Information Security System
EC-415-F

Lecture 2

Topics Covered

Block Cipher Mode of Operation

Multiple Encryption & DES

- clear a replacement for DES was needed
  - theoretical attacks that can break it
  - demonstrated exhaustive key search attacks
- AES is a new cipher alternative
- prior to this alternative was to use multiple encryption with DES implementations
- Triple-DES is the chosen form

Double-DES?

- could use 2 DES encrypts on each block
  - $C = E_{K2}(E_{K1}(P))$
- issue of reduction to single stage
- and have "meet-in-the-middle" attack
  - works whenever use a cipher twice
  - since $X = E_{K1}(P) = D_{K2}(C)$
  - attack by encrypting P with all keys and store
  - then decrypt C with keys and match X value
  - can show takes $O(2^{56})$ steps

Triple-DES with Two-Keys

- hence must use 3 encryptions
  - would seem to need 3 distinct keys
- but can use 2 keys with E-D-E sequence
  - $C = E_{K1}(D_{K2}(E_{K1}(P)))$
  - nb encrypt & decrypt equivalent in security
  - if K1=K2 then can work with single DES
- standardized in ANSI X9.17 & ISO8732
- no current known practical attacks
  - several proposed impractical attacks might become basis of future attacks

Triple-DES with Three-Keys

- although are no practical attacks on two-key Triple-DES have some indications
- can use Triple-DES with Three-Keys to avoid even these
  - $C = E_{K3}(D_{K2}(E_{K1}(P)))$
- has been adopted by some Internet applications, eg PGP, S/MIME

Modes of Operation

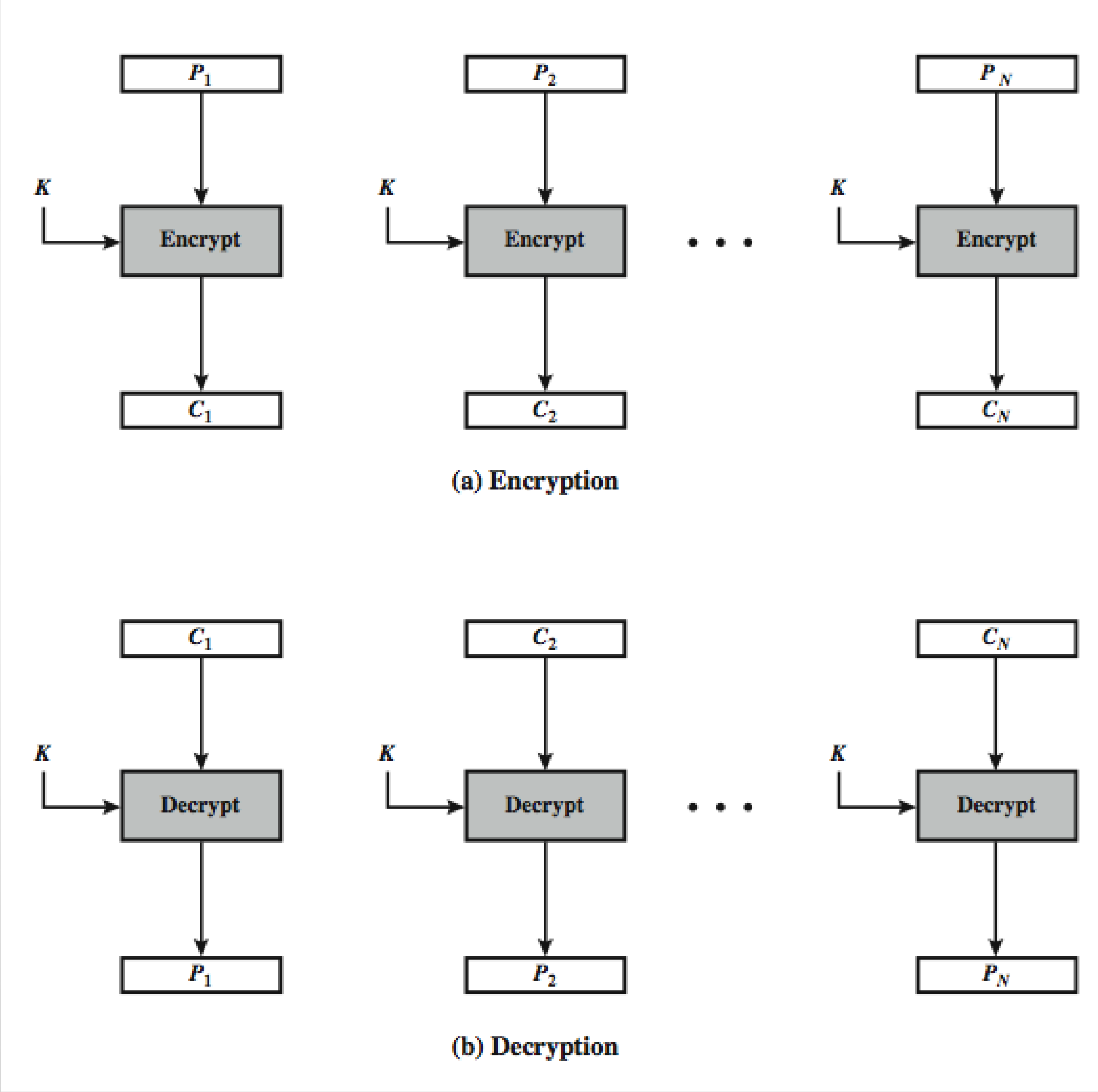
- block ciphers encrypt fixed size blocks
  - eg. DES encrypts 64-bit blocks with 56-bit key
- need some way to en/decrypt arbitrary amounts of data in practise
- NIST SP 800-38A defines 5 modes
- have **block** and **stream** modes
- to cover a wide variety of applications
- can be used with any block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

