

NICT07/Agrawal ch 6

Multiple Radio Access

(3-4 hours)

S.-M. Tseng*, Y.-C. Wang, C.-Y. Yu (2019余政育), and Y.-F. Liu, "Performance evaluation CSMA/CA in MAC layer and Markov Gaussian memory impulse noise channels in PHY layer," *Journal of Communications*, vol. 18, no. 11, pp. 739-747, Nov. 2023.

S.-M. Tseng, C. K. Chang(2020(職)張俊貴), M.-Y. Liu, Y.-C. Wang, "Throughput analysis of 2-D OCDMA/pure ALOHA networks with access control and two user classes of variable length for multimedia traffic," *Optik*, vol. 241, 166928, Sep. 2021.

Outline

Application

Introduction

Multiple Radio Access Protocols

Contention-based Protocols

- Pure (unslotted) ALOHA
- Slotted ALOHA
- CSMA (Carrier Sense Multiple Access)
- CSMA/CD (CSMA with Collision Detection)
- CSMA/CA (CSMA with Collision Avoidance)

Summary

Application

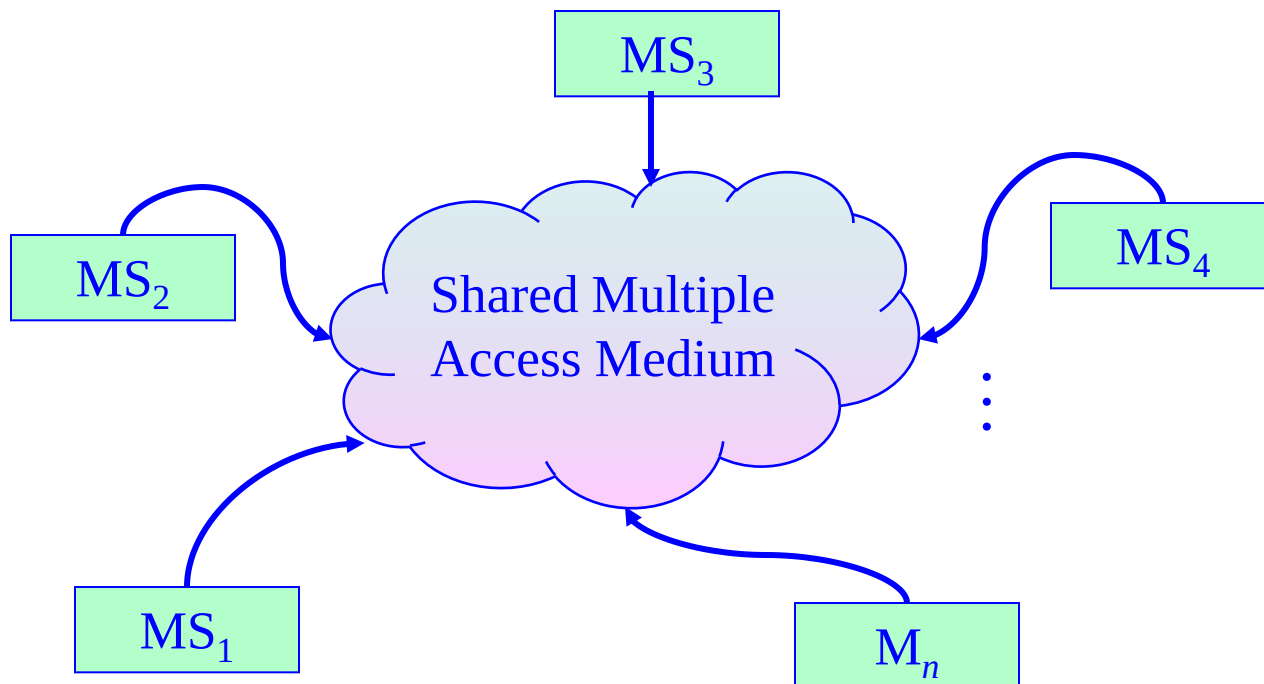
- Pure (unslotted) ALOHA: Sigfox LoRa for IoT- asynchronous, so can sleep for as little or as long as desire [Alam18]
- Slotted ALOHA- RACH in cellular systems
- CSMA (Carrier Sense Multiple Access)
- CSMA/CD (CSMA with Collision Detection): Ethernet
- CSMA/CA (CSMA with Collision Avoidance): WiFi

[Alam18] Alam, Muhammad Mahtab et al. (2018). A Survey on the Roles of Communication Technologies in IoT-based Personalized Healthcare Applications. IEEE Access.10.1109/ACCESS.2018.2853148.

Introduction

Multiple access channels

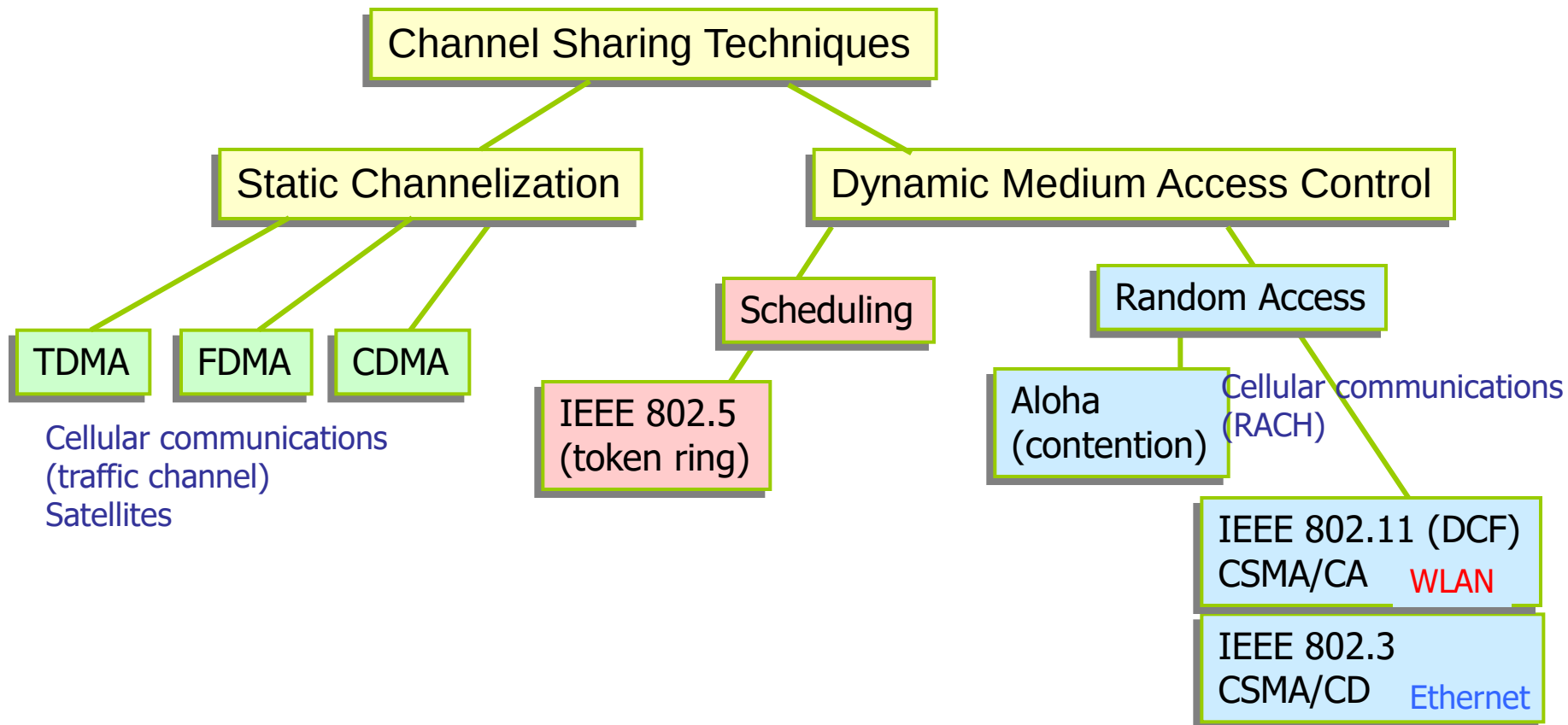
- Each Mobile Station (MS) is attached to a transmitter or receiver which communicates via a channel shared by other nodes
- Transmission from any MS is received by other MSs



Introduction (Cont'd)

- Multiple access issues
 - If more than one 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 (Dynamic Medium Access Control) resolve a collision after it occurs (for wireless, not received acknowledgement-ACK means collision). These protocols execute a collision resolution protocol after each collision
 - Collision-free protocols (Static Channelization) ensure that a collision can never occur.

