Network Security

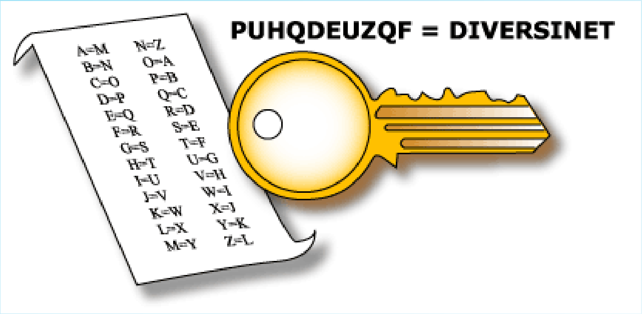
Conventional Encryption

Selected slides from
CSC290 Hofstra University and
Vitaly Shmatikov University of Texas

Caesar Cipher

plain: abcdefghijklmnopqrstuvwxyz

key: defghijklmnopqrstuvwxyzabc



cipher: PHHW PH DIWHU WKH WRJD SDUWB
plain: MEET ME AFTER THE TOGA PARTY

Basic Types of Ciphers

- **Transposition ciphers** – rearrange bits or characters in the data
- **Substitution ciphers** – replace bits, characters, or blocks of characters with substitutes

“Rail-Fence” Cipher

DISGRUNTLED EMPLOYEE

↓

```
D   R   L   E   O
 I G U T E   M L Y E
  S   N   D   P   E
```

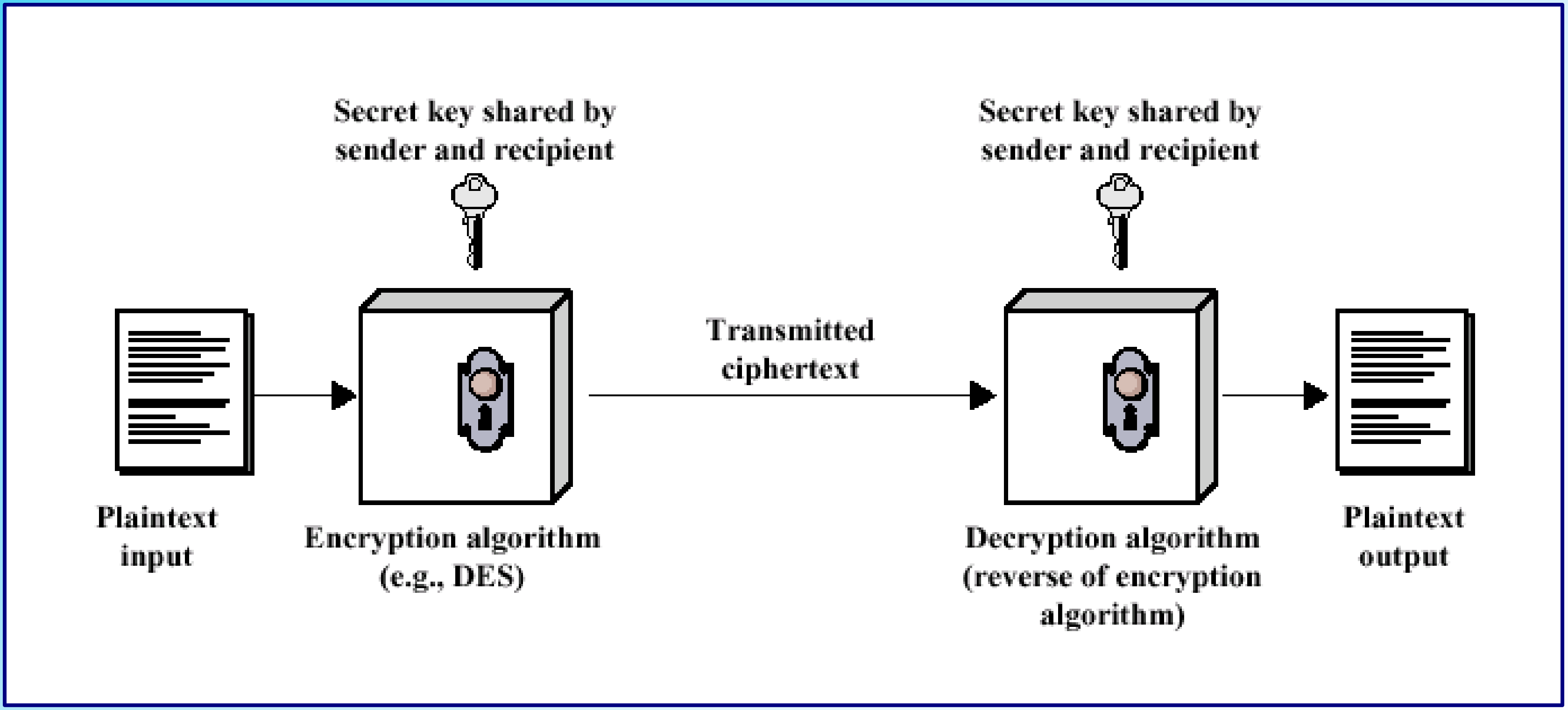
↓

DRLEOIGUTE MLYESNDPE

Encryption Methods

- The essential technology underlying virtually all automated network and computer security applications is **cryptography**
- Two fundamental approaches are in use:
  - **Conventional Encryption**, also known as symmetric encryption
  - **Public-key Encryption**, also known as asymmetric encryption

Conventional Encryption Model



Conventional Encryption

- The only form of encryption prior to late 1970s
- Long history
- Most widely used

Conventional Encryption

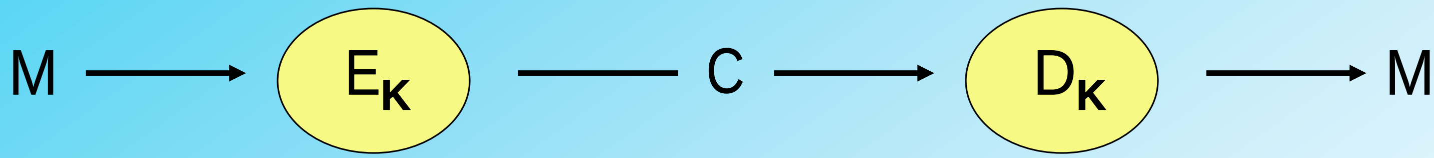
Five components to the algorithm

- **Plaintext**: The original message or data
- **Encryption algorithm**: Performs various substitutions and transformations on the plaintext
- **Secret key**: Input to the encryption algorithm. Substitutions and transformations performed depend on this key
- **Ciphertext**: Scrambled message produced as output. depends on the plaintext and the secret key
- **Decryption algorithm**: Encryption algorithm run in reverse. Uses ciphertext and the secret key to produce the original plaintext

