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FIT3031 INFORMATION & NETWORK SECURITY

Lecture 2:

Symmetric Encryption Techniques

Unit Structure: Lecture Topics

- ✓ OSI security architecture
  - **common security standards and protocols for network security applications**
  - **common information risks and requirements**
- ✓ operation of private key encryption techniques
- operation of public encryption techniques
- concepts and techniques for digital signatures, authentication and non-repudiation
- security threats of web servers, and their possible countermeasures
- Wireless Security Issues
- security threats of email systems and their possible countermeasures
- IP security
- intrusion detection techniques for security purpose
- risk of malicious software, virus and worm threats, and countermeasures
- firewall deployment and configuration to enhance protection of information assets
- network management protocol for security purpose

Review of Last Lecture

Key points from the last lecture:

- Security of Information stored or in transit during transmission is becoming increasingly important in internetworked environment
- Survey by UK Trade and Industry in 2012 revealed that 93% Large organizations & 76% small businesses suffered security breaches
  - This causes financial as well as productivity loss
- OSI security architecture provides a useful framework to systematically define the requirements and approaches to satisfy those requirements
- OSI Security Architecture focuses on three aspects of information security :
  - security attacks
  - security services
  - security mechanisms
- There are mainly two types of security attack
  - Passive attack – eavesdrop or monitoring, do not attempt to change data
  - Active attack – attempt to modify data or create false data
- X.800 defines security services into 6 major categories: Confidentiality, Authentication, Integrity, Non-repudiation, Access control and Availability
- Security mechanism are used to implement security services

LN2 : Outline

- Role of cryptography in achieving security
- Private key (symmetric) encryption principles
- Symmetric encryption algorithms
- Cipher block modes of operation
- Stream Ciphers
- Key Distribution

Cryptography

- **Derived from the Greek word *Crypto* which means *hidden***
- **Cryptography refers to the study of mathematical techniques to achieve secure communication**
- **Very important to protect data in transit**
  - **communication channels and IP protocol are insecure**
- **Cryptography is a major technique behind information & network security and a means to achieve**
  - **authentication**
  - **data integrity**
  - **confidentiality**
  - **digital signature**
  - **privacy**

Cryptographic Techniques

- **Main cryptographic techniques**
  - **Encryption**
    - Symmetric encryption
    - Asymmetric encryption
  - **Hash function**
- **Can also be used to protect data in file storage**

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Symmetric - Asymmetric encryption names

Symmetric	Asymmetric
Shared-secret encryption	Public key encryption
Single-key encryption	Dual-Key encryption
Secret-key encryption	Dual-key pair
One key encryption	Public Key Cryptography
Private-key encryption	
Shared Key encryption	
conventional encryption	

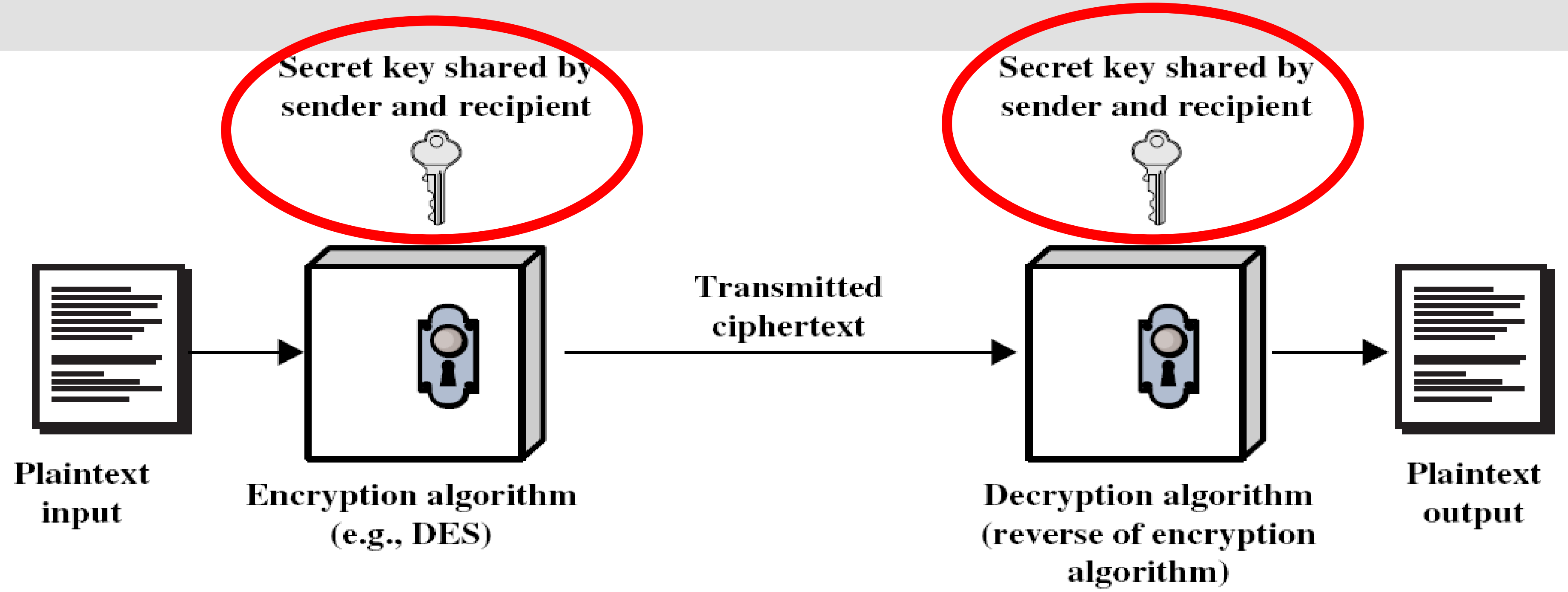
Encryption & Decryption

- ***Encryption*** **is the transformation of data into a form that is almost impossible to read without the *appropriate knowledge***
- ***Decryption*** **is the reverse of encryption - the transformation of encrypted data back into an intelligible form**
- **A *key* or *key pair* (appropriate knowledge) is necessary for encryption and decryption**
  - **A key is a digital object**

Symmetric Encryption

- A symmetric encryption scheme has five components:
  - plaintext
  - encryption algorithm
  - a secret key
  - ciphertext
  - decryption algorithm
- sender and recipient share a common key
- Security depends on the secrecy of the key,
- not the secrecy of the algorithm

Symmetric Encryption Model



A simplified model of symmetric encryption

Symmetric Encryption components

- **Five components:**
  - **plaintext** - the original message
  - **ciphertext** – the transformed (coded) message
  - **encryption algorithm** - algorithm that transforms plaintext to ciphertext
  - **a secret key** - information used by the algorithm and known only to sender/receiver
  - **decryption algorithm** – encryption algorithm in reverse; retrieve original message from coded message

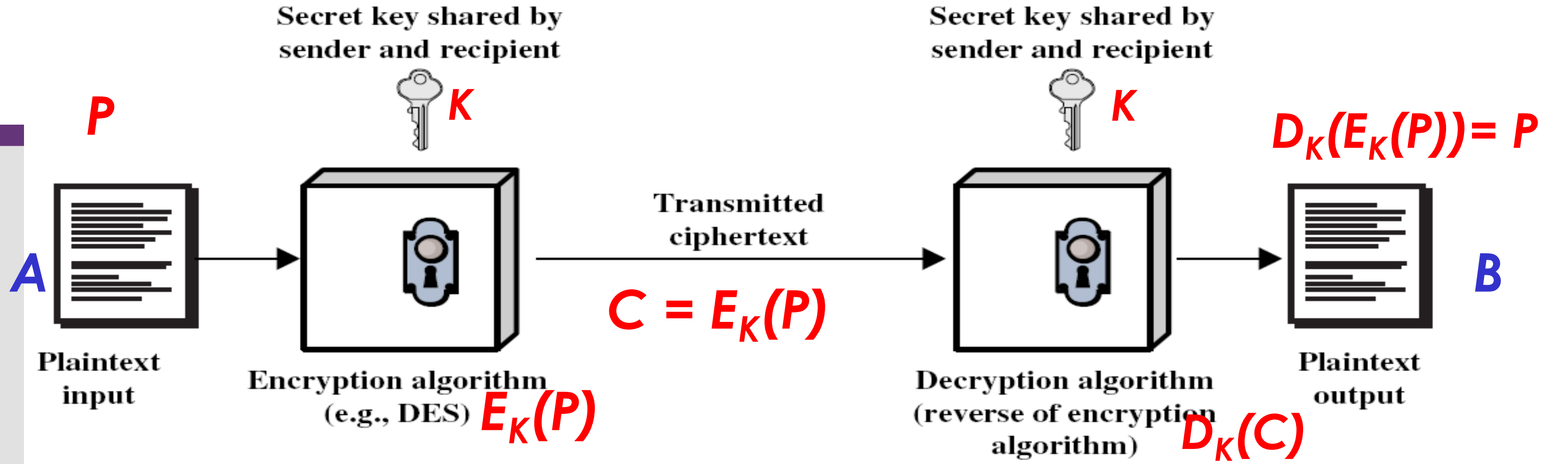
Encryption Example

- **Original message:**
  - This is a demonstration of symmetric encryption
- **Encryption key (128 bit):**
  - Qwopryoo58gj10pe
- **Encrypted message:**

  Result (encrypted with cast-128):

  DdPFY2X170I2Tg95Q5v1Oy/+1b6ZpQ6kT1gkkl/95N47+QZ27nCB4g5S4vlEGnqj
- **Decrypted message**
  - This is a demonstration of symmetric encryption
- **You may try these simple demos, linked to day-2 section**
- https://www.tools4noobs.com/online_tools/encrypt/
- https://www.tools4noobs.com/online_tools/decrypt/
- https://www.tools4noobs.com/online_tools/hash/

Symmetric Cryptography - Principle



- **A** shares a secret key ***K*** with **B**.
  - The key may be distributed by a key distribution center (KDC).
- **A** encrypts a plaintext message ***P*** by applying an ***encryption function E*** and the key ***K*** to create a ciphertext
  - $C = E_K(P)$
- **A** sends the ciphertext ***C*** to **B** over a communication channel. Even if anybody other than **B** gets hold of a copy of ***C***, he can't decrypt the message unless he has ***K***.
- If the key distribution is perfect or **B** does not accidentally or intentionally disclose it, then nobody other than **B** is supposed to have the key ***K***.
- On receiving ***C***, **B** applies ***decryption function D*** and key ***K*** on ***C*** to recover the plaintext message *P*:
  - $D_K(C) = D_K(E_K(P)) = P$

Cipher

- **Two types:**
  - **Block cipher:**
    - process one input block at a time
    - produce one output block for each input block
  - **Stream cipher:**
    - process input element continuously
    - produces one element at a time

Cryptanalysis

- An attacker may try different types of attacks on the encrypted message to discover plaintext or secret
- A brute-force attacker tries every possible key
- On an average a successful break would require half the number of all possible keys tried
- It is possible to try 1 million keys per μsec.
  - requires only ten hours to break a 56-bit symmetric encryption
- Higher length key does not necessarily make an encryption more secure
  - also **depends** on the **encryption** algorithm

Cryptanalytic Attacks

Table 2.1 Types of Attacks on Encrypted Messages

Type of Attack	Known to Cryptanalyst
Ciphertext only	• Encryption algorithm • Ciphertext to be decoded
Known plaintext	• Encryption algorithm • Ciphertext to be decoded • One or more plaintext–ciphertext pairs formed with the secret key
Chosen plaintext	• Encryption algorithm • Ciphertext to be decoded • Plaintext message chosen by cryptanalyst, together with its corresponding ciphertext generated with the secret key
Chosen ciphertext	• Encryption algorithm • Ciphertext to be decoded • Purported ciphertext chosen by cryptanalyst, together with its corresponding decrypted plaintext generated with the secret key
Chosen text	• Encryption algorithm • Ciphertext to be decoded • Plaintext message chosen by cryptanalyst, together with its corresponding ciphertext generated with the secret key • Purported ciphertext chosen by cryptanalyst, together with its corresponding decrypted plaintext generated with the secret key