Electronic Codebook Book (ECB)

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

  $C_i = E_K(P_i)$
- uses: secure transmission of single values

Electronic Codebook Book (ECB)



Advantages and Limitations of ECB

- message repetitions may show in ciphertext
  - if aligned with message block
  - particularly with data such graphics
  - or with messages that change very little, which become a code-book analysis problem
- weakness is due to the encrypted message blocks being independent
- main use is sending a few blocks of data

Cipher Block Chaining (CBC)

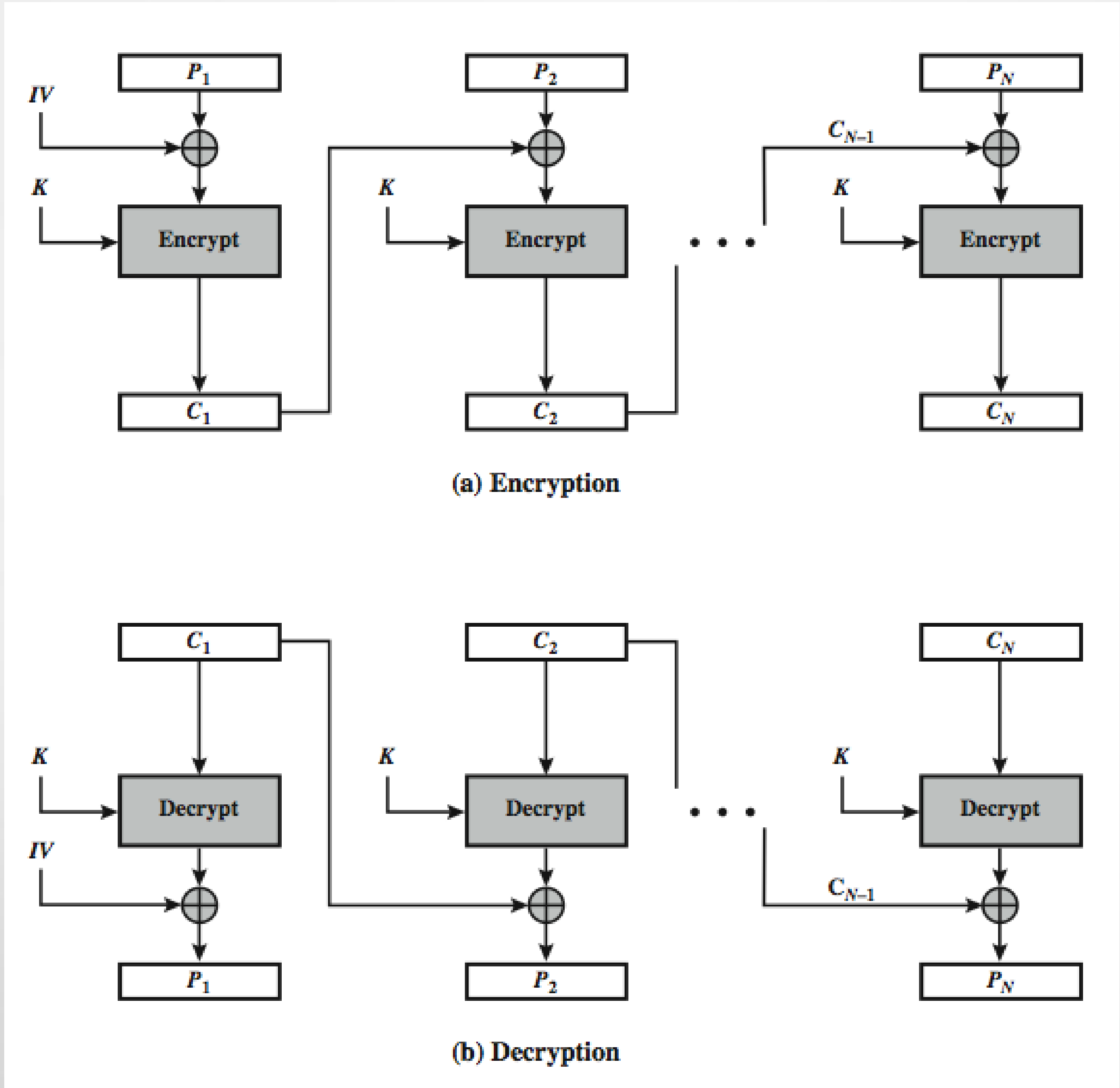
- message is broken into blocks
- linked together in encryption operation
- each previous cipher blocks is chained with current plaintext block, hence name
- use Initial Vector (IV) to start process

