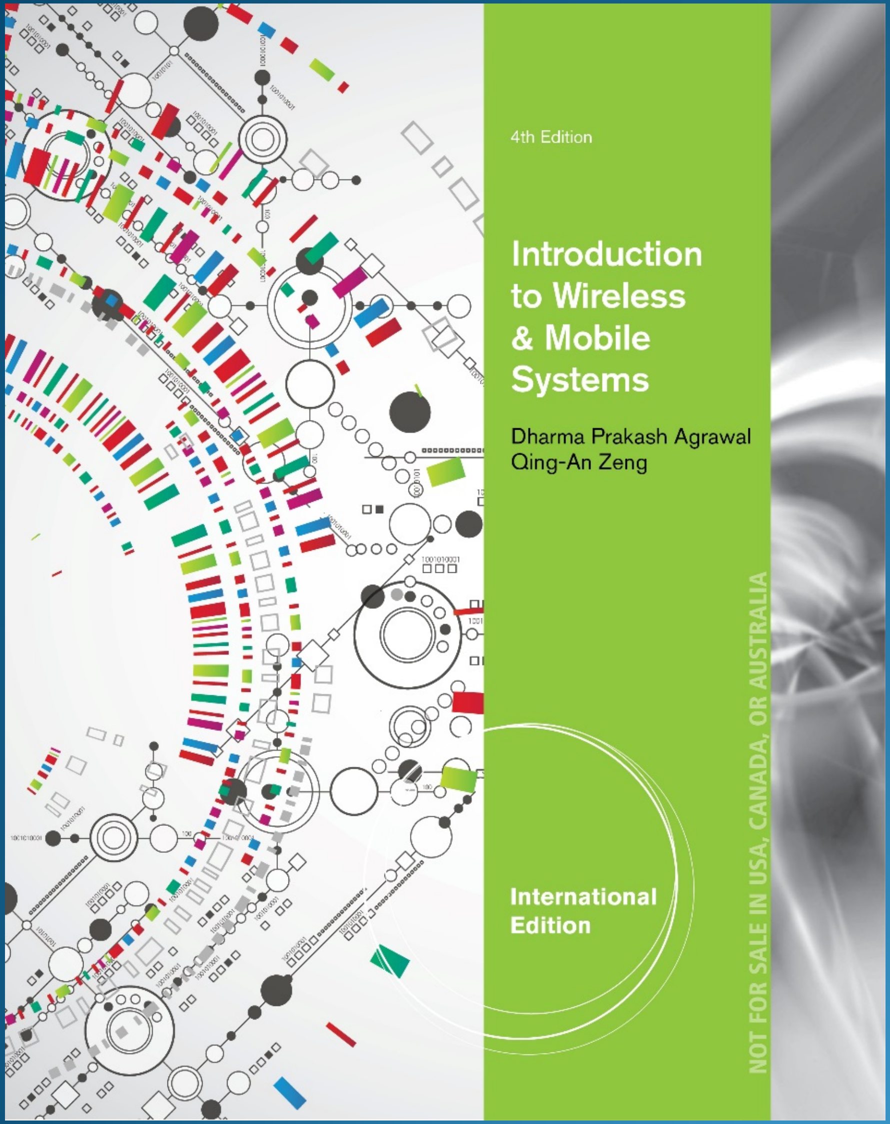


Chapter 6

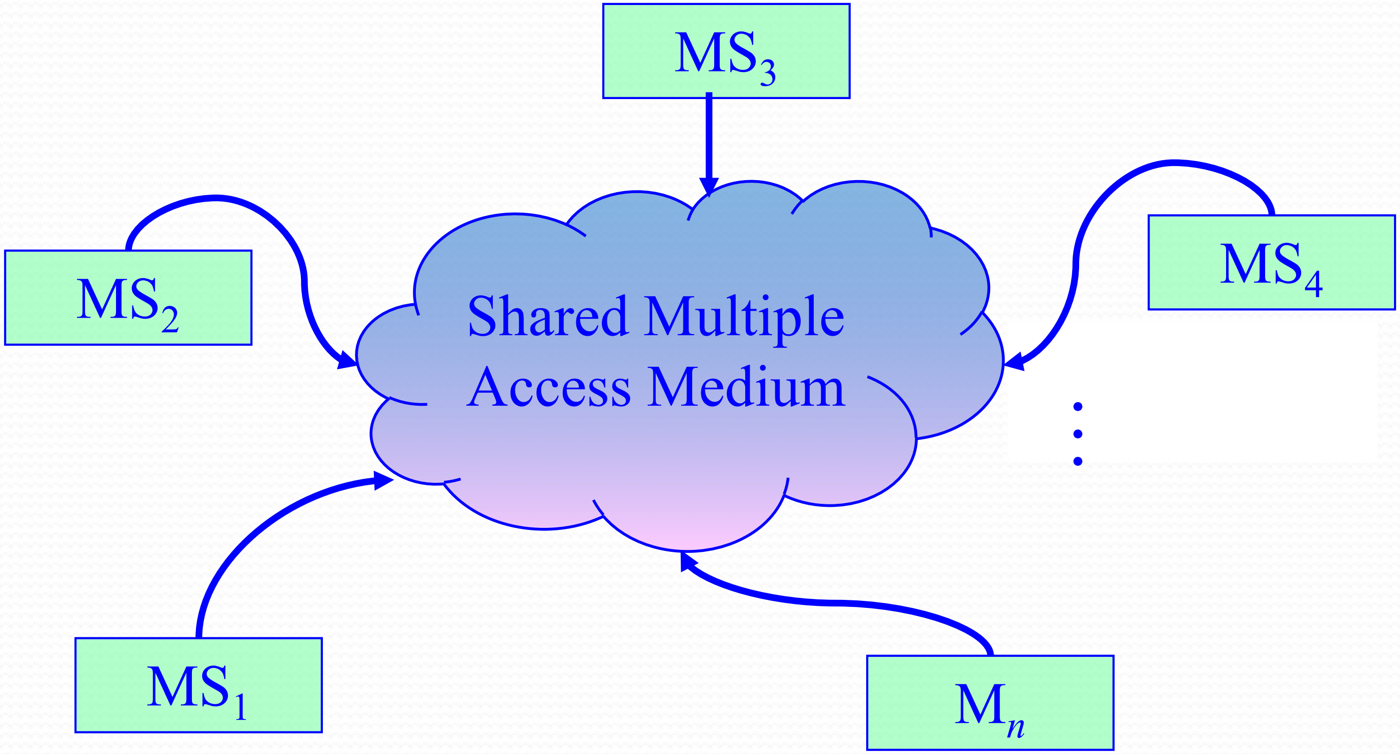
Multiple Radio Access

Outline

- Introduction
- Multiple Radio Access Protocols
- Contention-based Protocols
  - Pure ALOHA
  - Slotted ALOHA
  - CSMA (Carrier Sense Multiple Access)
  - CSMA/CD (CSMA with Collision Detection)
  - CSMA/CA (CSMA with Collision Avoidance)
- Summary

Introduction

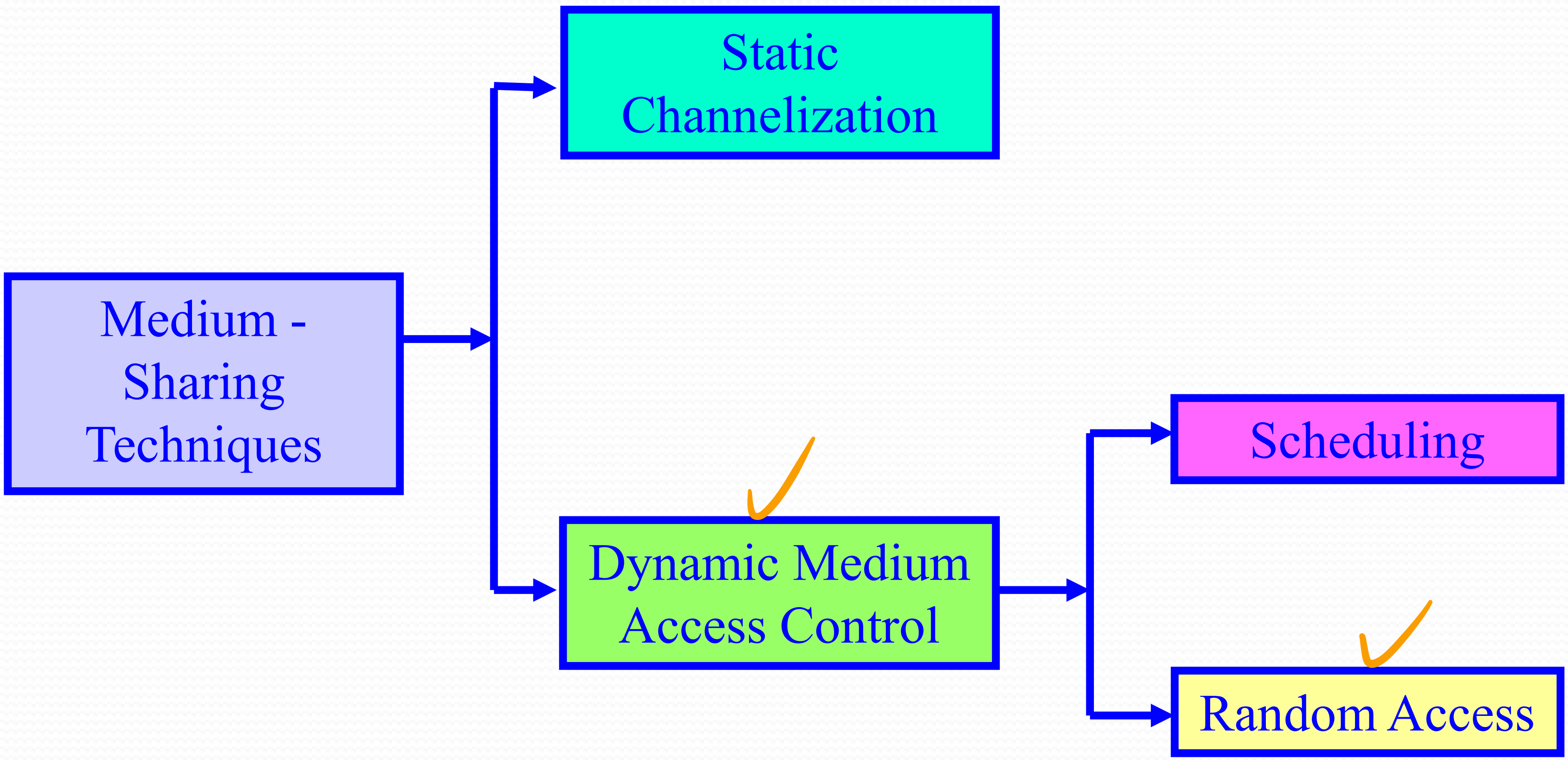
- Multiple access control channels
  - Each Mobile Station (MS) is attached to a transmitter or receiver which communicates via a channel shared by other nodes
  - Transmission from any MS is received by other MSs