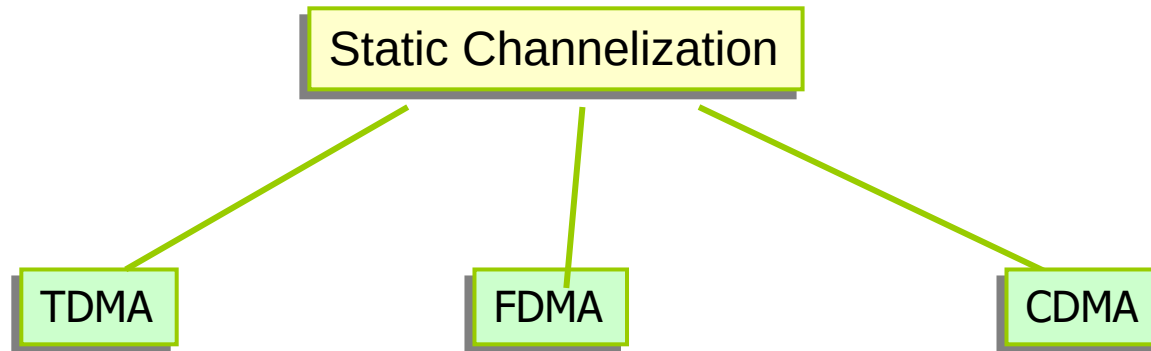
Channel Sharing Techniques



DCF: Distributed Coordination Function

Static Channelization

- Partition medium into separate channels, which are then dedicate to particular users.



Static Channelization

- Advantage:
 - No collisions
 - Perfect fairness-each node gets a dedicated transmission rate during each time interval (suitable for 'streaming data' or voice streams)
- Disadvantage:
 - Each user gets only a fraction on the full channel capacity, even when no other station is transmitting.

Channelization

- Bandwidth can be shared in (one-direction)
 - Frequency (FDMA) :
 - broadcast radio/TV ,analog cellular phone
 - Time (TDMA) :
 - telephone backbone, GSM digital cellular phone
 - Code (CDMA) :
 - 3G cellular

Channelization

PSTN: public switched telephone network

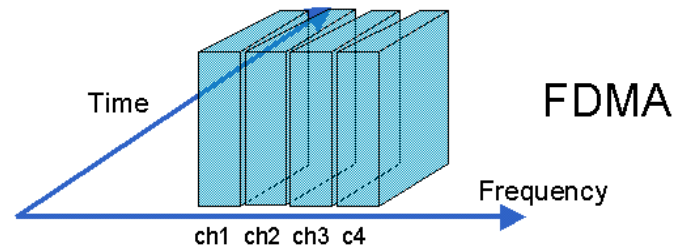
GSM: second generation (2G) cellular phone system

ISDN: integrated service digital network: voice, text, multimedia

DECT: cordless phone

■ **FDMA:**

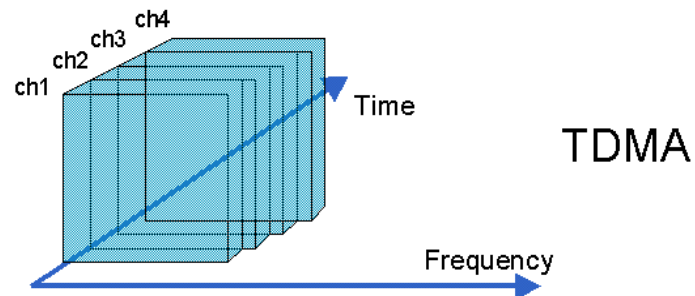
- Oldest, first in PSTN
- Used in GSM
uplink/downlink



& in OFDM

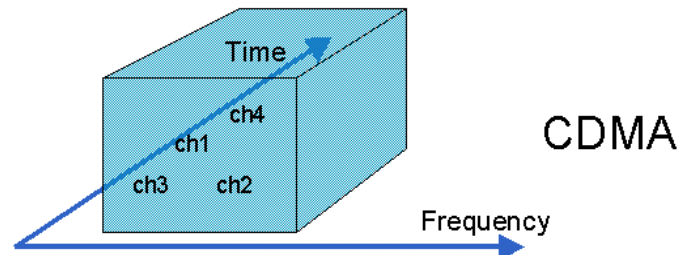
■ **TDMA:**

- ISDN-exchanges,
GSM calls
- Other applications:
DECT

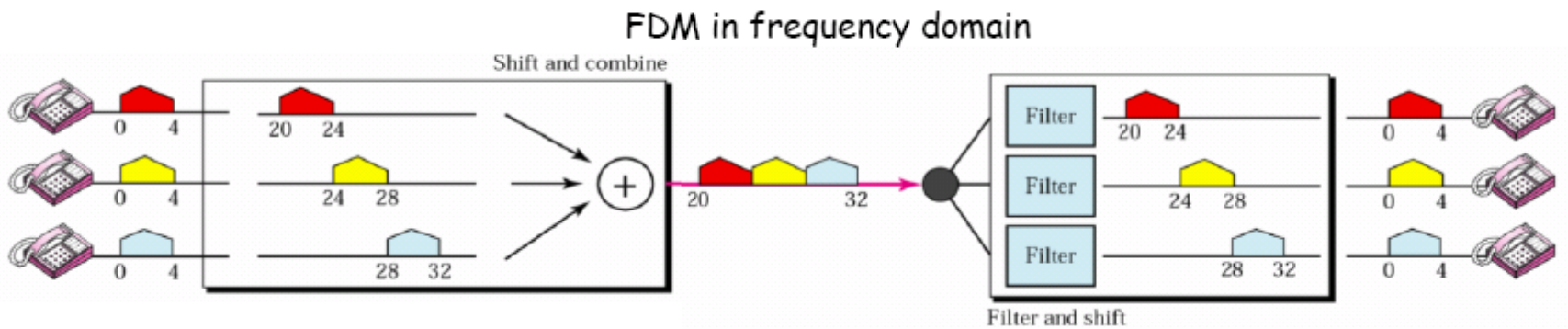
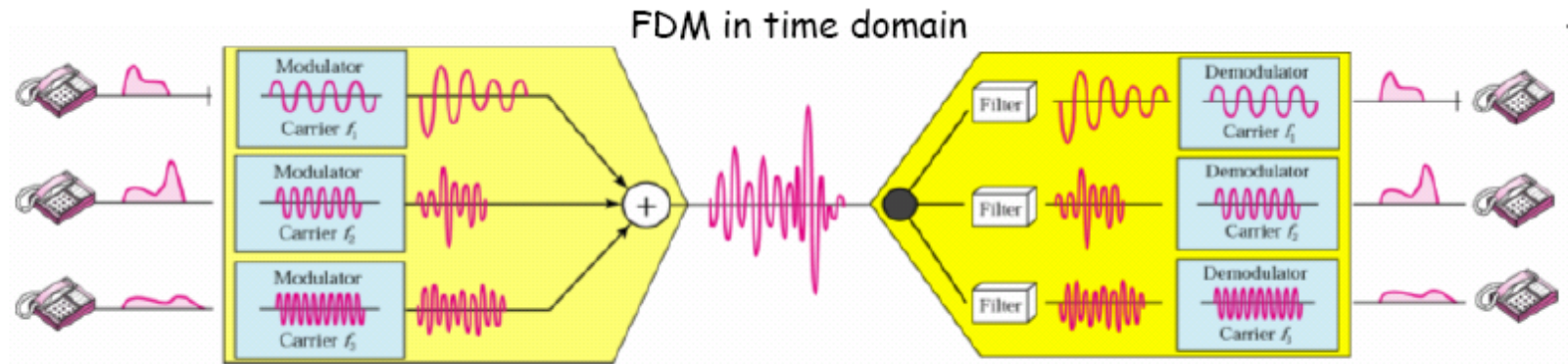


