Chapter 6
Multiple Radio Access

Adapted from class notes by
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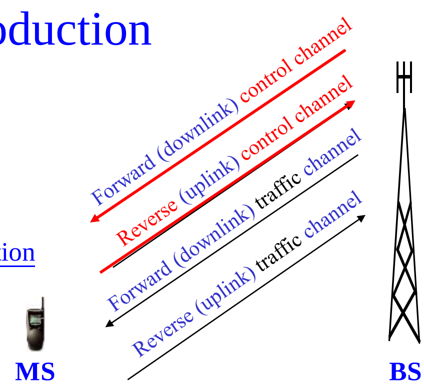
Most slides based on publisher's slides for 1st and 2nd edition of:
Introduction to Wireless and Mobile Systems by Agrawal & Zeng

6.1. Introduction

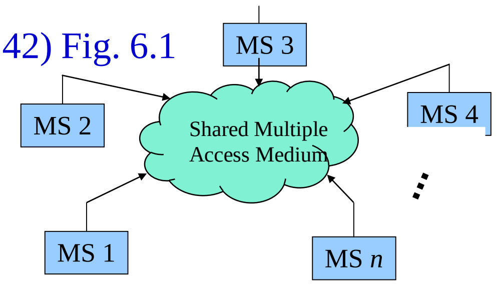
- Recall
  - Large # of traffic channels on each BS
    - Bec. traffic channels used by 1 MS exclusively for call duration
  - Small # of control channels (CC) on each BS
    - Bec. control channels shared by many MSs for short periods
      - Too expensive/inefficient to assign control channnel for call duration



p. 19 (頁19) Fig. 1.20

- MSs compete for these few shared control channels
    - For call setup, etc.

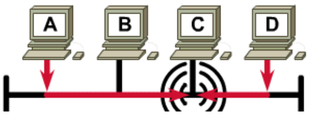
p. 126 (頁142) Fig. 6.1



- Multiple access issue
  - If more than one MS transmits at a time on a CC to BS, a collision occurs on this CC
  - How to determine which MS can transmit to BS?
- Multiple (medium) access protocols (control) (a.k.a. MAC sublayer protocols)
  - Solve multiple access issues
    - Specify how shared control channels are to be accessed by MS

 (Modified by LTL)

Introduction (Cont'd)

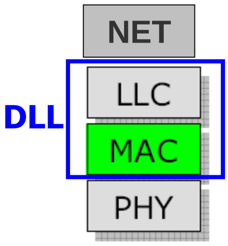


(Collision)

- Multiple access issues
  - If more than one node transmit at a time on the control channel to BS, a collision occurs
  - How to determine which node can transmit to BS?
- Multiple access protocols
  - Solving multiple access issues
  - Different types:
    - Contention protocols resolve a collision after it occurs. These protocols execute a collision resolution protocol after each collision. (Chapter 6)
    - Collision-free protocols (e.g., a bit-map protocol and binary countdown) ensure that a collision can never occur. (Chapter 7)

6.2. Multiple (Radio) Access Protocols = MAC Sublayer Protocols

- Recall ISO Open Systems Interconnection Reference Model for networks
  - Communication subnetwork = 3 lowest layers of OSI
    - Network layer (NET)
    - Data link layer (DLL)
    - Physical layer (PHY)



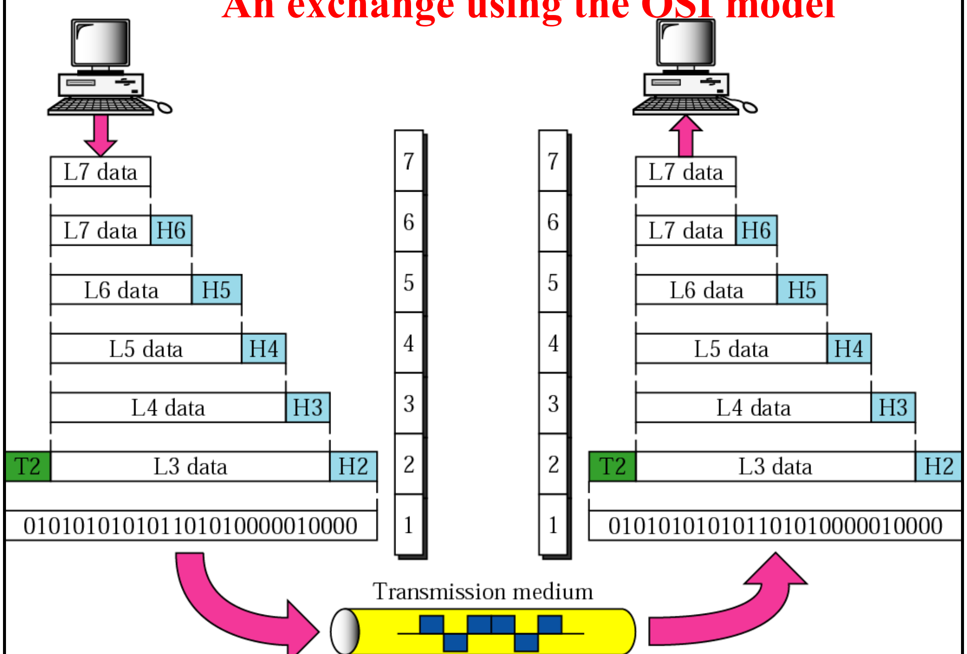
Why do we need MAC?

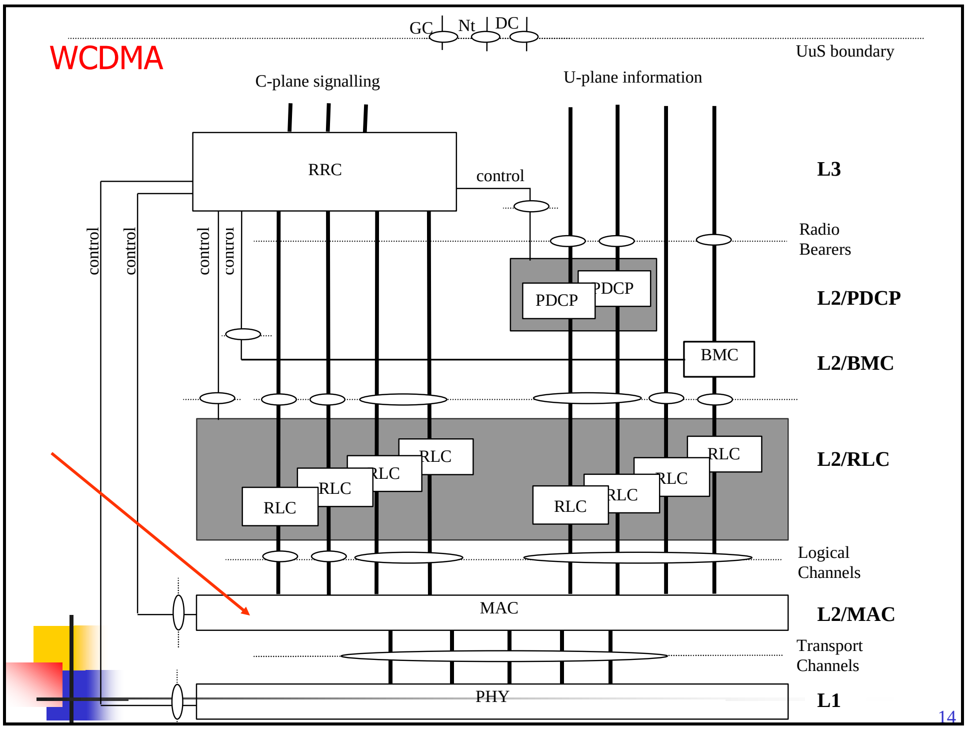
Contention and Collision Avoidance !

Why Do We Need MAC?

Fairness !!!

