6. Serialization of Matrix:**
    - Read the grid row by row to construct the cipher body.
  - 7. Salt Generation using Cipher Length:**
    - Encrypt the plaintext length and generate the salt by concatenating the encrypted length with random characters.
  - 8. Hash Generation:**
    - Compute the SHA-256 hash of the key, salt, and plaintext for integrity verification.
  - 9. Final Composition of Ciphertext:**
    - Combine the salt and cipher body to obtain the final ciphertext.
    - Output the ciphertext and its corresponding hash.

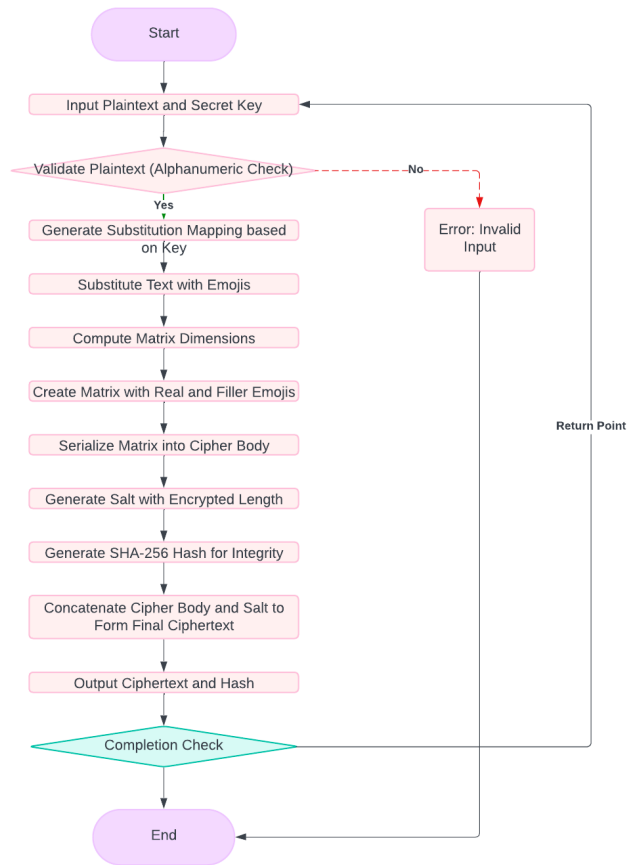


Fig. 4: Encryption Process Flowchart

## B. Decryption Process

### 1. Extract Salt:

- Extract the last 20 characters of the ciphertext as the salt.
- Decrypt the first 8 characters of the salt to obtain the plaintext length.

### 2. Grid Dimension Recalculation:

- Recalculate the number of rows and columns of the grid using the decrypted plaintext length and the expansion factor.
3. **Cipher Body Extraction:**
    - Remove the salt from the ciphertext to retrieve the cipher body.
    - Reconstruct the grid by reading the cipher body row by row.
  4. **Plaintext Emoji Extraction:**
    - Determine the positions of the actual emojis based on the ASCII sum of the key.
    - Extract the specified number of emojis corresponding to the plaintext length.
  5. **Reverse Substitution:**
    - Convert the extracted emojis back to their original alphanumeric characters using the reverse mapping.
  6. **Integrity Verification:**
    - Rehash the message and compare it to the received hash to confirm no tampering has occurred.
  7. **Output Plaintext:**
    - If integrity checks pass, output the decrypted message.

## VI. SECURITY ANALYSIS

ERFC's security is evaluated based on its resistance to common attacks, effectiveness of its *confusion and diffusion* mechanisms, and the strength of its *avalanche effect*.

### A. Confusion and Diffusion

- **Confusion:** ERFC employs a substitution mapping based on the secret key, which masks the mapping of plaintext characters to emojis. This approach creates difficulties in frequency analysis, as every character maps to a different, random emoji.
- **Diffusion:** By spreading the emojis throughout the entire grid and filling spaces with filler emojis, ERFC ensures that any change in the plaintext affects several areas of the ciphertext. The scattered distribution makes it challenging to establish patterns.

**Example:** Changing just one character in the plaintext results in different emojis and their positions in the grid, making it hard to discern patterns.