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

$$C_{-1} = IV$$

uses: bulk data encryption, authentication

Cipher Block Chaining (CBC)



Message Padding

- at end of message must handle a possible last short block
  - which is not as large as blocksize of cipher
  - pad either with known non-data value (eg nulls)
  - or pad last block along with count of pad size
    - eg. [b1 b2 b3 0 0 0 0 5]
    - means have 3 data bytes, then 5 bytes pad+count
  - this may require an extra entire block over those in message
- there are other, more esoteric modes, which avoid the need for an extra block

Advantages and Limitations of CBC

- a ciphertext block depends on **all** blocks before it
- any change to a block affects all following ciphertext blocks
- need **Initialization Vector** (IV)
  - which must be known to sender & receiver
  - if sent in clear, attacker can change bits of first block, and change IV to compensate
  - hence IV must either be a fixed value (as in EFTPOS)
  - or must be sent encrypted in ECB mode before rest of message

Stream Modes of Operation

- block modes encrypt entire block
- may need to operate on smaller units
  - real time data
- convert block cipher into stream cipher
  - cipher feedback (CFB) mode
  - output feedback (OFB) mode
  - counter (CTR) mode
- use block cipher as some form of **pseudo-random number** generator

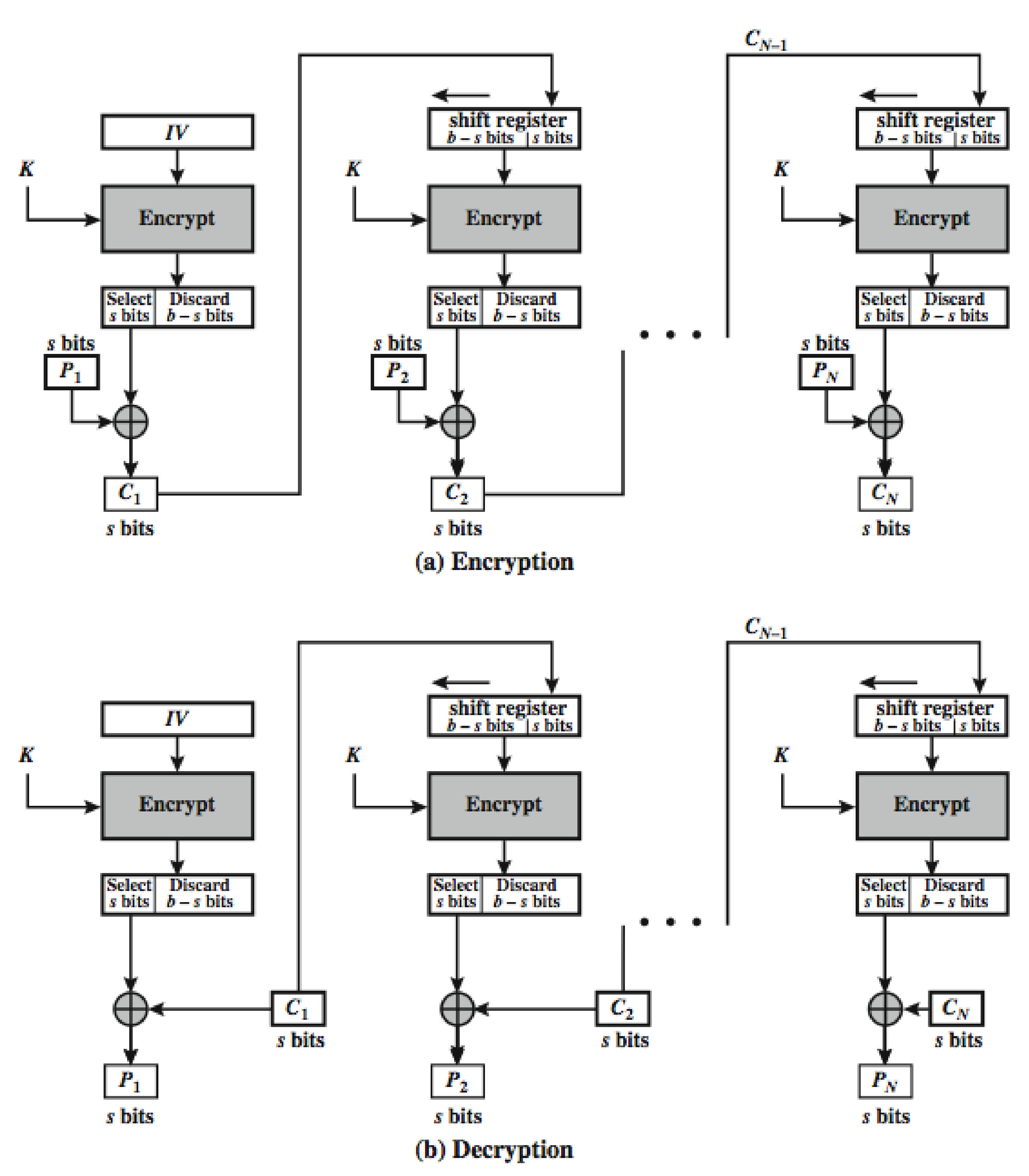
Cipher FeedBack (CFB)