■ **CDMA:**

- Supports statistical
multiplexing
- Suits well to wireless



Channelization



- FDMA/TDMA is used in 4G/5G, Internet of Thing (IoT) where frequent transmission (for example, periodic reporting sensing data)

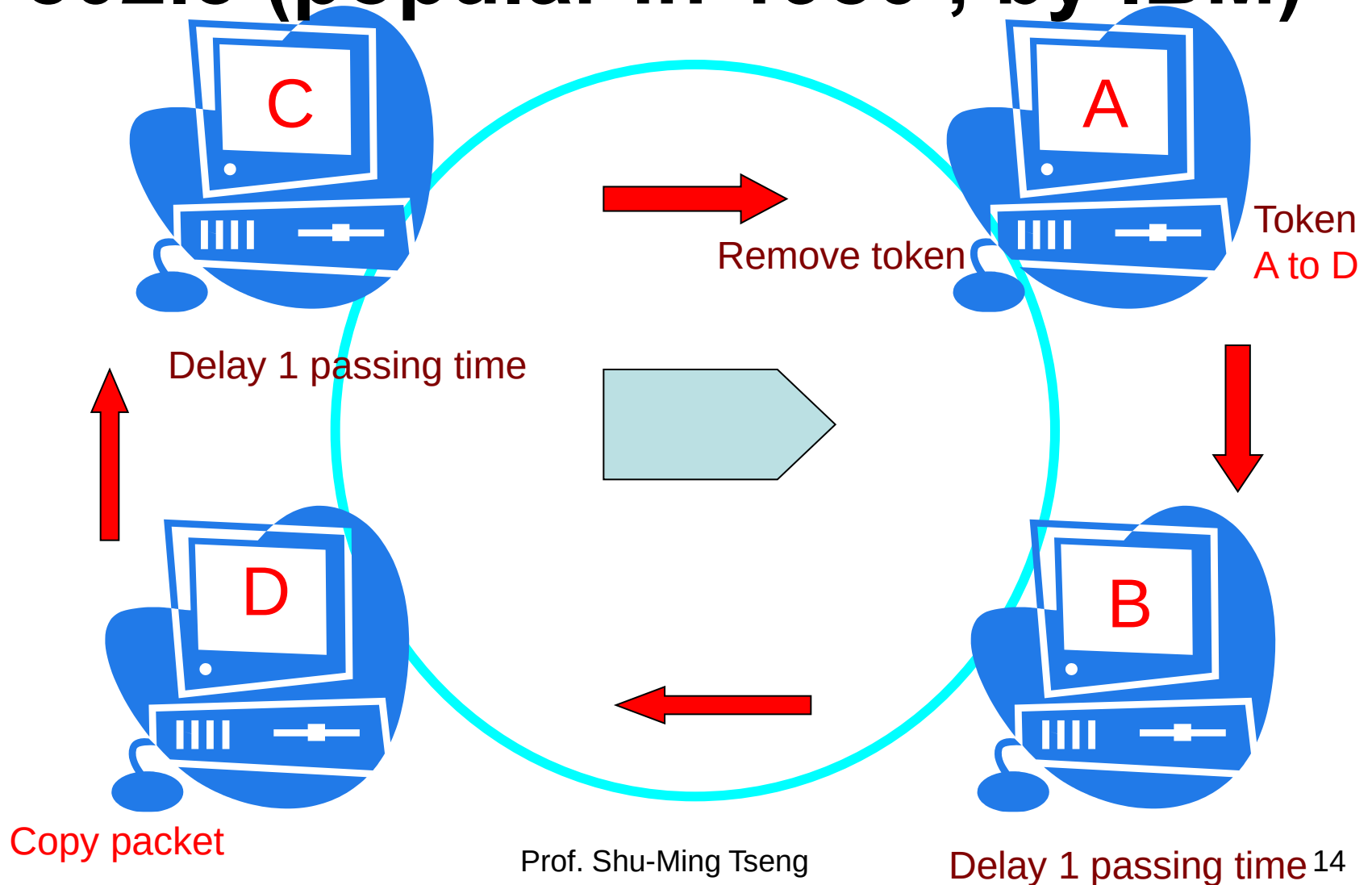
Dynamic Medium Access Control

The medium is shared on a 'per frame' basis.

Advantage:

- Transmitting node transmits at full rate of the channel
- Disadvantage:
- Simultaneous attempts by two or more stations to access channel result in 'collision'
- Collision can be minimized through scheduling or random access control

Scheduling- Token Ring: IEEE 802.5 (popular in 1980', by IBM)



Token Ring

procedure

1. node A has the blank Token
2. node A writes the letter to the token (envelope: sender A to receiver D) and pass to the next node B
3. Node B passes to the next node D
4. Node D copies the letter content and pass to the next node C
5. Node C pass to the next node A
6. Node A finds it is the sender, it takes and token and erases the content on the token

Contention Protocols

- **ALOHA**

- Developed in the 1970s by Hawaii University to connect all other campus to the main campus (radius of 300km from Honolulu).
- 1st **wireless** data network
- 1st **random access** data network
- Whenever a station has a data, it transmits. Sender finds out whether transmission was successful or experienced a collision by listening to the broadcast from the destination station. Sender retransmits after some random time if there is a collision.
- Status: IoT where infrequent transmission (e.g smoke detector)- no clock => low power

- **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.

Still used in two-way satellite network and random access channel of cellular phone systems (quiz ch1)

IEEE Communications Magazine • December 2009, p.22



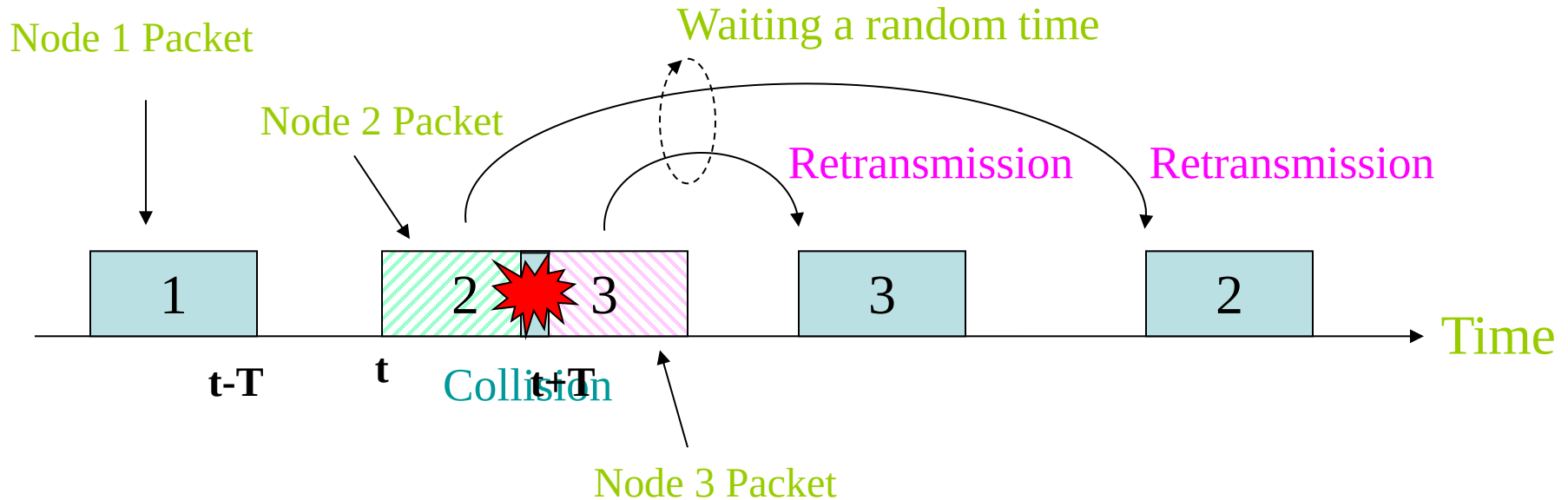
Landmark
like Taipei 101

1971

Contention Protocols (Cont'd)