Conventional Encryption

- More rigorous definition
- Five components to the algorithm
  - A Plaintext message space, $\mathcal{M}$
  - A family of enciphering transformations, $E_{\boldsymbol{K}}: \mathcal{M} \rightarrow \mathcal{C}$, where $K \in \mathcal{K}$
  - A key space, $\mathcal{K}$
  - A ciphertext message space, $\mathcal{C}$
  - A family of deciphering transformations, $D_{\boldsymbol{K}}: \mathcal{C} \rightarrow \mathcal{M}$, where $K \in \mathcal{K}$

Conventional Encryption



E_K defined by an encrypting algorithm E

D_K defined by an decrypting algorithm D

For given K, D_K is the **inverse** of E_K, i.e.,

$D_K(E_K(M))=M$

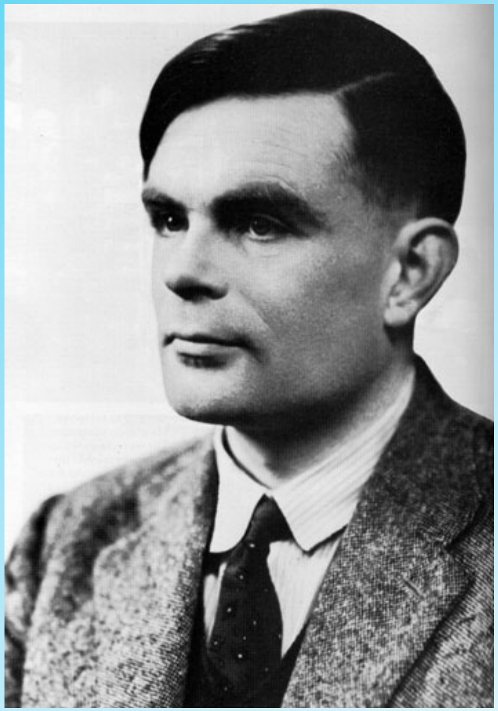
for every plain text message M

Requirements & Weaknesses

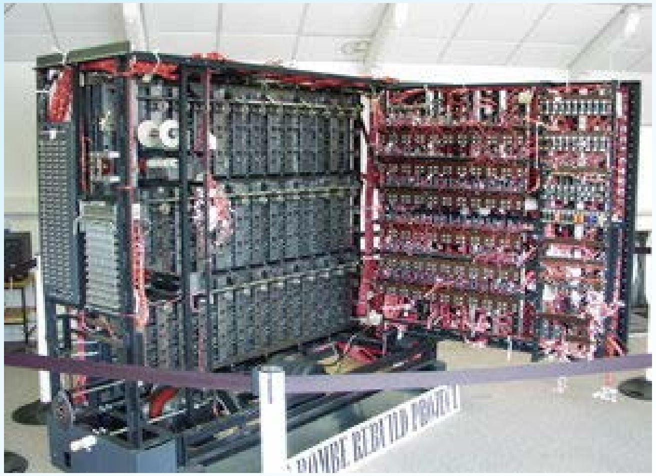
- Requirements
  - A **strong** encryption algorithm
  - Secure **process** for sender & receiver to **obtain secret keys**
- Methods of Attack
  - **Cryptanalysis**
  - **Brute force**

Cryptanalysis

- The process of attempting to discover the plaintext or key



Alan Turing broke the Enigma Code in WWII



Cryptanalysis

- Security depends on the key...
- ...NOT the secrecy of the algorithm
- Low cost chips are possible
- Principal security problem is maintaining the secrecy of the key!

Cryptographic Systems

- **Type of Transformation** – substitution and/or transposition; no information must be lost, i.e., reversible
- **Number of Keys Used** – symmetric, single key, conventional; asymmetric, two-key, public-key encryption
- **Plaintext Processing** – block or stream cipher

Attacks On Encrypted Msgs

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

Computationally Secure

- Cost of breaking cipher exceeds value of encrypted information
- Time to break cipher exceeds useful lifetime of the information

Exhaustive Key Search

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

Brute Force with massively parallel processors

English Redundancy

- Delete vowels and double letters

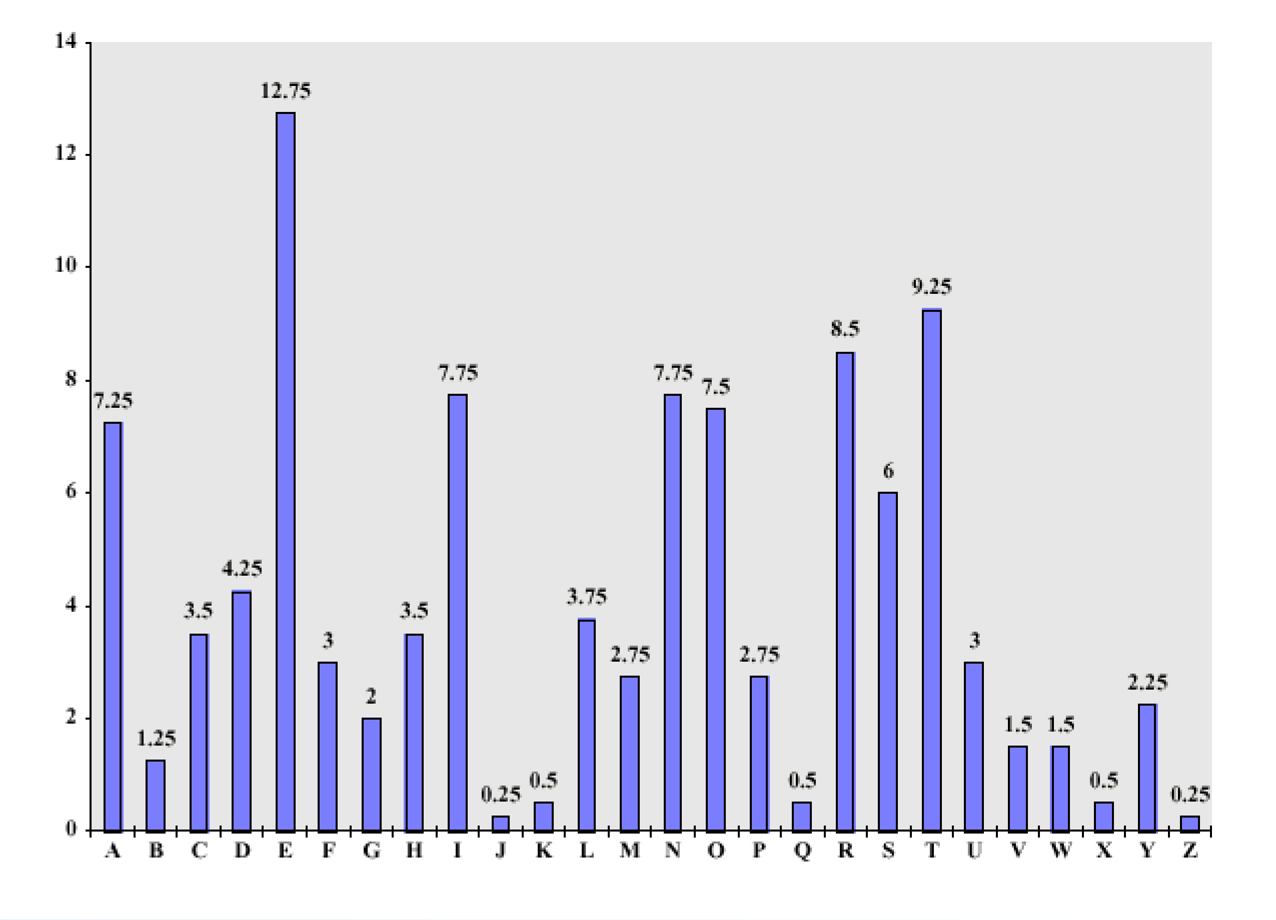
mst ids cn b xprsd n fwr ltrs,
bt th xprnc s mst nplsnt