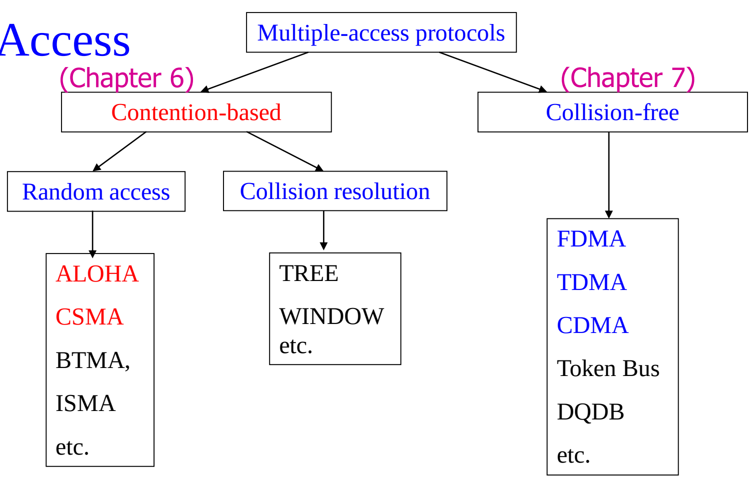
An exchange using the OSI model





Classification of Multiple Access Protocols

p. 127 (頁143) Fig. 6.3



BTMA: Busy Tone Multiple Access
ISMA: Idle Signal Multiple Access

DQDB: Distributed Queue Dual Bus

Random access protocols – upon collision, retransmit after a random delay

Collision resolution protocols - upon collision, retransmit according to a more sophisticated method

ALOHA and CSMA protocols will be discussed in this section.

6.3. Contention-Based Protocols

- Major categories of contention-based protocols
  1) ALOHA (a.k.a. Pure ALOHA)
  2) Slotted ALOHA
  3) CSMA (Carrier Sense Multiple Access)
     4) CSMA/CD (CSMA with Collision Detection)

     5) CSMA/CA (CSMA with Collision Avoidance)
     6) CSMA/CA with ACK
     7) CSMA/CA with RTS/CTS

Hawaii

- Honolulu

http://www.punjabigraphics.com/images/155/Aloha-Colorful-Flowers-Picture.jpg

http://a.abcnews.com/images/Travel/GTY_hawaii_kab_140620_12x5_1600.jpg

Honolulu

https://zh.wikipedia.org/wiki/檀香山#/media/File:Diamond_Head_Honolulu.jpg

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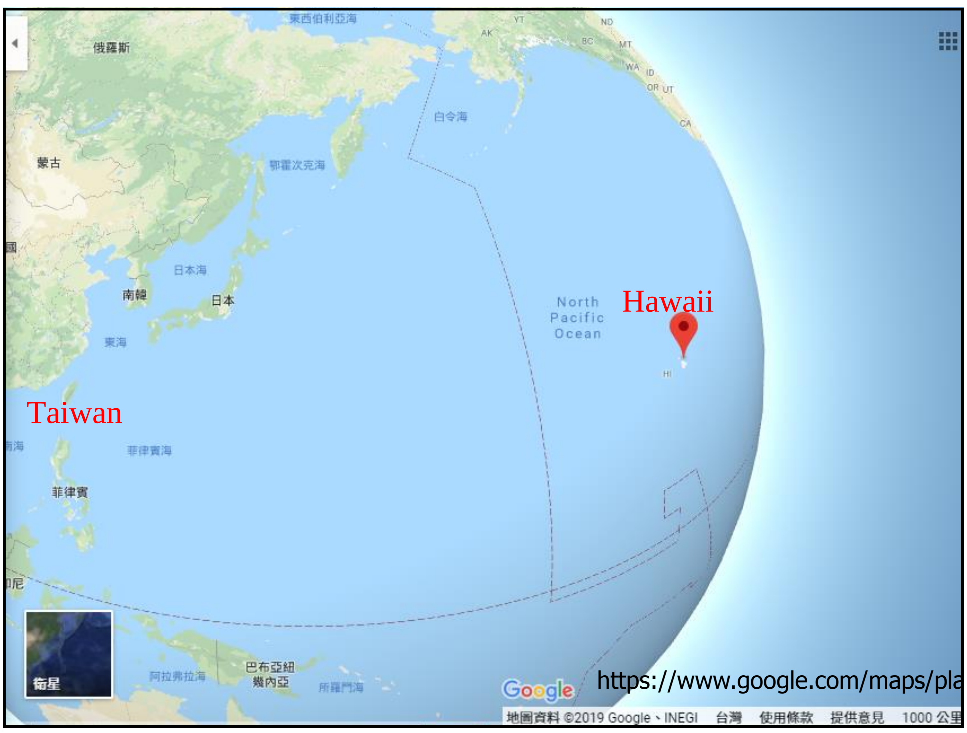

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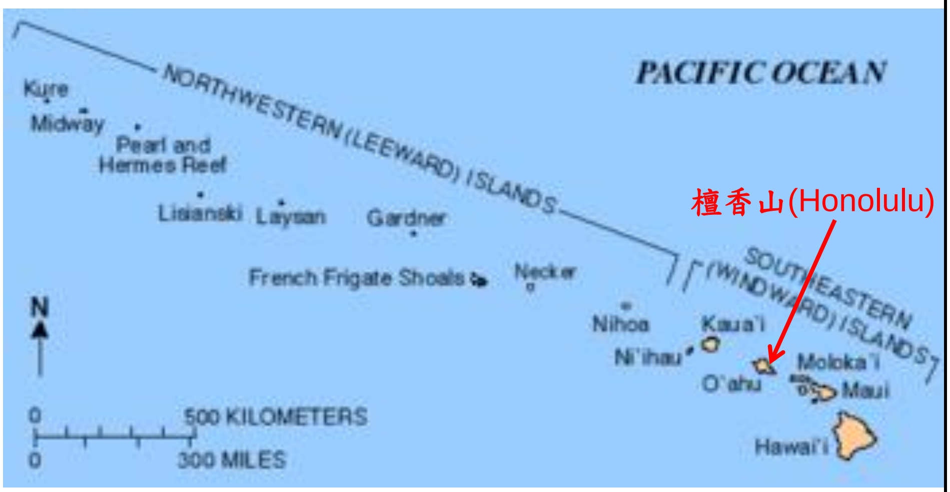
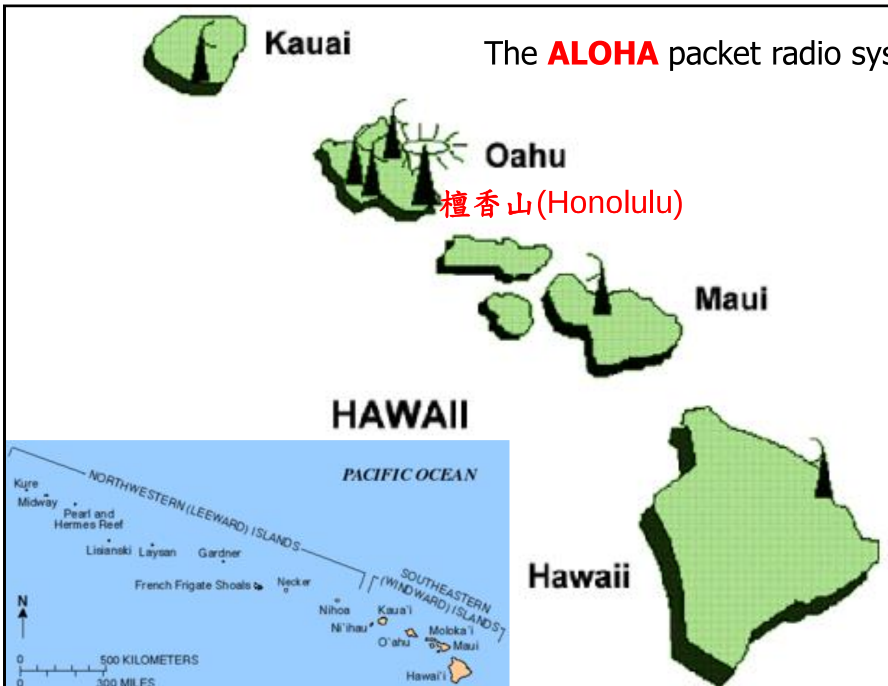


https://www.technologyuk.net/telecommunications/networks/images/aloha.gif

The **ALOHA** packet radio system



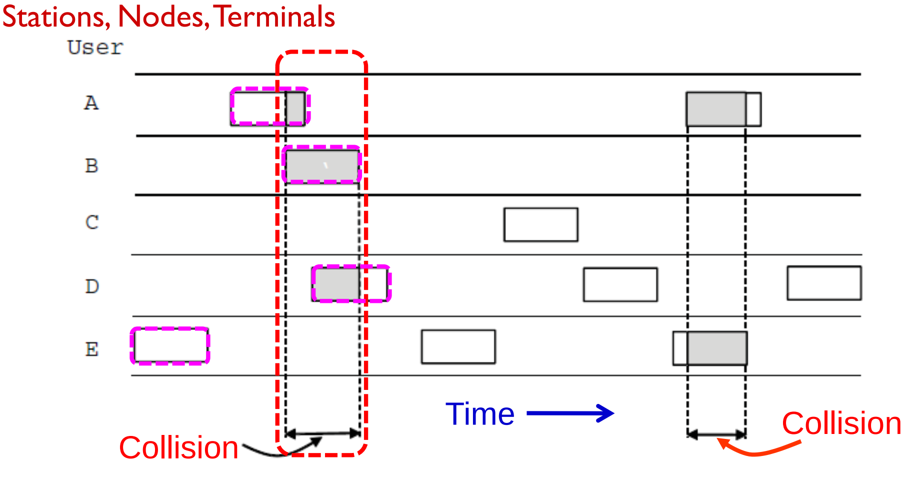
https://www.technologyuk.net/telecommunications/networks/images/aloha.gif