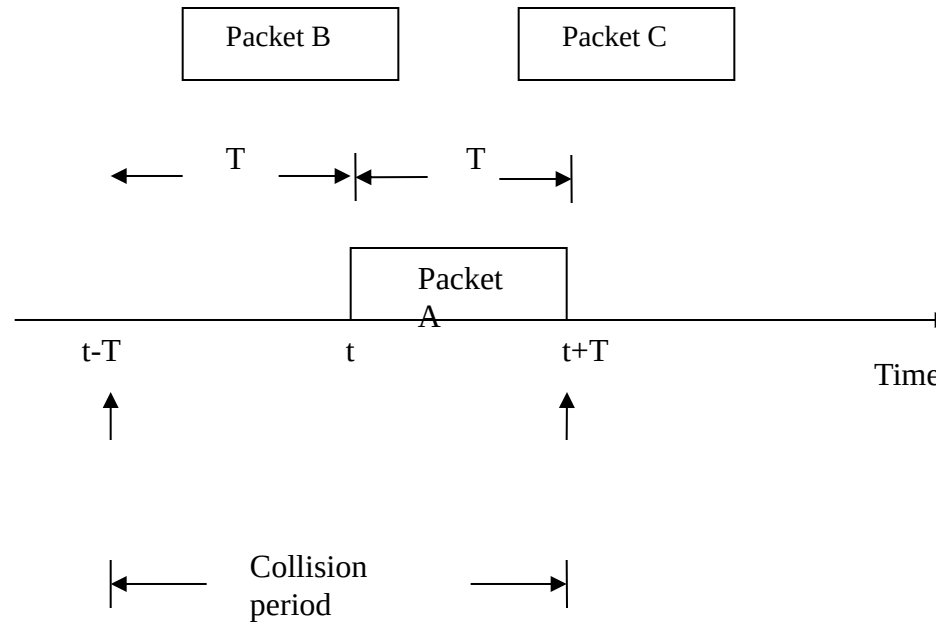
- **CSMA** (Carrier Sense Multiple Access)
 - Improvement: Start transmission only if no transmission is ongoing
 - Developed by UCLA
- **CSMA/CD** (CSMA with Collision Detection)
 - Improvement: Stop ongoing transmission if a collision is detected
 - -Ethernet
- **CSMA/CA** (CSMA with Collision Avoidance)
 - Improvement: random backoff (retransmission) between 0 and contention window (CW)-1
 - WiFi and WiMAX
- **CSMA/CA with ACK**
- **CSMA/CA with RTS/CTS**

ALOHA



Collision mechanism in ALOHA

Collision period=2T



Throughput of ALOHA (time unit=packet time)

- The probability that n packets arrive in two packets time $[t-T, t+T]$ is given by **Poisson distribution** (Argawal ch2)

$$P(n) = \frac{(2G)^n e^{-2G}}{n!}$$

where G is traffic load (average number of packets transmission per packet interval T). (=>2G packets over interval 2T)

- The probability $P(0)$ that a packet is successfully received without collision is calculated by letting $n=0$ in the above equation. We get

$$P(0) = e^{-2G}$$

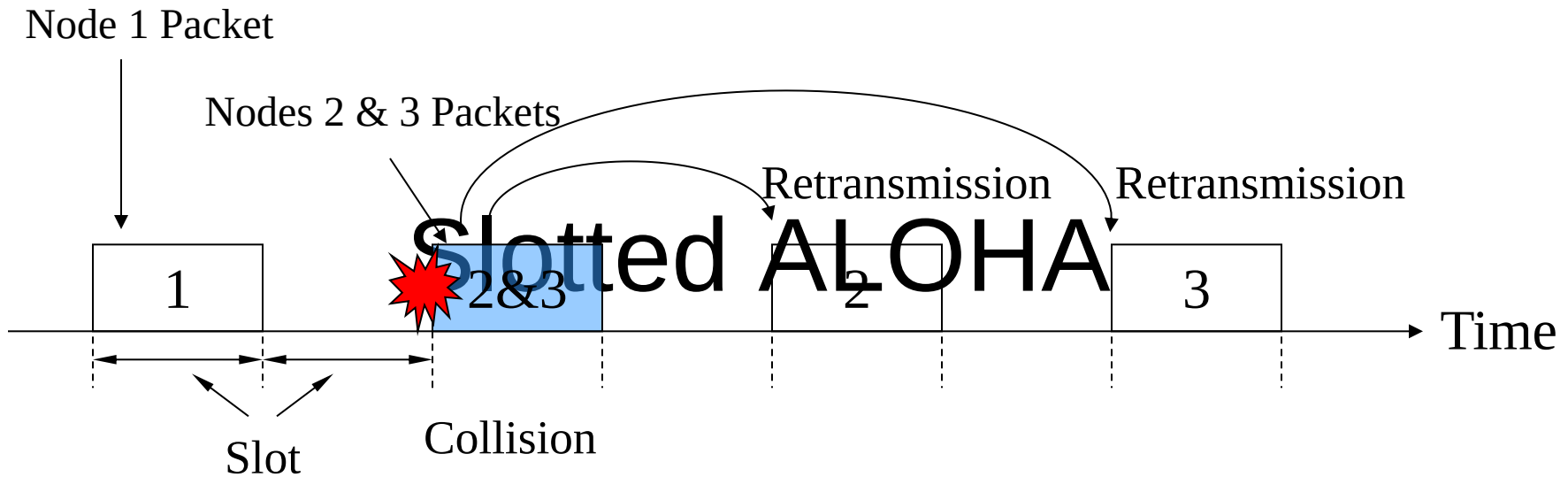
- We can calculate throughput S with a traffic load G as follows:

$$S = G \cdot P(0) = G \cdot e^{-2G} \quad \frac{dS}{dG} = -2Ge^{-2G} + e^{-2G} \quad e^{-2G}(1-2G) = 0$$

- The Maximum throughput of ALOHA is

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

Take differentiation on G (Calculus in freshman year) , $dS/dG=0$
 => $G=1/2$ => substitute $G=1/2$ into the above equation
 => $S_{\max} = 1/2e \approx 0.184$



