Block Ciphers

Lucifer, DES, RC5, AES

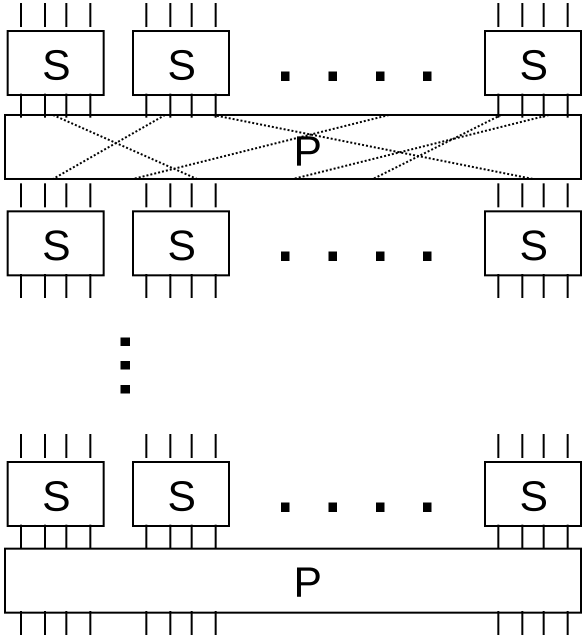
BİL 448/548

Internet Security Protocols

Ali Aydın Selçuk

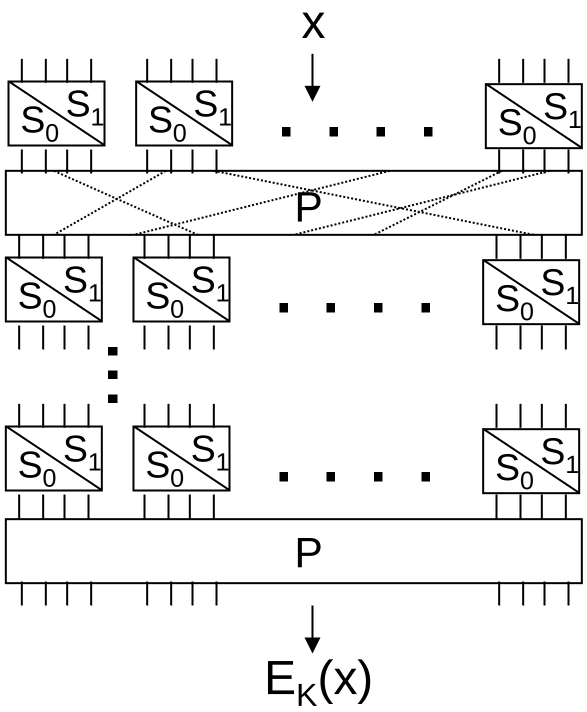
Block Ciphers & S-P Networks

- Block Ciphers: Substitution ciphers with large block size (≥ 64 bits)
- How to define a good substitution for such large blocks?
- "SP Networks" (Shannon, 1949)
  - small, carefully designed substitution boxes ("confusion")
  - their output mixed by a permutation box ("diffusion")
  - iterated a certain number of times



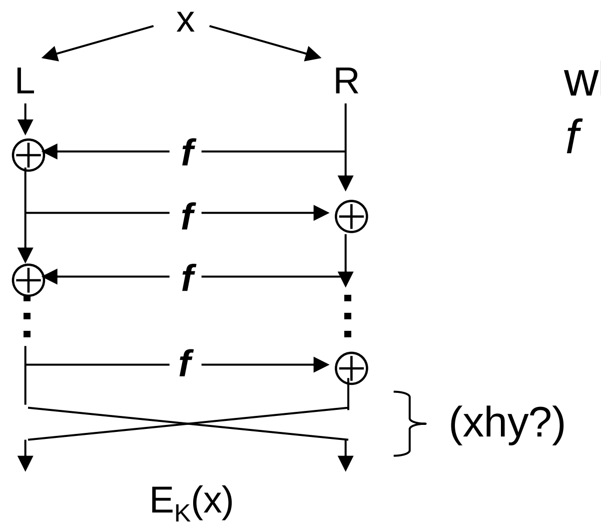
Lucifer

- Early 1970s: First serious needs for civilian encryption (in electronic banking)
- IBM's response: Lucifer, an iterated SP cipher
- Lucifer (v0):
  - Two fixed, 4x4 s-boxes, S_0 & S_1
  - A fixed permutation P
  - Key bits determine which s-box is to be used at each position
  - 8 x 64/4 = 128 key bits (for 64-bit block, 8 rounds)