6.3.1. ALOHA (a.k.a. Pure ALOHA)

- Developed in the 1970s for a packet radio network by University of Hawaii
  - To interconnect islands′ campuses / Single-hop network
- Principles:
  - Sender S may transmit a packet at any time (hoping no collision will occur)
  - S finds out whether transmission was successful or experienced a collision by listening for an ACK broadcast from the destination station
    - Successful if an ACK arrives within a time-out period T
    - If no ACK within T, S assumes that there was a collision
      - => packet was lost after colliding with packet of another station
  - If there was a collision, S retransmits after some random time
- Analogy: 2 people entering a doorway simultaneously
  - Collision can occur

 (Modified by LTL)

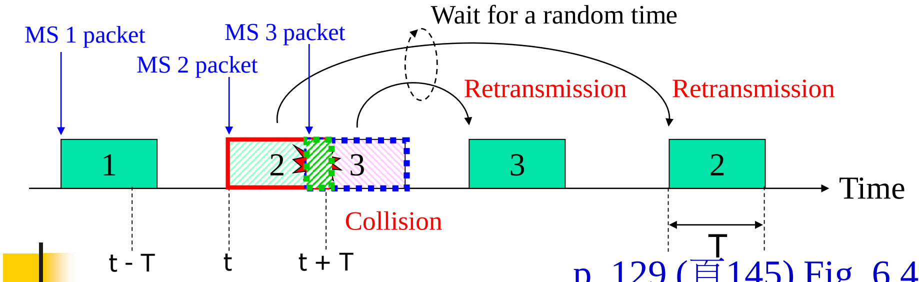
Pure ALOHA (in the 1970s)



In pure ALOHA, frames are transmitted at completely arbitrary times

6.3.1. ALOHA – cont.

- Recall ALOHA principles:
  - Sender S may transmit a packet at any time
  - S waits for an ACK broadcast from the destination station
  - If there was a collision, S retransmits after some random time
- Example: Packet 2 from MS2 & Packet 3 from MS3 collide
  - MS3 retransmits Packet 3 pretty soon (random wait)
  - MS2 retransmits Packet 2 much later (random wait)
- Note: Collision can block channel for period up to 2T (Vulnerable period)



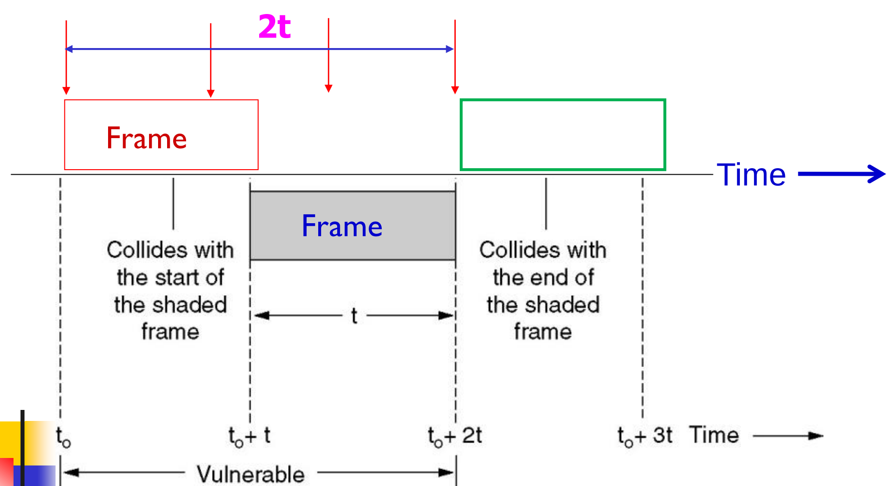
p. 129 (頁145) Fig. 6.4

Collision in Pure ALOHA (can last up to 2T)

(Modified by LTL)

Pure ALOHA: Performance

Vulnerable period (2t) for the shaded frame.



Throughput of ALOHA (cont.)

- T – packet length (duration)
- Successful Probability in time 2T:

$$P_s = P(\text{no collision})$$
$$= P(\text{no transmission in two packets time})$$
$$= P(\text{no transmission in 2T})$$
$$= P_0(2T) = \frac{(2gT)^0}{0!} e^{-2gT} = e^{-2G}.$$

where $G = gT$ is normalized offerred traffic load for the channel

- Throughput: $S_{th} = G \cdot P_0(2T) = G \cdot e^{-2G}$

- Maximum throughput for ALOHA (G=1/2)

$$S_{\max} = \frac{1}{2e} \approx 0.184$$

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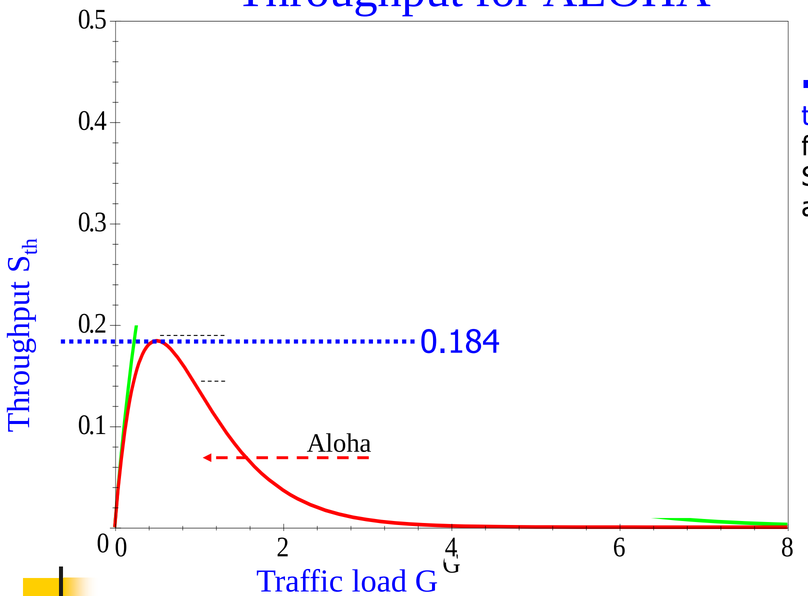
Throughput for ALOHA



- Max. throughput for ALOHA S_{th} = 0.184 at G = ½

p. 131 (頁147) Fig. 6.6

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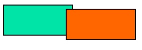
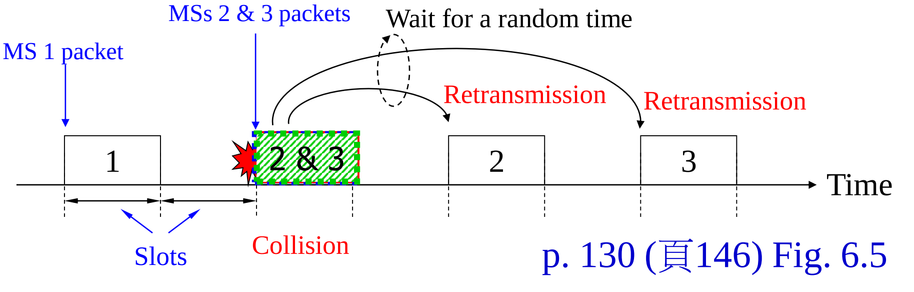
6.3.2. Slotted ALOHA

- Improvements over Pure ALOHA:
  - Time is slotted
    - Slot length = packet length (duration) = T
  - Packet transmission can start only at the beginning of a slot
  - This reduces collision duration
    