A common clock for slot synchronization

Collision mechanism in slotted ALOHA

Prof. Shu-Ming Tseng

Collision period $2T \Rightarrow T$

Throughput of Slotted ALOHA

- The probability of no collision is given by

$$P(0) = e^{-G}$$

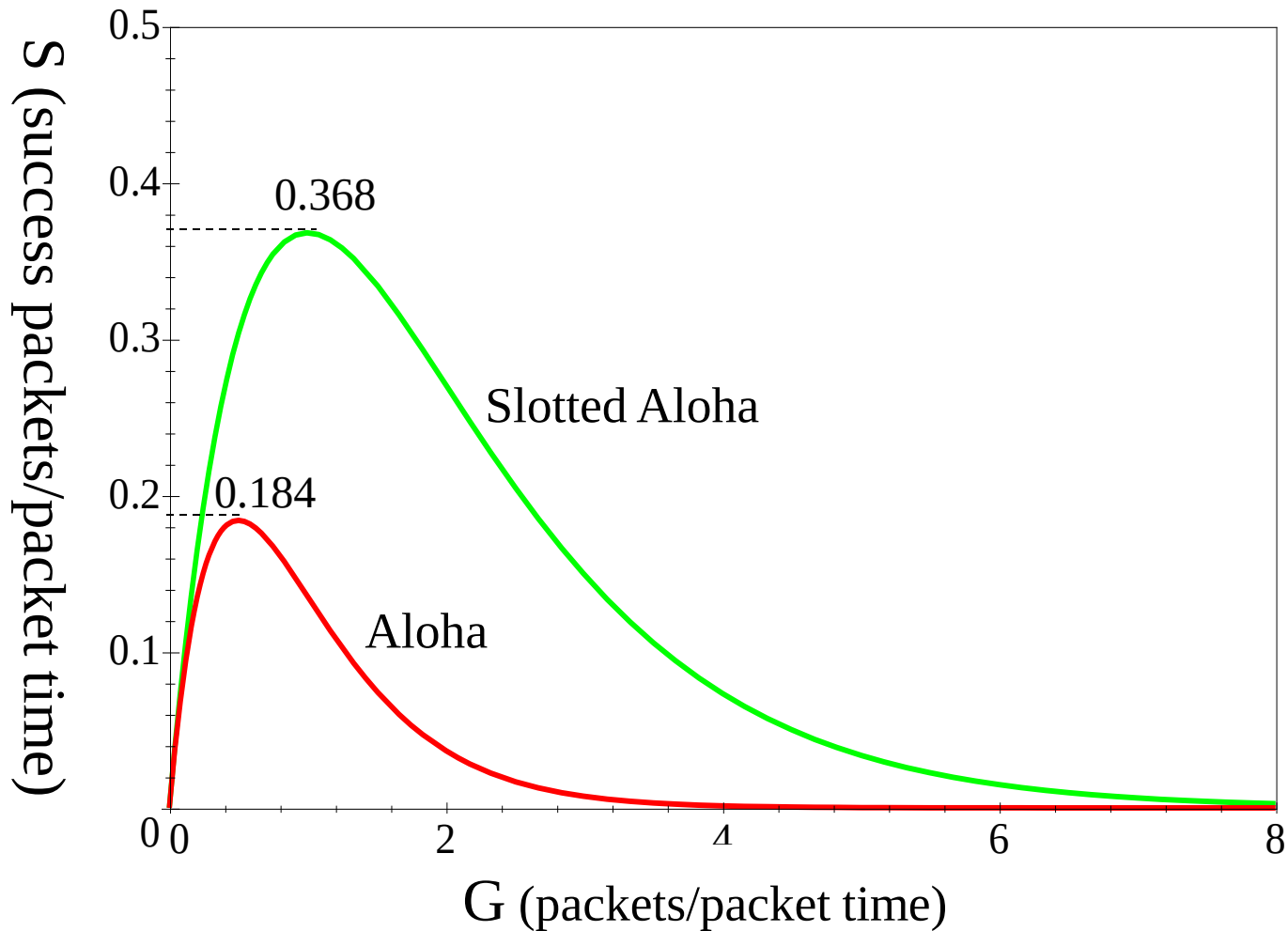
- The throughput S is

$$S = G \cdot P(0) = G \cdot e^{-G}$$

- The Maximum throughput of slotted ALOHA is

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

Throughput



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).- unlike ALOHA

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

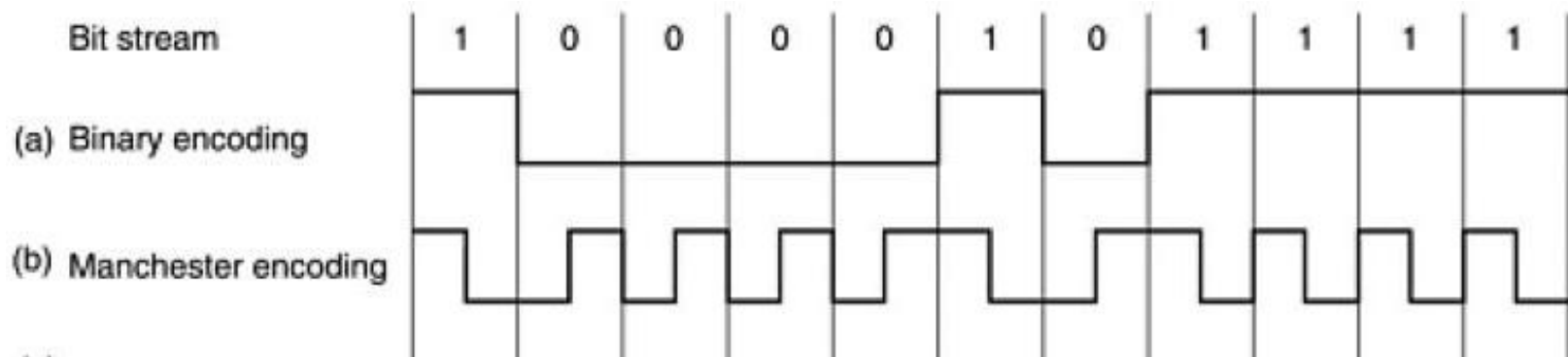
Step 1: If the medium is idle, transmit

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

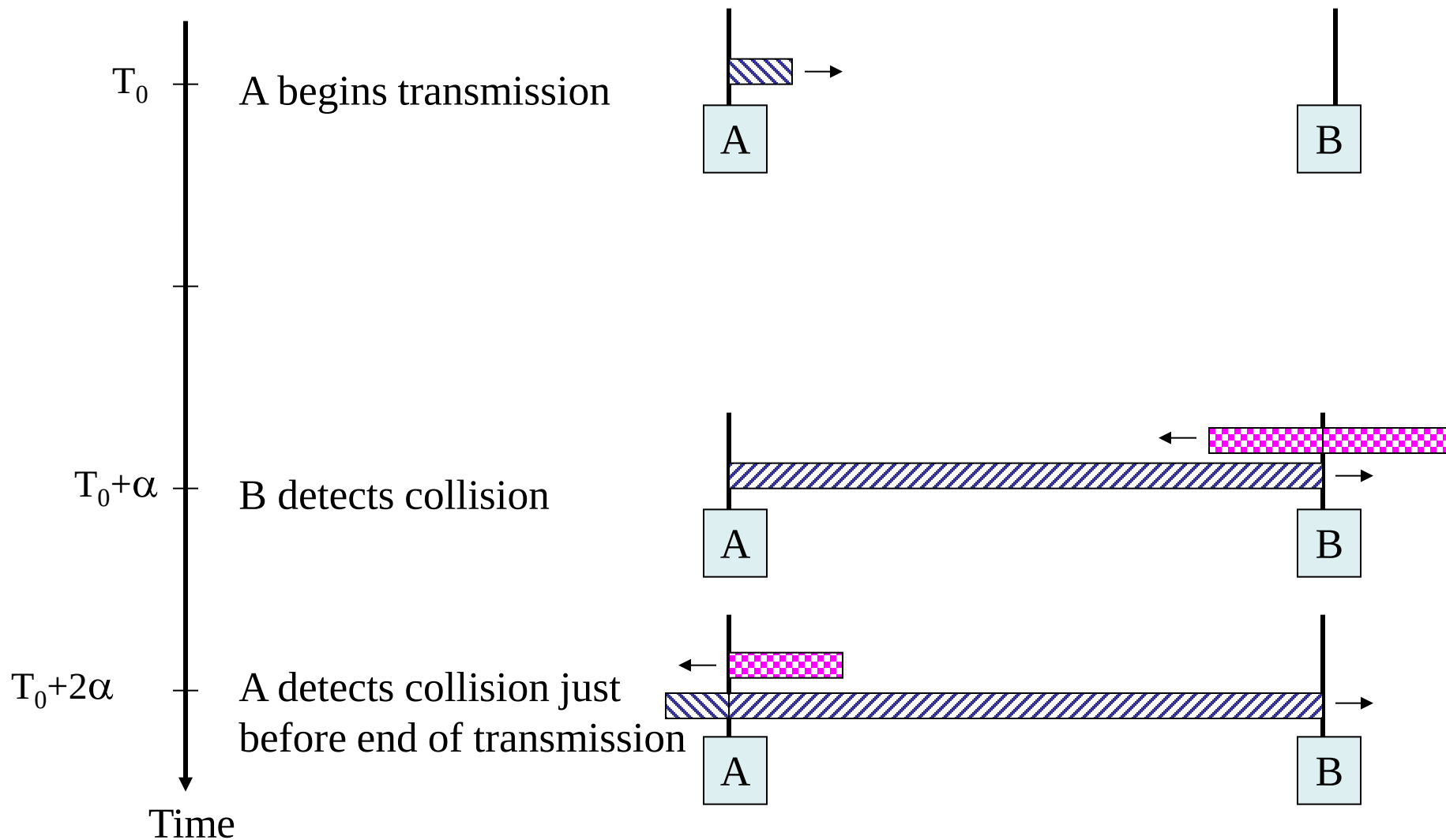
Step 3: If a collision is detected (voltage doubled) during transmission, cease transmitting