Introduction (Cont'd)

- Multiple access issues
  - If more than one MS transmit at a time on the control channel to BS, a collision occurs
  - How to determine which MS 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
    - Collision-free protocols (e.g., a bit-map protocol and binary countdown) ensure that a collision can never occur

Channel Sharing Techniques



Classification of Multiple Access Protocols

- Multiple-access protocols
  - Contention-based
    - Random access
      - ALOHA, CSMA, BTMA, ISMA, etc.
    - Collision resolution
      - TREE, WINDOW, etc.
  - Conflict-free
    - FDMA, TDMA, CDMA, Token Bus, DQDB, etc.

BTMA: Busy Tone Multiple Access
ISMA: Internet Streaming Media Alliance

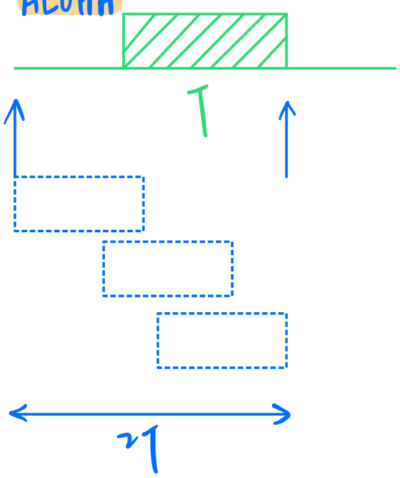
DQDB: Distributed Queue Dual Bus

Contention-based Protocols

①有data就傳送

- **ALOHA** ②若collision,則等一時間後重傳
  - Developed in the 1970s for a packet radio network by Hawaii University
  - Whenever a terminal (MS) has data, it transmits. Sender finds out whether transmission was successful or experienced a collision by listening to the broadcast from the destination station. If there is a collision, sender retransmits after some random time
- **Slotted ALOHA**
  - Improvement: Time is slotted and a packet can only be transmitted at the beginning of one slot. Thus, it can reduce the collision duration

★ · ALOHA



$G = \frac{\lambda}{\mu} = \lambda T$: offered load (平均一秒有多少package)

$P_n(t) = P_0(2T)$ 成功傳出的機率

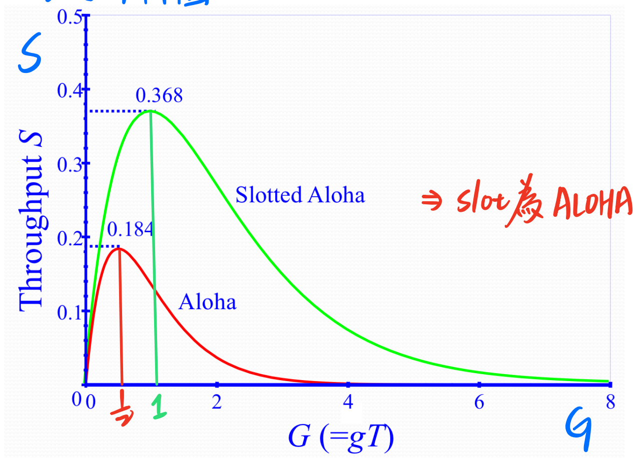
$= \frac{e^{-\lambda 2T}\cdot(\lambda 2T)^0}{0!} = e^{-2\lambda T} = e^{-2G}$

S = throughput $= G \cdot e^{-2G}$

$\frac{\partial S}{\partial G} = e^{-2G} - 2Ge^{-2G} = 0 \Rightarrow G = \frac{1}{2}$ 極值

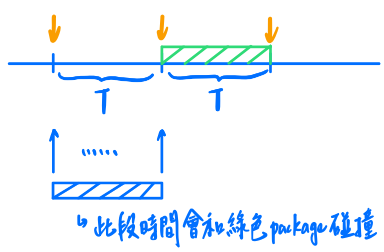
$\Rightarrow S = \frac{1}{2} \cdot e^{-2\cdot\frac{1}{2}} = 0.184 \Rightarrow 18.4\%$

* S對G作圖:



⇒ slot為ALOHA 2倍

· Slotted ALOHA: 在指定的時間點才能傳資料



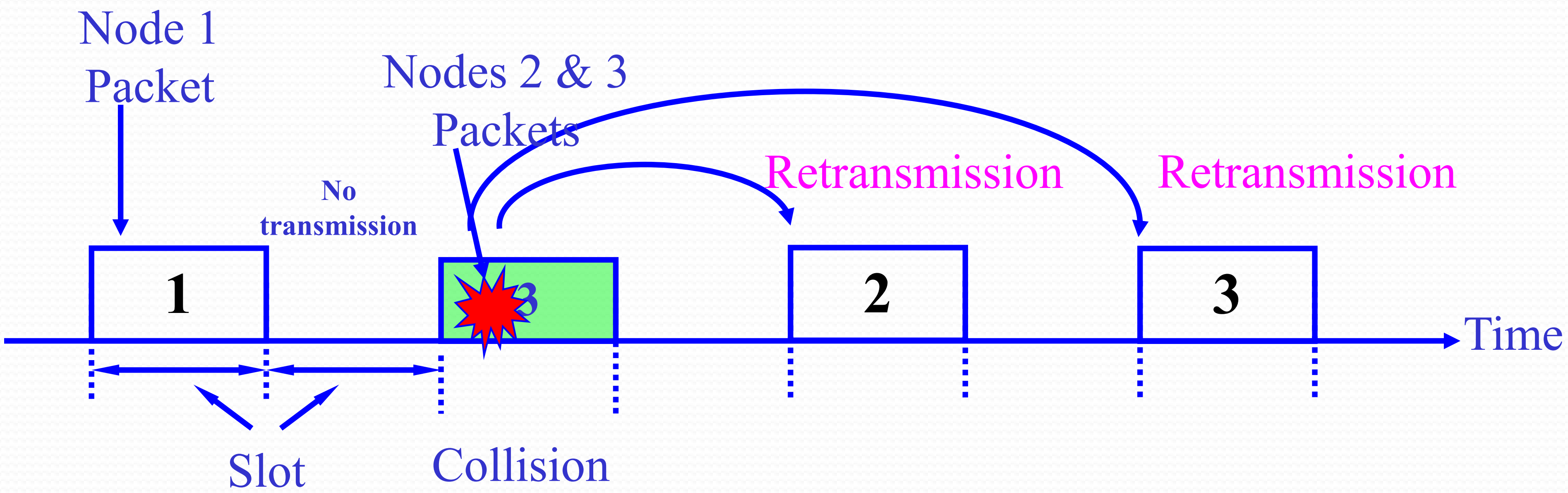
$P_n(t) = P_0(T) = \frac{e^{-\lambda T}(\lambda T)^0}{0!} = e^{-G}$

S_2 = throughput $= G \cdot e^{-G}$

$\frac{\partial S_2}{\partial G} = e^{-G} - Ge^{-G} = 0$ 極值 $\Rightarrow G = 1$

$\Rightarrow S_2 = e^{-1} = 0.368 = 36.8\%$

Slotted ALOHA



Collision mechanism in slotted ALOHA

Throughput of Slotted ALOHA

- The probability of successful transmission P_s is the probability no other packet is scheduled in an interval of length T

$$P_s = e^{-gT}$$

where g is the packet rate of the traffic

- The throughput S_{th} of pure Aloha as:

$$S_{th} = gTe^{-gT}$$

- Defining $G = gT$ to normalize offered load, we have

$$S_{th} = Ge^{-G}$$

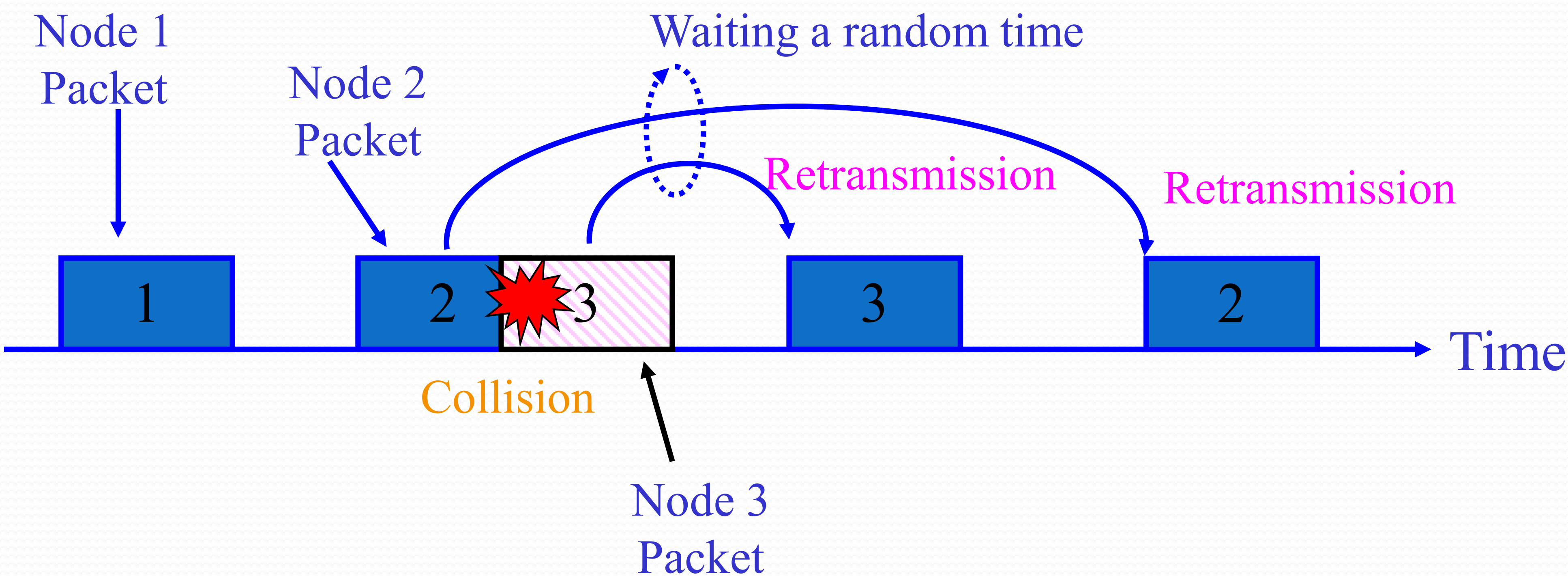
- Differentiating S_{th} with respect to G and equating to zero gives

