Feistel-Based Cryptographic Algorithm

Md Nahid Hasan | Phanidhar Akula | Robert Kilgore | Sudhir Yadav

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1. Introduction

This cryptographic algorithm uses a Feistel network to provide reversible encryption and decryption. It operates on 32-bit blocks that are split into two 16-bit halves. A 32-bit master key seeds an LFSR (Linear Feedback Shift Register) to generate unique 16-bit subkeys for each round. In each round, the algorithm applies a key-dependent 4×4 S-box (substitution layer) and a fixed P-box (permutation layer) to provide nonlinearity and diffusion, respectively.

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2. Algorithm Overview

Feistel Structure

- **Encryption Process:**
  1. **Block Splitting:** The 32-bit plaintext is split into two 16-bit halves, L (left) and R (right).
  2. **Subkey Generation:** A 32-bit master key seeds an LFSR, which generates a unique 16-bit subkey for each round.
  3. **Round Operations:** For each round, the right half is processed through the S-box and P-box, then XORed with the subkey. The halves are then swapped.
  4. **Recombination:** After all rounds, the two halves are combined into a 32-bit ciphertext.

- **Decryption Process:**
  1. **Block Splitting:** The 32-bit ciphertext is divided into L and R.
  2. **Subkey Regeneration:** The same LFSR is used with the 32-bit master key to regenerate subkeys in the same order.
  3. **Inverse Rounds:** The rounds are then processed in reverse order using the same subkeys (applied in reverse) along with the inverses of the S-box and P-box.
  4. **Recombination:** The original plaintext is recovered by recombining the halves.

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3. Key Scheduling (LFSR-Based)

3.1. How It Works

- **Initialization:**
  The algorithm starts with a 32-bit master key that seeds a Linear Feedback Shift Register (LFSR).
- **Subkey Generation:**
  For each round, the LFSR is shifted one bit to the right. Specific bits (at positions 0, 1, 21, and 31) are XORed to produce a new bit, which is then inserted at the MSB. The lower 16 bits of the new LFSR state become the subkey for that round.

3.2. Security Contribution

- **Uniqueness:**
  Each round uses a different 16-bit subkey derived from the master key, which prevents attackers from easily predicting key material.
- **Randomness:**
  The pseudo-random nature of the LFSR introduces randomness in the subkeys, which thwarts differential and linear attacks.

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4. S-Boxes (Substitution Layer)

4.1. How It Works

- **Basic Operation:**
  The S-box in this implementation is a 4×4 table. It processes 4-bit nibbles (values 0–15). For each 16-bit half, the data is split into four 4-bit nibbles; each nibble is substituted by looking up its value in the S-box.
- **Key Dependency and Seed the Random Generator:**
  The S-box is generated randomly based on the 32-bit master key. The master key is used to seed a pseudo-random number generator. This ensures that the same master key always produces the same sequence of "random" numbers. This random permutation is used as the S-box mapping, and its inverse is computed for decryption.

4.2. Security Contribution

- **Non-linearity:**
  The S-box introduces non-linear transformations, which are crucial for thwarting linear and differential cryptanalysis.
- **Confusion:**
  It ensures that a small change in the input will produce a dramatically different output (avalanche effect), making it hard for an attacker to predict relationships.

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5. Permutation Layer (P-Box)

5.1. How It Works

- **Bit Permutation:**
  The P-box takes a 16-bit input and permutes its bits. In this implementation, each bit at position i is moved to the new position given by the formula:
  new position = (i × 3) mod 16

5.2. Security Contribution

- **Diffusion:**
  The permutation layer spreads the influence of each input bit across multiple output bits, ensuring that small changes in the plaintext are diffused throughout the ciphertext.
- **Resistance:**
  By shuffling the bit positions, the P-box disrupts predictable patterns, making differential cryptanalysis more difficult.