Step 4: Wait a random amount of time and repeats the same algorithm

Manchester coding: easier to detect double voltage



CSMA/CD (Cont'd)



(α is the propagation time)

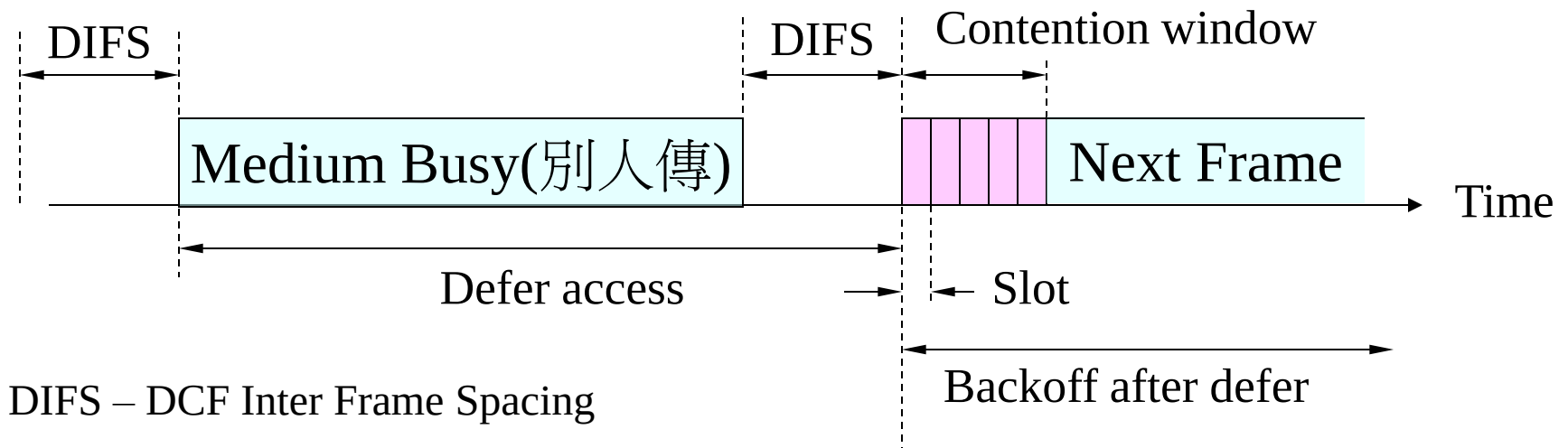
minimum package size

- Consider a 10Mbps Ethernet, because the 2α is $51.2\mu\text{s}$ (Define in CSMA/CD system), so we can get the result as below :

$$10^7 \frac{\text{bit}}{\text{sec}} 51.2 \times 10^{-6} \text{ sec} = 512 \text{ bit} = 64 \text{ byte}$$

It's mean that need 64byte at least to fill the channel, so the minimum package size should be 64 byte and the station could detect the collision before end of transmission.

Basic CSMA/CA (CSMA with Collision Avoidance) Fig. 6.13



DIFS – DCF Inter Frame Spacing

(no DIFS in CSMA/CD on p.27, give priority to SIFS)

Basic CSMA/CA (1/3)

- Under basic CSMA/CA technique, all MSs watch the channel in the same way as CSMA/CD.
- Terminal ready to transmit senses the medium and the collision.
- Instead of starting traffic immediately after the **medium becomes idle**, the MS will transmit its data if the medium is idle for a time interval exceeds DIFS (DCF interframe Space).(DCF: distributed coordinate function).

Basic CSMA/CA (2/3)

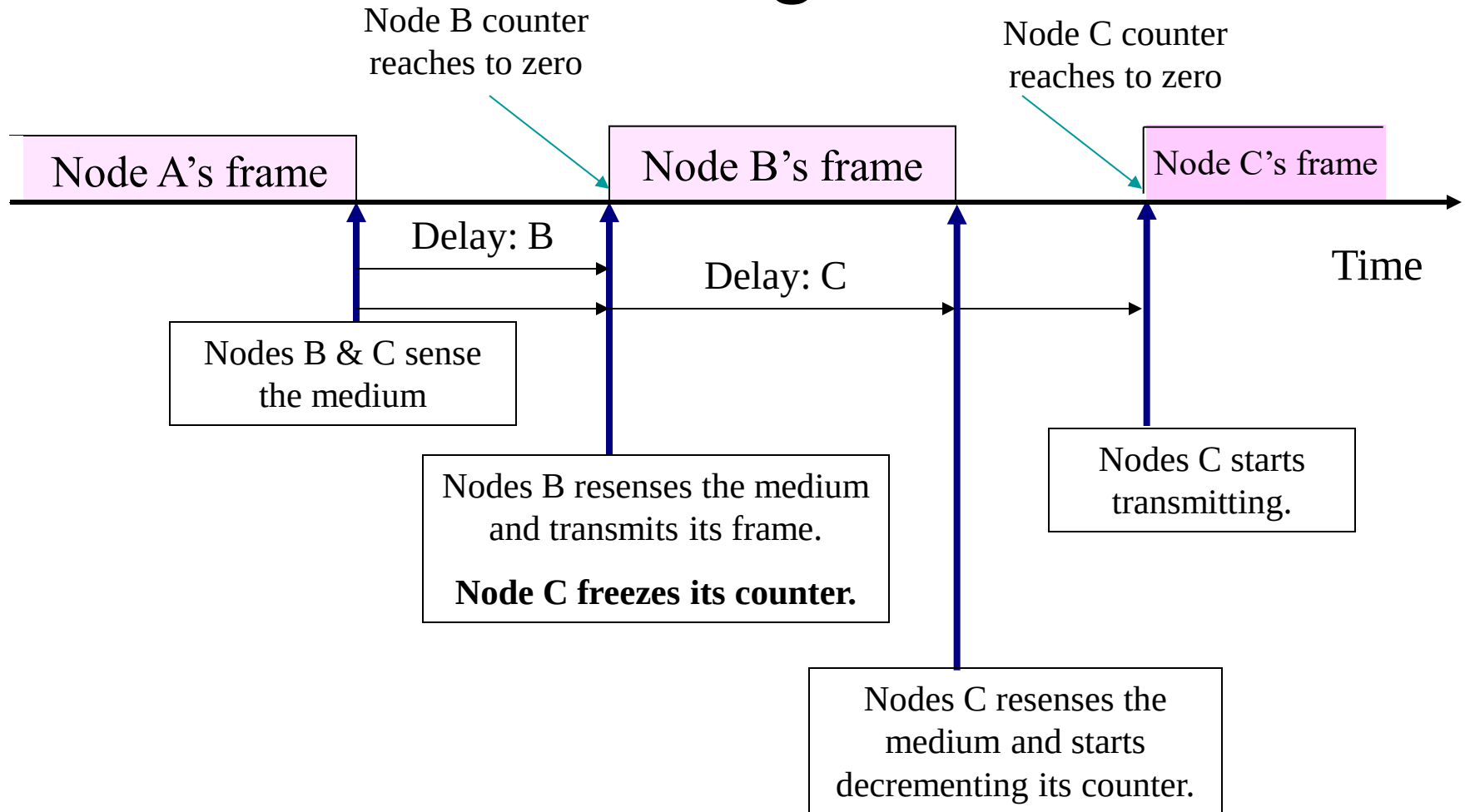
- Otherwise (medium busy in fig 2 pages earlier), it waits for an additional predetermined time period DIFS Then picks up a random number of slots (the initial value of backoff counter) within a contention window to wait before transmitting its frame.
- The backoff counter can count down only when the medium is idle. Otherwise, it is **frozen** as soon as the medium gets busy.
- After the busy period, counting down of the backoff counter resumes only after the medium has been free longer than DIFS.
- The MS can start transmitting its data when the backoff counter becomes zero