Exhaustive Key Search / Brute Force Attack

- **Always possible to simply try every key**
- **Most basic attack, proportional to key size**
- **Assume either know / recognize plaintext**

Table 2.2 Average Time Required for Exhaustive Key Search

Key Size (bits)	Number of Alternative Keys	Time Required at 1 Decryption/μs	Time Required at 10^6 Decryptions/μs
32	$2^{32} = 4.3 \times 10^9$	$2^{31} \mu s = 35.8$ minutes	2.15 milliseconds
56	$2^{56} = 7.2 \times 10^{16}$	$2^{55} \mu s = 1142$ years	10.01 hours
128	$2^{128} = 3.4 \times 10^{38}$	$2^{127} \mu s = 5.4 \times 10^{24}$ years	5.4×10^{18} years
168	$2^{168} = 3.7 \times 10^{50}$	$2^{167} \mu s = 5.9 \times 10^{36}$ years	5.9×10^{30} years
26 characters (permutation)	$26! = 4 \times 10^{26}$	$2 \times 10^{26} \mu s = 6.4 \times 10^{12}$ years	6.4×10^{6} years

Feistel Cipher

- Virtually all ***conventional block encryption*** algorithms, including DES (Data Encryption Standard) have a structure first described by **Horst Feistel** of IBM in 1973
- The realization of a Feistel Network depends on the choice of the parameters used and design features

Feistel Cipher Structure

- **Fiestel Cipher operation (see figure in next slide):**
  - Split the plaintext block into two equal pieces, (L0, R0)
  - ***n*** rounds of processing for each half before combining to produce ciphertext
  - For each round $i = 1,2,...,n$, compute

$$L_i = R_{i-1}$$

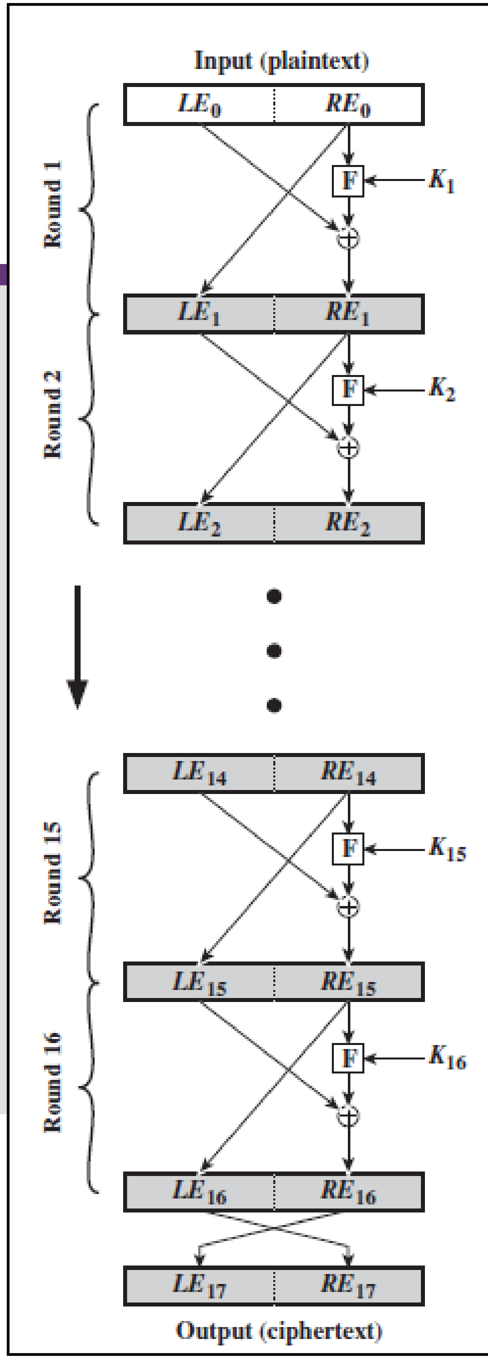
$$R_i = L_{i-1} \oplus \boldsymbol{f}(R_{i-1}, K_i)$$

  - where ***f*** is the round function and K_i is the sub-key
  - After ***n*** round the ciphertext is (L_n, R_n).
  - Regardless of the function ***f***, decryption is accomplished via

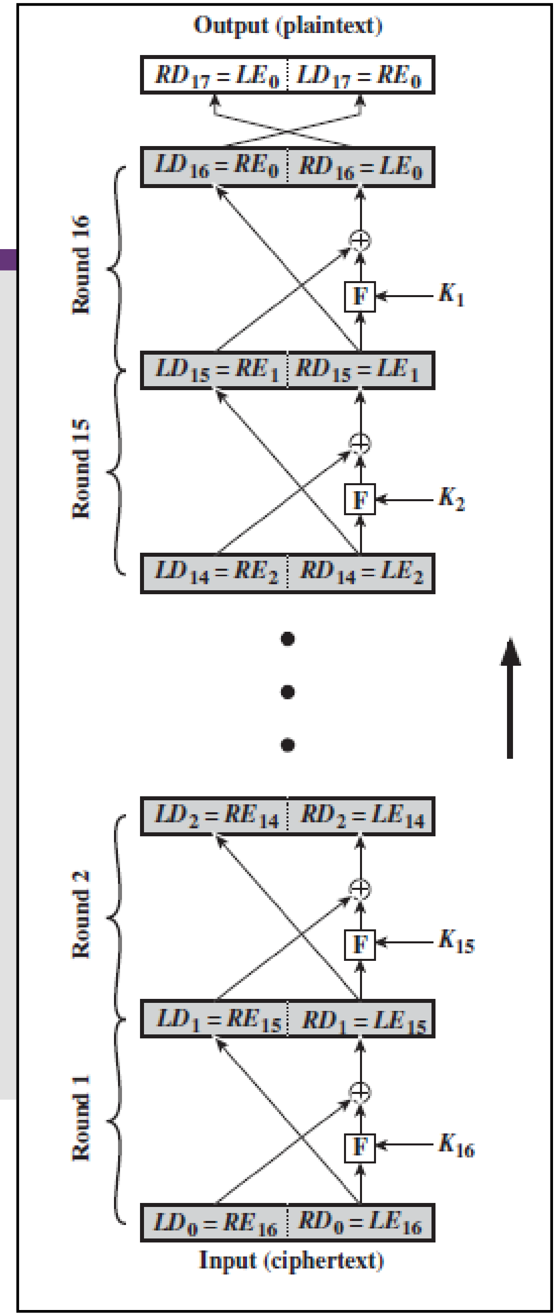
$$R_{i-1} = L_i$$

$$L_{i-1} = R_i \oplus f(R_{i-1}, K_i)$$

Classical Feistel Network



Feistel Encryption (16 rounds)



Feistel Decryption (16 rounds)

Feistel Cipher Parameters

- **Fiestel Cipher depends on:**
  - **Block size:** larger block sizes mean greater security
  - **Key Size:** larger key size means greater security
  - **Number of rounds:** multiple rounds offer increasing security, typically 16 rounds
  - **Subkey generation algorithm:** greater complexity will lead to greater difficulty of cryptanalysis.
  - **Round function:** greater complexity means greater resistance

Symmetric Encryption Algorithms

- **Data Encryption Standard (DES)**
  - The most widely used encryption scheme
  - The algorithm is referred to as the Data Encryption Algorithm (DEA)
  - DES is a block cipher
    - processed in 64-bit blocks
    - 56-bits key
      - 8 parity bits are stripped off from the full 64-bit key (8 character)
    - 16 subkeys created for 16 rounds
  - **Concern**: Proved insecure in today's fast processing power

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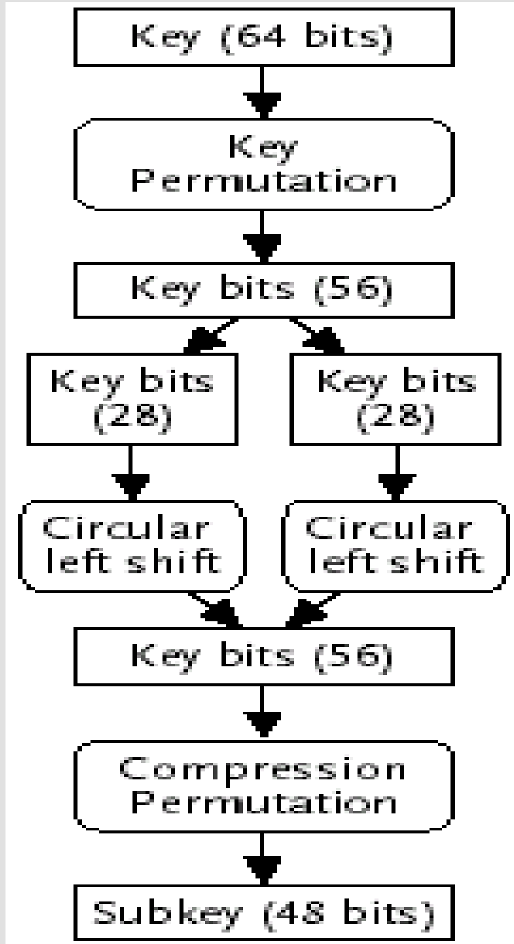
Substitution & Permutation

- **Substitution**
  - a binary word is **replaced/substituted** by some other binary word
  - also known as **S-box**
  - impractical to build 64-bit blocks
    - multiple S-boxes of smaller blocks are used
  - Example: for an input ’011001’ to an S-box, the output may be ’1001’
- **Permutation:**
  - A binary word has its bits **reordered** (permute)
  - Also known as **P-box**
  - Example: 1^{st} bit may become 7^{th} bit, 2^{nd} bit 12^{th} bit and so on

DES Subkey Generation - round # 1

- **drop 8 parity bits**
  - effective key size 56 bits
- **permute the bits and divide into two 28-bits**
- **rotate the bits left by single bit**
- **permute and extract 48 bits as a subkey**



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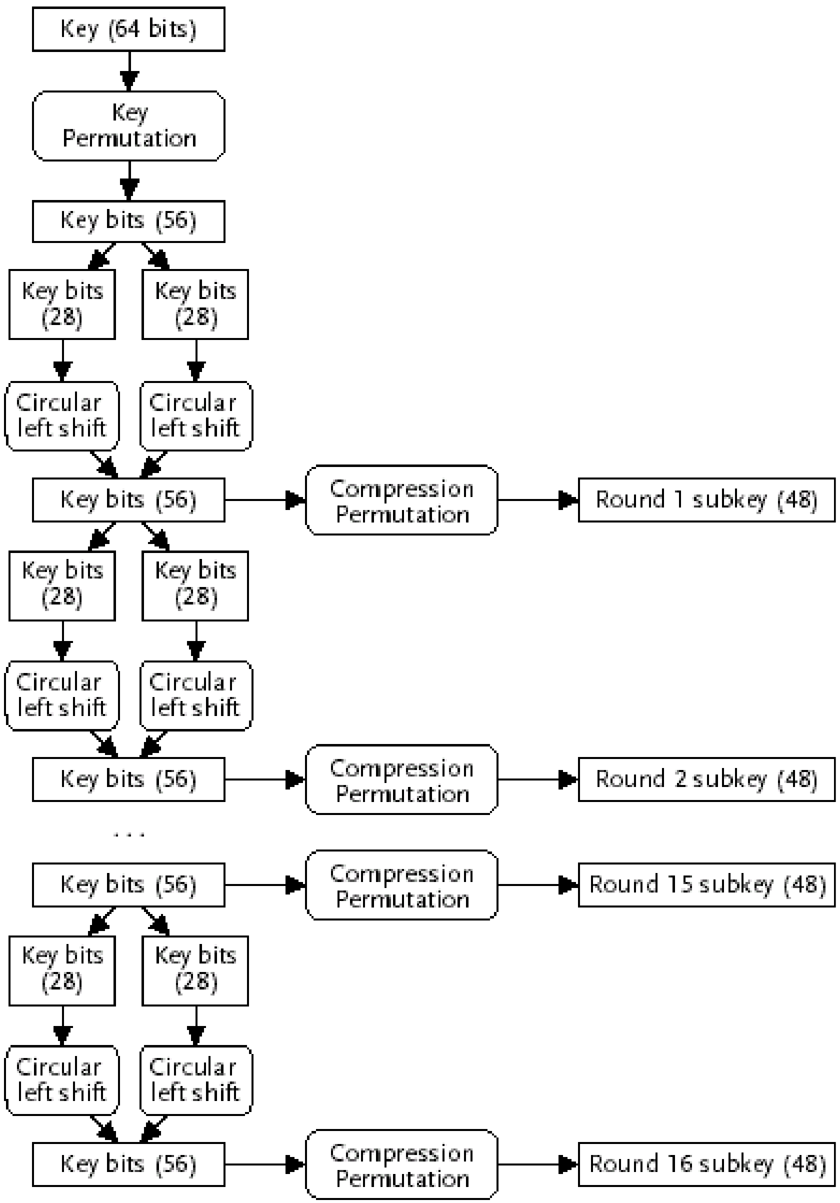
DES Subkey Generation