### B. Avalanche Effect

Cryptography's *Avalanche Effect* refers to the phenomenon where a slight change in input (usually in plaintext and/or key) generates considerable variations in the output, i.e., the ciphertext. ERFC exhibits the avalanche property through the following factors:

- **Key Dependency:** A minor alteration to the key results in a change in the substitution mapping, which, in turn, causes a completely different set of emojis to represent the same input message.
- **Random Placement:** Even when the same key is used, modifying the plaintext size changes the grid size and the

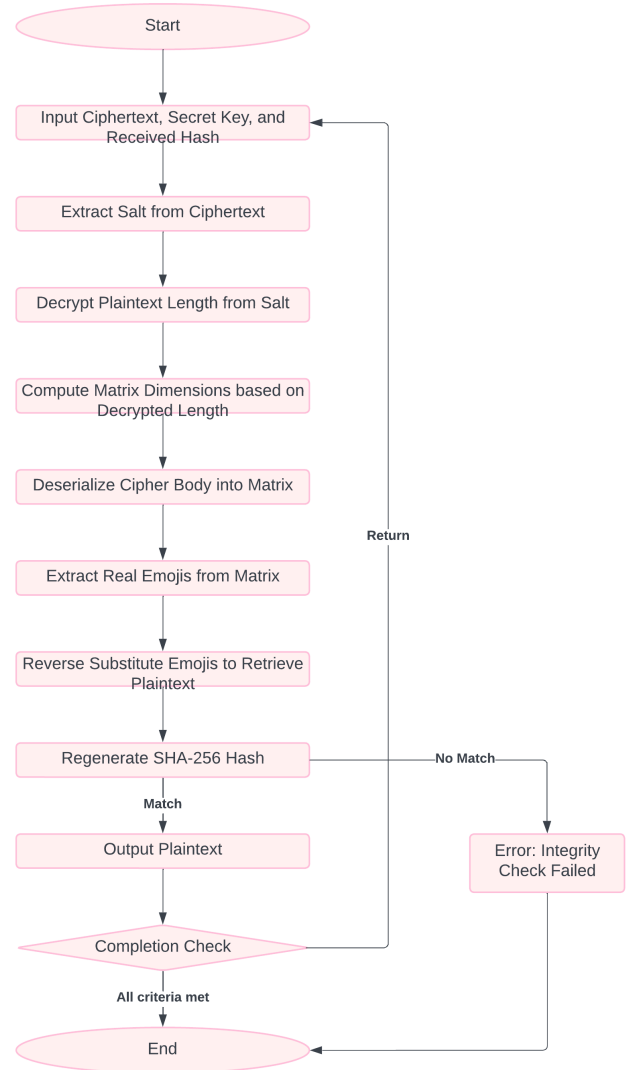


Fig. 5: Decryption Process Flowchart

location of the emojis. This results in a different structure for the ciphertext.

**Example:** Two keys differing by just one character will result in a completely different set of emoji substitutions and ciphertext, demonstrating the avalanche effect.

### C. Resistance to General Attacks

- **Frequency Analysis:** With the random nature of emoji substitution and the arbitrary placement of the grid, frequency analysis is not useful if the mapping of substitution is unknown.
- **Known-Plaintext Attacks:** Even if an attacker is aware of parts of the plaintext, the substitution mapping cannot be deduced without the key.
- **Brute Force Attacks:** The strength of ERFC depends on the complexity of the key. A strong key significantly makes brute-force attacks more difficult.

- **Integrity Attacks:** The use of a **SHA-256** hash ensures that any form of tampering with the ciphertext or salt can be detected during decryption.

**Note:** Although ERFC is more secure than the classical Rail Fence Cipher, it does not come close to modern algorithms such as **AES** or **RSA**. It is best used in applications where moderate security combined with user-friendly characteristics is desired.

## VII. PERFORMANCE EVALUATION

Evaluating ERFC's performance involves analyzing its computational efficiency, scalability, and security compared to traditional ciphers.