Basic CSMA/CA (3/3)

- Collisions can occur only when two or more terminals select the same time slot in which to transmit their frames.
- Whenever collision occurs, the size of CW is doubled so that the range of random time delay is increased to reduce the probability of any future collision.
- This process is repeated until the transmission is successful and then the CW is reset to the original value.

CSMA/CA (Cont'd)

DIFS ignored



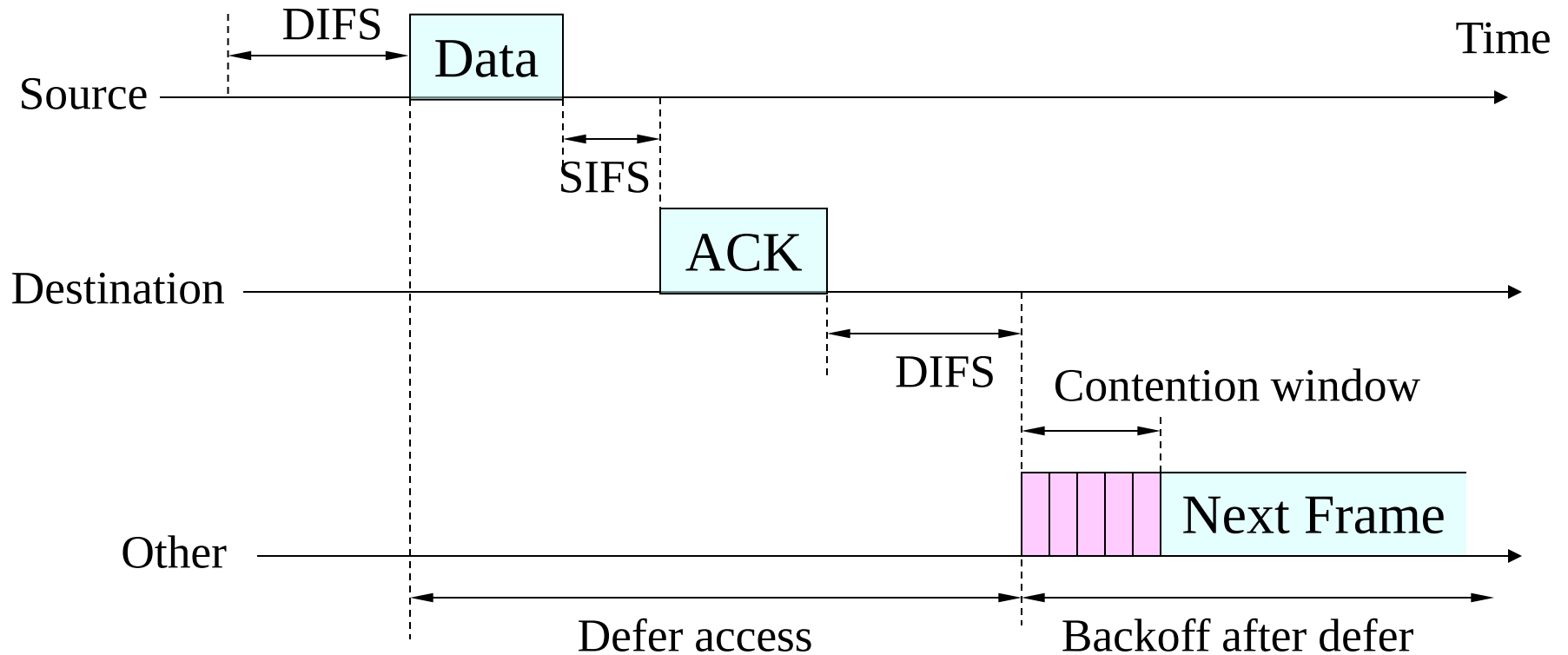
Adaptive CW size

- For 802.11b: $CW_{\min}=32$, $CW_{\max}=1024$,
backoff stage 0~7 (32 64 128 256 512
1024 1024 1024) last three backoffs have
the same CW) ◦
- When collision, CW double if not greater
than $CW_{\max}$; otherwise, $CW=CW_{\max}$
- When successful transmission, $CW=CW_{\min}$

CSMA/CA with ACK

- ACK frame transmitted after time interval SIFS (*Short Inter-Frame Space*)
- $SIFS < DIFS$, so no other terminal (must wait DIFS) can use the medium
- Receiver transmits ACK without sensing the medium.
- If ACK is lost, retransmission done.
- So SIFS has priority.

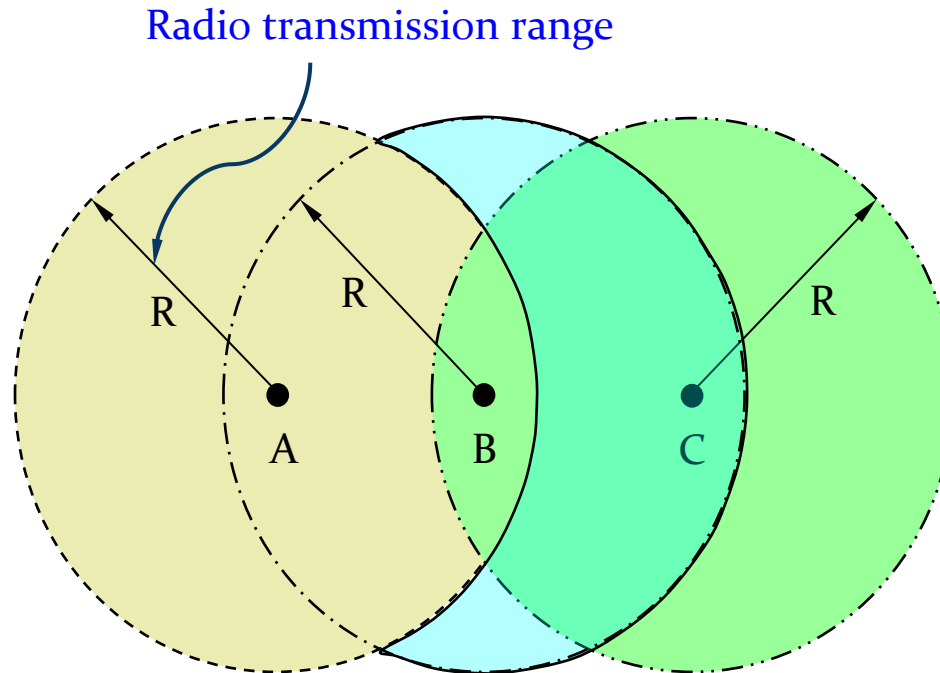
CSMA/CA/ACK (Fig. 6.14)



SIFS – Short Inter Frame Spacing

Typical values: DIFS 50 μ s SIFS 20 μ s slot time 10 μ s (CW unit)