    - Pure ALOHA: If Packet 1 is almost finished when it collides with just-starting Packet 2, collision can lasts for nearly T+T = 2T
    
    - Slotted ALOHA: 2 Packets can collide only when both are just starting => collision can last at most T

 (Modified by LTL)

6.3.2. Slotted ALOHA – cont.

- Example: Packet 2 from MS2 & Packet 3 from MS3 collide
  - MS2 retransmits Packet 2 pretty soon (random wait)
  - MS3 retransmits Packet 3 much later (random wait)
- Note: Shows again that collision can block channel for period T



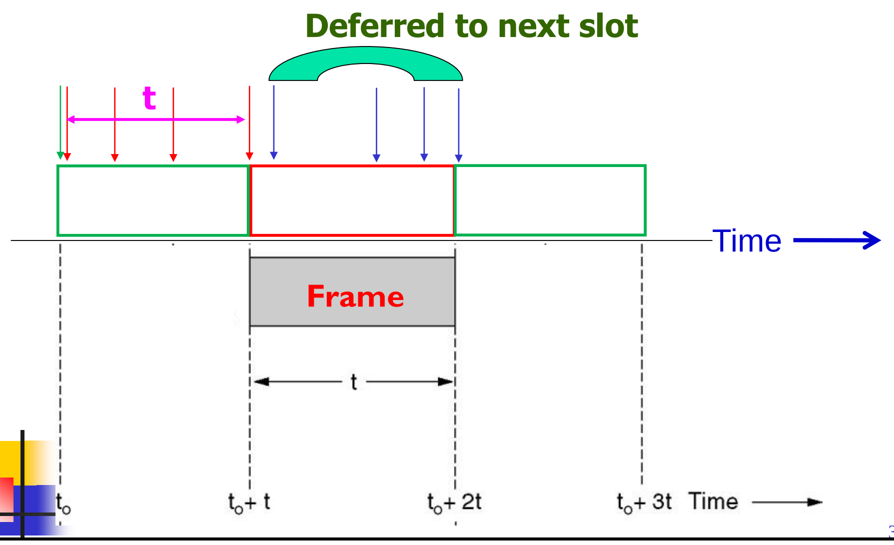
p. 130 (頁146) Fig. 6.5

Collision in Slotted ALOHA (can last max. T)

 (Modified by LTL)

Slotted ALOHA: Performance

Vulnerable period (**t**) for the shaded frame.



Throughput of Slotted ALOHA

- Probability of no collision

$$P_0(T) = e^{-G}, G = gT.$$

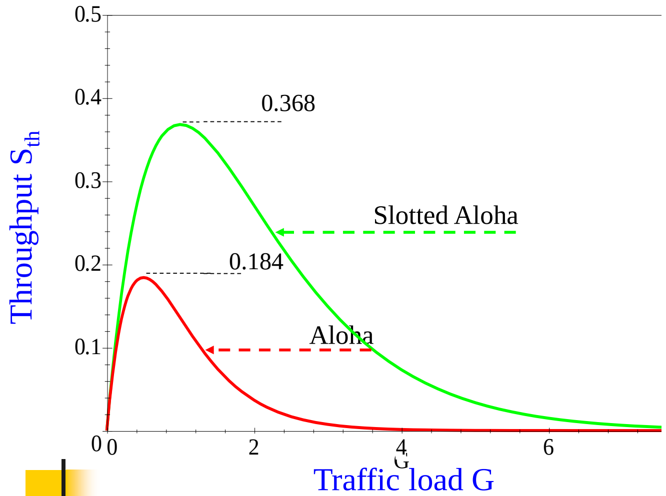
- Throughput:

$$S_{th} = G \cdot P_o(T) = G \cdot e^{-G}$$

- Maximum throughput for slotted ALOHA (G = 1)

$$S_{\max} = \frac{1}{e} \approx 0.368$$

Comparison of Throughputs for ALOHA and Slotted ALOHA



p. 131 (頁147) Fig. 6.6

- Max. throughput for ALOHA (A) S_{th} = 0.184 at G = ½
- Max. throughput for Slotted ALOHA (SA) S_{th} = 0.368 at G = 1
- Notice that S_{th} for SA is exactly 2 x bigger than S_{th} for A
  - Hypothesis: bec. max. duration of a collision for SA (=2T) is 2 x smaller than for A (=T)

(Modified by LTL)

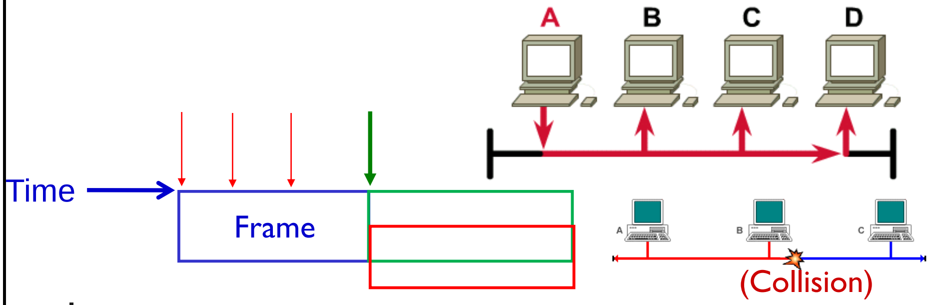
6.3.2-B. CSMA (Carrier Sense Multiple Access) Group of Protocols

- Max. throughputs for Pure & Slotted ALOHA are 0.184 & 0.368
- CSMA protocols give better throughput than both Aloha protocols
  - By avoiding collisions
- Basic improvement in all CSMA protocols over ALOHA protocols:

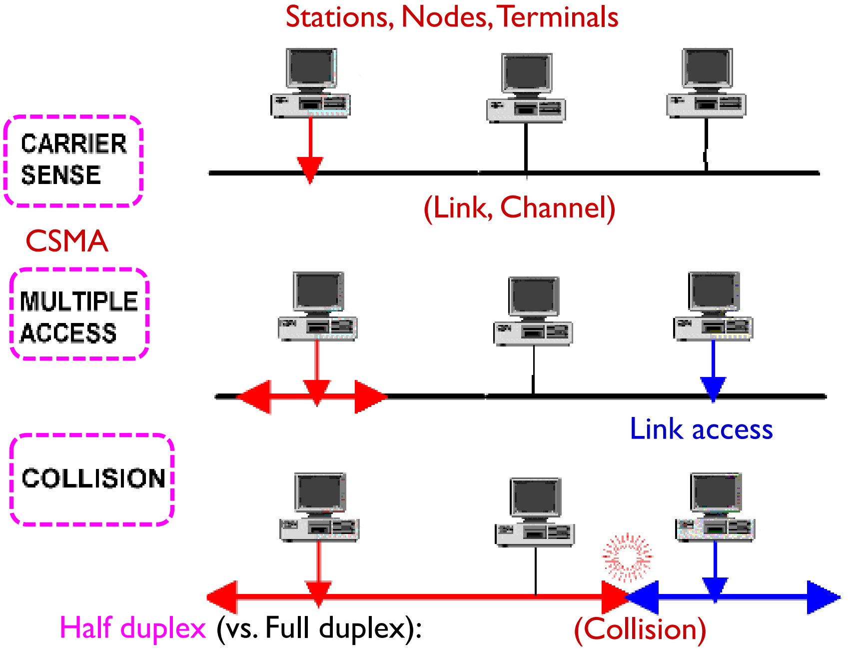
  Listen to the channel ("**sense**" for the presence of the "carrier") before transmitting a packet
  - Don't transmit if channel busy
    - Avoids some collisions - but not all

Carrier Sense Multiple Access (CSMA)

- 1-persistent CSMA
  - Listen before transmit: If the (Link) channel is busy, the station waits until it becomes idle.