Simple Cryptanalysis

CIPHERTEXT:

UZQSOVUOHXMOPVGPOZPEVSGZWSZOPFPESXUDBMETSXAIZ
VUEPHZHMDZSHZOWSFPAPPDTSVPQUZWYMXUZUHSX
EPYEPOPDZSZUFPOMBZWPFUPZHMDJUDTMOHMQ

Letter Frequency In the English Language



Simple Cryptanalysis

PLAINTEXT:

IT WAS DISCLOSED YESTERDAY THAT SEVERAL INFORMAL BUT DIRECT CONTACTS HAVE BEEN MADE WITH POLITICAL REPRESENTATIVES OF THE VIET CONG IN MOSCOW

20th Century Encryption

- 20’s & 30’s bootleggers made heavy use of cryptography
- FBI create an office for code-breaking
- Japanese Purple Machine
- German Enigma Machine
- Navajo Code Talkers - Windtalkers

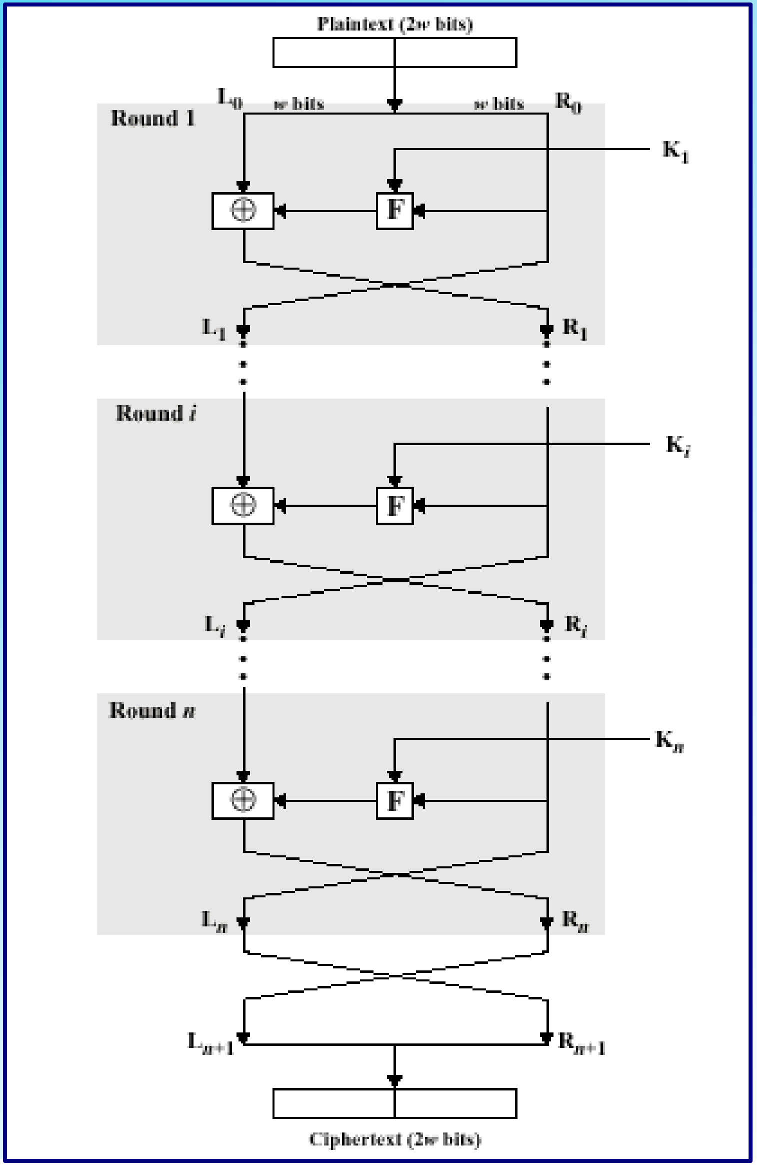
Hedy Lamarr

- 1941, Lamarr and composer George Antheil received a patent for their invention of a classified communication system that was especially useful for submarines
- It was based on radio frequencies changed at irregular periods that were synchronized between the transmitter and receiver
- **Spread Spectrum** – wireless devices

Feistel Cipher Structure

- Horst Feistel of IBM, 1973
- Input is plaintext block of length $2w$ bits (usually 64) and a key K
- Block is divided into two halves, L_0 and R_0
- Each round i has inputs L_{i-1} and R_{i-1}, derived from the previous round, along with subkey K_i
- Substitution is performed on the left half of the data
- **Round function** F applied to right half and then XOR'd with left

Feistel Cipher Structure



Things to consider:

