# Block Cipher Design Principles

# Block Cipher Design Principles

- number of rounds
  - more is better, exhaustive search best attack
- function f:
  - provides “confusion”, is nonlinear, avalanche
- key schedule
  - complex subkey creation, key avalanche

# Modes of Operation

- block ciphers encrypt fixed size blocks
- eg. DES encrypts 64-bit blocks, with 56-bit key
- need way to use in practise, given usually have arbitrary amount of information to encrypt
- four were defined for DES in ANSI standard **ANSI X3.106-1983 Modes of Use**
- subsequently now have 5 for DES and AES
- have **block** and **stream** modes

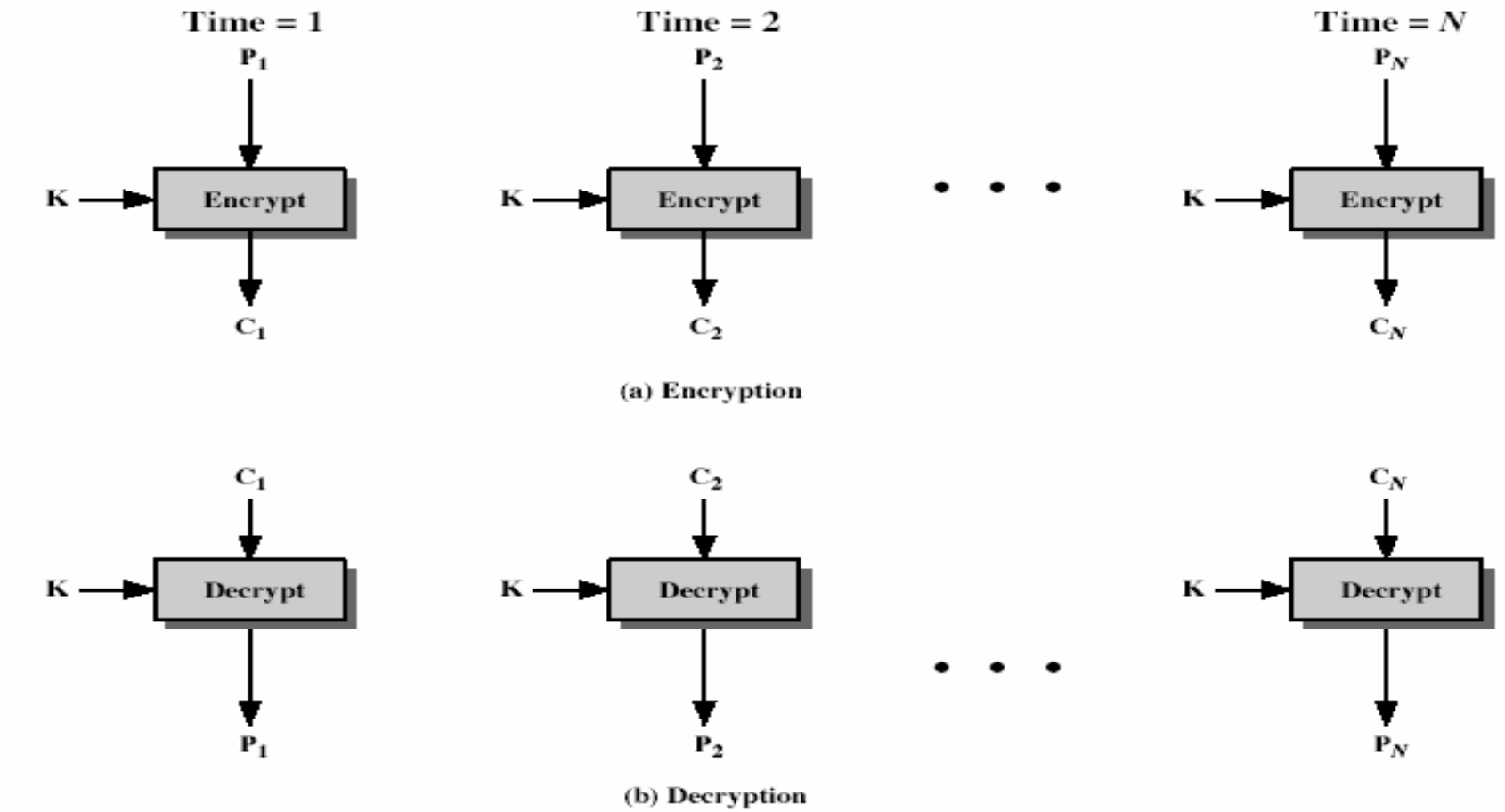
# Electronic Codebook Book (ECB)