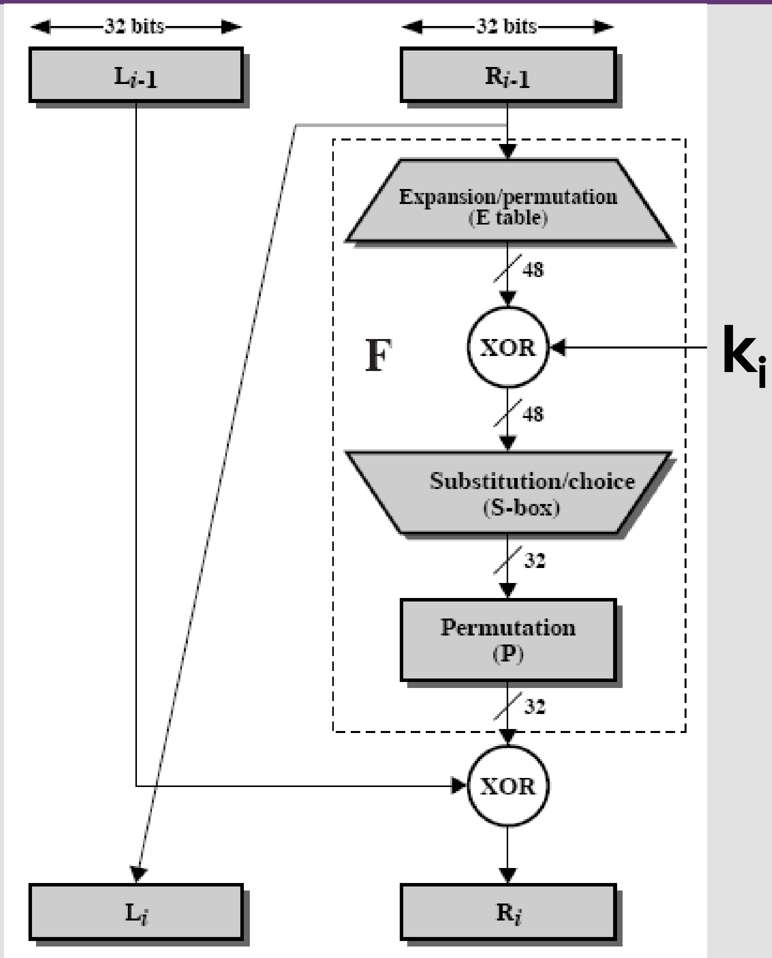


- **One bit shift – for round 1,2,9 and 16**
- **Two bit shift for the remaining rounds 3,4,5,6,7,8,10, …..15**

DES Round

- Each of the sixteen rounds takes a **64-bit block as input** and produces a **64-bit block as output**
- The output from the initial permutation is the input to round one
- Round one's output is the input to round two
- Round two's output is the input to round three
- …
- The output from round sixteen is the 64-bit block of final ciphertext

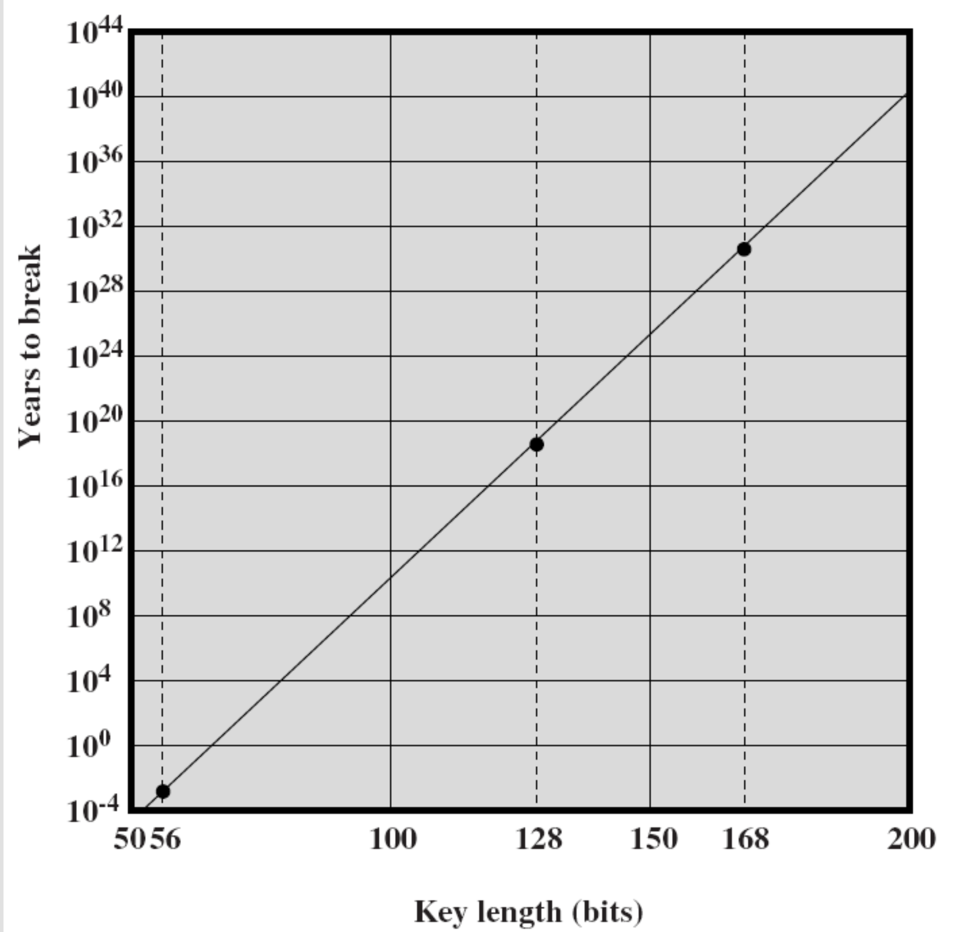
Single DES Round



- Similar to Fiestel Cipher structure
- 64-bit plaintext is divided into two 32-bit blocks (L &R)
- L_i is the unchanged R_{i-1} (previous round)
- R_{i-1} goes through F function
  - E table-expanded to 48bits and permuted
  - 48 bits XORed with subkey K_i
  - Substitution produces 32-bit
    - 8 S-boxes
    - each takes 6 bits and produces 4 bits
    - transformation is defined by substitution tables
    - different substitution table for each S-box
  - Permutes the output of S-box
- R_i is L_{i-1} XORed with permuted output

Encryption Algorithms (DES…):Time to break a code

Time to break a code (10^6 decryptions/µs)



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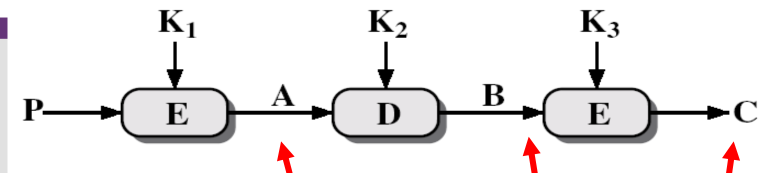
Encryption Algorithms: Triple DES



(a) Encryption

- Apply DES algorithm **three** times
- Use **three** keys and **three** executions of the DES algorithm (encrypt-decrypt-encrypt)

$$C_{stage\text{-}1} = E_{K1}[P]$$

$$C_{stage\text{-}2} = D_{K2}[\ E_{K1}[P]\ ]$$

$$\boxed{C_{stage\text{-}3} = E_{K3}[\ D_{K2}[\ E_{K1}[P]\ ]\ ]}$$

C = ciphertext

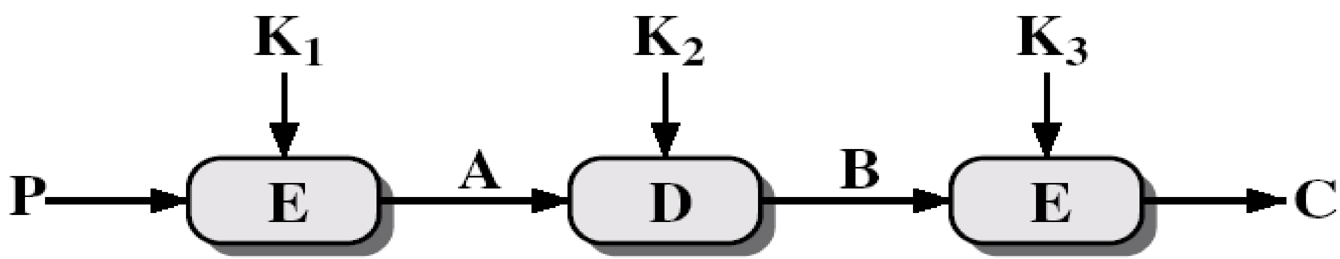
P = Plaintext

$E_K[X]$ = encryption of X using key K

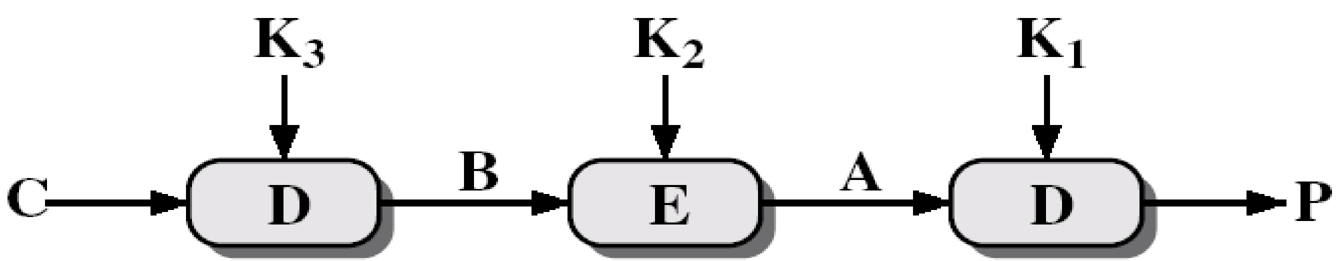
$D_K[Y]$ = decryption of Y using key K

- Effective key length of 168 bits
- Decryption: same operation with keys reversed

Encryption Algorithms: Triple DES…



(a) Encryption



(b) Decryption

Other Encryption Algorithms

- **International Data Encryption Algorithm (IDEA)**
  - **Was developed to replace DES**
  - **128-bit key, 64-bit block cipher**
  - **different round function and subkey generation from DES**
  - **Used in PGP**
- **Blowfish**
  - **DES-like algorithm: 64-bit cipher, 16 rounds**
  - **variable key length upto 448: 128-bit common**
  - **easy to implement, high execution speed, low memory requirement**

Other Encryption Algorithms…

- **RC5**
  - suitable for hardware and software
  - fast and simple
  - adaptable to processors of different word lengths
  - variable number of rounds
  - variable-length key
  - low memory requirement
  - high security
  - data-dependent rotations