-Block size (64)

-Key Size (128)

-# of rounds (16)

-SubKey Generation

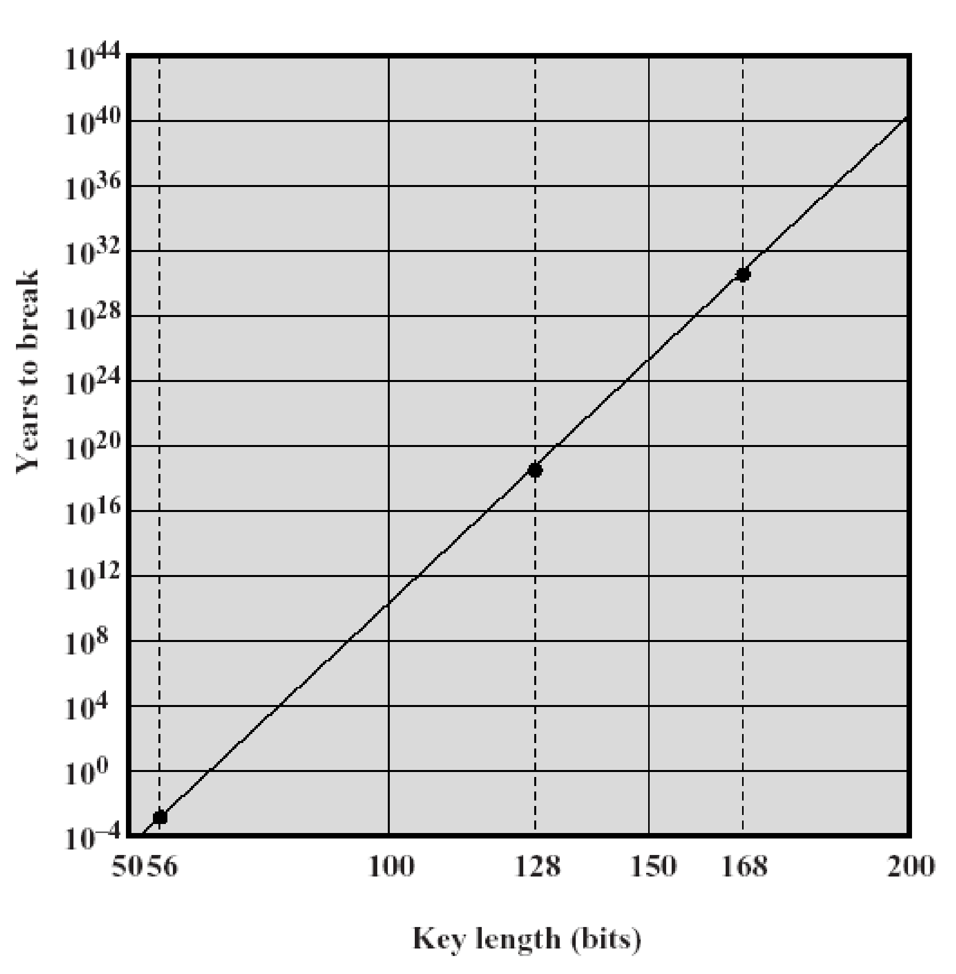
-Round function

Data Encryption Standard (DES)

- Adopted in 1977, reaffirmed for 5 years in 1994, by NBS(NIST)
- Plaintext is 64 bits (or blocks of 64 bits), key is 56 bits
- Plaintext goes through 16 iterations, each producing an intermediate value that is used in the next iteration
- DES is now too easy to crack to be a useful encryption method

Strength of DES

- Concerns about the algorithm itself
- Concerns about 56-bit key – this is the biggest worry