- If channel sensed idle: transmit entire frame



Half duplex (vs. Full duplex):
nodes at both ends of link can transmit, but not at same time

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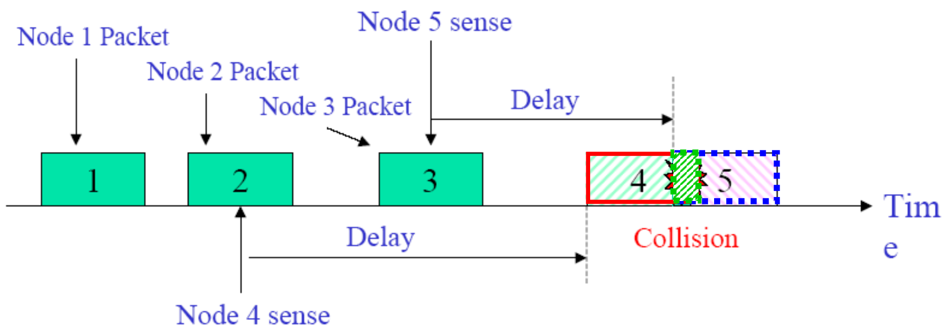
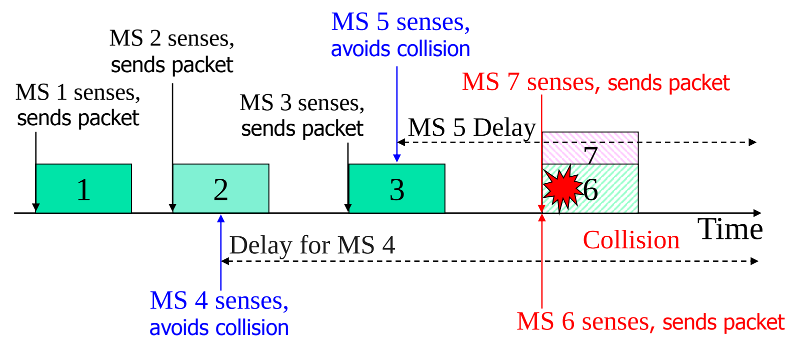
Collision Mechanism in CSMA



p. 131 (頁148) Fig. 6.7

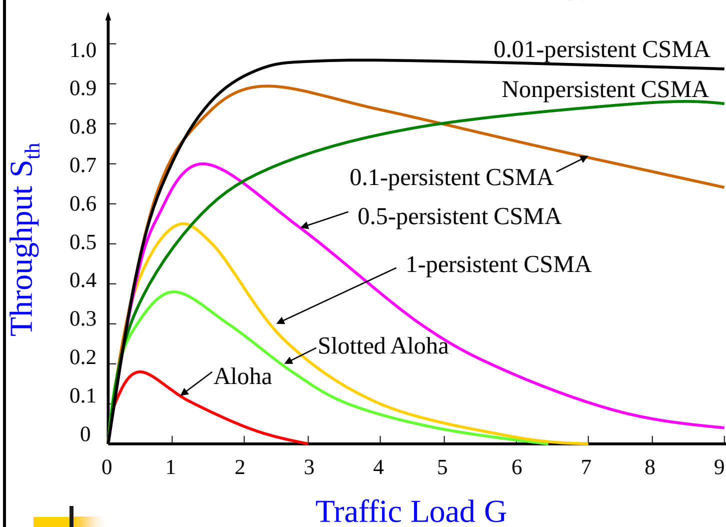
Basic Collision Mechanism in CSMA Protocols



- Some collisions avoided
  - Packet 4 was not sent so it did not collide with Packet 2
  - Packet 5 was not sent so it did not collide with Packet 3
- Collisions can still occur if sensing occurs nearly simulta-neously
  - Packet 6 collided with Packet 7

 (Modified by LTL)

Throughput for Different ALOHA and CSMA Protocols with α=0.01



p. 135 (頁152) Fig. 6.9

$\alpha = \tau / T$ (p. 132)
τ - propagation delay
T – packet transmission time

Recall:
p-persistent: transmit with probability p if medium idle

Observe:
p = 0.01 is best in this Fig. (others suffer more collisions reducing thruput => "don't hurry too much")

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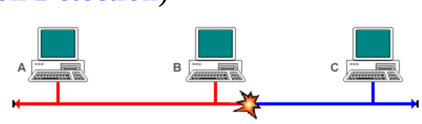
Types of CSMA Protocols

1) Basic CSMA, often just CSMA (Carrier Sense Multiple Access)
Sender S starts transmission only if no transmission is ongoing

2) CSMA/CD (CSMA with Collision Detection)



http://www.technologyuk.net/telecommunications/networks/images/csma_cd_04.gif

3) CSMA/CA (CSMA with Collision Avoidance)

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http://www.techforshare.com/wp-content/uploads/2016/01/wifi-logo.jpg

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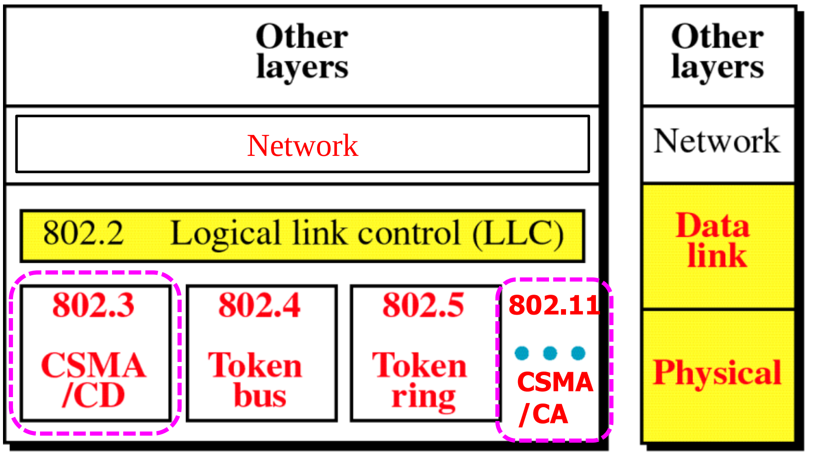
IEEE Project 802

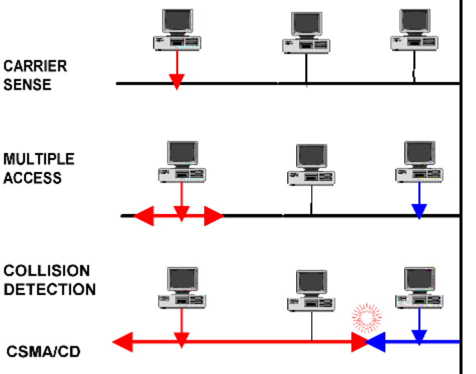


Project 802 OSI Model

6.3.4. CSMA/CD (CSMA with Collision Detection)

- In Basic CSMA: If 2 terminals begin sending packets at the same time, each will transmit its complete packet
  - Even if collision is taking place
- Problem: Wasting medium for an entire packet duration
- Solution principle (main CSMA/CD idea):

  Backoff immediately after a collision



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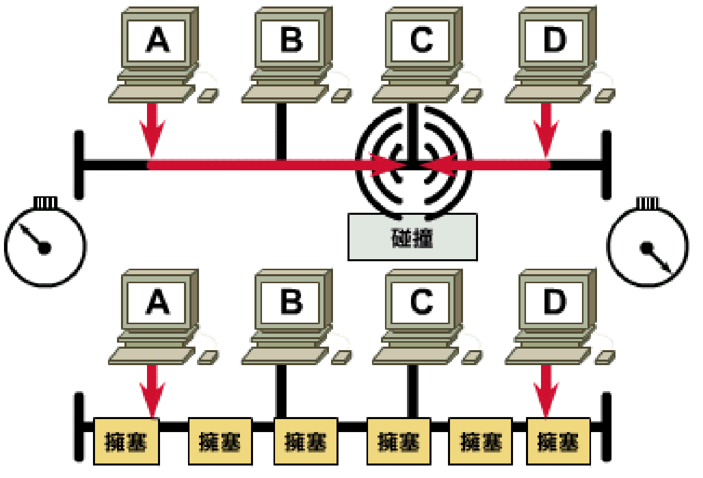
 Modified by LTL

Ethernet MAC Sublayer Protocol

- 碰撞(collision)