$$\frac{dS_{th}}{dG} = -Ge^{-G} + e^{-G} = 0$$

- The Maximum throughput of ALOHA is

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

Pure ALOHA



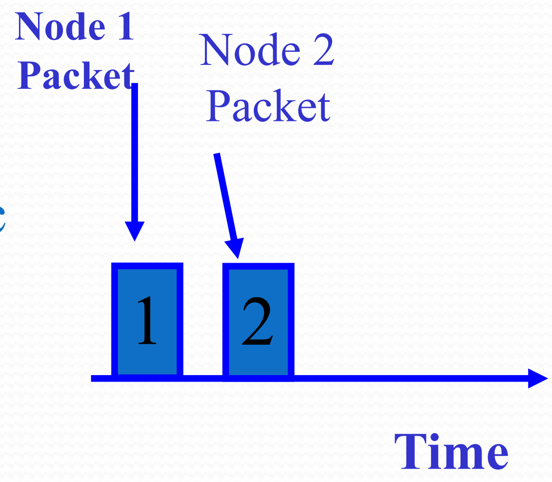
Collision mechanism in ALOHA

Throughput of Pure ALOHA

- The probability of successful transmission P_s is the probability no other packet is scheduled in an interval of length $2T$

$$P_s = P(no\_collision)$$
$$= e^{-2gT}$$

where g is the packet rate of the traffic



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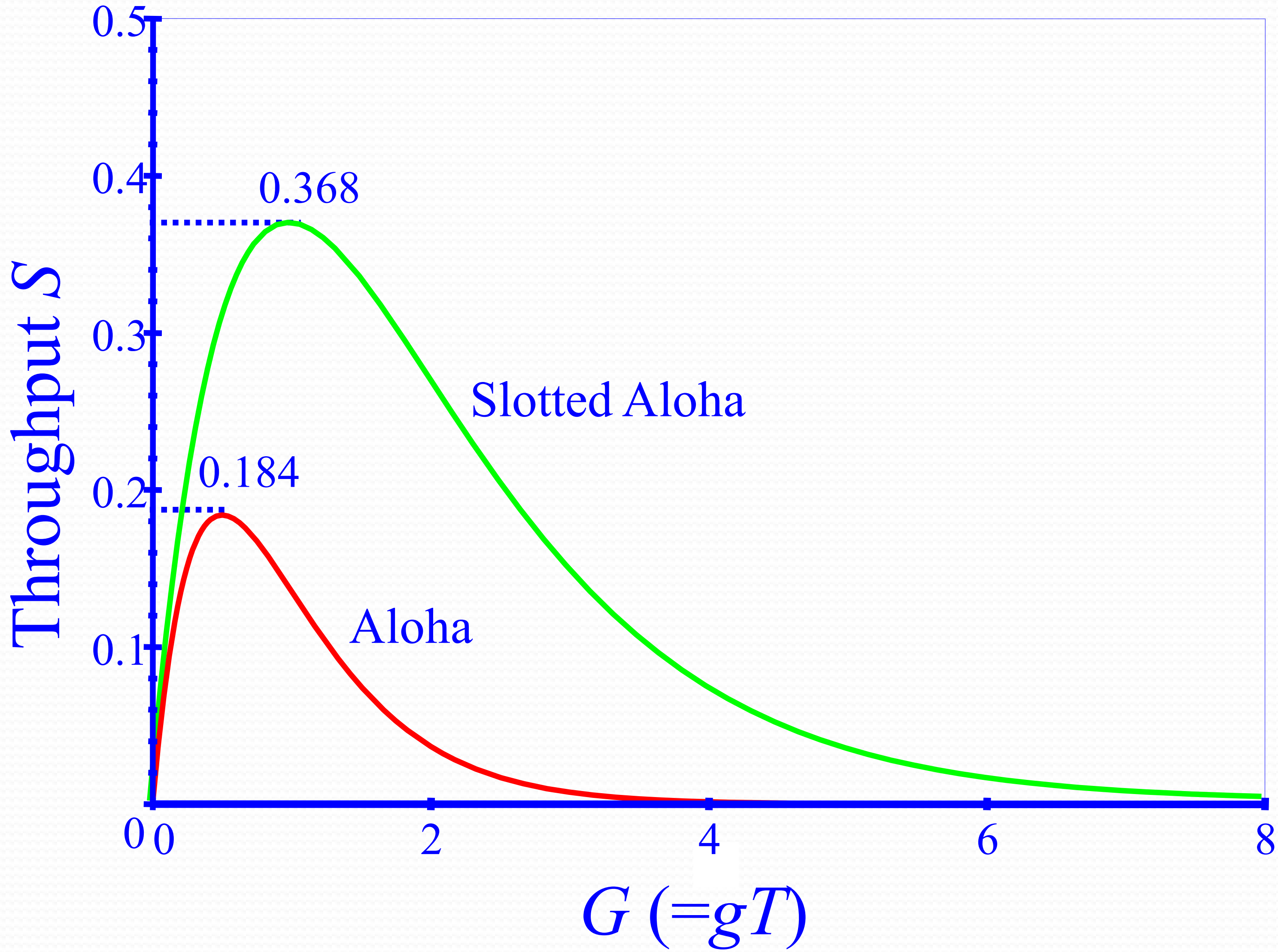
$$\frac{dS_{th}}{dG} = -2Ge^{-2G} + e^{-2G} = 0$$

- The Maximum throughput of ALOHA is

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

Throughput


0.5
0.4
0.3
0.2
0.1
0
0.368
0.184
Slotted Aloha
Aloha
Throughput S
0
2
4
6
8
G (=gT)

Contention Protocols (Cont'd)

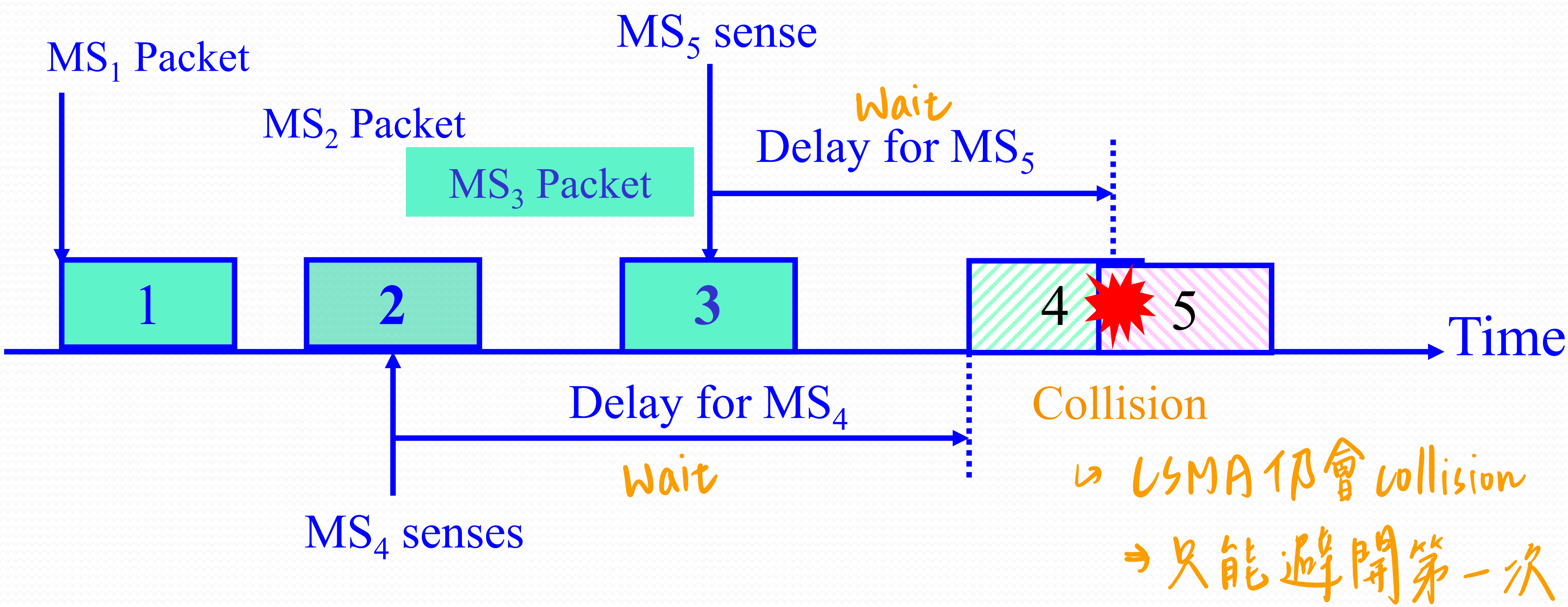
- **CSMA (Carrier Sense Multiple Access)**
  - Improvement: Start transmission only if no transmission is ongoing ↳ 傳之前確定沒人在傳 (carrier sense)
- **CSMA/CD (CSMA with Collision Detection)**
  - Improvement: Stop ongoing transmission if a collision is detected
- **CSMA/CA (CSMA with Collision Avoidance)**
  - Improvement: Wait a random time and try again when carrier is quiet. If still quiet, then transmit
- **CSMA/CA with ACK**
- **CSMA/CA with RTS/CTS**