- message is broken into independent blocks which are encrypted
- each block is a value which is substituted, like a codebook
- each block is encoded independently of the other blocks

$$C_i = DES_{K1}(P_i)$$

- uses: secure transmission of single values

# Electronic Codebook Book (ECB)



# Advantages and Limitations of ECB

- repetitions in message may show in ciphertext
  - or with messages that change very little
- weakness due to encrypted message blocks being independent
- main use is sending a few blocks of data

# Cipher Block Chaining (CBC)

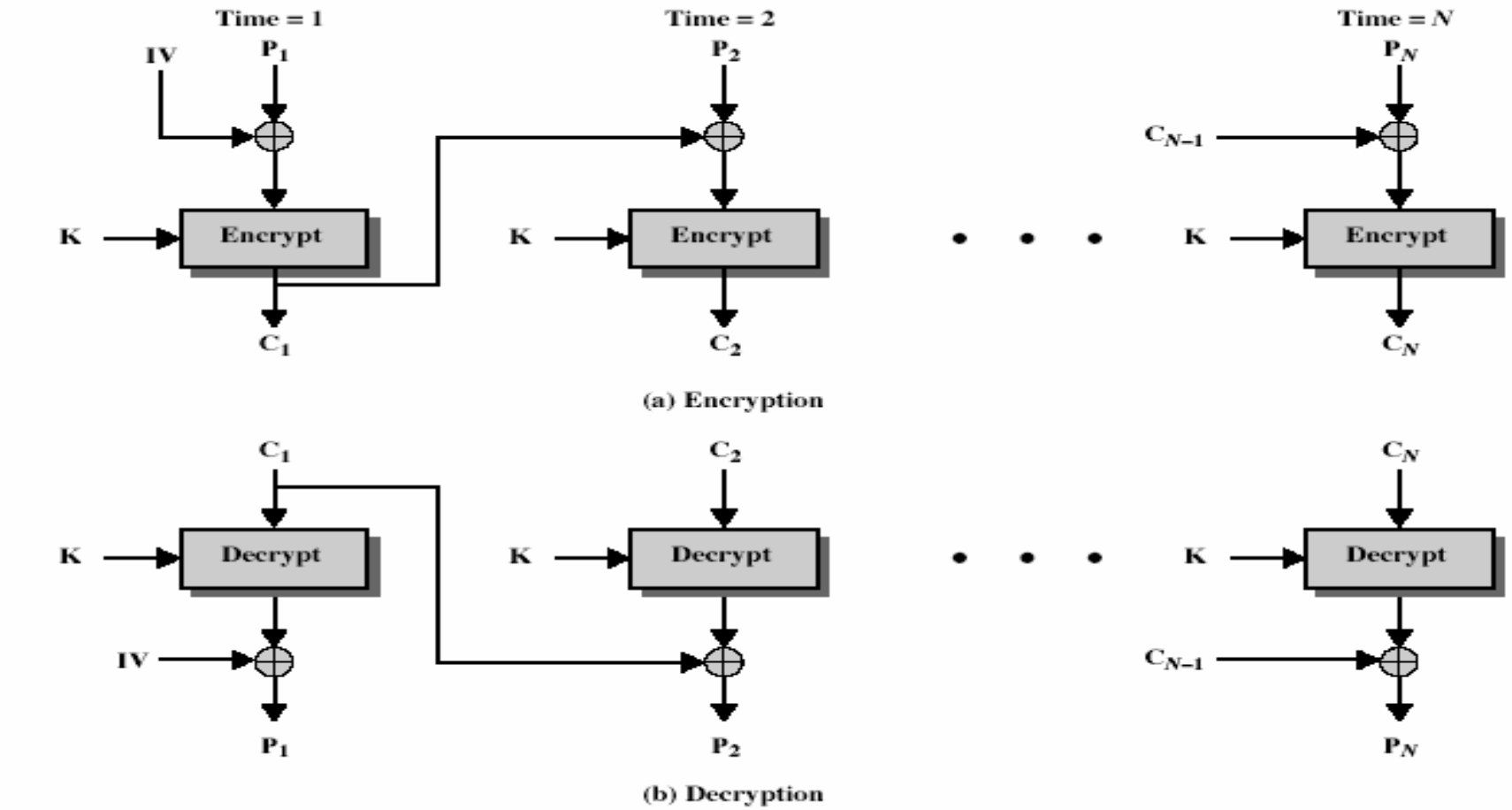
- message is broken into blocks
- but these are linked together in the encryption operation
- each previous cipher blocks is chained with current plaintext block, hence name
- use Initial Vector (IV) to start process