BEBA:
Binary Exponential Backoff Algorithm



6.3.5 Types of CSMA/CA

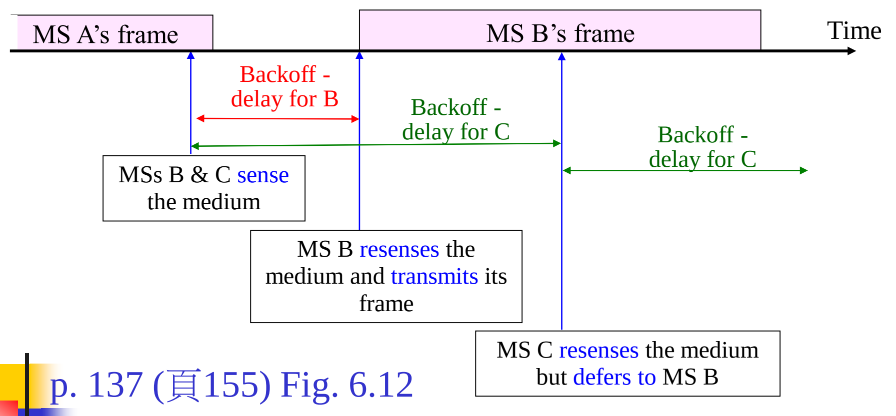
- Types of CSMA/CA
  1) Basic CSMA/CA
  2) CSMA/CA with ACK
  3) CSMA/CA with RTS and CTS

http://www.tkec.com.tw/image/product/201008/109622_M.jpg?w=130&h=130&t=20131209114632

http://www.techforshare.com/wp-content/uploads/2016/01/wifi-logo.jpg

6.3.5. CSMA/CA (CSMA with Collision Avoidance)

- A basic collision avoidance (CA) scheme
- CSMA/CA rule: Backoff before collision (to avoid collisions)



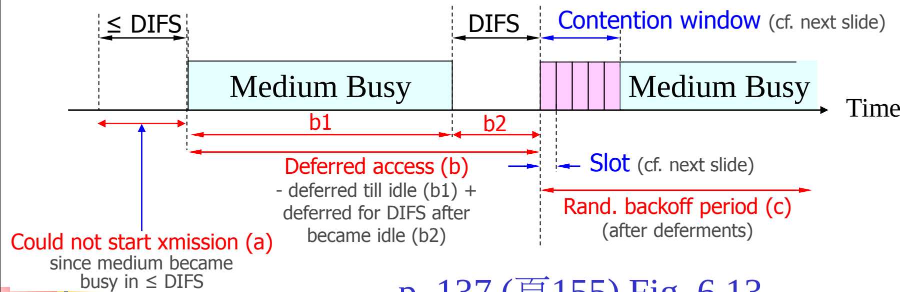
p. 137 (頁155) Fig. 6.12

1) Basic CSMA/CA

- Terminal T senses the medium before xmission

1) If medium is busy, T defers access until the end of current xmission - (b1) in Fig.

2) If medium is idle or once it becomes idle:
  - T defers access for time period DIFS - (a) and (b2) in Fig.
  - T picks a random backoff period - (c) in Fig.
  - As long as medium idle during this backoff period, T keeps counting down
  - Whenever medium busy during this backoff period, T freezes its counter
  - After medium becomes idle again:
    - T defers access for the DIFS period
    - T resumes countdown
  - T can start transmission when backoff counter = 0



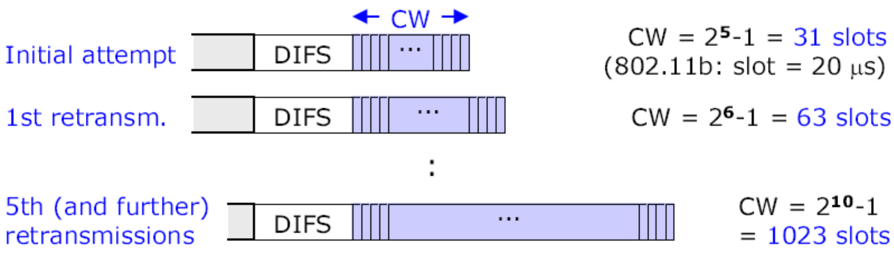
p. 137 (頁155) Fig. 6.13

1) Basic CSMA/CA – cont. 3

Contention Window (CW)

- Recall: Backoff counter is decreased by 1 each time medium is detected to be idle for an interval of one time slot

  => backoff period = backoff number (bn) = # of idle slots within CW to wait before being allowed to transmit a frame
- Random bn value is chosen based on CW size
  - CW_size: 31 - 1023 slots (=> bn can be from 31 to 1032)
  - bn value: uniform distribution over 0 ... CW_size
- If transmission of a frame unsuccessful & frame to be re-transmitted => CW_size is doubled before retran. (up to 1023)

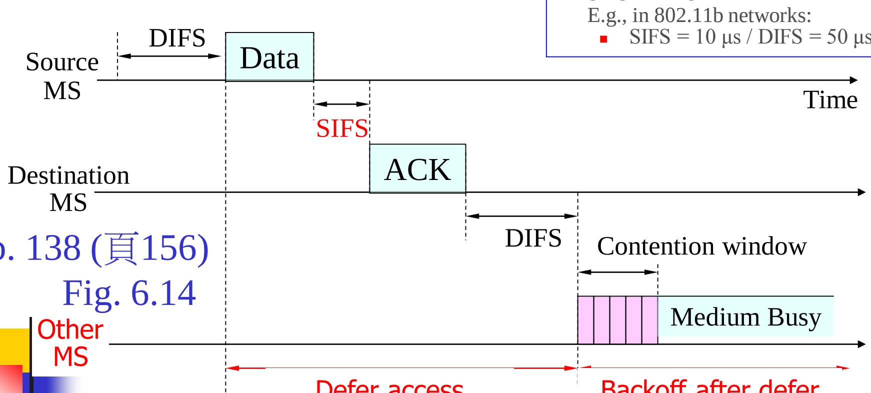


2) CSMA/CA with ACK

- Positive Acknowledgement (ACK) frame from receiver upon reception of each data frame
- ACK sent after receipt + after time interval SIFS
  - SIFS = Short Interframe Space
- Receiver transmits ACK without sensing the medium (cf. next)
- If ACK lost, retransmission of ACK

- SIFS < DIFS

  E.g., in 802.11b networks:
  - SIFS = 10 μs / DIFS = 50 μs



p. 138 (頁156)
Fig. 6.14

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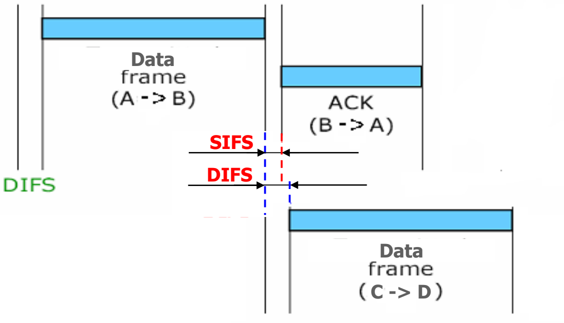
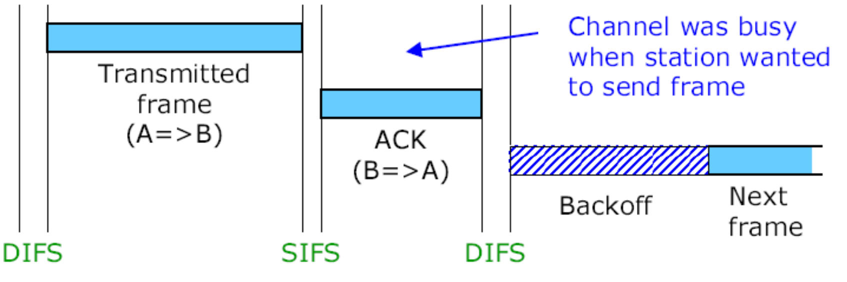
CSMA/CA with ACK – cont. 3

- Recal: SIFS < DIFS -- E.g., in 802.11b: SIFS = 10 μs / DIFS = 50 μs
- When 2 stations try to access the medium at the same time, the one that has to wait for the shorter SIFS period "wins over" the one that has to wait for the longer DIFS period
  - "Wins over" = waits for shorter time
    - Just bec. SIFS < DIFS
- In other words, ACK frame waiting for SIFS has higher priority over Data frame waiting for DIFS
- Now you see why medium "reserved" in quotes - not real reservation, just given an advantage to guarantee it always wins a race



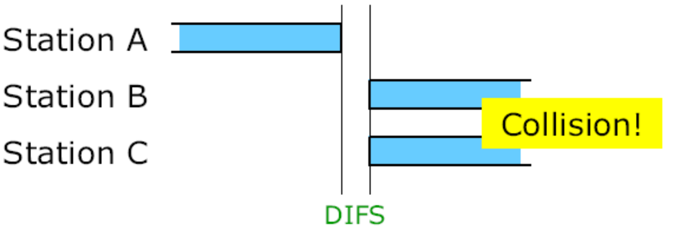
CSMA/CA with ACK – cont. 4



- When Station S wants to send a frame & channel busy
  => S must wait a backoff time before it may to transmit frame
- Reason? Next two slides...