Other Encryption Algorithms…

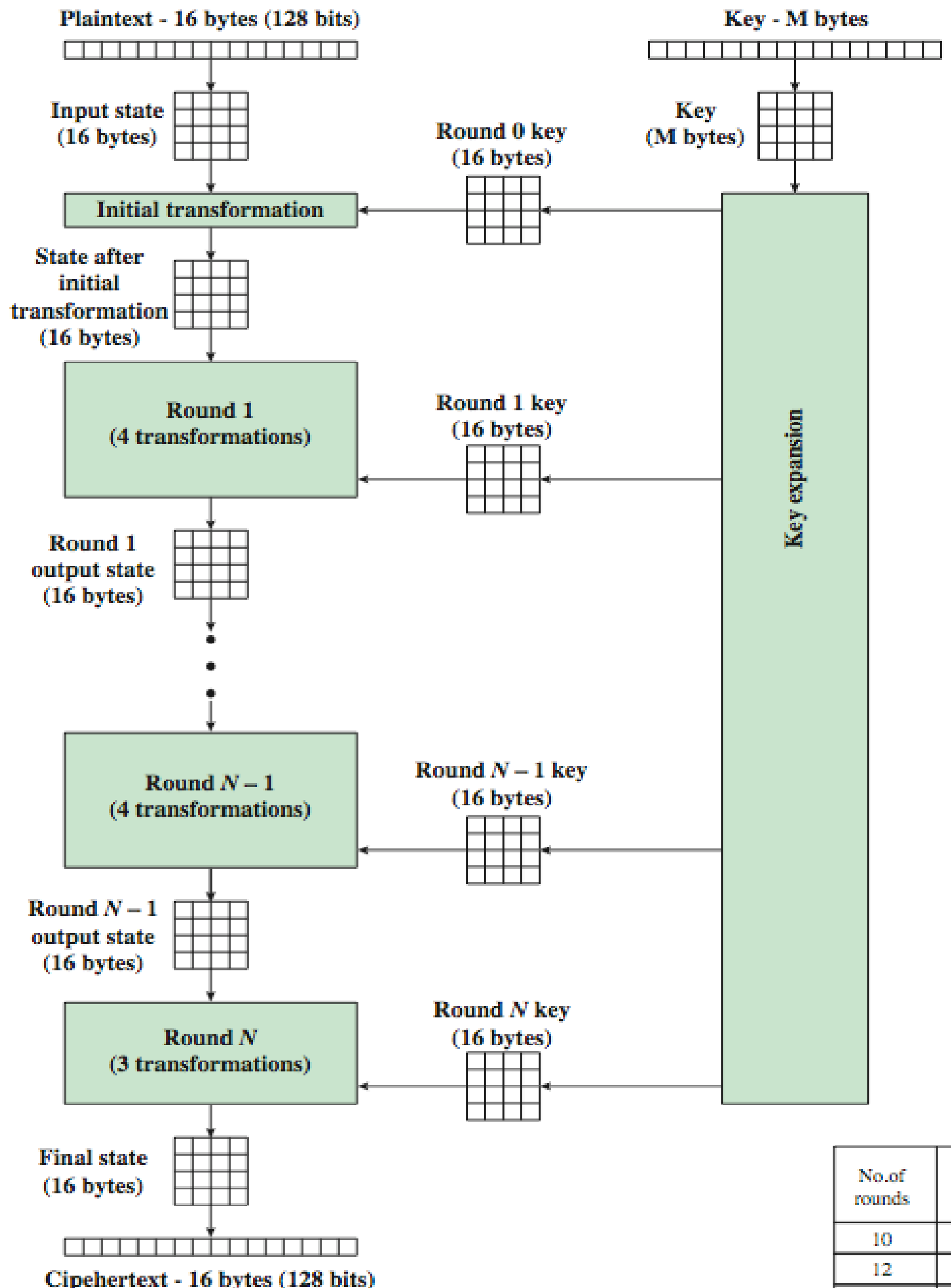
- **Triple DES enjoyed widespread use for few years, but has severe drawbacks:**
  - sluggish in software
  - use 64-bit block size. A larger length is desirable for efficiency and security
- **In 1997, US National Institute of Standards and Technology (NIST) officially endorsed Advanced Encryption Standard (AES) to replace DES based on:**
  - security, computational efficiency, memory requirements, hardware and software suitability, flexibility

Encryption Algorithms (AES)

- **Developed by Joan Daemen and Vincent Rijmen from Belgium – also known as Rijndael algorithm**
- **The algorithm uses**
  - 128-bit block cipher with three different key length: 128, 192 and 256 bits & support 10 to 14 rounds
  - Design **simplicity** / **flexibility** / **efficient** / **fast** for both implementations in **software** and **hardware**, and code **compactness** on many CPUs
  - It works fast even on small devices such as smart phones, smart cards etc.
  - AES provides more security due to larger block size and longer keys.
  - AES uses 128 bit fixed block size and works with 128, 192 and 256 bit keys.
  - offers lots of flexibility: AES in general is flexible enough to work with key and block size of any multiple of 32 bit with minimum of128 bits and maximum of 256 bits.
  - Security: Resistance to power analysis and other implementation attacks

AES Encryption Process

- The cipher consists of **N** rounds, ***where the number of rounds depends on the key length***: 10 rounds for a 16-byte key; 12 rounds for a 24-byte key; and 14 rounds for a 32-byte key.
- The first N – 1 rounds consist of four distinct transformation functions: SubBytes, ShiftRows, MixColumns, and AddRoundKey
- The final round N contains only 3 transformation functions: SubBytes, ShiftRows, and AddRoundKey
- Each transformation takes one or more 4 x 4 matrices as input and produces a 4 x 4 matrix as output.
- key expansion function generates N + 1 round keys, each of which is a distinct 4 x 4 matrix



No.of rounds	Key Length (bytes)
10	16
12	24
14	32

AES Structure

- **data block of 4 columns of 4 bytes is state**
- **key is expanded to array of 32-bit words (44/52/60)**
- **Has N-1 rounds 9/11/13 identical rounds in which state undergoes:**
  - **byte substitution** (1 S-box used on every byte)
  - **shift rows** (simple permutation)
    - 1st row-no_shift, 2nd row -1Byte left_circular_shift, 3rd row - 2Byte, 4th row – 3Byte))
  - **mix columns** (subs using matrix multiply of groups)
  - **add round key** (XOR state with the expanded key words)
  - **view the whole operation as alternating** XOR key & scramble data bytes
- **initial XOR key material & incomplete last round (10th / 12th / 14th)**
- **with fast XOR & table lookup implementation**