- 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, 64 or 128 etc) to be feed back
  - denoted CFB-1, CFB-8, CFB-64, CFB-128 etc
- most efficient to use all bits in block (64 or 128)

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

  $C_{-1} = IV$
- uses: stream data encryption, authentication

s-bit Cipher FeedBack (CFB-s)



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

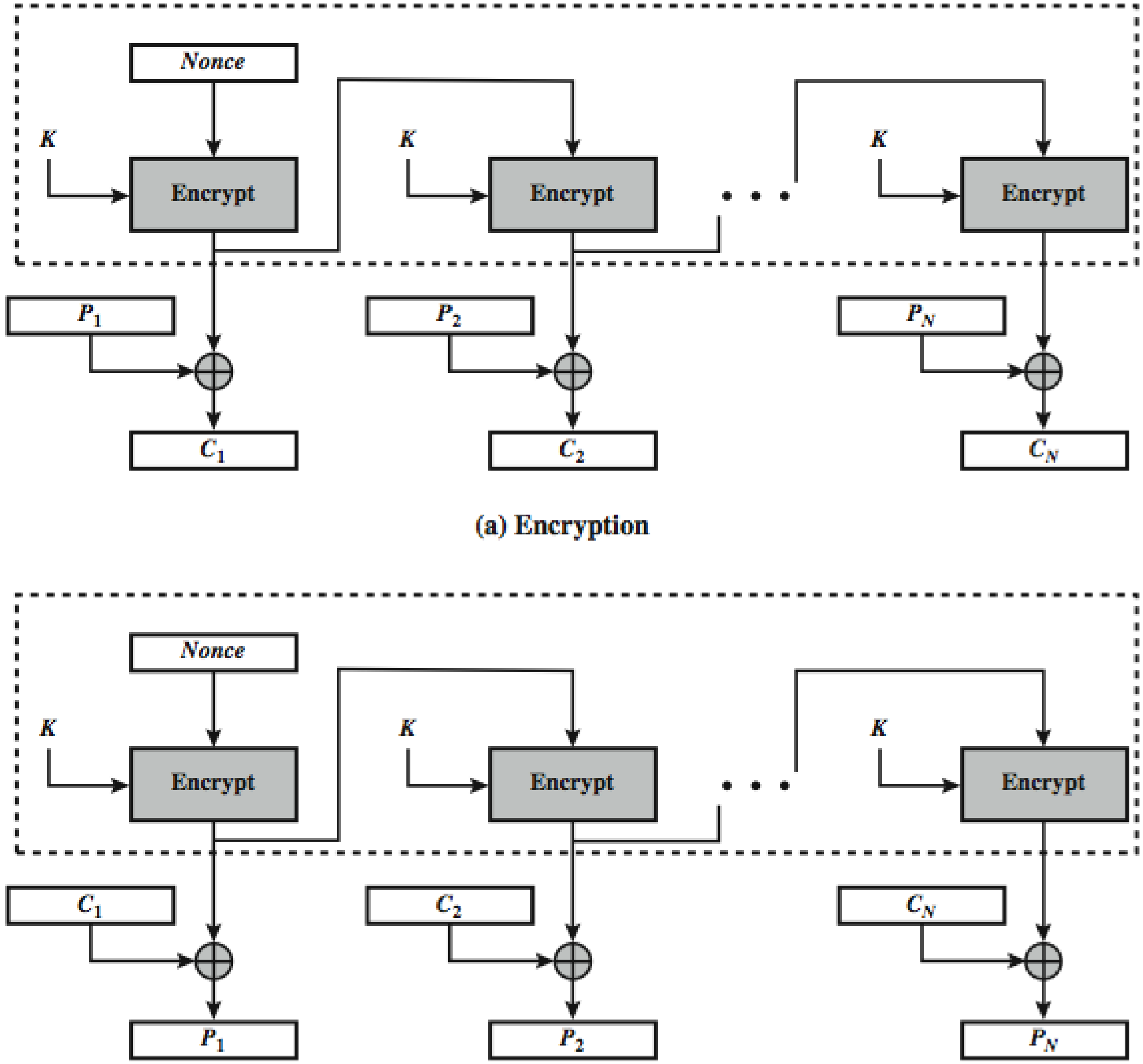
  $O_i = E_K(O_{i-1})$

  $C_i = P_i \text{ XOR } O_i$

  $O_{-1} = IV$

- uses: stream encryption on noisy channels

Output FeedBack (OFB)



(a) Encryption

(b) Decryption

Advantages and Limitations of OFB