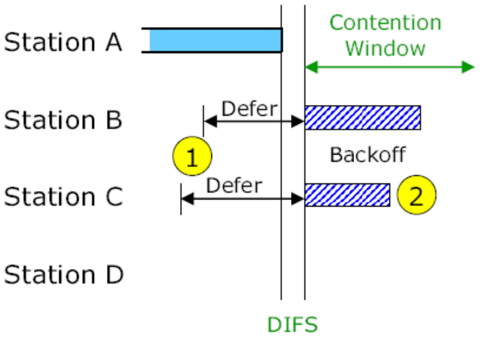
CSMA/CA with ACK – cont. 5

- No backoff => collision is certain
- Suppose that stations B and C waiting to access channel
- When channel becomes idle,
  B & C start sending their packets at the same time
  => collision!



Example for CSMA/CA with ACK

- Four stations: A, B, C, D

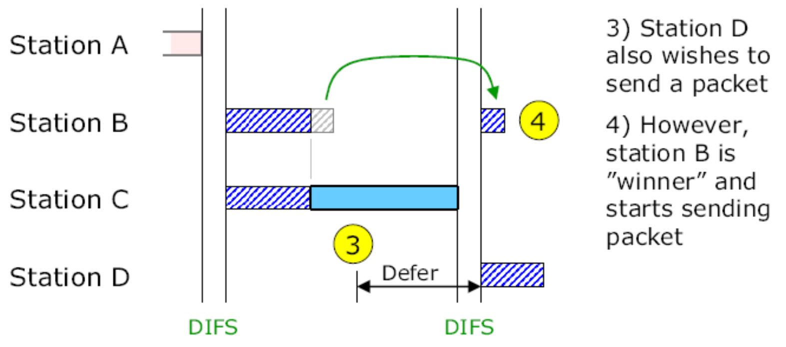


1) While station A is sending a packet, stations B and C also wish to send packets, but have to wait (defer + backoff)

2) Station C is "winner" (backoff time expires first) and starts sending packet

- Observe:
  - C attempts to access medium before B does
    - Coincidentally, C's backoff number is smaller

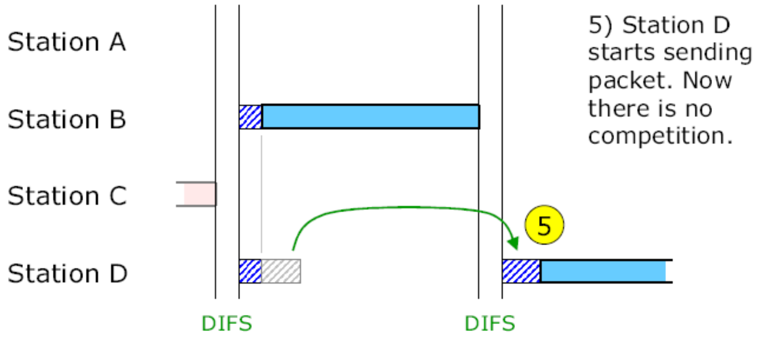
Example for CSMA/CA with ACK – cont. 1



- Observe backoff counter for B:
  - Frozen when medium becomes busy
    - When C starts xmission (when C's backoff counter becomes 0)
  - B resumes countdown when medium becomes idle
    - After C completes its xmission

 (Modified by LTL)

Example for CSMA/CA with ACK – cont. 2

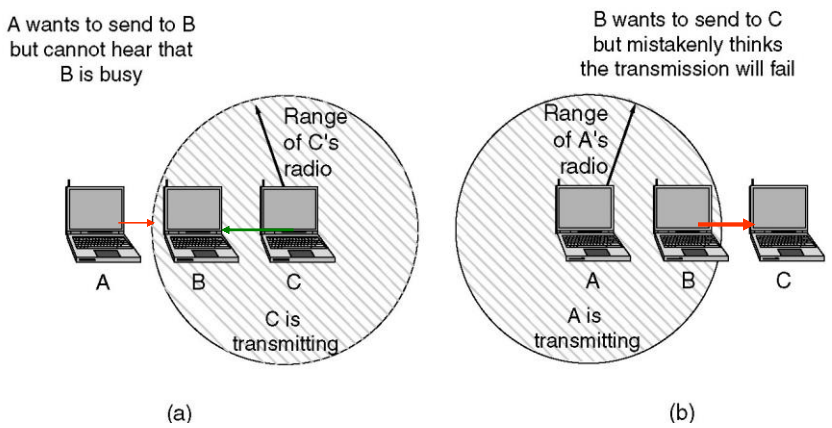


- Observe backoff counter for D:
  - Frozen when medium becomes busy
    - When B starts xmission (when B's backoff counter becomes 0)
  - D resumes countdown when medium becomes idle
    - After B completes its xmission

 (Modified by LTL)

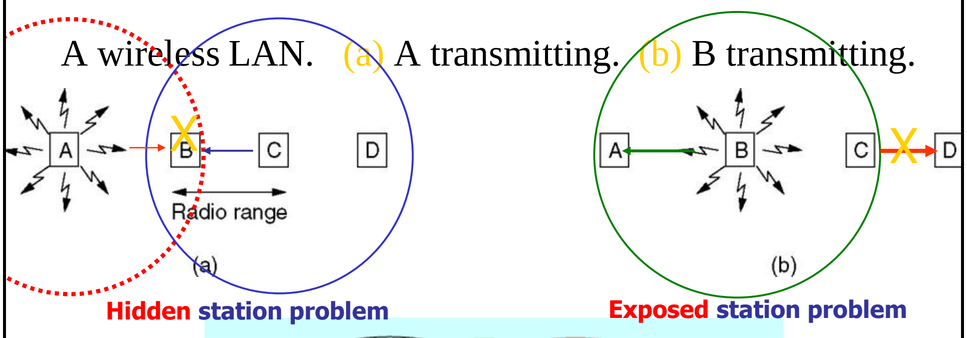
The hidden/exposed station problem (1)

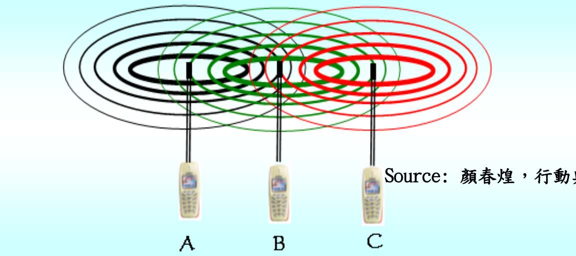
(a) The hidden station problem.
(b) The exposed station problem.



The hidden/exposed station problem (2)

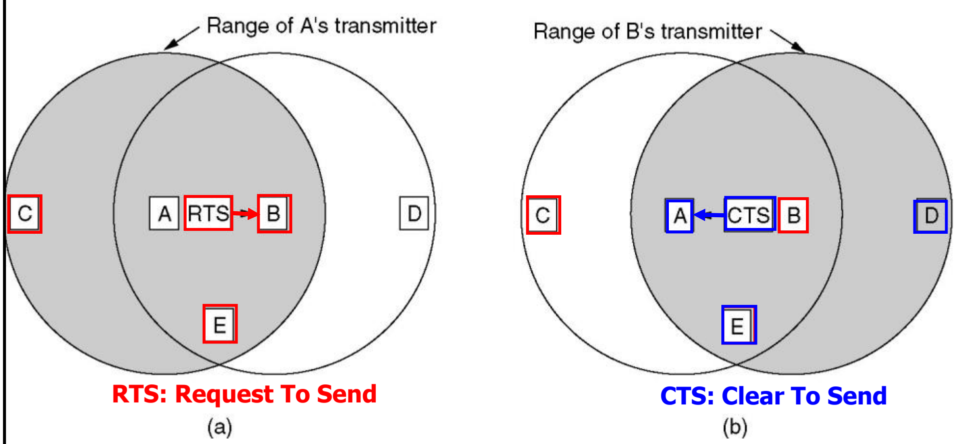
A wireless LAN. (a) A transmitting. (b) B transmitting.