CSMA (Carrier Sense Multiple Access)

- Max throughput achievable by slotted ALOHA is 0.368
- CSMA gives improved throughput compared to Aloha protocols
- Listens to the channel before transmitting a packet (avoid avoidable collisions)

① 傳之前確定沒人在傳(carrier sense),否則就wait
② 有data就傳送
③ 若collision,則等一時間後重傳

Collision Mechanism in CSMA



Kinds of CSMA CSMA家族

- CSMA
  - Nonpersistent CSMA (no wait) 不等
    - Unslotted Nonpersistent CSMA
    - Slotted Nonpersistent CSMA
      ↳有時槽
  - Persistent CSMA (wait) 等待
    - Unslotted persistent CSMA
    - Slotted persistent CSMA
      ↳有時槽
    - 1-persistent CSMA
    - *p*-persistent CSMA
      ↳P值越小，throughput越不易減少

p-persistent CSMA Protocols

- ***p*-persistent CSMA Protocol:**

Step 1: If the medium is idle, transmit with probability *p*, and delay for worst case propagation delay by one packet with probability (1-*p*)

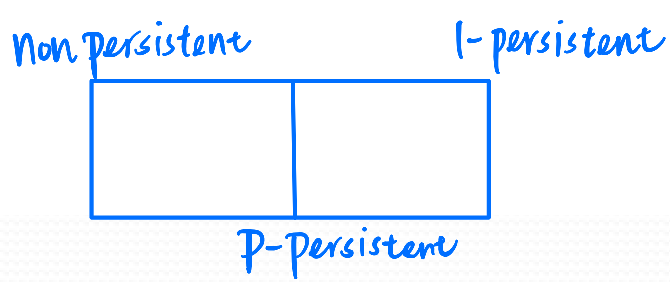
↳ 等一個 slot (1-p 的機率)

Special case of p=0 and p=1

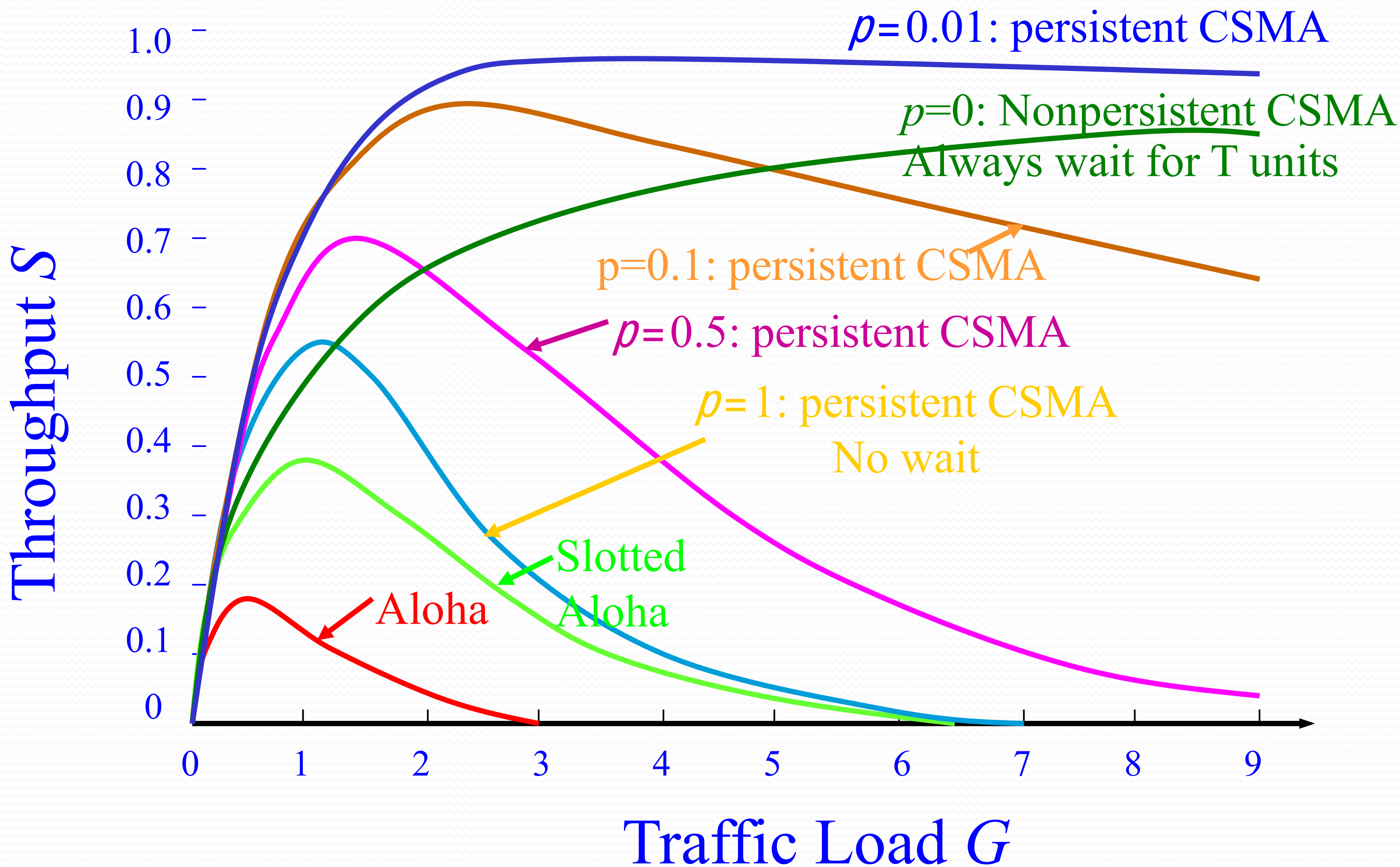
Step 2: If the medium is busy, continue to listen until medium becomes idle, then go to Step 1

Step 3: If transmission is delayed by one time slot, continue with Step 1

- p=0: nonpersistent and p=1: 1-persistent CSMA
- A good tradeoff between nonpersistent and 1-persistent CSMA



Throughput



p=0.01: persistent CSMA
p=0: Nonpersistent CSMA
Always wait for T units
p=0.1: persistent CSMA
p=0.5: persistent CSMA
p=1: persistent CSMA
No wait
Slotted
Aloha
Aloha
Throughput S
Traffic Load G
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9

Nonpersistent/*p*-persistent CSMA Protocols

- **Nonpersistent CSMA Protocol:**

→用 carrier sense 判斷

Step 1: If the medium is idle, transmit immediately (same as p=1)

Step 2: If the medium is busy, wait a random amount of time and repeat Step 1

- Random backoff reduces probability of collisions
- Waste idle time if the backoff time is too long

參考

For unslotted nonpersistent CSMA, the throughput is given by:

$$S_{th} = \frac{Ge^{-2\alpha T}}{G(1+2\alpha)+e^{-\alpha G}} \qquad where\ \alpha = \frac{\tau}{T} = \frac{propagation\ delay}{packet\ transmission\ time}$$

For slotted nonpersistent CSMA, the throughput is given by:

$$S_{th} = \frac{\alpha Ge^{-2\alpha T}}{(1-e^{-\alpha G}+\alpha)}$$

1-persistent CSMA Protocols

1-persistent CSMA Protocol:

Step 1: If the medium is idle, transmit immediately

Step 2: If the medium is busy, continue to listen until medium becomes idle, and then transmit immediately ↳一等到idle就馬上傳

- There will always be a collision if two nodes want to retransmit (usually you stop transmission attempts after few tries)

參考 ↳若遇到2個人同時在等待，則必會碰撞

For unslotted 1-persistent CSMA, the throughput is given by

$$S_{th} = \frac{G\left[1+G+\alpha G(1+G+\alpha G/2)\right]e^{-G(1+2\alpha)}}{G(1+2\alpha)-(1-e^{-\alpha G})+(1+\alpha G)e^{-G(1+\alpha)}}$$

For slotted 1-persistent CSMA, the throughput is given by

$$S_{th} = \frac{G(1+\alpha-e^{-\alpha G})e^{-G(1+\alpha)}}{(1+\alpha)(1-e^{-\alpha G})+\alpha e^{-G(1+\alpha)}}$$

How to Select Probability *p*?