AES Encryption / Decryption Process

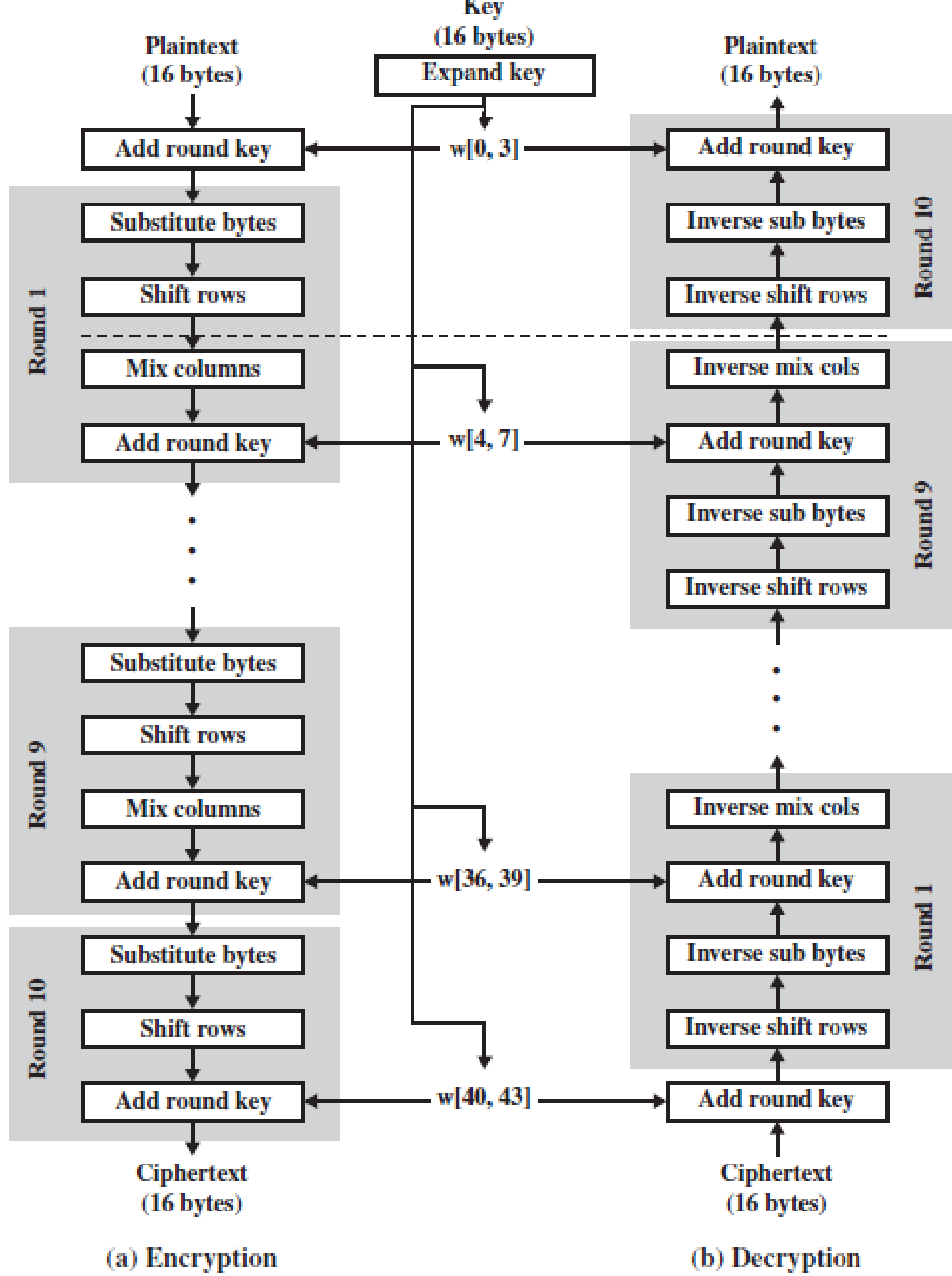


Figure 2.5 AES Encryption and Decryption

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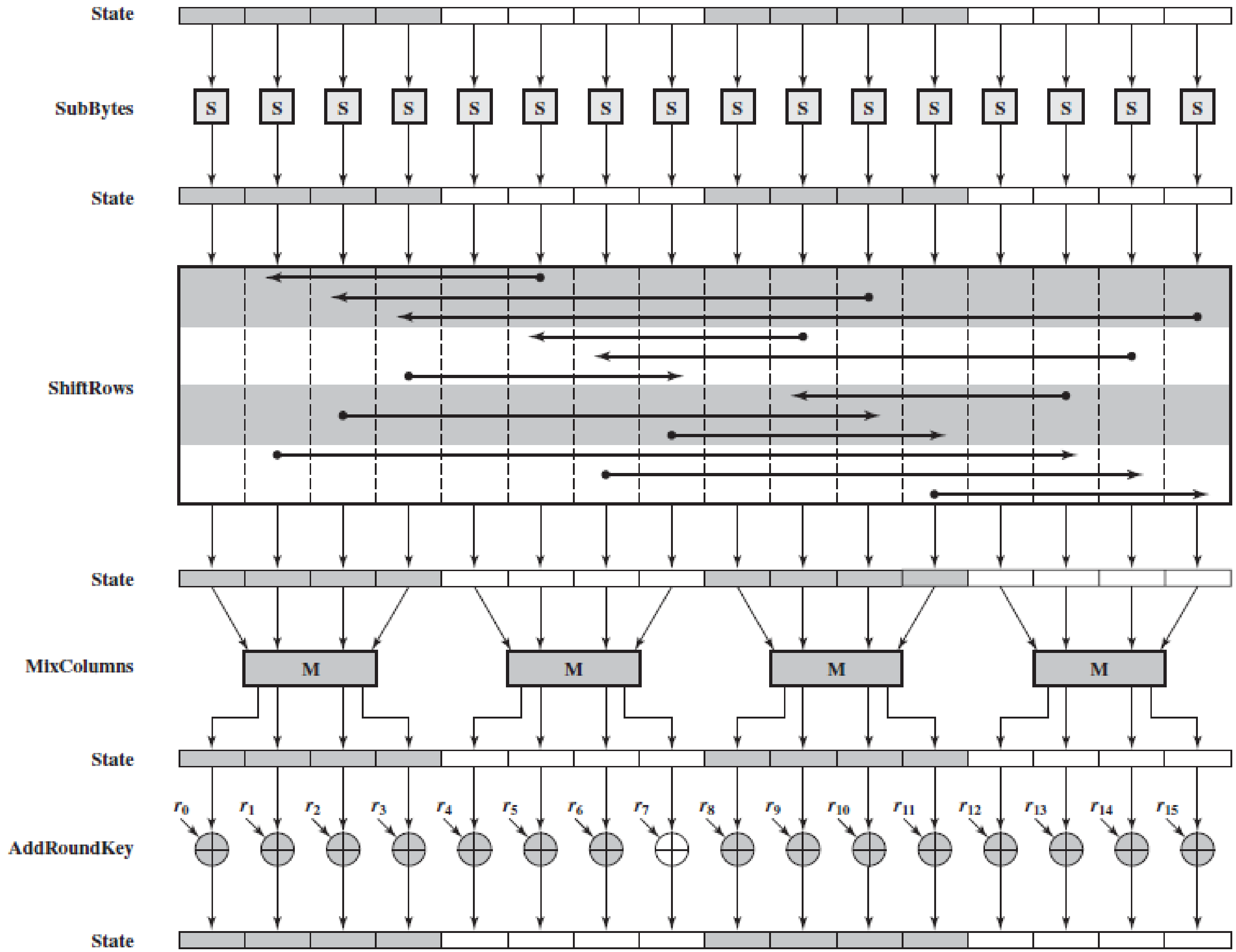
AES single Round



Modes of Operation

- block ciphers encrypt fixed size blocks
  - e.g. DES encrypts 64-bit blocks with 56-bit key
- need some way to en/decrypt arbitrary amounts of data in practice
- NIST SP 800-38A defines 5 modes of operations
- have block and stream modes
- to cover a wide variety of applications
- can be used with any block cipher

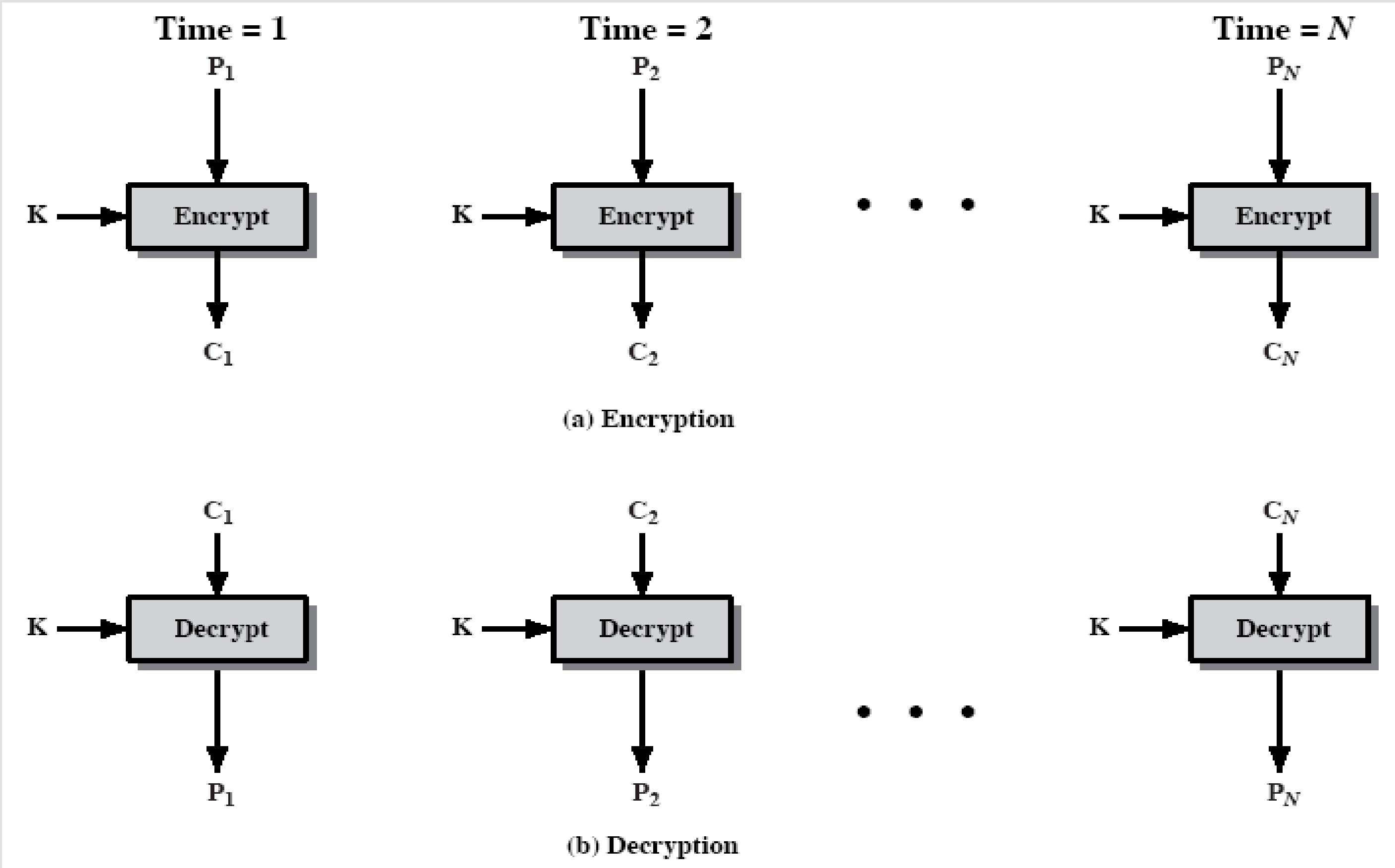
Cipher **Block** Modes of Operations

- **Five common modes in which plaintext, secret key and / or ciphertext are combined to encrypt/decrypt arbitrary size blocks**
  - Electronic Codebook (ECB) mode
  - Cipher Block Chaining (CBC) mode
  - Cipher Feedback (CFB) mode
  - Output Feedback (OFB) mode
  - Counter (CTR) mode

ECB (Electronic Codebook) mode

- **Simplest mode of operation**
- **Each block (64bits) is processed at a time**
  - input data is padded out to an integer number of block size
  - each block is encrypted and decrypted independently
  - lost data blocks do not affect decryption of other blocks
  - error is not propagated, limited to single block
  - All blocks are encrypted with the same key
- **Concern:**
  - same plaintext produces same ciphertext
    - ➢ does not hide pattern
    - ➢ if message contains repetitive elements, these elements can be identified
    - ➢ traffic analysis is possible

ECB mode…

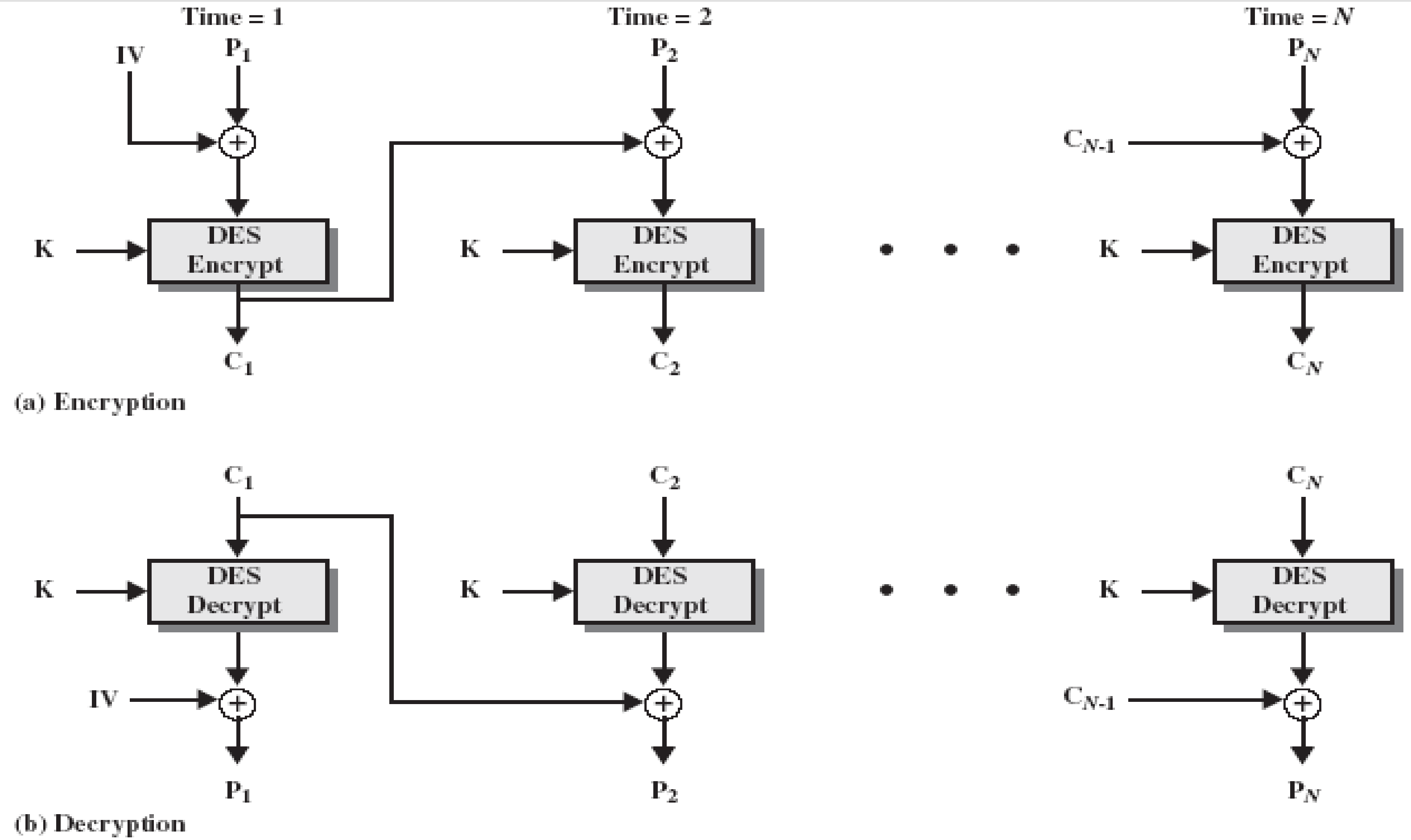


Time = 1
P_1
K
Encrypt
C_1
Time = 2
P_2
K
Encrypt
C_2
Time = N
P_N
K
Encrypt
C_N
(a) Encryption
C_1
K
Decrypt
P_1
C_2
K
Decrypt
P_2
C_N
K
Decrypt
P_N
(b) Decryption

CBC (Cipher Block Chaining) mode

- **Most commonly used mode**
- **Each plaintext block is XORed with the previous ciphertext block and encrypted (see next slide)**
  - first plaintext block is XORed with an initialization vector (IV)
  - same encryption key is used for each block
- **More secure**
  - effectively scrambles plaintext prior to each encryption step
  - repetitive patterns are not exposed
  - different IV for different messages with the same key
- **Disadvantage:**
  - **encryption of a data block becomes dependent on all the blocks prior to it**
  - **a lost block of data will prevent decoding of the next block of data**