- needs an IV which is unique for each use
  - if ever reuse attacker can recover outputs
- bit errors do not propagate
- more vulnerable to message stream modification
- sender & receiver must remain in sync
- only use with full block feedback
  - subsequent research has shown that only **full block feedback** (ie CFB-64 or CFB-128) should ever be used

Counter (CTR)

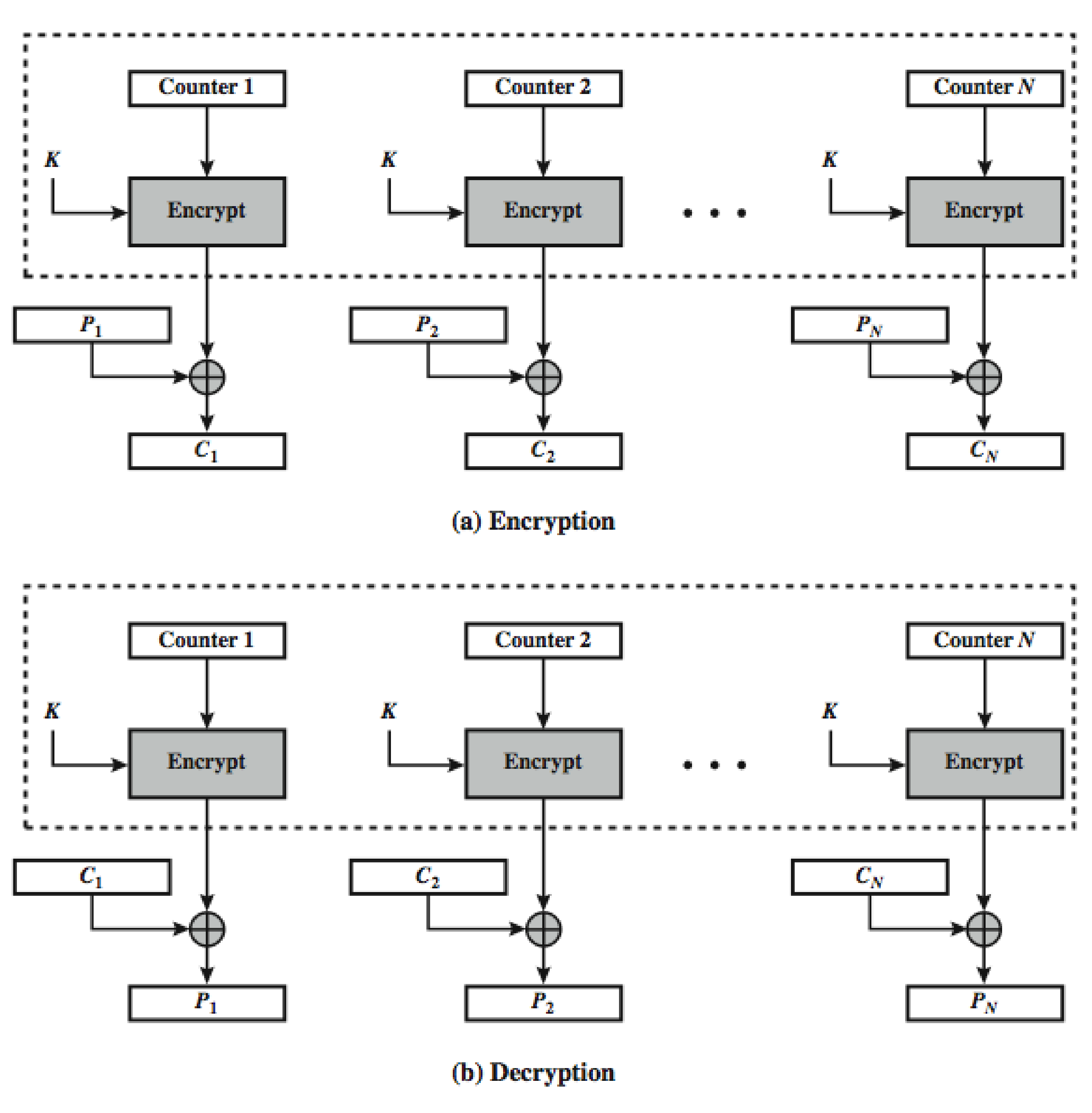
- a "new" mode, though proposed early on
- similar to OFB but encrypts counter value rather than any feedback value
- must have a different key & counter value for every plaintext block (never reused)