- Assume that N nodes have a packet to send and the medium is busy
- *Then*, Np is the expected number of nodes that will attempt to transmit once the medium becomes idle
- If $Np > 1$, then a collision is expected to occur

Therefore, network must make sure that to avoid collision, where N is the maximum number of nodes that can be active at a time

p-persistent CSMA Protocol

If N terminals have packets to send, Np terminals will attempt to transmit once the medium becomes idle. If Np>1, then collision is expected. Therefore, Np 1. Throughput S as:

参考

$$S_{th}(G,p,\alpha)=\frac{(1-e^{-\alpha G})\left[P_s^{'}\pi_0+P_s(1-\pi_0)\right]}{(1-e^{-\alpha G})[\alpha\overline{t'}\pi_0+\alpha\overline{t}(1-\pi_0)+1+\alpha]+\alpha\pi_0}$$

where G is offered traffic rate

$\alpha=\tau/T=$ propagation delay/packet transmission time

where $P_s^{'}, P_s, \overline{t'}, \overline{t}$ and π_0 are given by the following equations:

$$P_s^{'}=\sum_{n=1}^{\infty}P_s(n)\pi_n^{'} \qquad P_s=\sum_{n=1}^{\infty}P_s(n)\frac{\pi_n}{1-\pi_0}$$

$$\overline{t'}=\sum_{n=1}^{\infty}\overline{t_n}\pi_n^{'} \qquad \overline{t}=\sum_{n=1}^{\infty}\overline{t_n}\frac{\pi_n}{1-\pi_0}$$

p-persistent CSMA Protocol

Where:

$$\pi_n = \frac{[(1+\alpha)G]^n}{n!} e^{-(1+\alpha)G}, n \geq 0, \quad P_s(n) = \sum_{l=n}^{\infty} \frac{lp(1-p)^{l-1}}{1-(1-p)^l} \Pr\{L_n = l\}$$

$$\pi'_n = \frac{g^n e^{-g}}{n!(1-e^{-g})}, n \geq 1 \qquad \bar{t}_n = \sum_{k=0}^{\infty} \Pr\{\overline{t_n} > k\}$$

$$where \quad \Pr\{L_n = l\} = \sum_{k=1}^{\infty} \frac{(kg)^{l-n}}{(l-n)!} e^{-kg} \quad \Pr\{t_n = k\} + [1-(1-p)^n]\delta_{l,n}, l \geq n$$

and $\delta_{i,j}$ is the Kronecker *delta.*

CSMA/CD (CSMA with Collision Detection)

- In CSMA, if 2 terminals begin sending packet at the same time, each will transmit its complete packet (although collision is taking place)
- Wasting medium for an entire packet time
- **CSMA/CD:** ⇒ Ethernet (乙太網路) IEEE 802.3 (token bus)

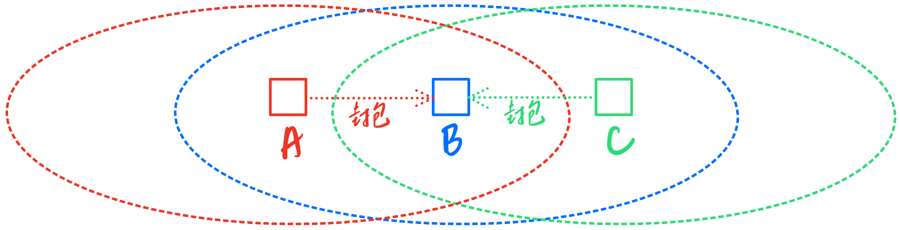
Step 1: If the medium is idle, transmit

Step 2: If the medium is busy, continue to listen until the channel is idle then transmit

Step 3: If a collision is detected during transmission, cease transmitting (detection not possible by wireless devices) ↳ 偵測碰撞 (一碰就停)

Step 4: Wait a random amount of time and repeats the same algorithm ↳ 等一下再用

§ Hidden terminal problem (HTP)

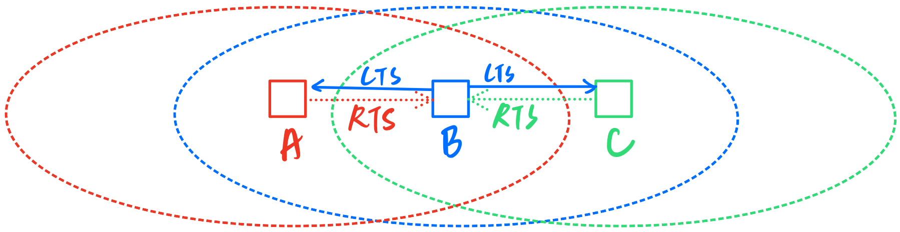


* A & C in B's range
* B is in A range, but not C
* B is in C range, but not A

When A → B & C → B at same time, collision occur!
(B一直收到A和C互相干擾的封包，且A和C互為 hidden terminal)

↳ CSMA/CD failed

- Solution



* RTS: request to send (註明 sender A, receiver B)
* CTS: clear to send (註明 sender B, receiver A)

- Priority waiting:
  - PIFS (point interframe space)
  - SIFS (small interframe space)
  - DIFS (distributed interframe space)
  - EIFS (extended interframe space)

↑ 高優先權

- Acknowledgement
- Back off: Freeze + resume

CSMA/CD in Ethernet (Cont'd)

T_0 — A begins transmission

$\boxed{T_0+\tau}-\varepsilon$ — B begins transmission

↳ A送達

$T_0+\tau+\boxed{\tau_{cd}}$ — B detects collision ⇒ stop

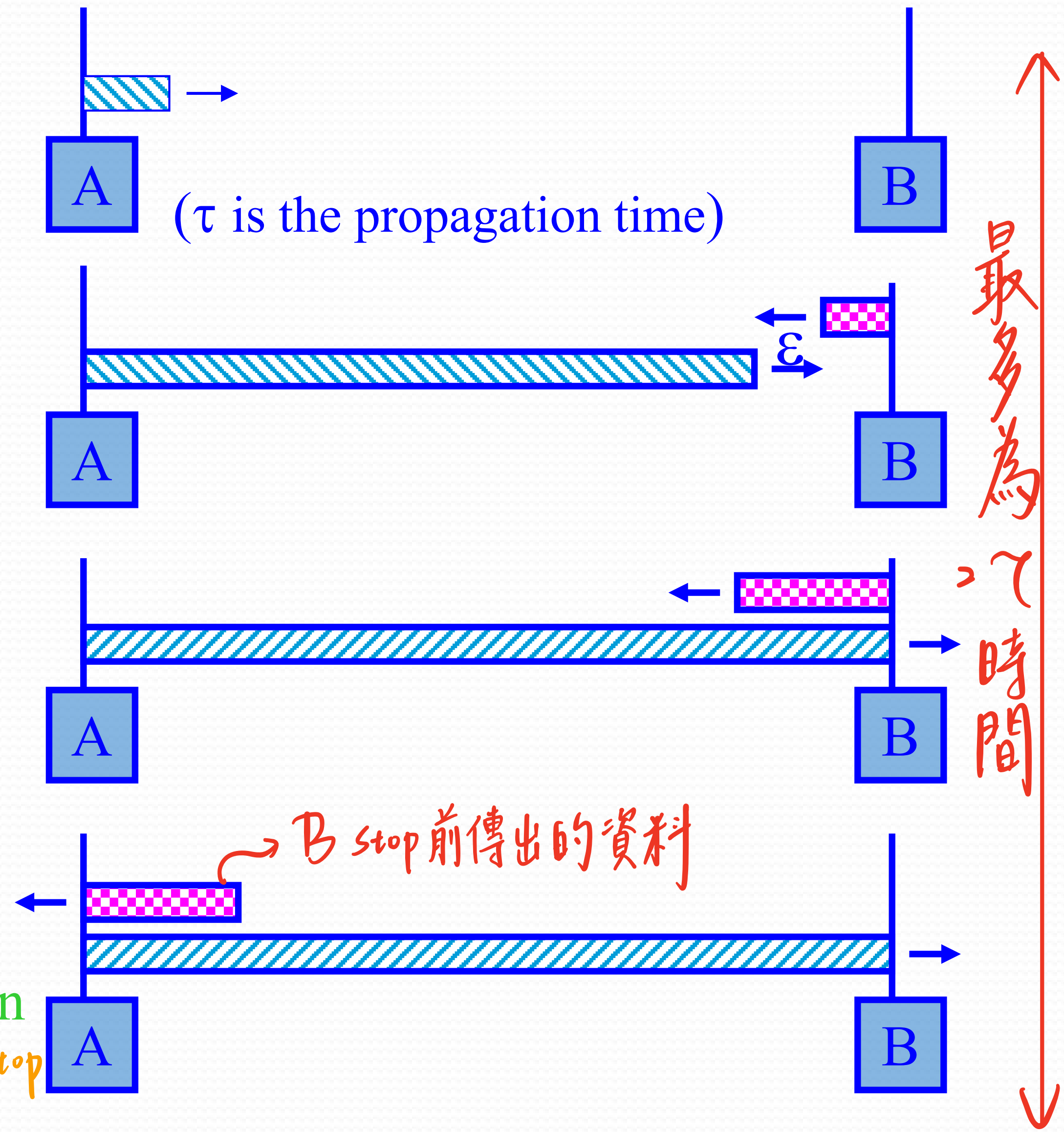
↳ B collision detection 時間

$T_0+2\tau+\tau_{cd}+\tau_{cr}-\varepsilon$ — A detects collision just before end of transmission