$$C_i = DES_{K1}(P_i \text{ XOR } C_{i-1})$$

$$C_{-1} = IV$$

- uses: bulk data encryption, authentication

# Cipher Block Chaining (CBC)



# Advantages and Limitations of CBC

- each ciphertext block depends on **all** message blocks
- thus a change in the message affects all ciphertext blocks after the change as well as the original block
- need **Initial Value** (IV) known to sender & receiver
  - however if IV is sent in the clear, an attacker can change bits of the first block, and change IV to compensate
  - hence either IV must be a fixed value or it must be sent encrypted in ECB mode before rest of message
- at end of message, handle possible last short block
  - by padding either with known non-data value or pad last block with count of pad size

# Cipher FeedBack (CFB)

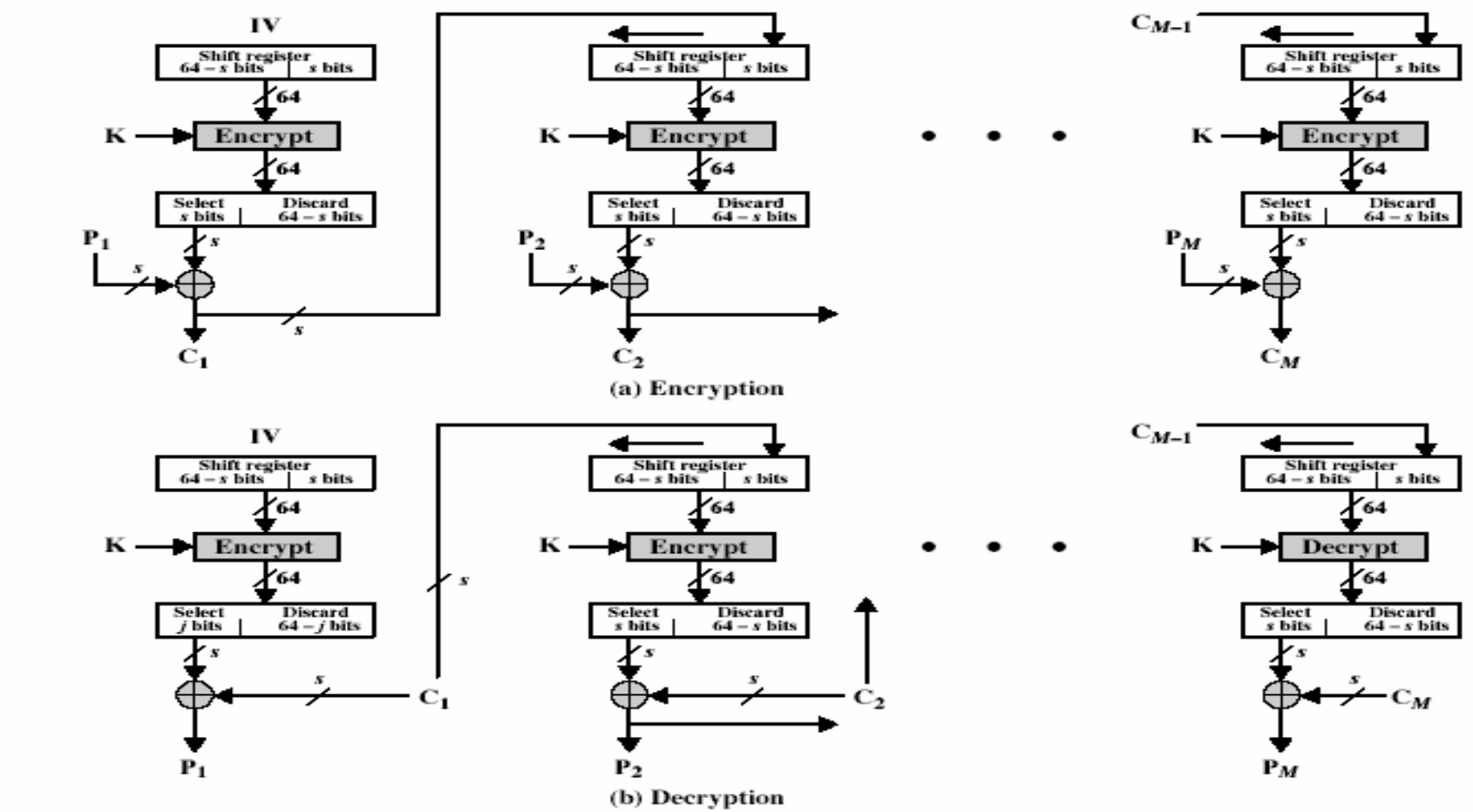
- message is treated as a stream of bits
- added to the output of the block cipher
- result is feed back for next stage (hence name)
- standard allows any number of bit (1,8 or 64 or whatever) to be feed back
  - denoted CFB-1, CFB-8, CFB-64 etc
- is most efficient to use all 64 bits (CFB-64)

$$C_i = P_i \text{ XOR } DES_{K1}(C_{i-1})$$

$$C_{-1} = IV$$

- uses: stream data encryption, authentication

# Cipher FeedBack (CFB)



# Advantages and Limitations of CFB

- appropriate when data arrives in bits/bytes ,most common stream mode
- limitation is need to stall while do block encryption after every n-bits
- note that the block cipher is used in **encryption** mode at **both** ends
- errors propogate for several blocks after the error

# Output FeedBack (OFB)

- message is treated as a stream of bits
- output of cipher is added to message
- output is then feed back (hence name)
- feedback is independent of message
- can be computed in advance