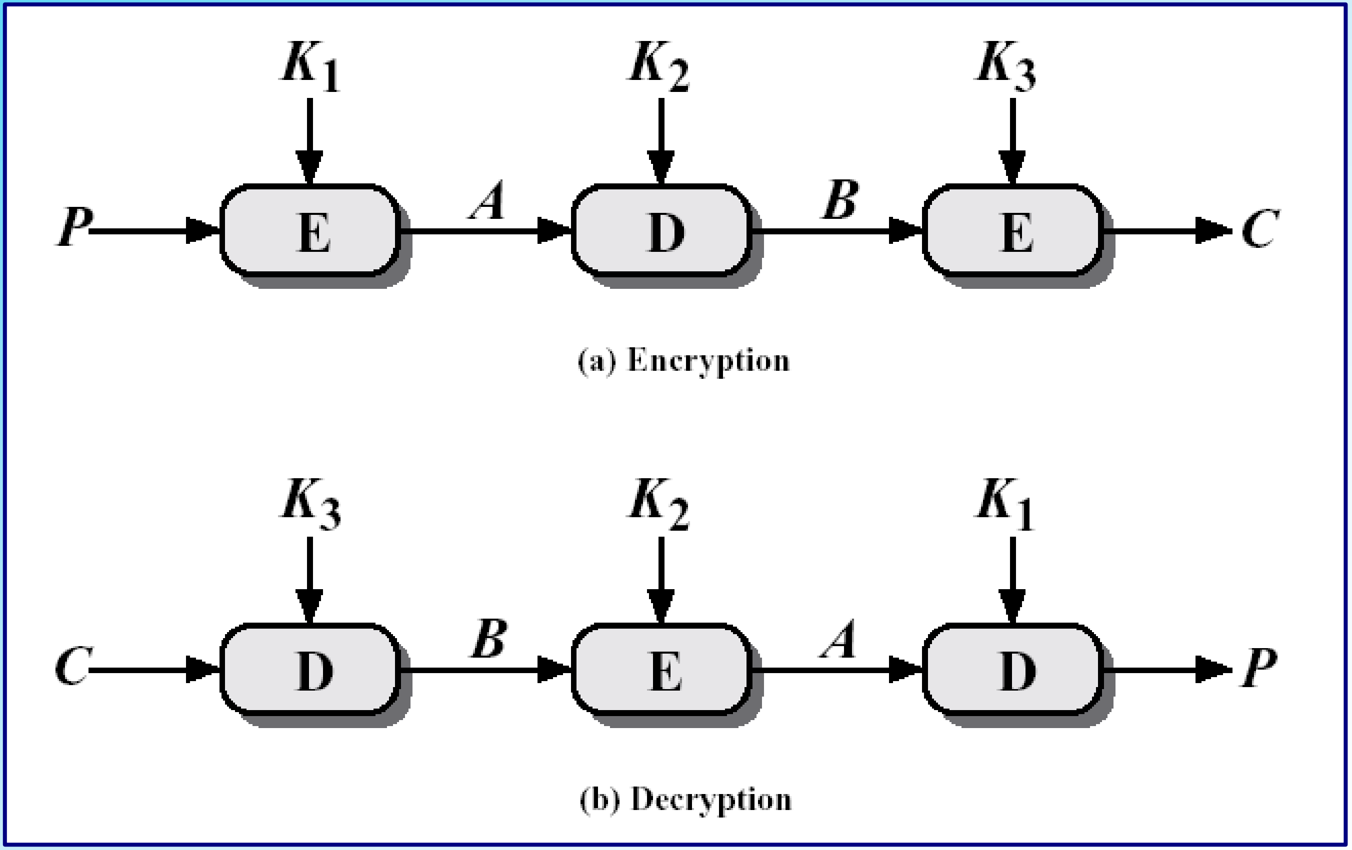


Strength of DES

- DES is the most studied encryption algorithm in existence
- No one has succeeded in discovering a fatal weakness
- 1998, DES Cracker from Electronic Frontier Foundation, built for $250,000
- Solution: Use a bigger key

Triple DES

$$C = E_{K_3}[D_{K_2}[E_{K_1}[P]]]$$



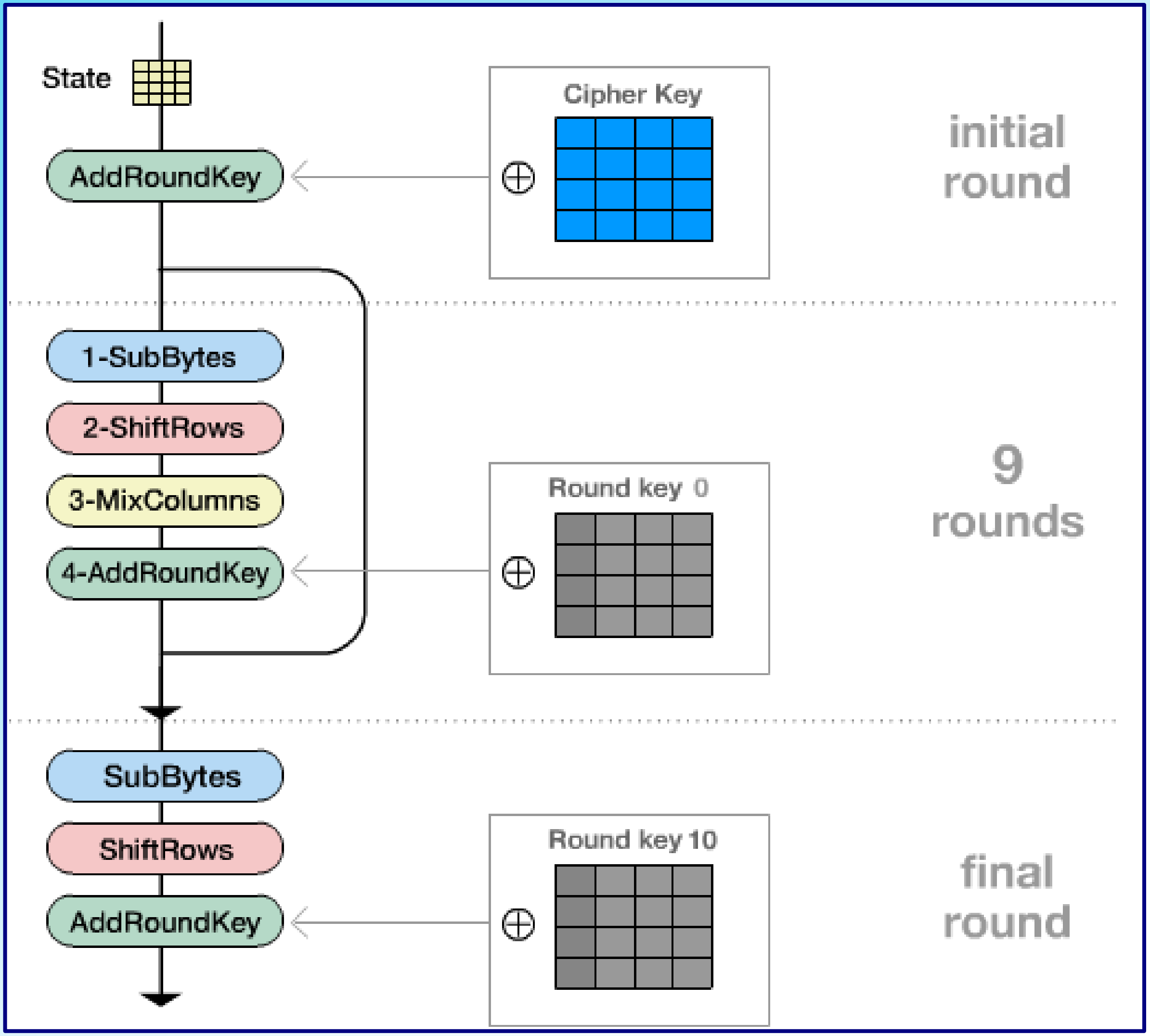
Triple DES

- Alternative to DES, uses multiple encryption with DES and multiple keys
- With three distinct keys, 3DES has an effective key length of 168 bits, so it is essentially immune to brute force attacks
- Backward compatible with DES
- Principal drawback of DES is that the algorithm is relatively sluggish in software

Advanced Encryption Standard

- NIST call for proposals in 1997
- Nov, 2001 – **Rijndael** [rain´ dow]
- Symmetric block cipher (128 bits) and key lengths 128, 192, 256
- Two Flemish cryptographers: Joan Daeman and Vincent Rijmen

Overview of AES



4Transformations:

- Substitute Bytes
- Shift Rows
- Mix Columns
- Add Round Key

AES URLS

- http://csrc.nist.gov/CryptoToolkit/aes/rijndael/ - NIST AES
- http://www.esat.kuleuven.ac.be/~rijmen/rijndael/ - Rijndael Home Page
- http://www.esat.kuleuven.ac.be/~rijmen/rijndael/Rijndael_Anim.zip - Great Animation

IDEA
International Data Encryption Algorithm

- 1991 by Swiss Federal Institute of Technology
- Uses 128-bit key
- Complex functions replace S-boxes
- Highly resistant to cryptanalysis
- Used in PGP