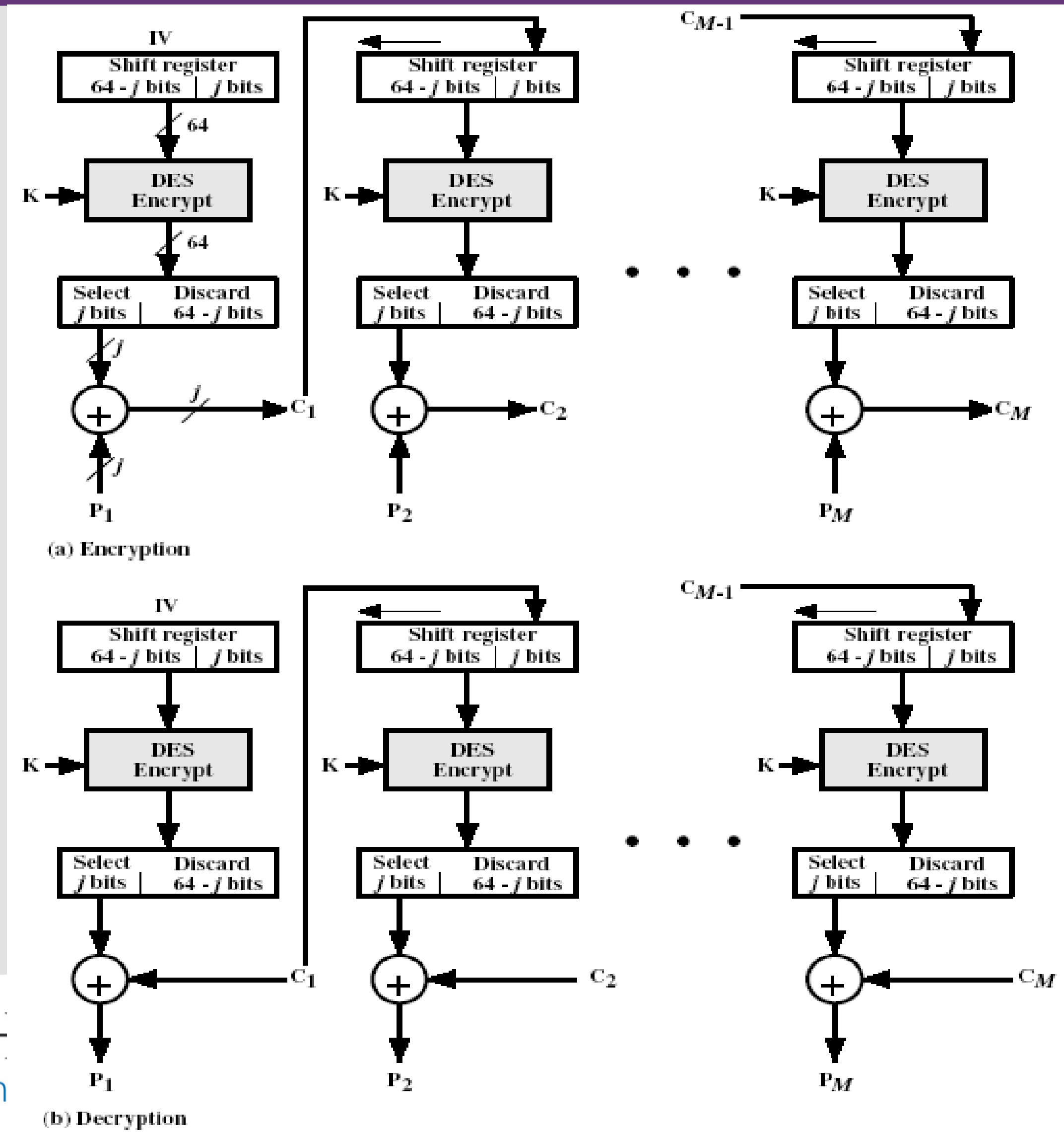
CBC (Cipher Block Chaining) mode



CFB (Cipher feedback) mode

- **Message is treated as a stream of bits**
- **Stream cipher does not require any padding**
- **Added to the output of the block cipher**
- **Result is fed-back for next stage (hence the name)**
- **standard allows any number of bits (1,8 or 64 or whatever) to be fed-back**
  - denoted by CFB-1, CFB-8, CFB-64 etc.
- **It is most efficient to use all 64 bits (CFB-64)**
  - $C_i = P_i \text{ XOR } DES_{K1}(C_{i-1})$
  - $C_{-1} = IV$
- **uses: stream data encryption, authentication**

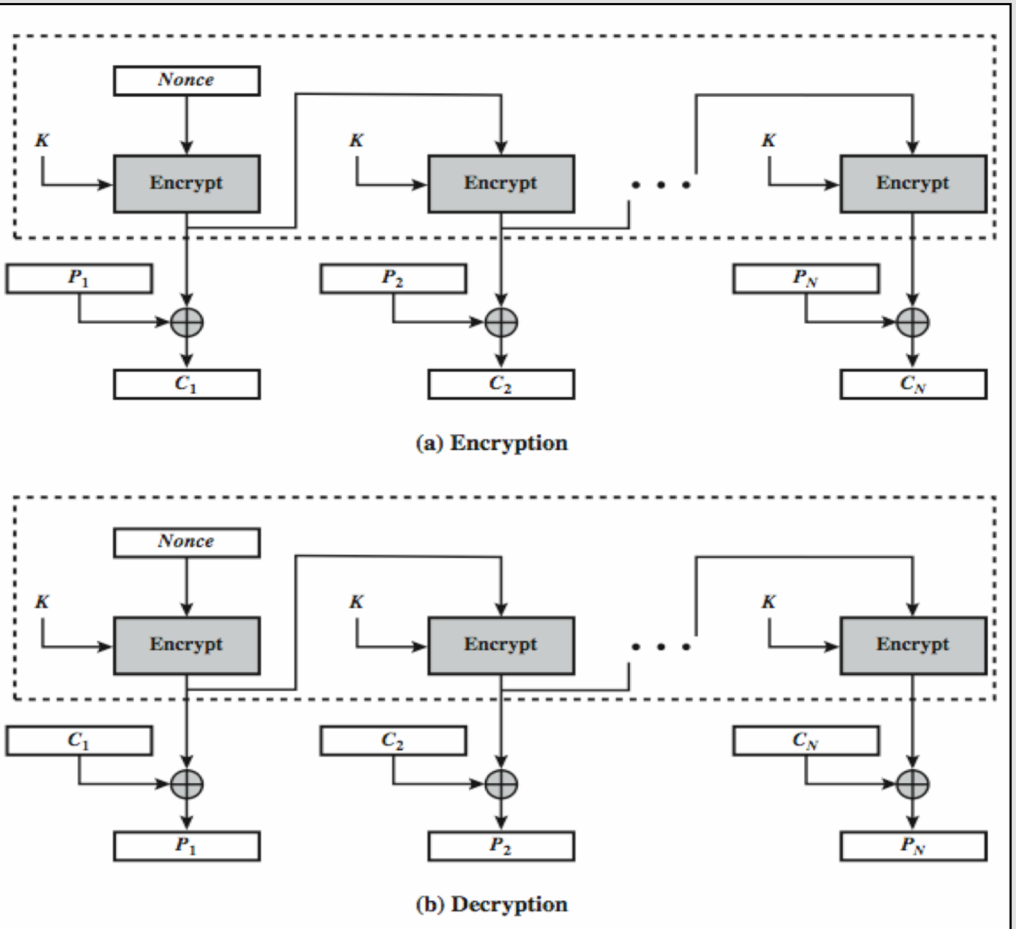
CFB (Cipher feedback) mode



OFB (Output feedback) mode

- **Message is treated as a stream of bits**
- **Similar to CFB, but**
  - quantity XORed with each plaintext block is generated independently of both the plaintext and ciphertext
  - output of cipher block is added to message
- **Feedback is independent of message**
- **uses: stream encryption over noisy channels**

OFB (Output feedback) mode



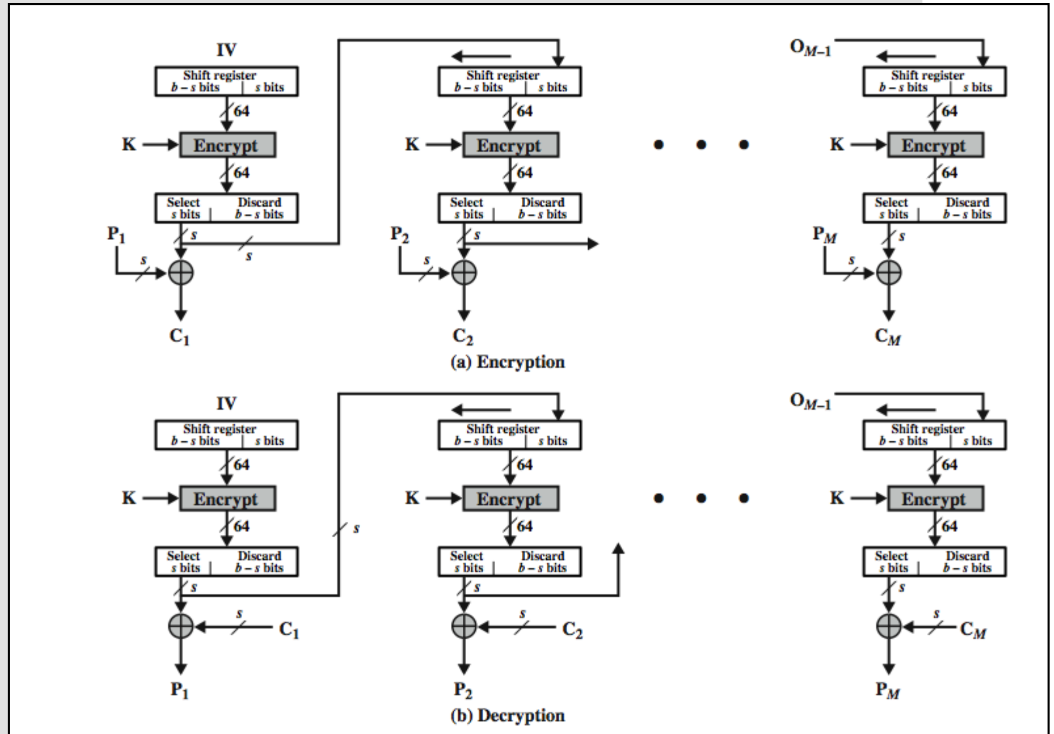
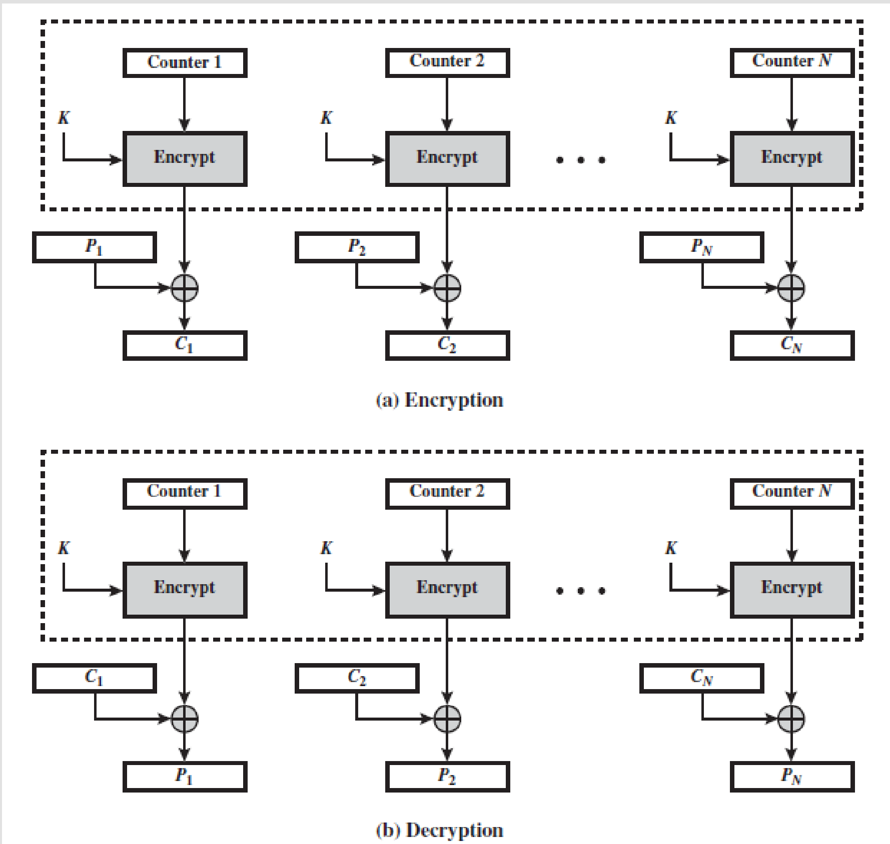