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6. Feistel Structure (Encryption & Decryption Process)

6.1. Encryption Process

1. **Block Splitting:**
   The plaintext 32-bit block is divided into two 16-bit halves: L and R.
2. **Round Operations:**
   For each round (from 1 to N):
   - **Subkey Generation:** A 16-bit subkey is generated using the LFSR.
   - **Round Function:** The right half (R) is passed through the S-box (substitution) and then the P-box (permutation). The result is then XORed with the subkey.
   - **Swap and Update:** The new left half becomes the old right half, and the new right half is computed by XORing the old left half with the result of the round function.
3. **Block Recombination:**
   The final L and R halves are combined to form the ciphertext.

6.2. Encryption Pseudocode

```
function Encrypt_Block(plaintext_32, KEY_32, N):
    (L, R) ← split_into_16_bit_halves(plaintext_32)
    Subkeys ← KeySchedule_Expand(KEY_32)

    for i from 1 to N:
        F = P_BOX( S_BOX(R) ) XOR Subkeys[i]
        new_L = R
        new_R = L XOR F
        (L, R) = (new_L, new_R)

    return combine_halves(L, R)
```

6.3. Decryption Process

1. **Block Splitting:**
   The ciphertext is split into L and R.
2. **Subkey Regeneration:**
   The same subkeys are regenerated using the LFSR (using the 32-bit master key).
3. **Inverse Rounds:**
   For each round (from N down to 1):
   - The subkeys are applied in reverse order.
   - The inverse operations of the round function (using the inverse S-box and P-box) are applied to recover the original halves.
   - The halves are swapped back accordingly.
4. **Block Recombination:**
   The original plaintext is recovered by recombining the halves.

6.4. Decryption Pseudocode

```
function Decrypt_Block(ciphertext_32, KEY_32, N):
    (L, R) ← split_into_16_bit_halves(ciphertext_32)
    Subkeys ← KeySchedule_Expand(KEY_32)

    for i from N down to 1:
        F = P_BOX( S_BOX(L) ) XOR Subkeys[i]
        new_R = L
        new_L = R XOR F
        (L, R) = (new_L, new_R)

    return combine_halves(L, R)
```

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7. Security Analysis

Protection Against Attacks

- **Brute Force Attack:**
  The 32-bit key provides 2^{32} (approximately 4.29 billion) possible unique keys, making exhaustive search computationally challenging.
- **Linear Cryptanalysis:**
  The S-box introduces non-linearity that disrupts simple linear relationships between the input and output, thus hindering linear cryptanalysis.
- **Differential Cryptanalysis:**
  The combined effect of the S-box and P-box creates an avalanche effect and diffusion, making differences in the input unpredictable in the output.
- **Statistical Attacks:**
  The Feistel structure and randomized subkeys ensure that the statistical distribution of ciphertext bits does not reveal patterns from the plaintext.
- **Related-Key Attack:**
  The LFSR key scheduling produces unique subkeys per round, reducing the risk of related-key attacks.