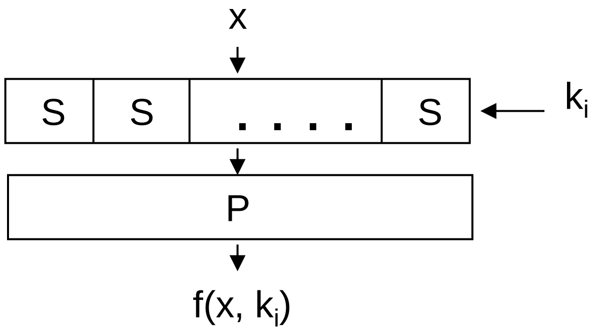


Feistel Ciphers

- A straightforward SP cipher needs twice the hardware: one for encryption (S, P), one for decryption (S^{-1}, P^{-1}).
- Feistel's solution:



where the *f* function is SP:



- Lucifer v1: Feistel SP cipher; 64-bit block, 128-bit key, 16 rounds.

Data Encryption Standard (DES)

- Need for a standardized cipher to protect computer and communications data
- NBS’ request for proposals (1973)
- IBM’s submission Lucifer is adopted after a revision by NSA, reducing the key size to 56 bits.

The DES Contraversy

- Design process was not made public.
  Any hidden trapdoors in the s-boxes?

(Now, with the design criteria better understood, this speculation is mostly over.)

- 56-bit key length is too short.
  So that NSA can break it?

Strengthening DES

- Multiple DES encryption

  3DES: $E_{K3}(D_{K2}(E_{K1}(x)))$

- DES-X (Rivest, 1995)

  $$E_K(x \oplus K1) \oplus K2$$

  - overhead cost minimal
  - construction is provably secure (Rogaway & Killian)

After the DES

- DES was designed mainly for h/w; it was slow in s/w. It was also suspect, due to the secret design process.
- By the late ’80s, need for an independently developed, fast-in-s/w cipher was clear.
- Several prominent examples emerged in this era: IDEA, Blowfish, RC5…

RC5

(Rivest, 1994)

- Extremely simple & flexible
- Variable block size (w), key size (b), no. of rounds (r); specified as RC5-w/r/b.
- Encryption algorithm:

```
$L_1 = L_0 + K_0$
$R_1 = R_0 + K_1$
**for** i = 2 **to** 2r+1 **do**
    $L_i = R_{i-1}$
    $R_i = ((L_{i-1} \oplus R_{i-1}) <<< R_{i-1}) + K_i$
```

- For 64-bit block size (w=32), 24 rounds (r=12) is secure

Advanced Encryption Standard (AES)

Successful public design process:

- NIST’s request for proposals for a new enc. standard to replace DES (1997)
- 15 submissions (1998)
- 5 finalists (1999)

  Mars (IBM)

  RC6 (RSA)

  Twofish (Schneier et al.)

  Serpent (Anderson et al.)

  Rijndael (Daemen & Rijmen)
- Winner: Rijndael (2000)

AES (Rijndael)

- An SP cipher with one algebraically designed s-box (optimal against linear & diff. cryptanalysis)
- 128-bit block size
  128, 192, or 256-bit key.
- 10-14 rounds of:

  ByteSub, ShiftRow, MixColumn, AddRoundKey
- Decryption is similar to encryption (by design)
- Very good security; also very high performance in s/w, h/w, and restricted devices (smart cards)