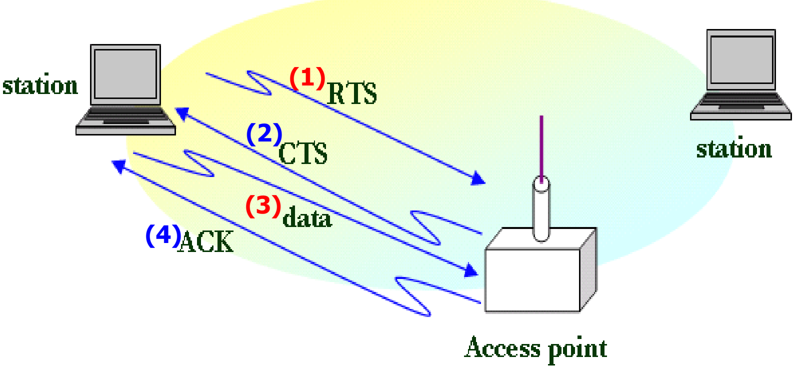
Source: 顏春煌，行動與無線通訊，金禾。

CSMA/CA with RTS & CTS



The MACA (Multiple Access with Collision Avoidance) protocol. (a) A sending an RTS to B. (b) B responding with a CTS to A.

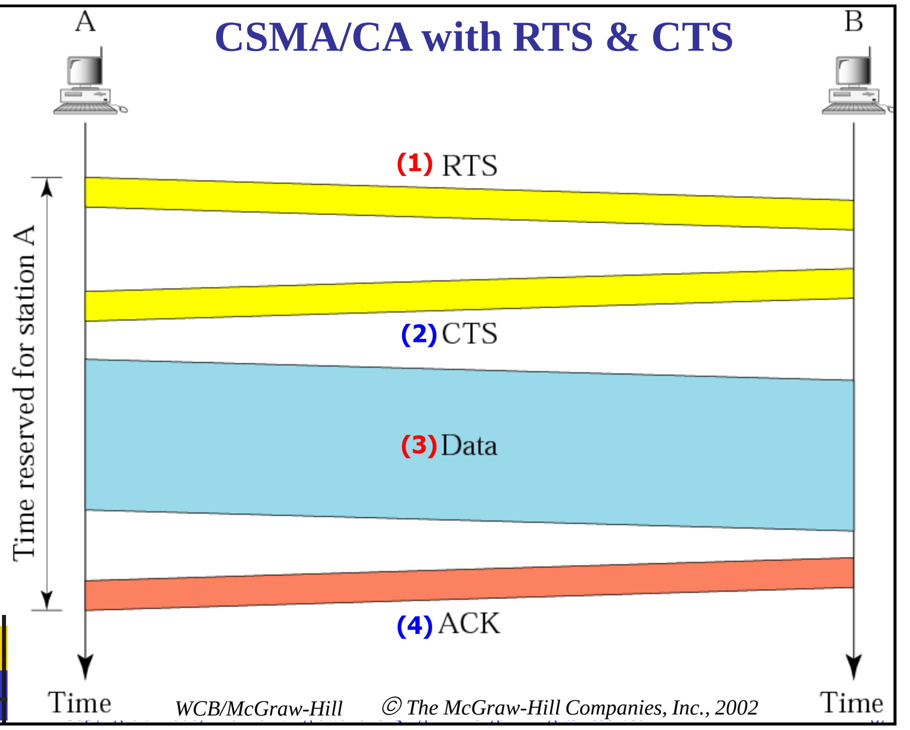
存取點(access point)與節點(station)之間的通訊模式



RTS: Request To Send

CTS: Clear To Send

Source：顏春煌，行動與無線通訊，金禾。



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3) CSMA/CA with RTS and CTS

- Transmitter sends an RTS (Request To Send) after medium has been idle for time interval > DIFS
- Receiver responds with CTS (Clear To Send) after medium has been idle for SIFS
- Data can be transmitted (after SIFS)
- ACK sent after SIFS

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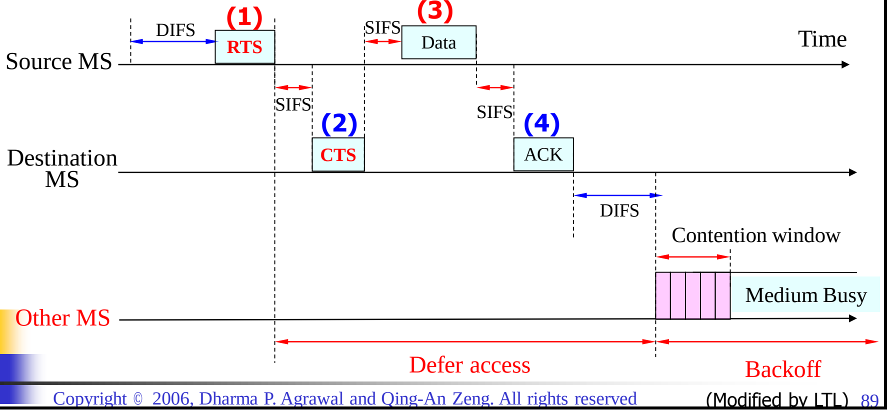
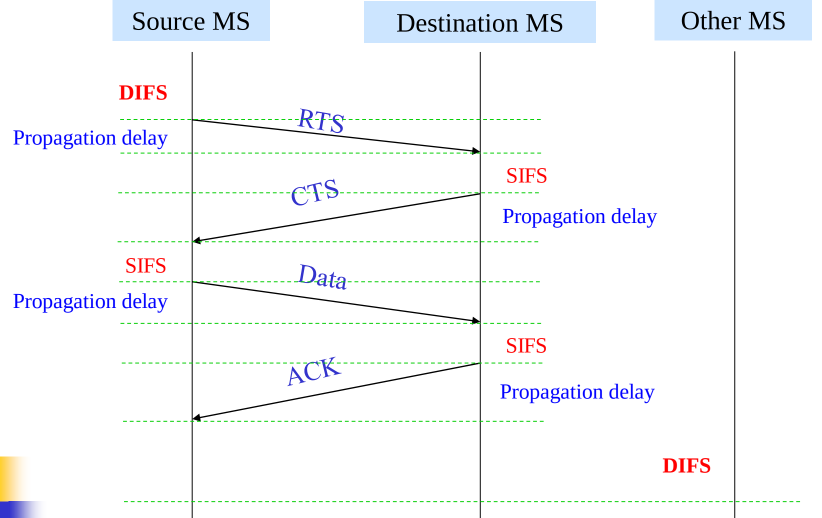


 (Modified by LTL) 89

3) CSMA/CA with RTS and CTS – cont. 1a

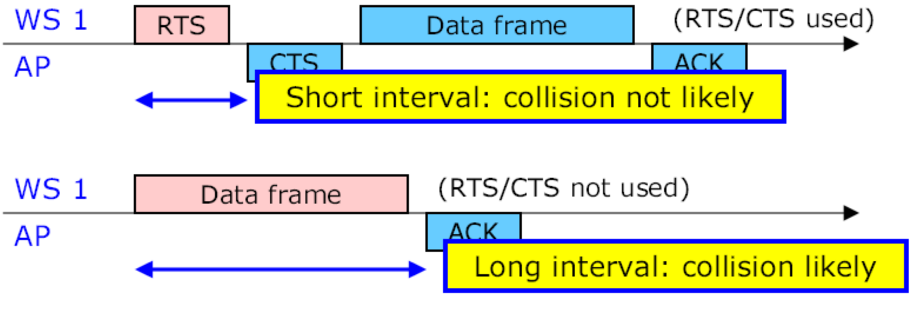
Ladder Diagram for CSMA/CA with RTS/CTS

Compare this diagram to the previous one



Advantages of RTS & CTS

- Advantage #1 of RTS/CTS:
  Reduces collision probability if the data frame is very long compared to the RTS frame
  - Does not prevent collisions during very short RTS frames
    - Not a big problem - they are not very likely
  - Prevents more likely collisions during long data frame



The End of Section 6

Exercises:

P6.10 碰撞偵測(Collision detection)與碰撞避免(Collision avoidance)的差異為何?

P6.11 在CSMA/CA使用RTS/CTS的目的為何?

P6.21 利用您喜愛的網站搜尋，找出何謂隱藏終端節點問題與暴露節點問題，請詳加描述您如何處理這種問題。