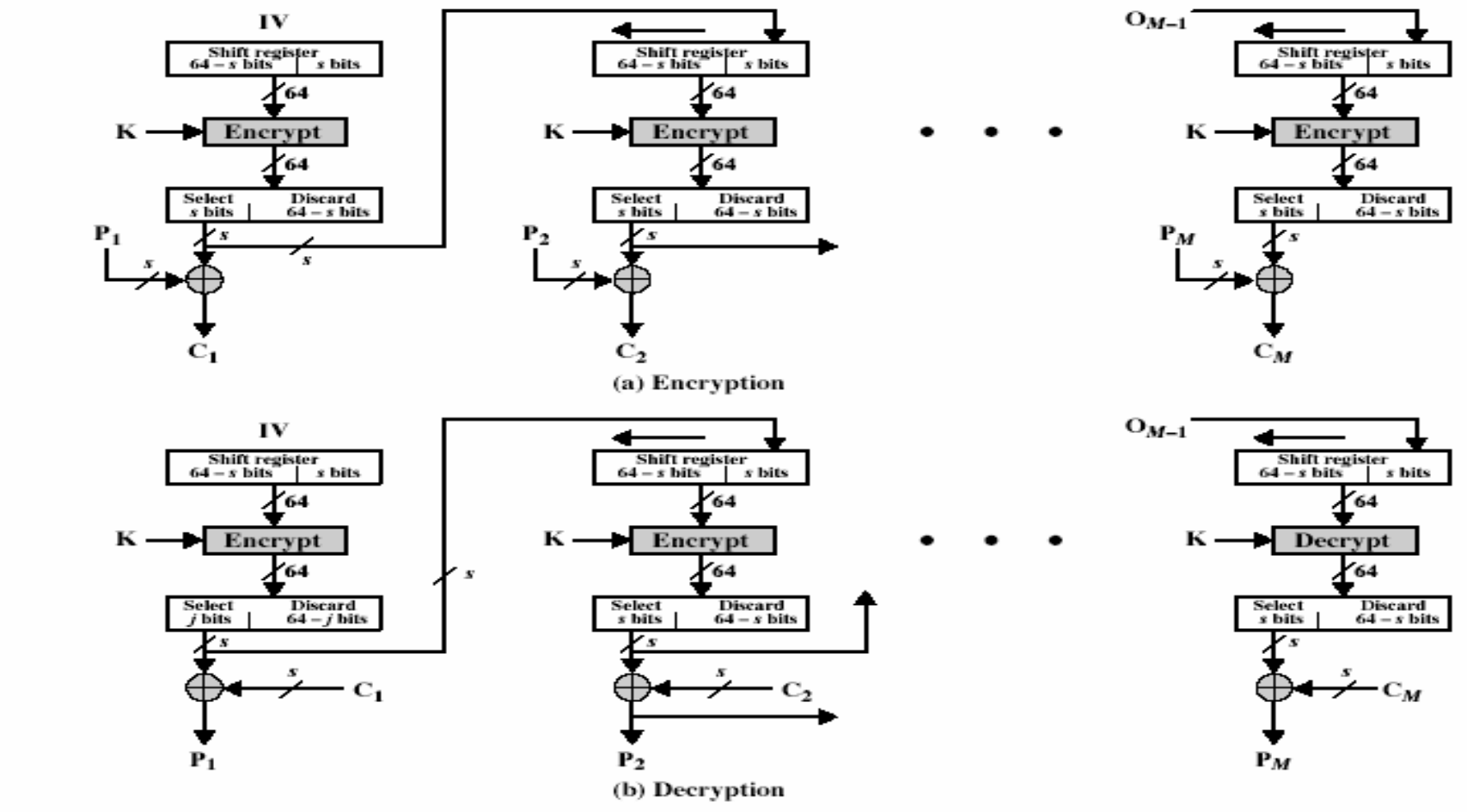
$$C_i = P_i \text{ XOR } O_i$$

$$O_i = DES_{K1}(O_{i-1})$$

$$O_{-1} = IV$$

- uses: stream encryption over noisy channels

# Output FeedBack (OFB)



# Advantages and Limitations of OFB

- used when error feedback a problem or where need to encryptions before message is available
- superficially similar to CFB
- but feedback is from the output of cipher and is independent of message
- a variation of a Vernam cipher
  - hence must **never** reuse the same sequence (key+IV)
- sender and receiver must remain in sync, and some recovery method is needed to ensure this occurs
- originally specified with m-bit feedback in the standards