Blowfish

- 1993 by Bruce Schneier
- Easy to implement; high execution speed
- Variable key length up to 448 bits
- Used in a number of commercial applications

RC5

- 1994 by Ron Rivest, one of the inventors of RSA algorithm
- Defined in RFC2040
- Suitable for hardware and software
- Simple, fast, variable length key, low memory requirements
- High security

CAST-128

- 1997, Entrust Technologies
- RFC 2144
- Extensively reviewed
- Variable key length, 40-128 bits
- Used in PGP

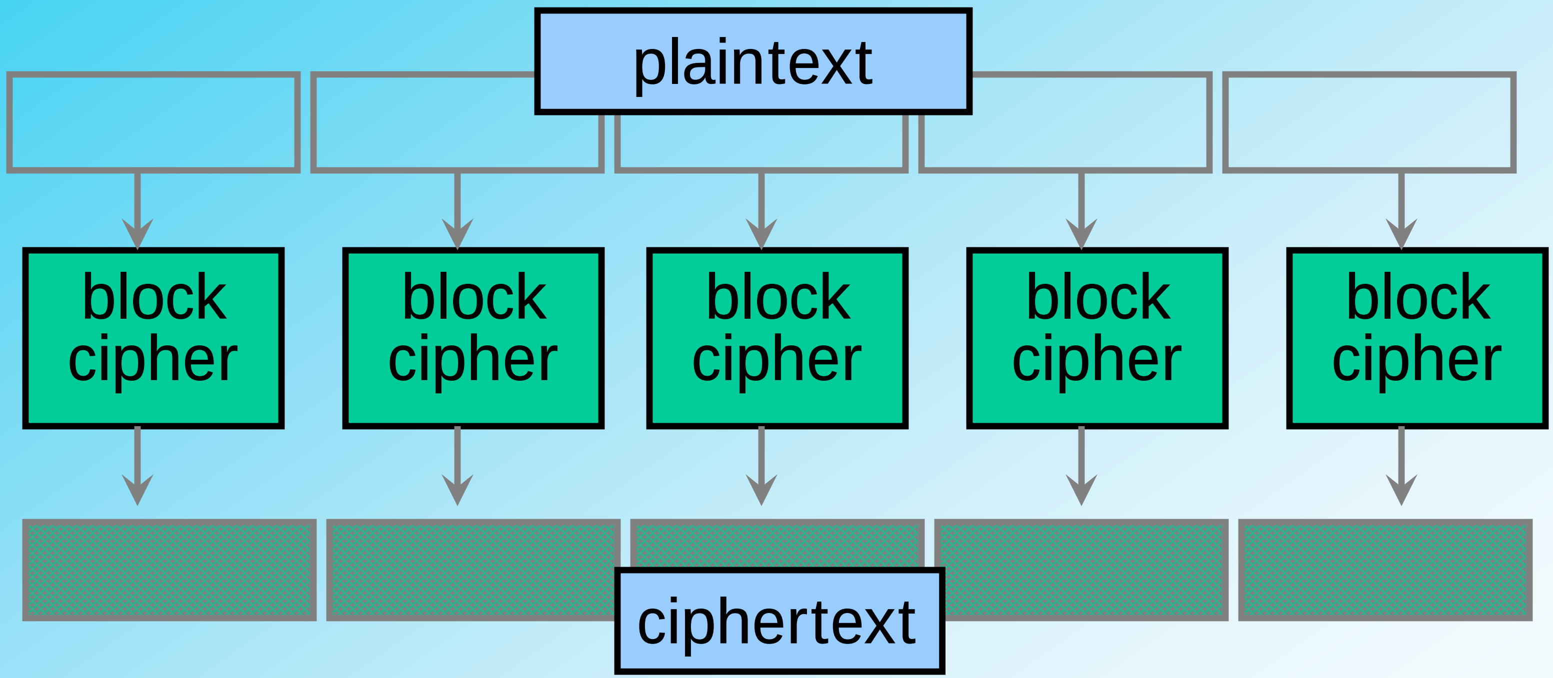
Conventional Encryption Algorithms

Algorithm	Key Size (bits)	Block Size (bits)	Number of Rounds	Applications
DES	56	64	16	SET, Kerberos
Triple DES	112 or 168	64	48	Financial key management, PGP, S/MIME
AES	128, 192, or 256	128	10, 12, or 14	Intended to replace DES and 3DES
IDEA	128	64	8	PGP
Blowfish	variable to 448	64	16	Various software packages
RC5	variable to 2048	64	variable to 255	Various software packages