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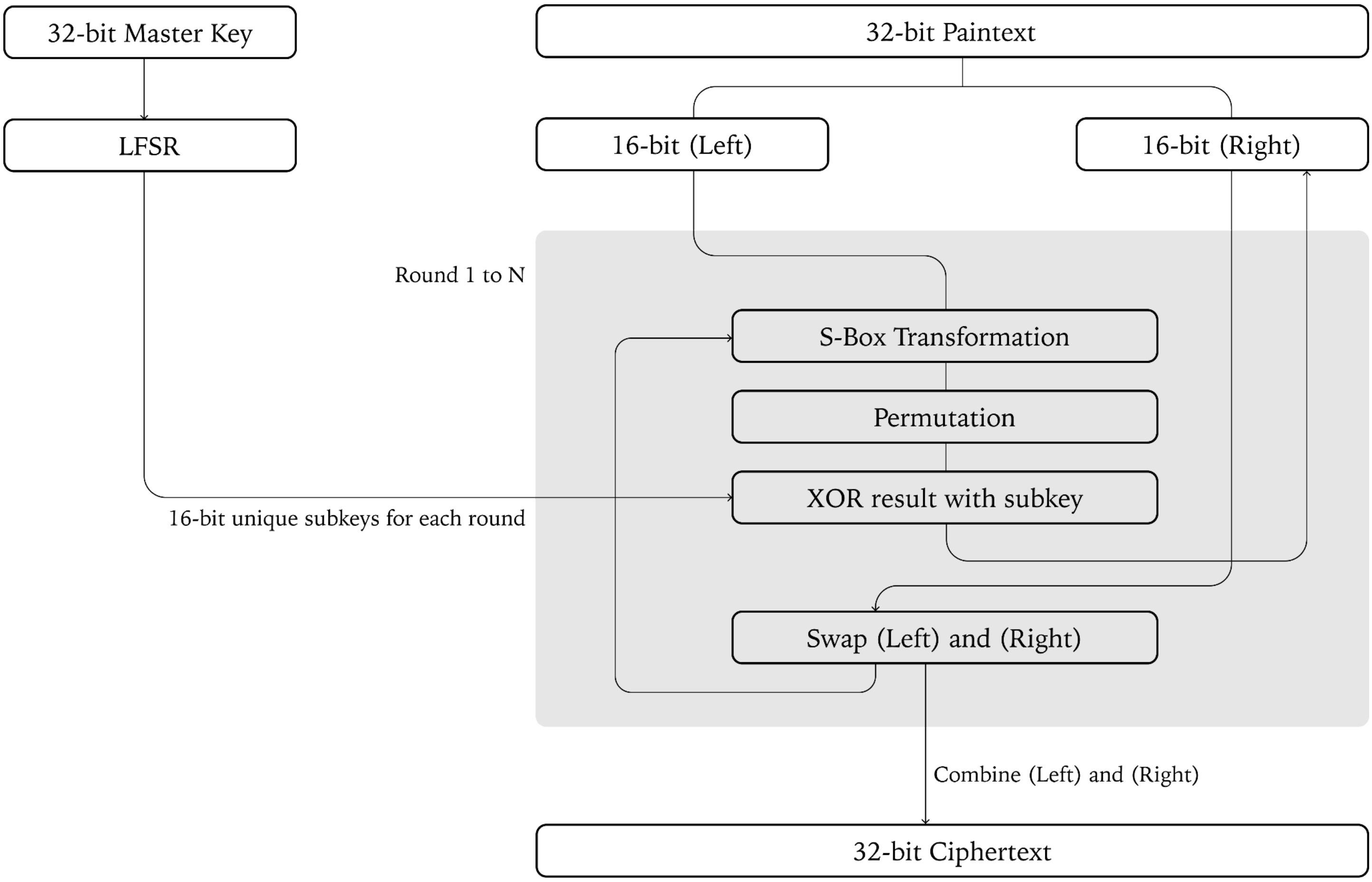
8. Flow Chart



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9. Conclusion

The Feistel-based cryptographic algorithm presented in this report integrates several crucial components to provide secure encryption:

- **Key Scheduling:**
  A 32-bit master key is used with an LFSR to generate a unique 16-bit subkey for each round, ensuring a large key space and dynamic key evolution.
- **S-Box Transformation:**
  A key-dependent 4×4 S-box introduces non-linearity, making the cipher resistant to linear and differential cryptanalysis.
- **Permutation Layer (P-Box):**
  A fixed P-box permutes the bits to achieve diffusion, ensuring that each bit of the plaintext influences many bits of the ciphertext.
- **Feistel Structure:**
  The reversible Feistel network structure ensures that encryption and decryption are efficient and maintain data integrity.

By combining these elements, the algorithm achieves a balance between complexity and reversibility. While the 32-bit key and block sizes are primarily educational and not sufficient for high-security applications in real-world scenarios, the design principles exemplify modern encryption mechanisms and serve as a valuable learning model.