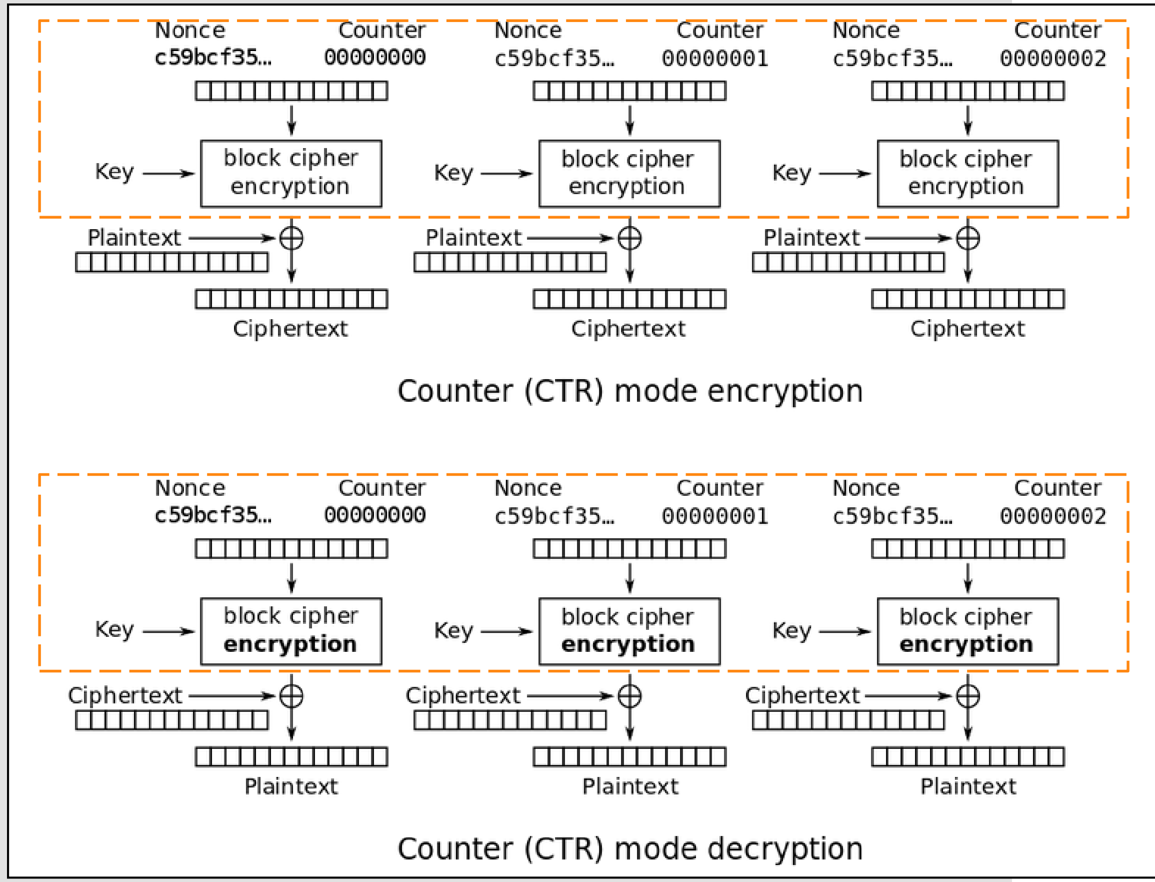
Figure 6.6 ***s*-bit Output Feedback (OFB) Mode**

Counter (CTR)

- **a "new" mode, though proposed early on**
- **similar to OFB but encrypts using counter value rather than any feedback value**
- **must have a different counter value for every plaintext block (never reused)**
  - $O_i = E_K(i)$
  - $C_i = P_i \text{ XOR } O_i$
- **uses: high-speed network encryptions**

Counter (CTR)


Counter 1
Counter 2
Counter N
K
Encrypt
P1
P2
PN
C1
C2
CN
(a) Encryption
Counter 1
Counter 2
Counter N
K
Encrypt
C1
C2
CN
P1
P2
PN
(b) Decryption


Nonce
c59bcf35...
Counter
00000000
00000001
00000002
Key
block cipher encryption
Plaintext
Ciphertext
Counter (CTR) mode encryption
Nonce
c59bcf35...
Counter
00000000
00000001
00000002
Key
block cipher encryption
Ciphertext
Plaintext
Counter (CTR) mode decryption

Advantages and Limitations of CTR

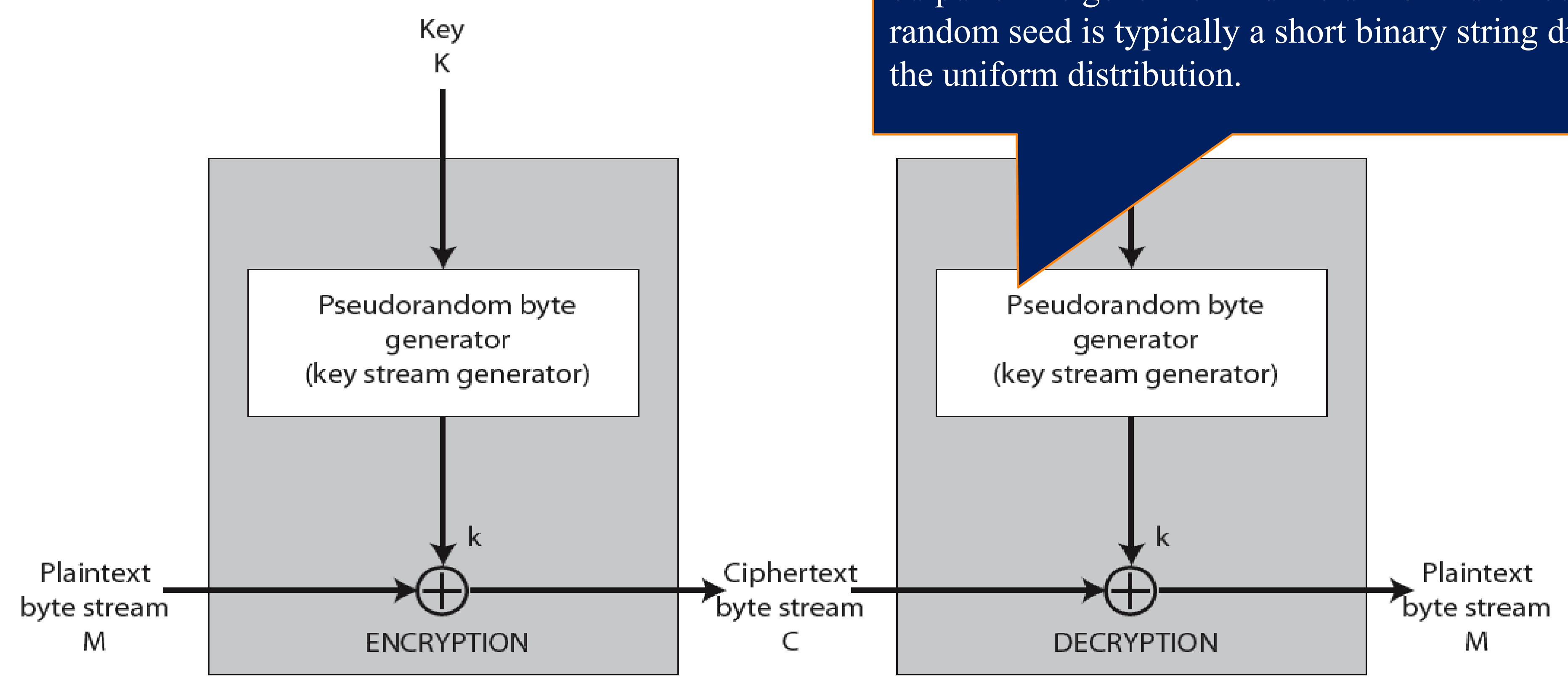
- **efficiency**
  - can do parallel encryptions in h/w or s/w
  - can pre-process in advance of need
  - good for bursty high speed links
- **random access to encrypted data blocks**
- **provable security (good as other modes)**
- **but must ensure never reuse counter values, otherwise could break (cf OFB)**

Stream Ciphers

- **process message bit by bit (as a stream)**
- **have a pseudo random** keystream
- **combined (XOR) with plaintext bit by bit**
- **randomness of** stream key **completely destroys statistical properties in message**
  - $C_i = M_i \text{ XOR } StreamKey_i$
- **but must never reuse stream key**
  - otherwise can recover messages (book cipher)

Stream Cipher Structure

A pseudorandom generator (PRG) is a class of statistical tests is a deterministic procedure that maps a random seed(Key K) to a longer pseudorandom string such that no statistical test in the class can distinguish between the output of the generator and the uniform distribution. The random seed is typically a short binary string drawn from the uniform distribution.



Stream Cipher Properties

- **some design considerations are:**
  - long period with no repetitions
  - statistically random
  - depends on large enough key
  - large linear complexity
- **properly designed, can be as secure as a block cipher with same size key**
- **but usually simpler & faster**
- **Example RC4**

RC4

- a proprietary cipher owned by RSA DI Management
- another Ron Rivest design, simple but effective
- variable key size, byte-oriented stream cipher
- widely used (web SSL/TLS, wireless WEP)
- key forms random permutation of all 8-bit values
- uses that permutation to scramble input info processed a byte at a time

RC4 Key Schedule

- **starts with an array S of numbers: 0..255**
- **use key to well and truly shuffle**
- **S forms internal state of the cipher**

```
/* Initialization */
for  i = 0 to 255 do
S[i] = i;
T[i] = K[i mod keylen];
```

```
/* Initial Permutation of S */
j = 0;
for  i = 0 to 255 do
    j = (j + S[i] + T[i]) mod 256;
    Swap (S[i], S[j]);
```

- RC4 has a programmable secret key of length from 1 to 256 bytes and a state table of 256 bytes
- secret key is used to initialize the state table
- state table is used to generate a pseudo random sequence of bytes and then a pseudo random stream of bits.