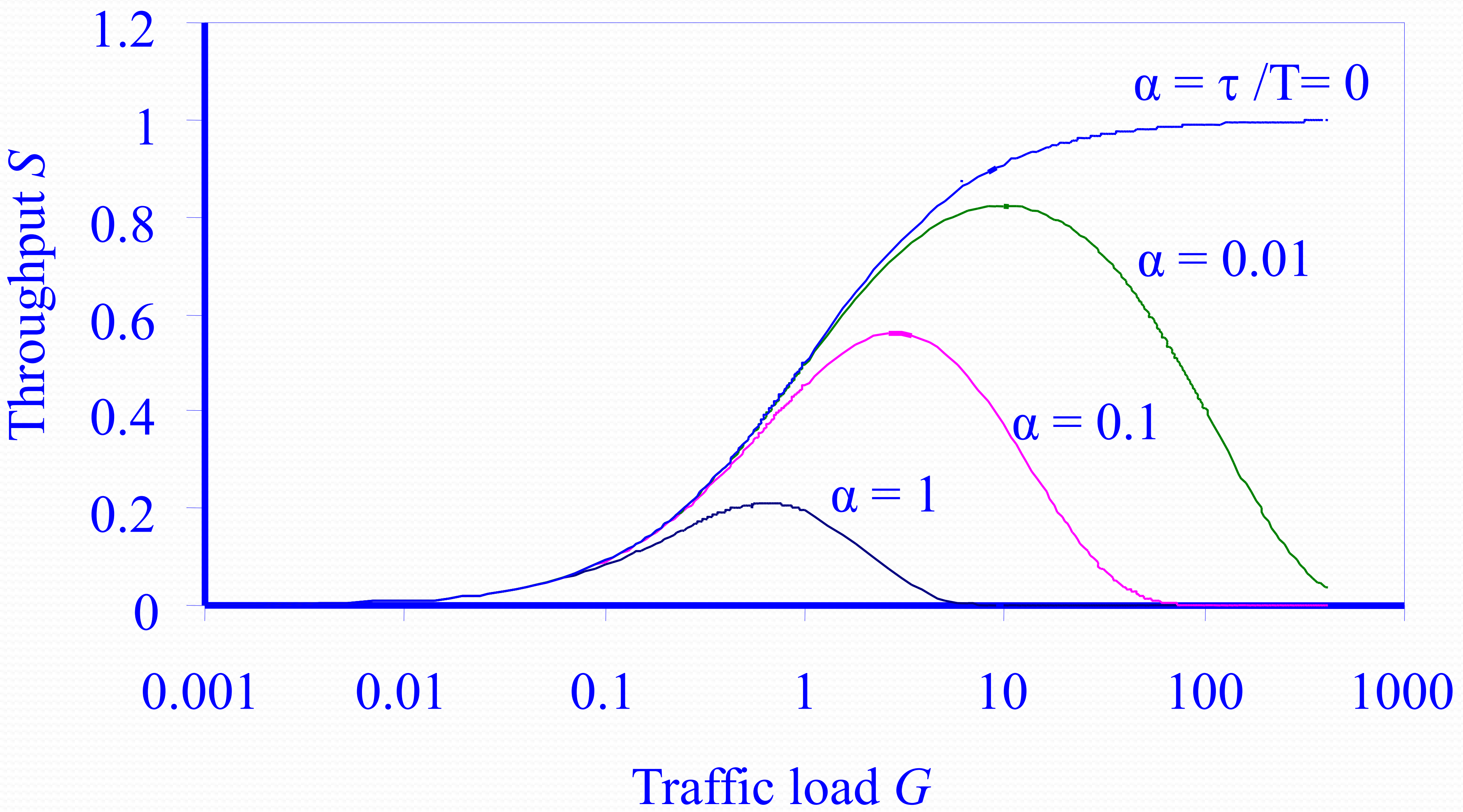
↳ concensus reinforcement

↳ A看到碰撞後才stop

Time



Throughput of Slotted Nonpersistent CSMA/CD

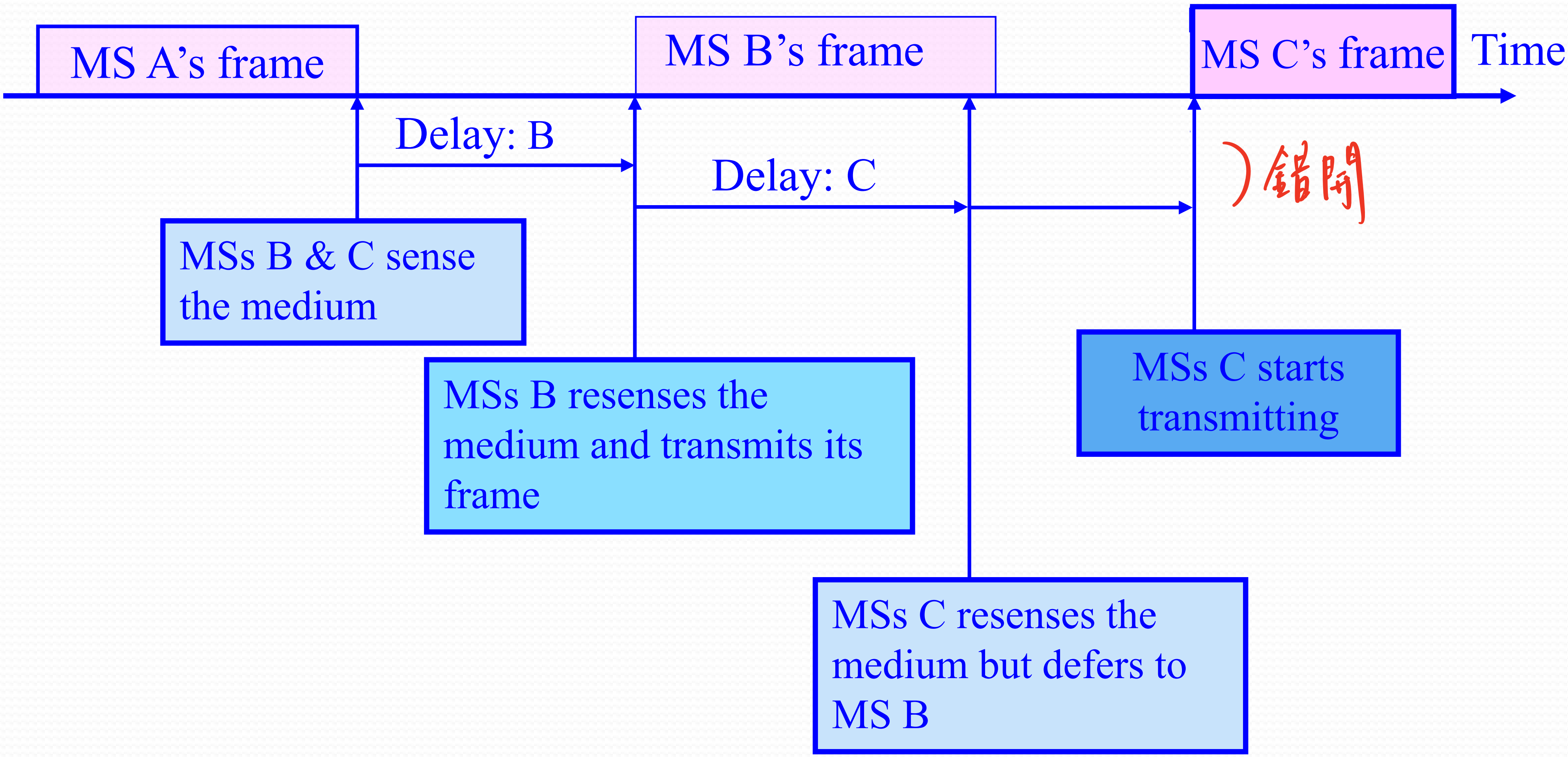


CSMA/CA (CSMA with Collision Avoidance)

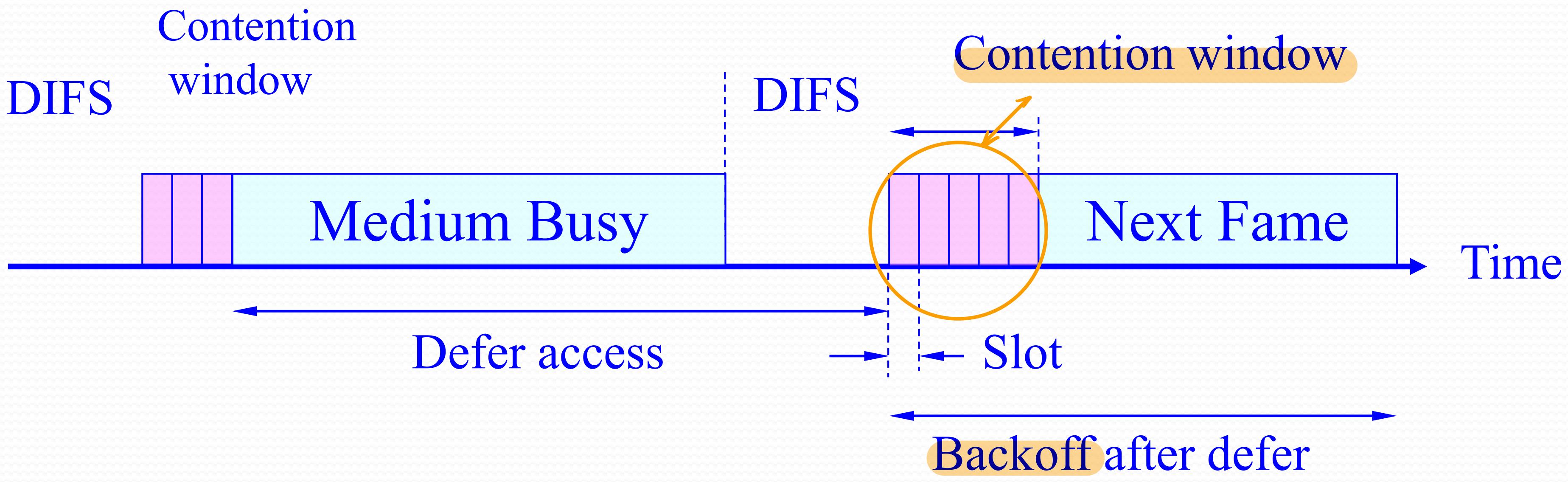
↳ 802.11 = WIFI

- All terminals listen to the same medium as CSMA/CD
- Terminal ready to transmit senses the medium
- If medium is busy it waits until the end of current transmission
- It again waits for an additional predetermined time period DIFS (Distributed inter frame Space)
- Then picks up a random number of slots (the initial value of backoff counter) within a contention window to wait before transmitting its frame
- If there are transmissions by other MSs during this time period (backoff time), the MS freezes its counter
- It resumes count down after other MSs finish transmission plus DIFS. The MS can start its transmission when the counter reaches to zero

CSMA/CA (Cont'd)