Encrypting a Large Message

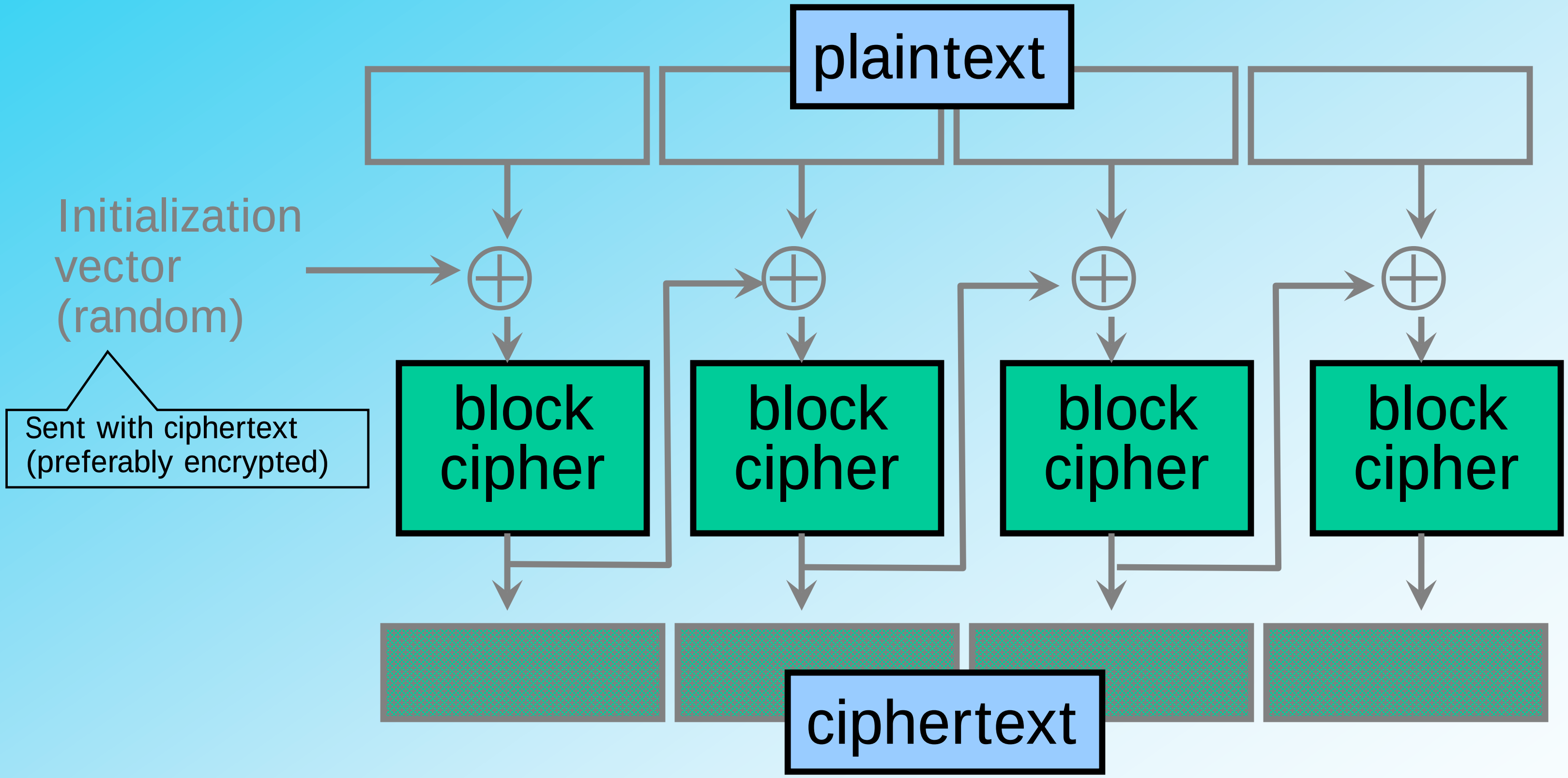
- So, we've got a good block cipher, but our plaintext is larger than 128-bit block size
- Electronic Code Book (ECB) mode
  - Split plaintext into blocks, encrypt each one separately using the block cipher
- Cipher Block Chaining (CBC) mode
  - Split plaintext into blocks, XOR each block with the result of encrypting previous blocks
- Also various counter modes, feedback modes, etc.

ECB Mode



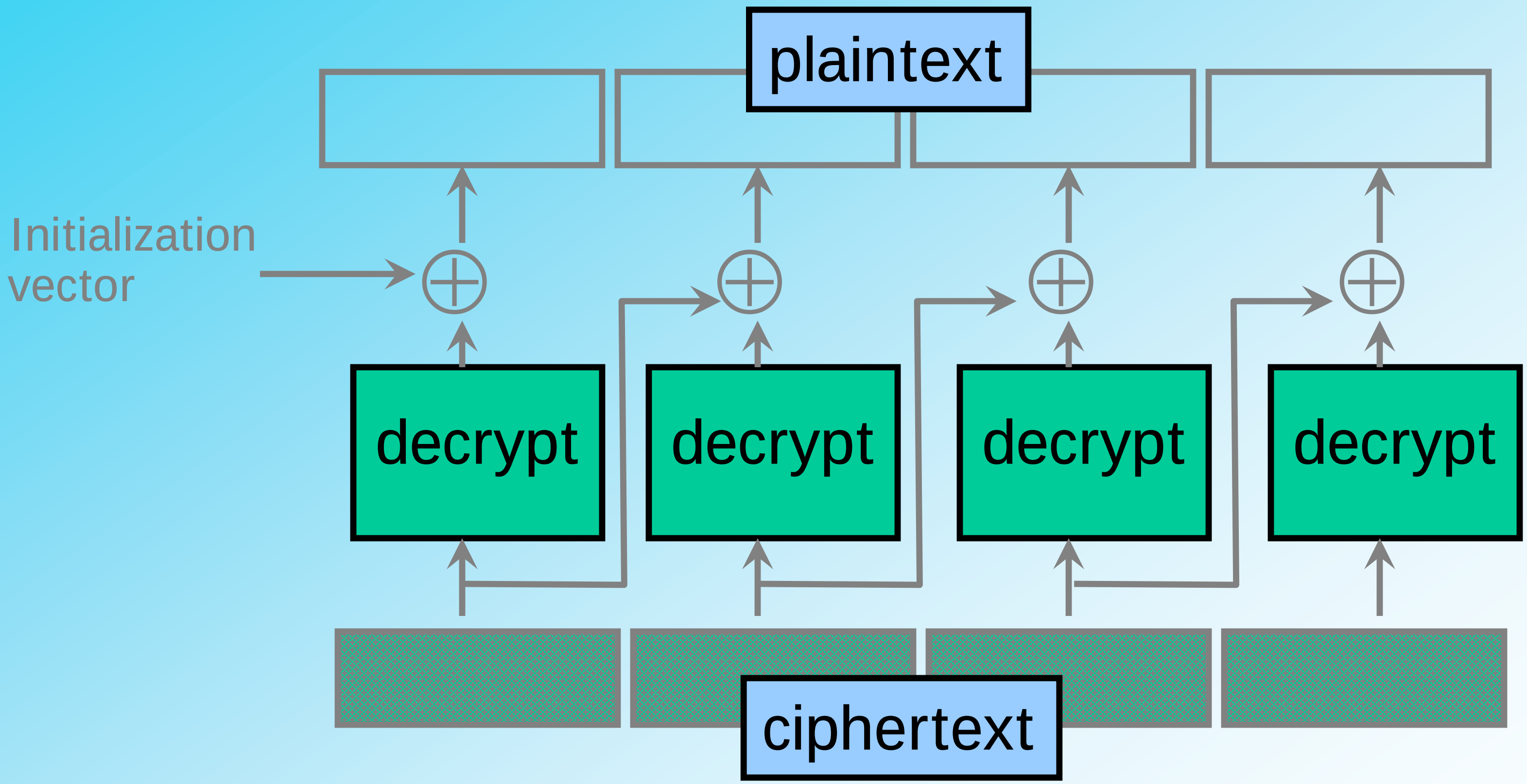
- Identical blocks of plaintext produce identical blocks of ciphertext
- No integrity checks: can mix and match blocks

CBC Mode: Encryption



- Identical blocks of plaintext encrypted differently
- Last cipherblock depends on entire plaintext