RC4 Encryption

- **Encryption: continues shuffling array values**
- **sum of shuffled pair selects "stream key" value from permutation**
- **XOR S[t] with next byte of message to en/decrypt**

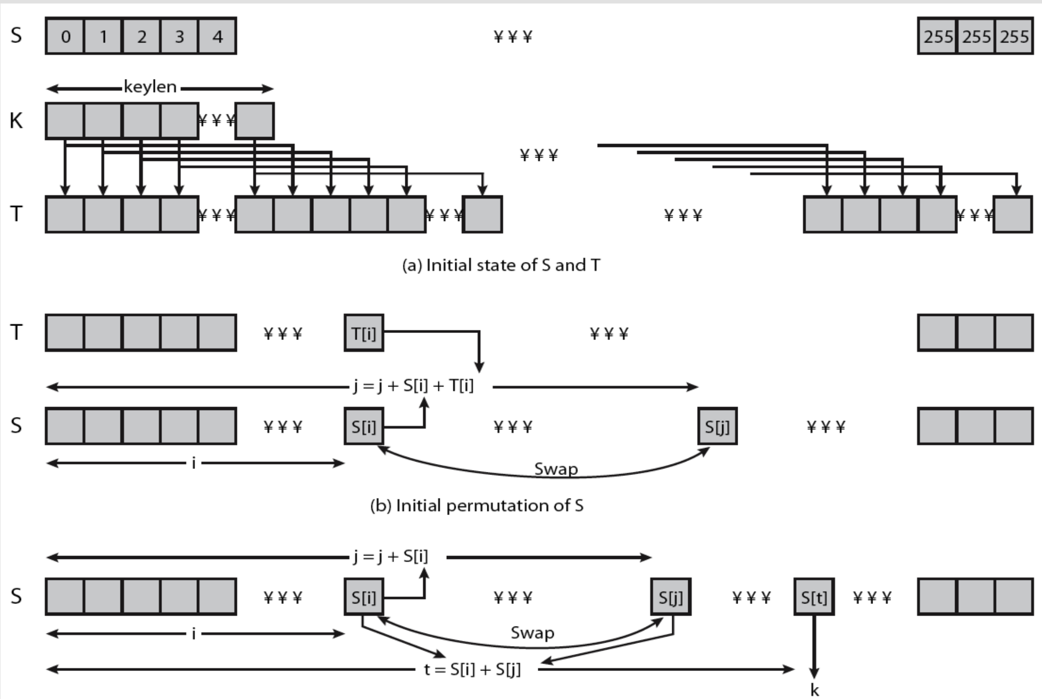
```
/* Stream Generation */
i, j = 0;

while (true)
    i = (i + 1) mod 256;
    j = (j + S[i]) mod 256;
    Swap (S[i], S[j]);
    t = (S[i] + S[j]) mod 256;
    k = S[t];
```

Ci = Mi XOR S[t]

- such bit stream is XORed with the plaintext to produce the ciphertext
- every element (byte) in the state table is swapped at least once

- **To encrypt**, XOR the value k with the next byte of **plaintext**. **To decrypt**, XOR the value k
- with the next byte of **ciphertext**.

RC4 Overview



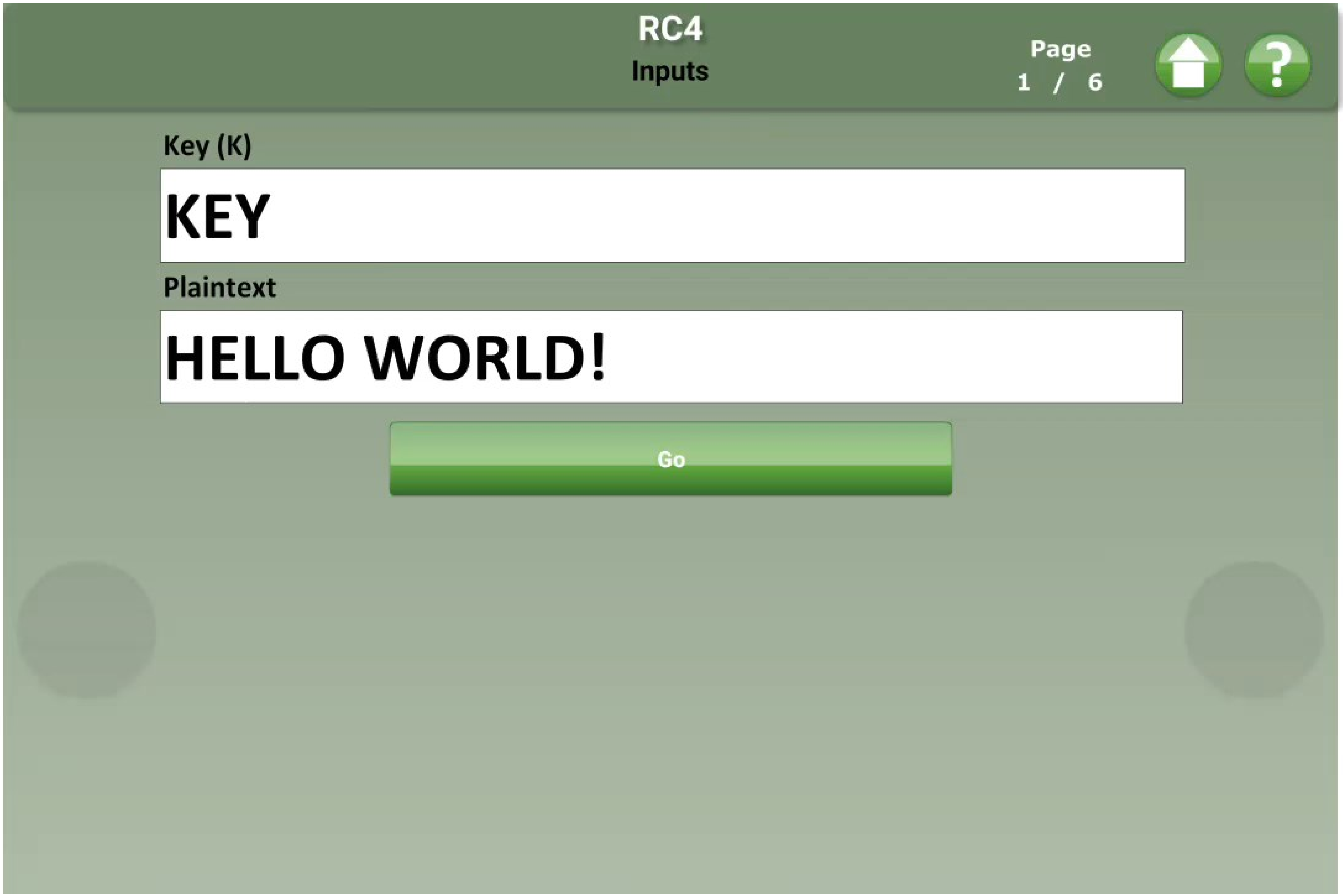
(a) Initial state of S and T

(b) Initial permutation of S

(c) Stream Generation

- RC4 consists of two parts:
  - – key schedule (to initialize the state table)
  - – pseudo random generation, also called even key-stream generator
  - – and the data path, which is simply the XOR of the data bit stream and the generated pseudo random key stream
- this is very similar to the structure of a generic symmetric key block cipher

RC4 Animation



RC4 Security

- **claimed secure against known attacks**
  - have some analyses, none practical
- **result is very non-linear**
- **since RC4 is a stream cipher, must** never reuse a key
- **have a concern with WEP, but due to key handling rather than RC4 itself**

Key Distribution

- **Key distribution is an important issue**
  - both parties must exchange the secret key in a secure manner
- **Key exchange**
  - a key could be selected by **A** and physically delivered to **B**
  - a third party could select the key and physically deliver it to **A** and **B**
  - if **A** and **B** have previously used a key, one party could transmit the new key to the other, encrypted using the old key
  - if **A** and **B** each have an encrypted connection to a third party **C**, **C** could deliver a key on the encrypted links to **A** and **B**

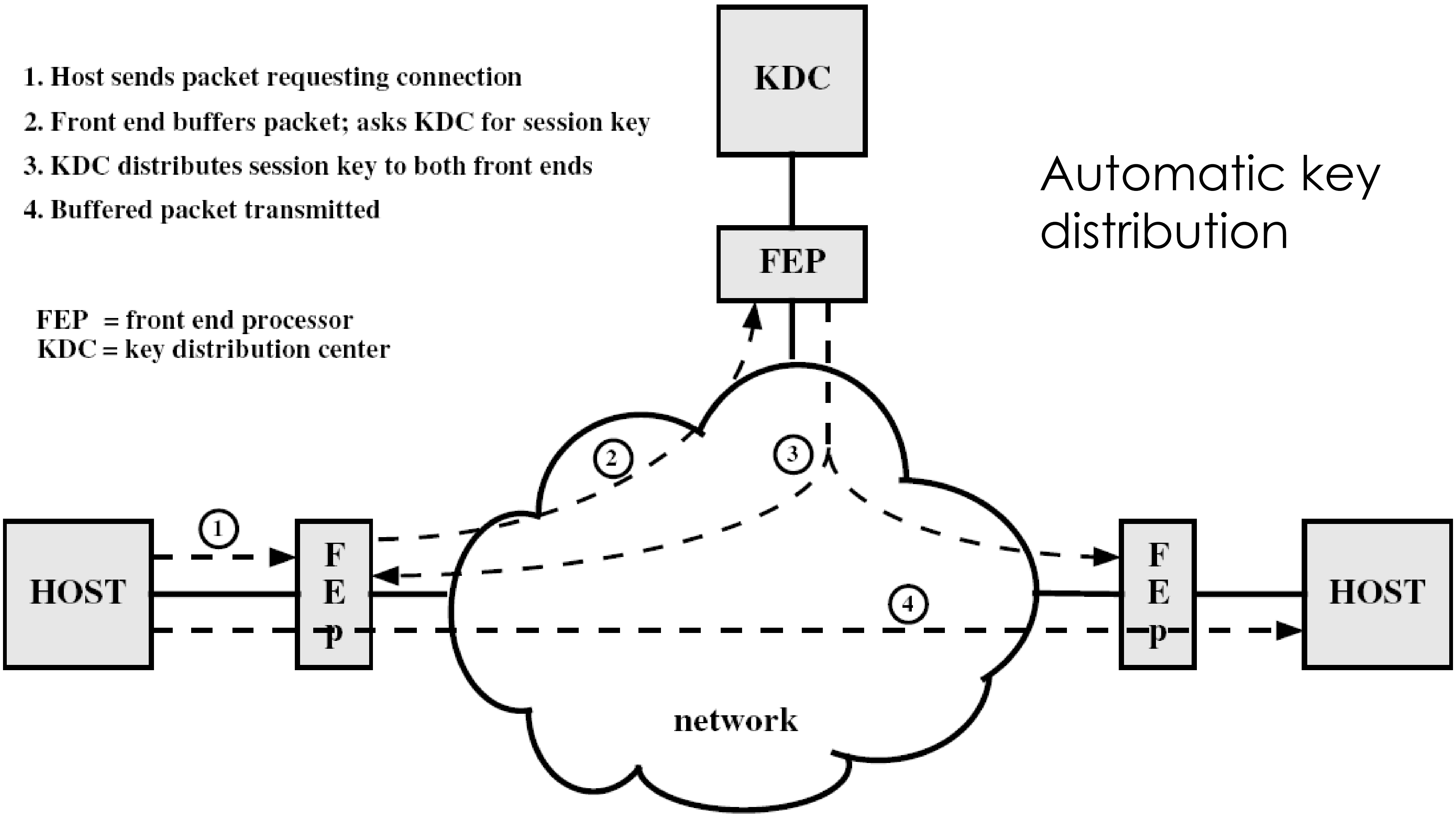
Key Distribution…

- **For communicating between small number of parties, manual distribution of keys may be feasible**
  - impossible for large number of parties
  - concept of Key Distribution Center (KDC) is more practical
    - determines which systems are allowed to communicate with each other
    - If connection is granted, distribute the session key
  - Front end processor obtains session keys on behalf of host
- **Session key:**
  - data encrypted with a one-time session key
  - destroyed when the session ends
- **Permanent key:**
  - used between entities for the purpose of distributing session keys

Key Distribution….

1. Host sends packet requesting connection
2. Front end buffers packet; asks KDC for session key
3. KDC distributes session key to both front ends
4. Buffered packet transmitted

FEP = front end processor
KDC = key distribution center



Automatic key distribution

Further Reading

- **Study Guide 2**
- **Chapter 2 & Section 4.1 of the textbook: *Network Security Essentials-Application & Standards" by William Stallings* 5th Edition, Prentice Hall, 2013**
- **Additional resources for this week**

- **Acknowledgement: part of the materials presented in the slides was developed with the help of Instructor's Manual and other resources made available by the author of the textbook.**