# Counter (CTR)

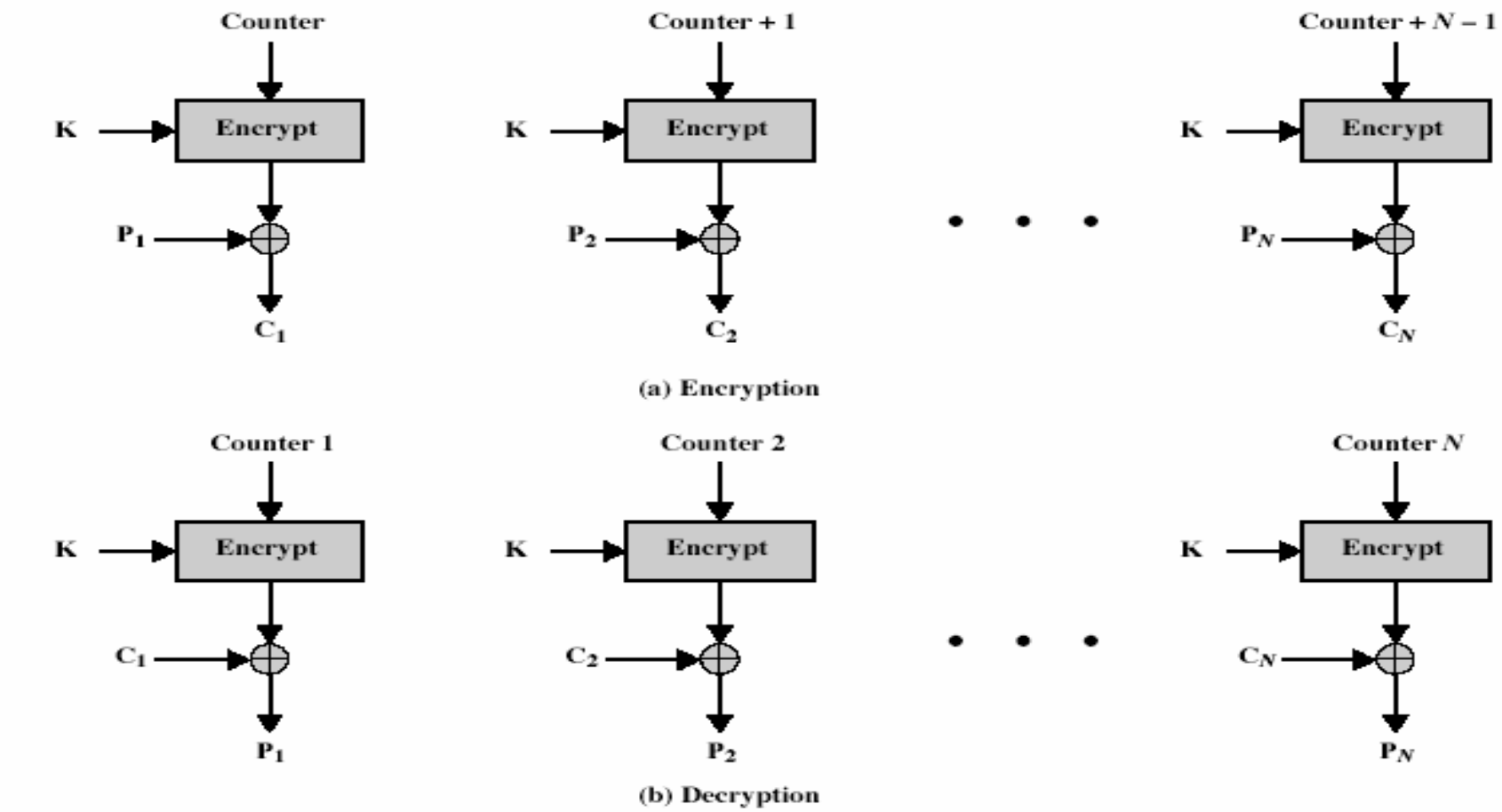
- a “new” mode, though proposed early on
- similar to OFB but encrypts counter value rather than any feedback value
- must have a different key & counter value for every plaintext block (never reused)

$$C_i = P_i \text{ XOR } O_i$$

$$O_i = DES_{K1}(i)$$

- uses: high-speed network encryptions

# Counter (CTR)


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

# Advantages and Limitations of CTR

- efficiency
  - can do parallel encryptions
  - 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 key/counter values, otherwise could break (cf OFB)