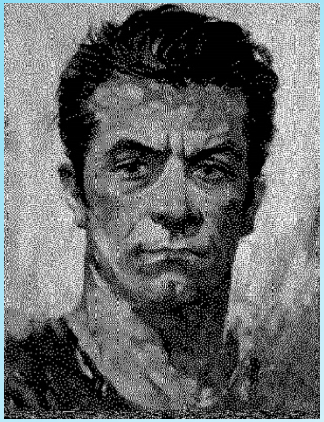
CBC Mode: Decryption



Cipher Block Chaining Mode

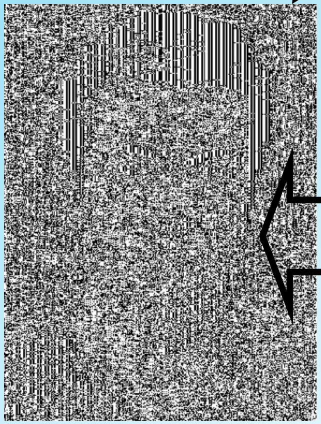
- Input to algorithm is the **XOR** of current plaintext block and preceding ciphertext block
- **Repeating patterns** are **not** exposed

ECB vs. CBC (due to Bart Preneel)

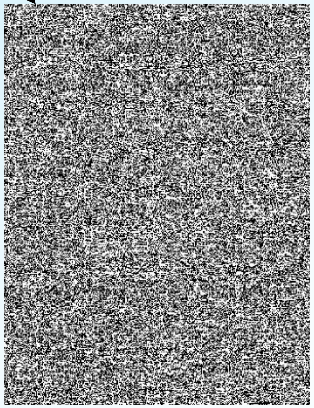


AES in ECB mode

AES in CBC mode



Similar plaintext
blocks produce
similar ciphertext
blocks (not good!)



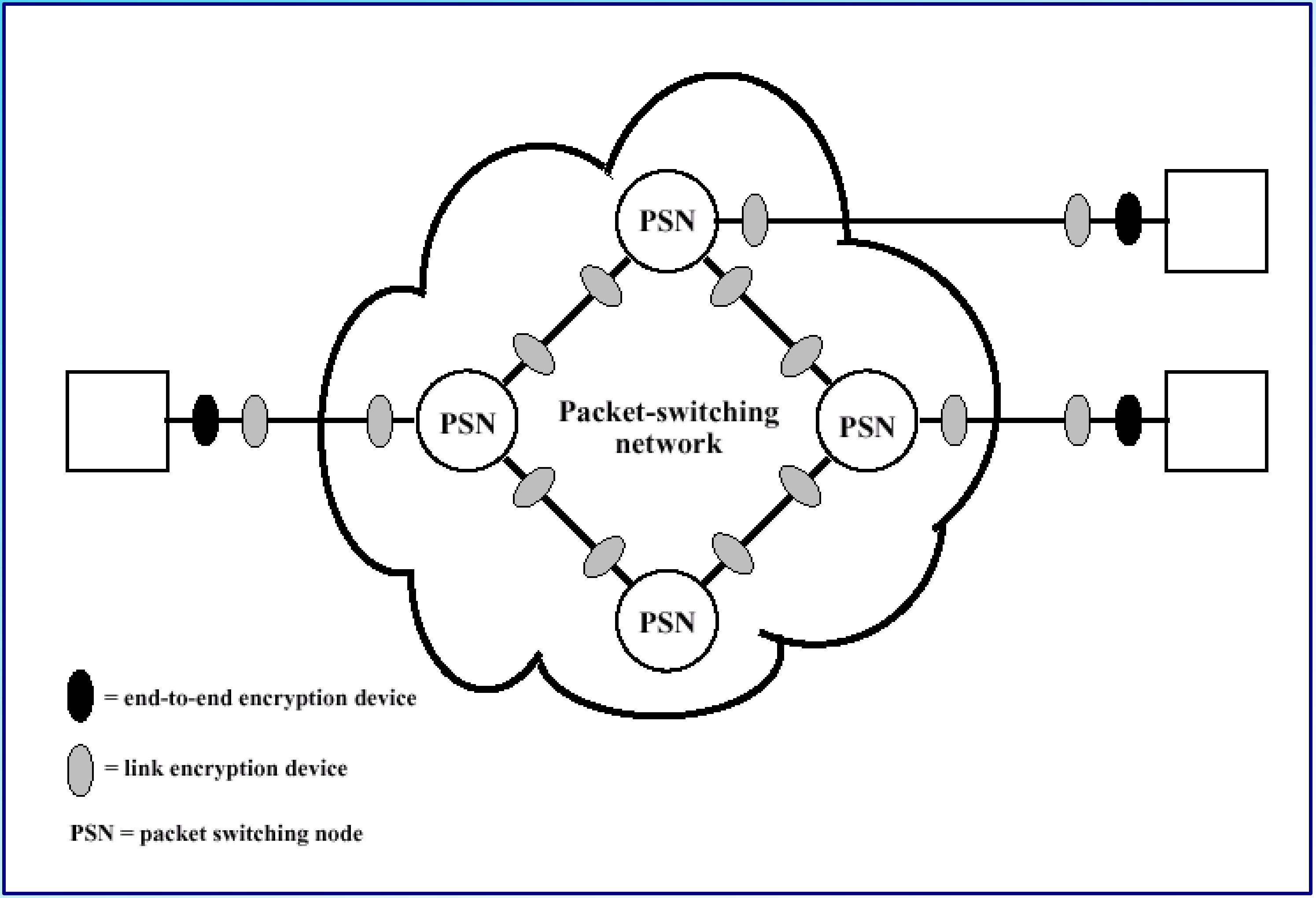
Location of Encryption Devices

- **Link Encryption**
  - Each vulnerable communications link is equipped on both ends with an encryption device
  - All traffic over all communications links is secured
  - Vulnerable at each switch

Location of Encryption Devices

- **End-to-end Encryption**
  - The encryption process is carried out at the two end systems
  - Encrypted data are transmitted unaltered across the network to the destination, which shares a key with the source to decrypt the data
  - Packet headers cannot be secured

Location of Encryption Devices



Key Distribution

- **Both parties** must have the **secret key**
- Key is **changed frequently**
- Requires either manual **delivery** of keys, or a third-party encrypted channel
- Most effective method is a **Key Distribution Center** (e.g. Kerberos)

Key Distribution