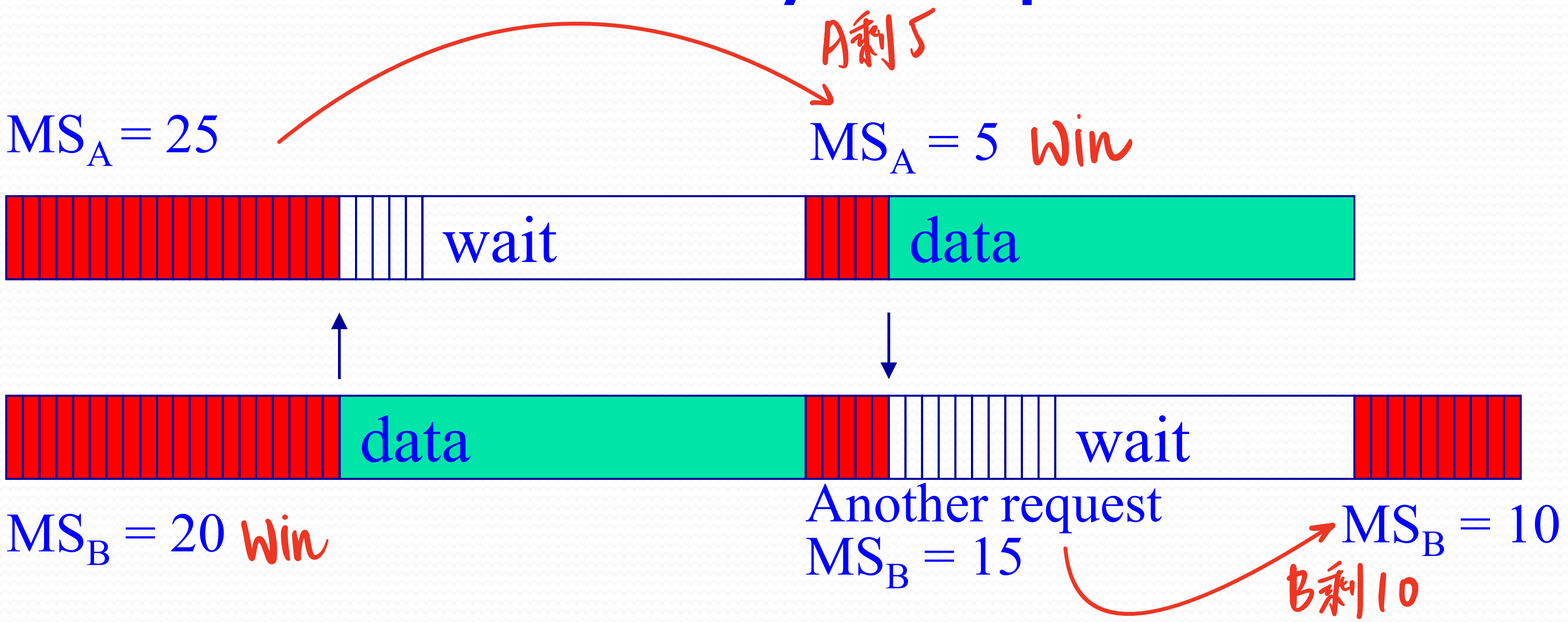


CSMA/CA Explained



DIFS – Distributed Inter Frame Spacing

Random Delay helps CSMA/CA



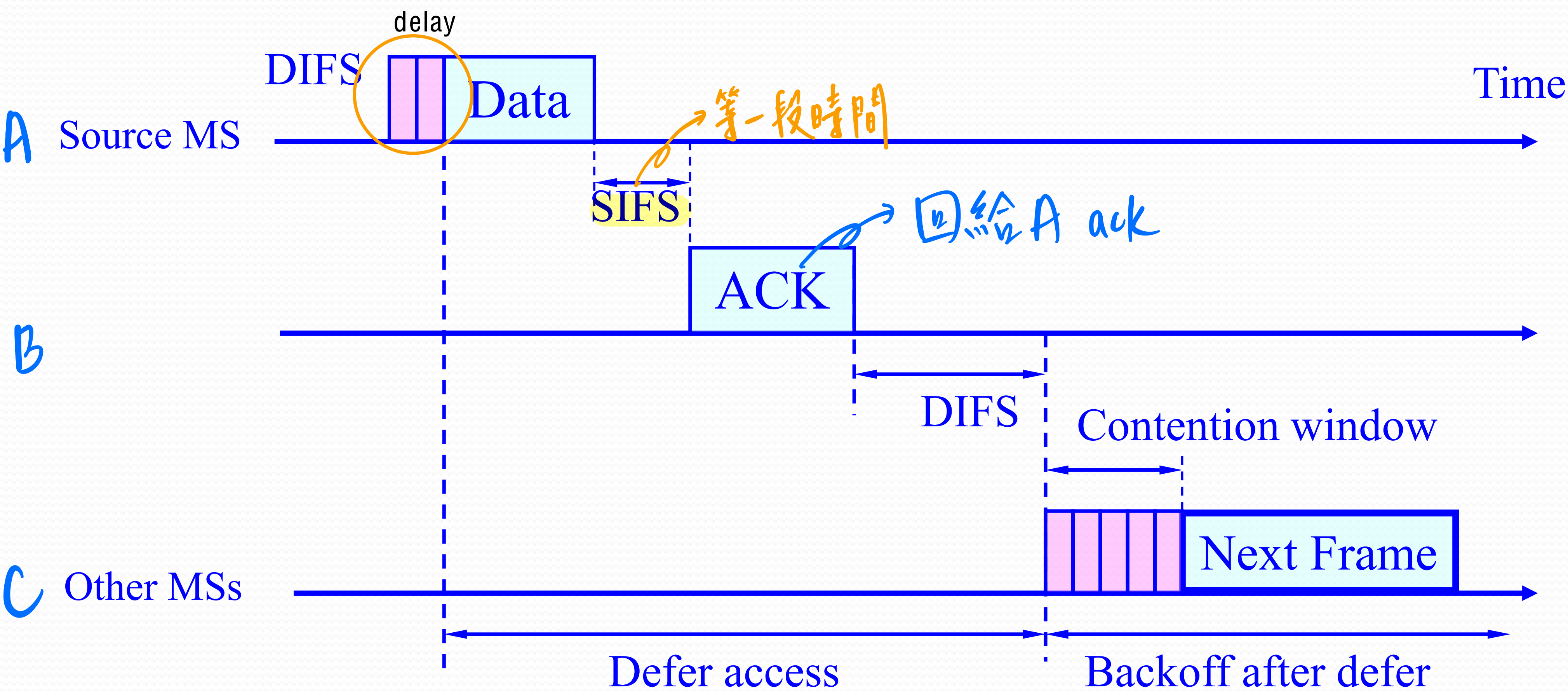
CW = 31, MS_A and MS_B are backoff intervals at nodes A and B

- MS_A and MS_B are the backoff intervals of MS_A and MS_B
- We assume for this example that CW = 31
- MS_A and MS_B have chosen a backoff interval of 25 and 20, respectively
- MS_B will reach zero before five units of time earlier than MS_A
- When this happens, MS_A will notice that the medium became busy and freezes its back-off interval currently at 5 ↳ A倒數剩5
- As soon as the medium becomes idle again, MS_A resumes its backoff countdown and transmits its data once the backoff interval reaches zero

CSMA/CA with ACK for ad hoc networks

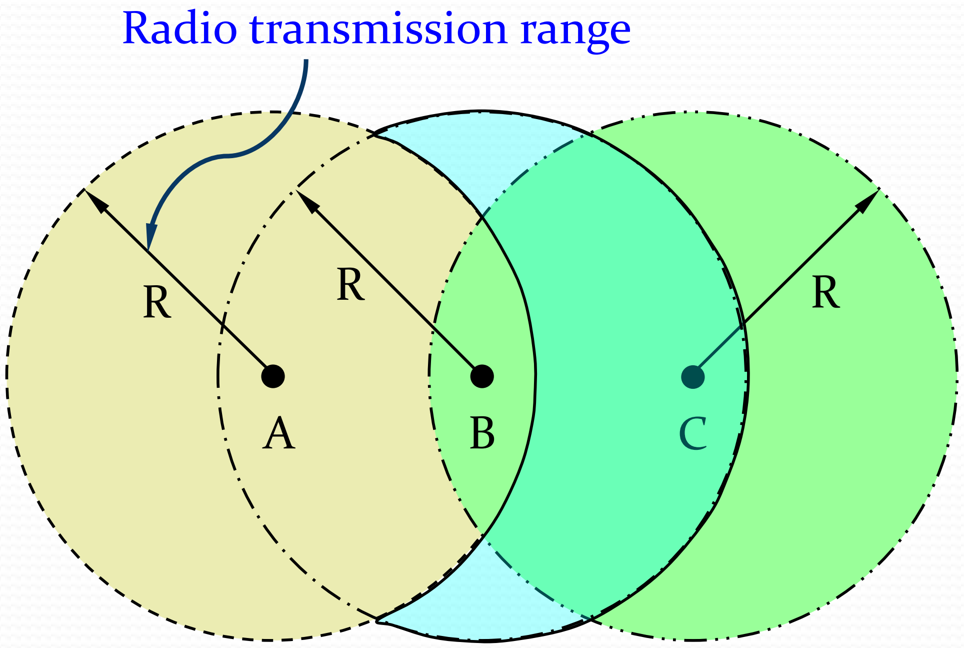
- Immediate Acknowledgements from receiver upon reception of data frame without any need for sensing the medium
- ACK frame transmitted after time interval SIFS (*Short Inter-Frame Space*) (*SIFS* < *DIFS*)
- Receiver transmits ACK without sensing the medium
- If ACK is lost, retransmission done