### A. Efficiency Metrics

- **Time Complexity:**
  - *Encryption:*  $O(n)$ , linear in plaintext length.
  - *Decryption:*  $O(n)$ , linear in ciphertext length.
- **Space Complexity:**
  - *Ciphertext Size:* Approximately  $5\times$  the plaintext length, due to grid expansion.

| Metric           | ERFC                     | Rail Fence Cipher        | AES-256            |
|------------------|--------------------------|--------------------------|--------------------|
| Time Complexity  | <i>Linear</i>            | <i>Linear</i>            | <i>Linear</i>      |
| Space Complexity | $\sim 5\times$ Plaintext | $\sim 1\times$ Plaintext | Fixed (block size) |
| Encryption Speed | <b>Fast</b>              | Very Fast                | Moderate           |
| Decryption Speed | <b>Fast</b>              | Very Fast                | Moderate           |

TABLE I: Efficiency Metrics Comparison

### B. Comparison with Traditional Ciphers

| Feature               | ERFC                                    | Rail Fence Cipher        | AES-256                               |
|-----------------------|---|--------------------------|---------------------------------------|
| Security Level        | <b>Moderate</b>                         | Low                      | High                                  |
| Ciphertext Size       | $\sim 5\times$ Plaintext                | $\sim 1\times$ Plaintext | Fixed (block size)                    |
| Speed                 | <b>Fast</b>                             | Very Fast                | Moderate                              |
| Complexity            | <b>Moderate</b>                         | Simple                   | Complex                               |
| Ease of Use           | <b>User-Friendly</b>                    | Very User-Friendly       | Requires Libraries                    |
| Resistance to Attacks | <b>Good for basic attacks</b>           | Poor                     | Excellent                             |
| Key Dependency        | <b>High</b>                             | Low                      | High                                  |
| Implementation Effort | <b>Moderate</b>                         | Very Low                 | High                                  |
| Cipher Type           | <i>Substitution &amp; Transposition</i> | <i>Transposition</i>     | <i>Substitution &amp; Permutation</i> |

TABLE II: Comparison of ERFC with Traditional Ciphers

## VIII. APPLICATIONS AND USE CASES

ERFC's combination of security and user-friendly features makes it suitable for various applications:

- **Personal Communication:** Encrypting messages on social media platforms using emojis for added privacy and engagement.
- **Educational Tools:** Teaching basic cryptography concepts through an engaging, emoji-based cipher.
- **Gaming:** Incorporating ERFC in games to encrypt in-game messages, adding a puzzle-solving layer for players.
- **Social Media Security:** Protecting sensitive information shared via emojis in posts or direct messages.
- **Artistic Projects:** Integrating cryptography with digital art using emojis to embed secret messages into artistic creations.

### Limitations:

- **Scalability:** Ciphertext expansion may be inefficient for large datasets.
- **Standardization:** Limited adoption in professional security contexts due to a lack of standardization.

## IX. FUTURE WORK

ERFC is a promising approach to secure emoji-based encryption, and several directions remain to be explored:

- **Enhanced Security Features:** Integrate modern cryptographic primitives to strengthen resistance against advanced attacks.
- **Scalability Improvement:** Optimize grid size and reduce ciphertext expansion for large-scale data transfers.
- **User Experience:** Develop user-friendly tools (mobile apps, web plugins) that seamlessly integrate ERFC into popular communication platforms.
- **Formal Security Analysis:** Conduct a rigorous cryptographic security proof to identify potential vulnerabilities and strengthen ERFC.
- **Standardization and Protocol Integration:** Work toward standardizing ERFC and integrating it with existing cryptographic protocols (e.g., TLS, SSH) for broader adoption.

## X. CONCLUSION

The Enhanced Rail Fence Cipher (ERFC) introduces a novel encryption method by embedding emojis within a transposition-based structure. ERFC offers a balance between security and user engagement by providing a *key-dependent substitution mapping*, randomized grid placement, encrypted length embedded in salt, and SHA-256 integrity hashing.

Although ERFC does not match the strength of AES or RSA, it is ideal for contexts where **moderate security** and **user-friendliness** are paramount. Future enhancements will target scalability, formal security proofs, and broader integration into mainstream communication tools.

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