$$O_i = E_K(i)$$

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

- 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
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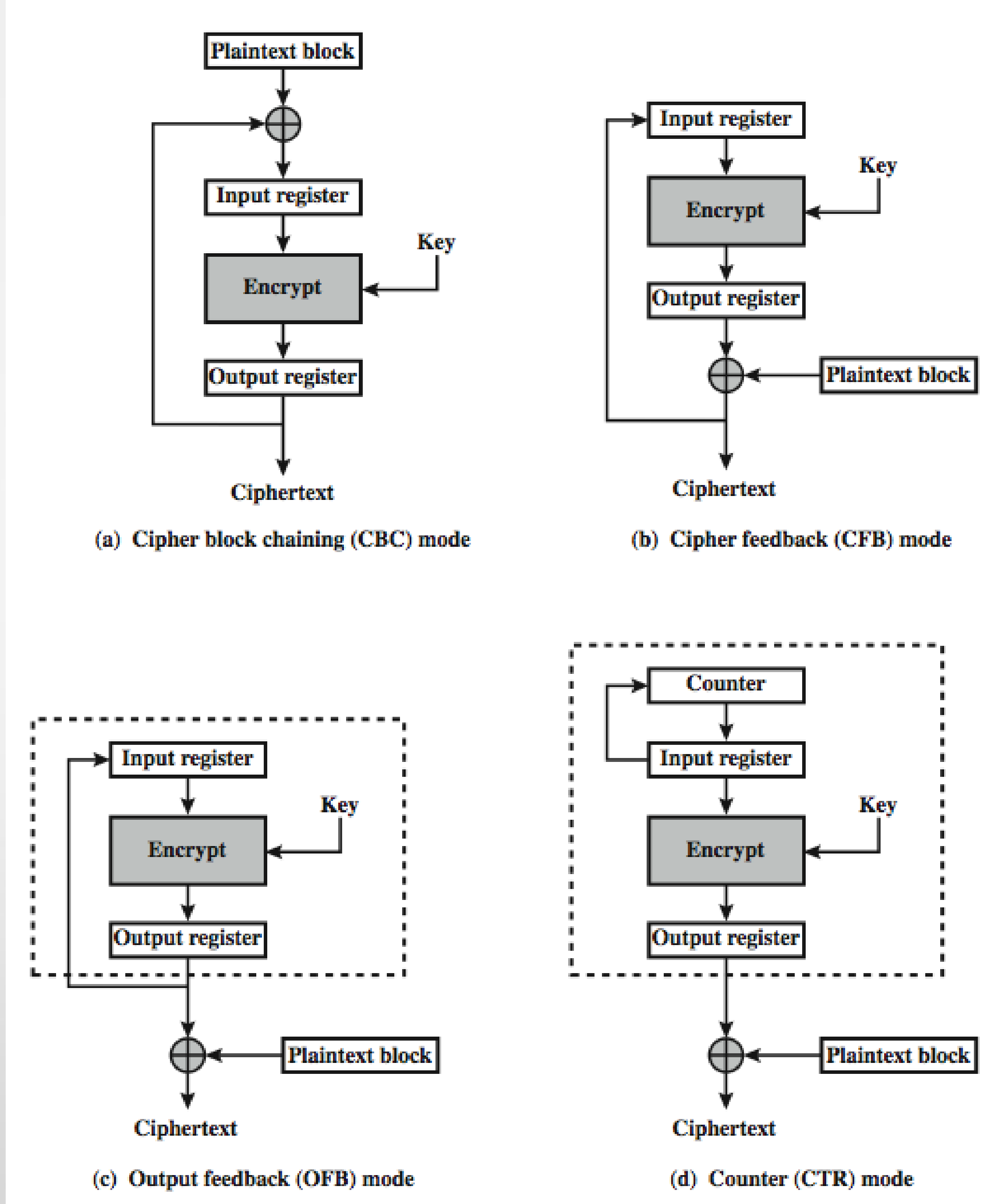
CN
P1
P2
PN
(b) Decryption