CSMA/CA/ACK



SIFS – Short Inter Frame Spacing

Hidden Terminal Problem

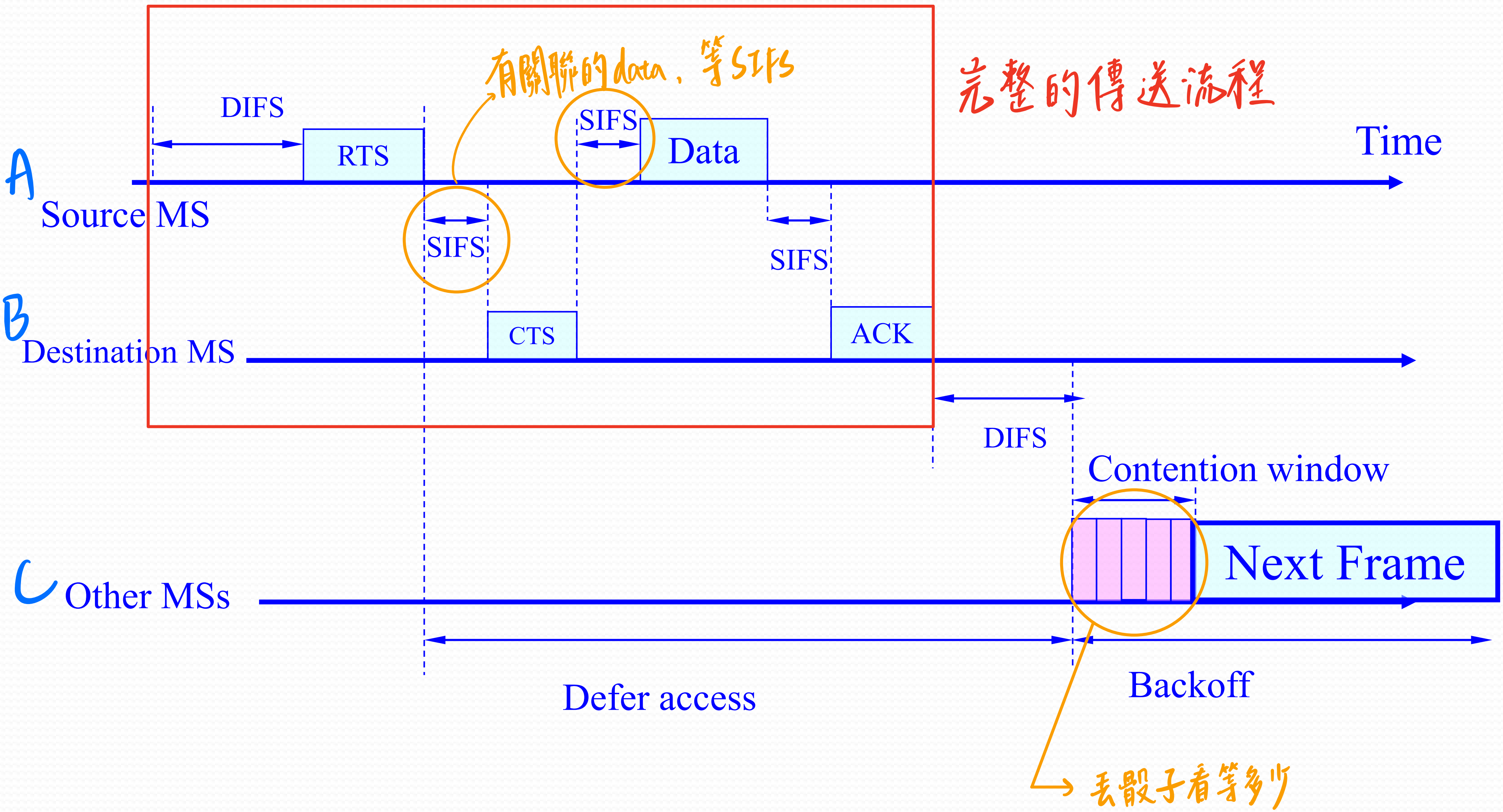


Nodes A and C are hidden with respect to each other

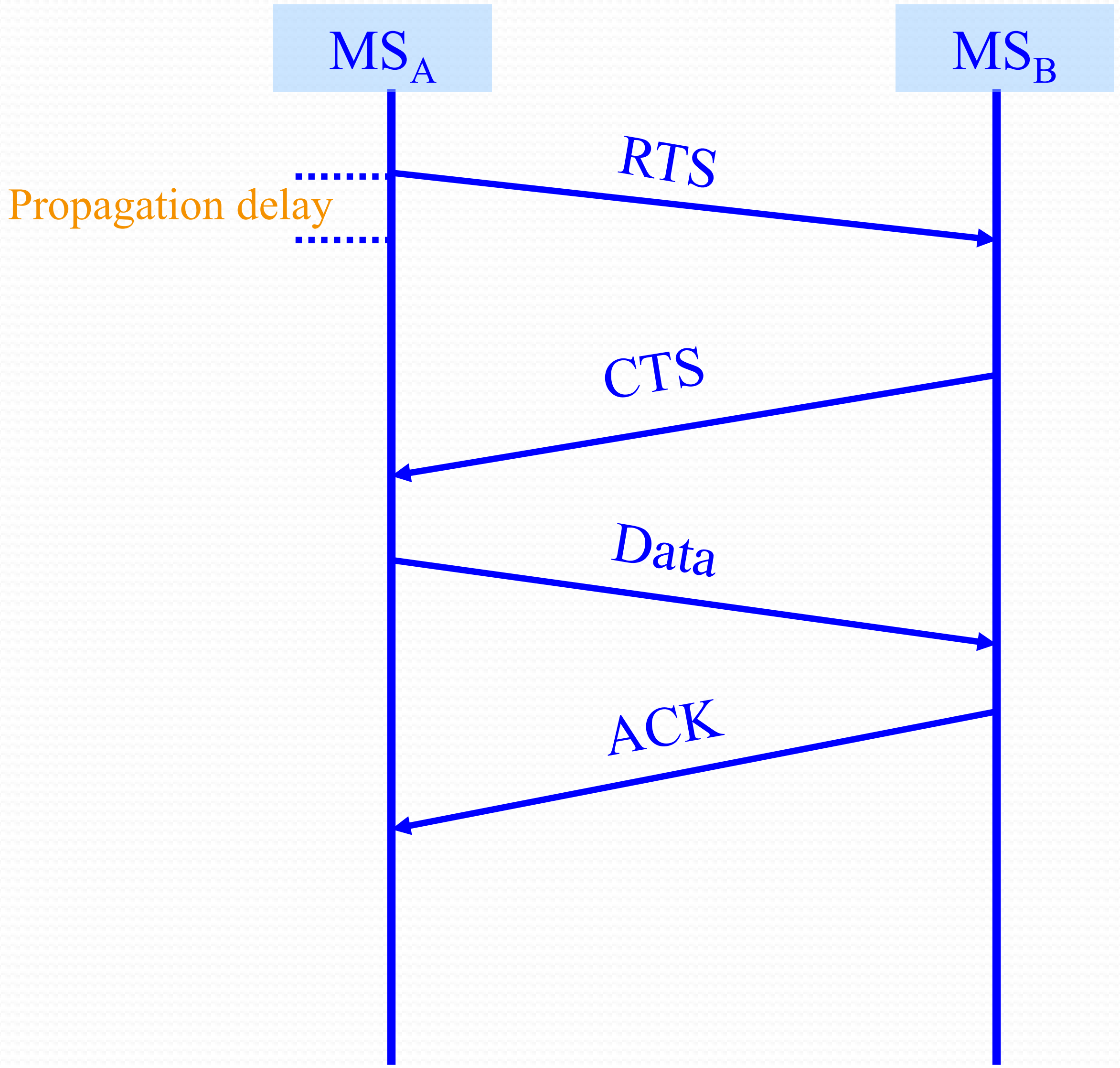
CSMA/CA with RTS/CTS

- Transmitter sends an RTS (request to send) after medium has been idle for time interval more than DIFS
- Receiver responds with CTS (clear to send) after medium has been idle for SIFS
- Then Data is exchanged
- RTS/CTS is used for reserving channel for data transmission so that the collision can only occur in control message

CSMA/CA with RTS/CTS

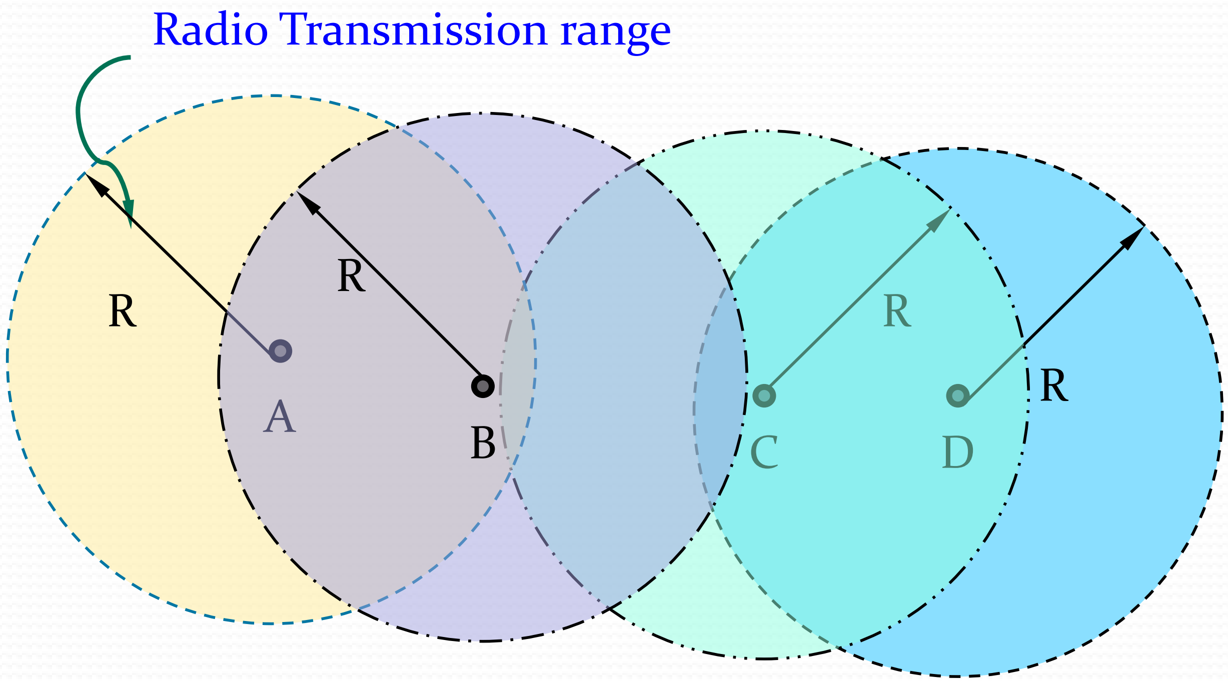


RTS/CTS



This helps avoid hidden terminal problem in Ad hoc networks

Exposed Terminal Problem



Transmission at Node A forces Node C (Exposed) to stop transmission to Node D