Advantages and Limitations of CTR

- efficiency
  - can do parallel encryptions in h/w or s/w
  - can preprocess 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)

Feedback Character-istics



XTS-AES Mode

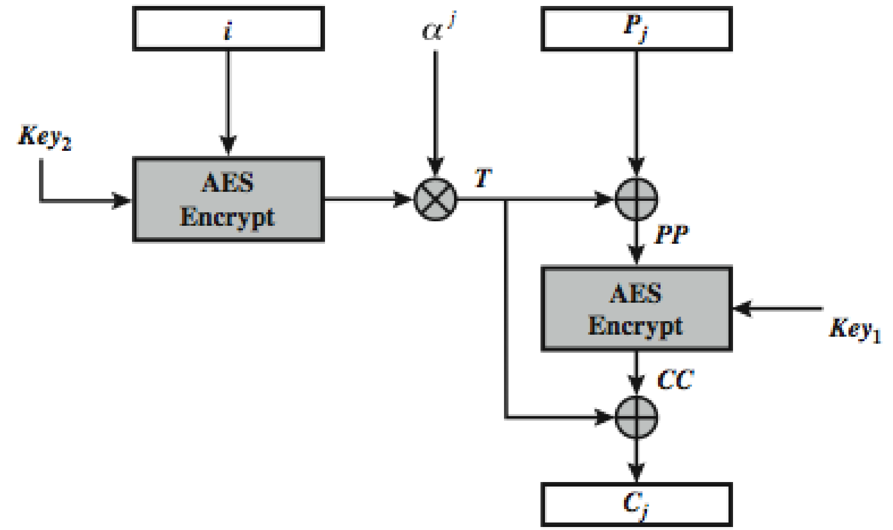
- new mode, for block oriented storage use
  - in IEEE Std 1619-2007
- concept of tweakable block cipher
- different requirements to transmitted data
- uses AES twice for each block

  $T_j = E_{K2}(i) \text{ XOR } \alpha^j$

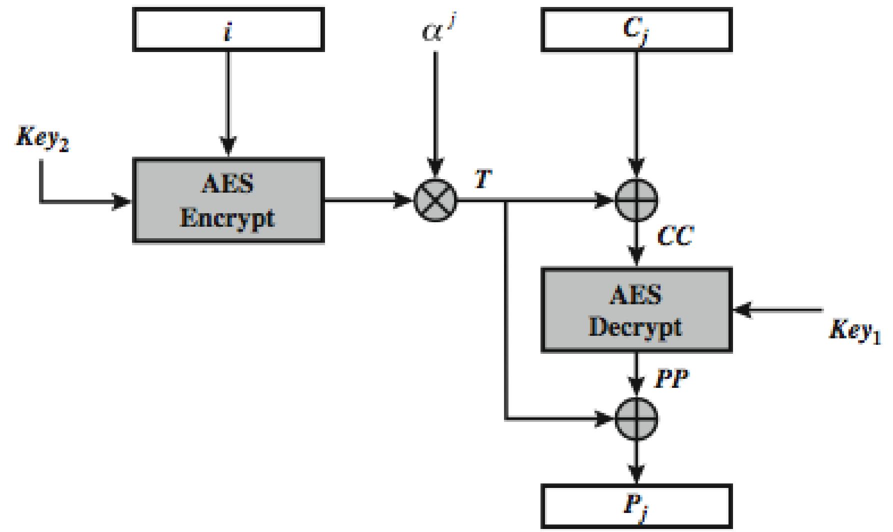
  $C_j = E_{K1}(P_j \text{ XOR } T_j) \text{ XOR } T_j$

  where i is tweak & j is sector no
- each sector may have multiple blocks

XTS-AES Mode per block

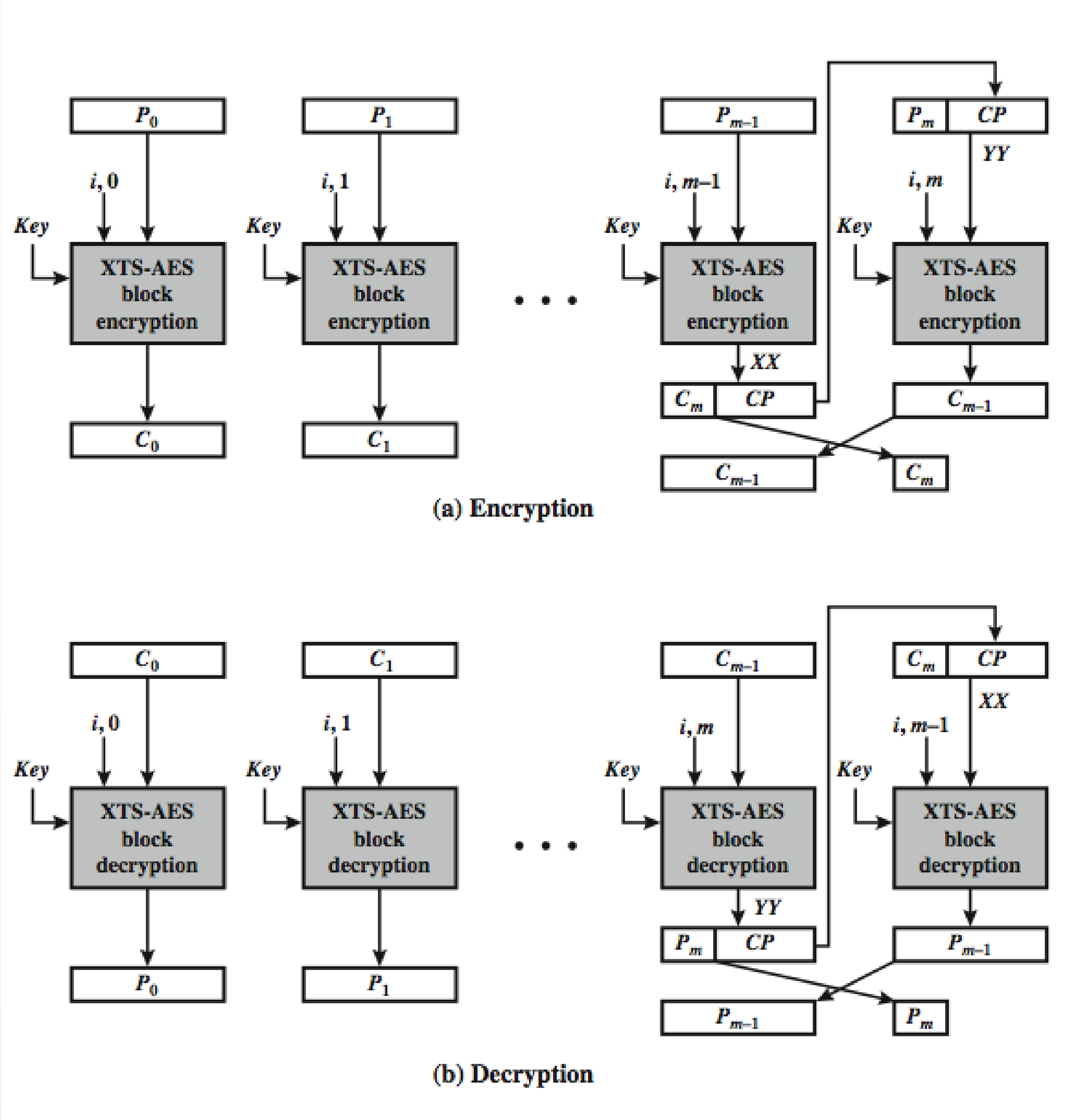


(a) Encryption



(b) Decryption

XTS-AES Mode Overview



Advantages and Limitations of XTS-AES

- efficiency
  - can do parallel encryptions in h/w or s/w
  - random access to encrypted data blocks
- has both nonce & counter
- addresses security concerned related to stored data

Summary

- Multiple Encryption & Triple-DES
- Modes of Operation
  - ECB, CBC, CFB, OFB, CTR, XTS-AES