Hidden Terminal Problem (Fig. 6.15)



Nodes A and C are hidden with respect to each other

Hidden terminal problem

- B, A hear each other
- B, C hear each other
- A, C can not hear each other

means A, C unaware of their interference at B

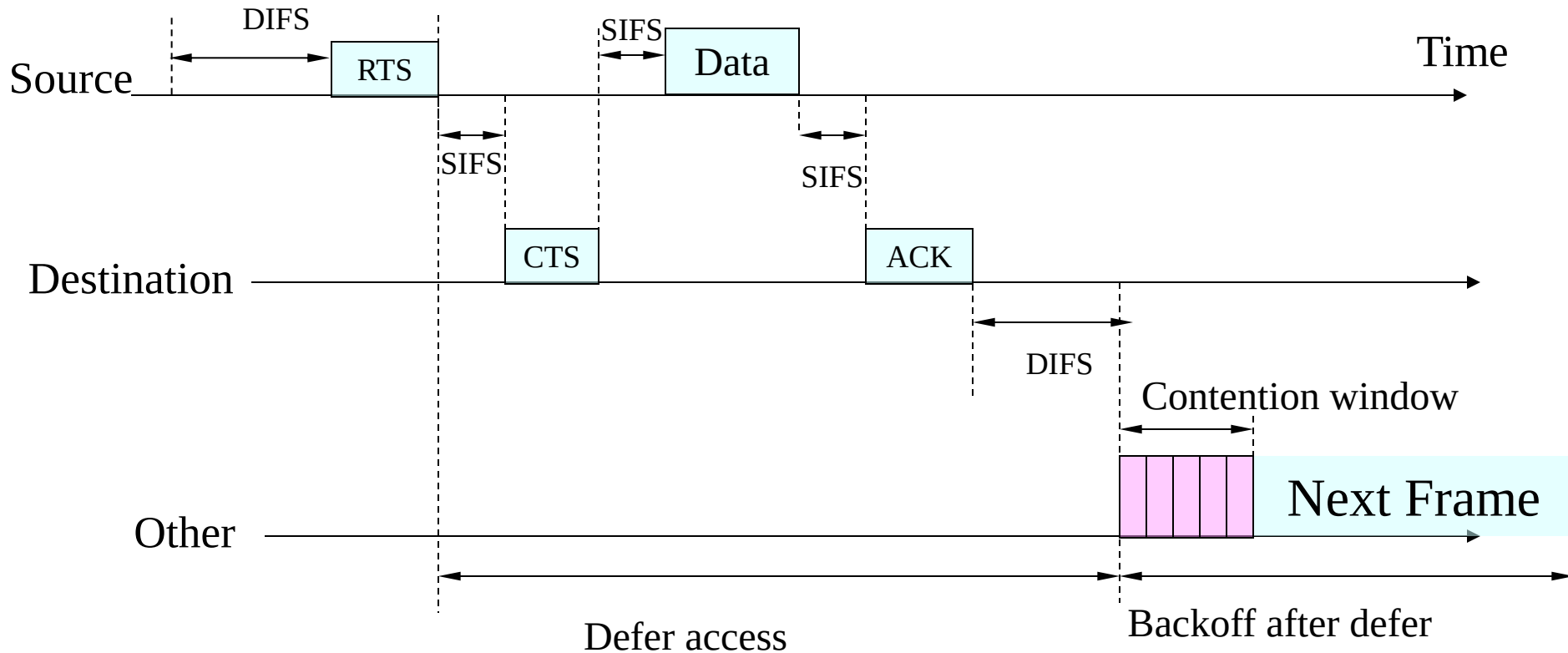
A doesn't know $C \rightarrow B$, so $A \rightarrow B$

CSMA/CA with RTS/CTS (handshaking)

- optional in WLAN standard ◦
- 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.
- When the other nodes hear CTS , they don't transmit (shut up)

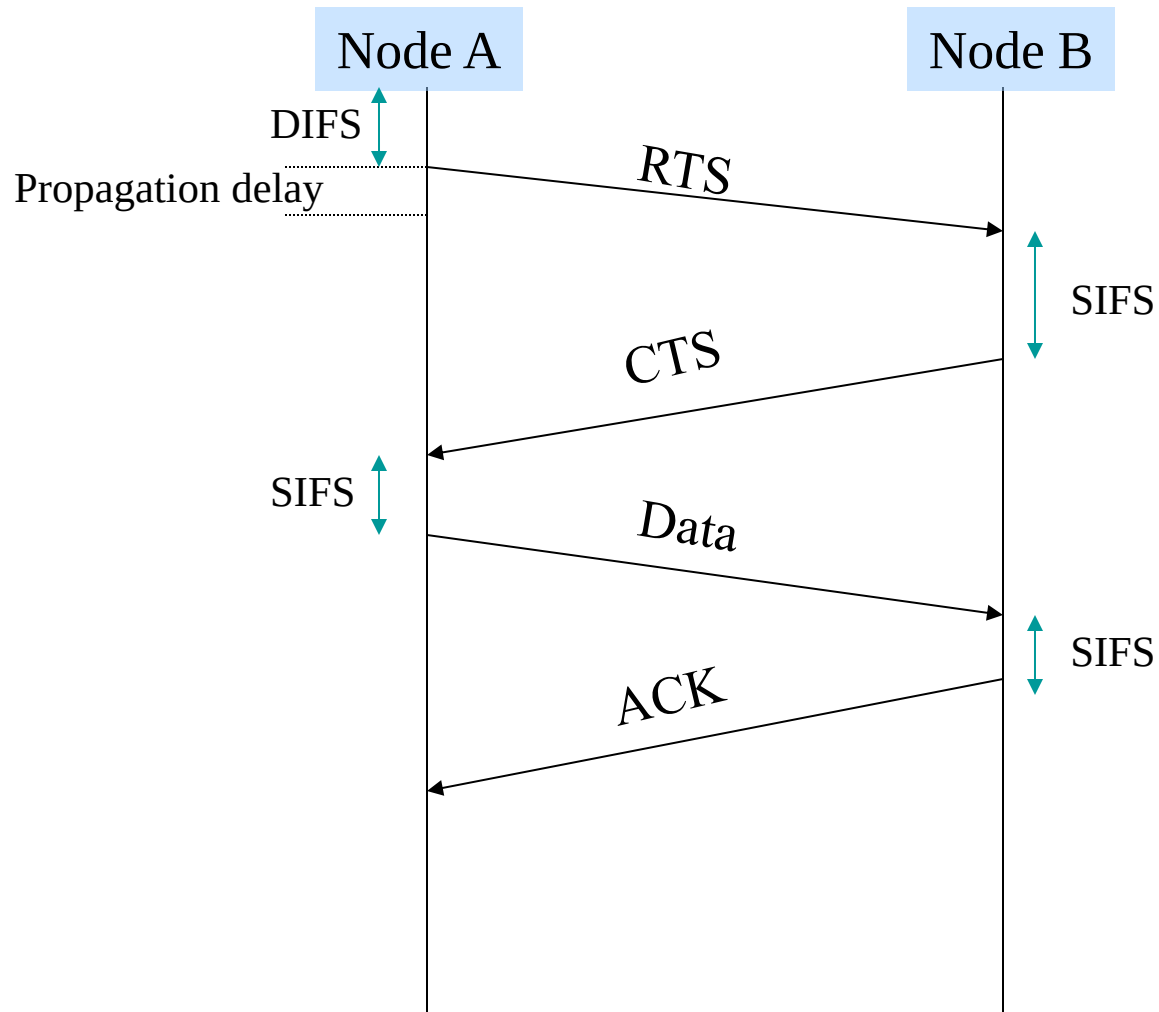
CSMA/CA with RTS/CTS (Cont'd) Fig. 6.16

Note that $SIFS < DIFS$, so this DATA has priority

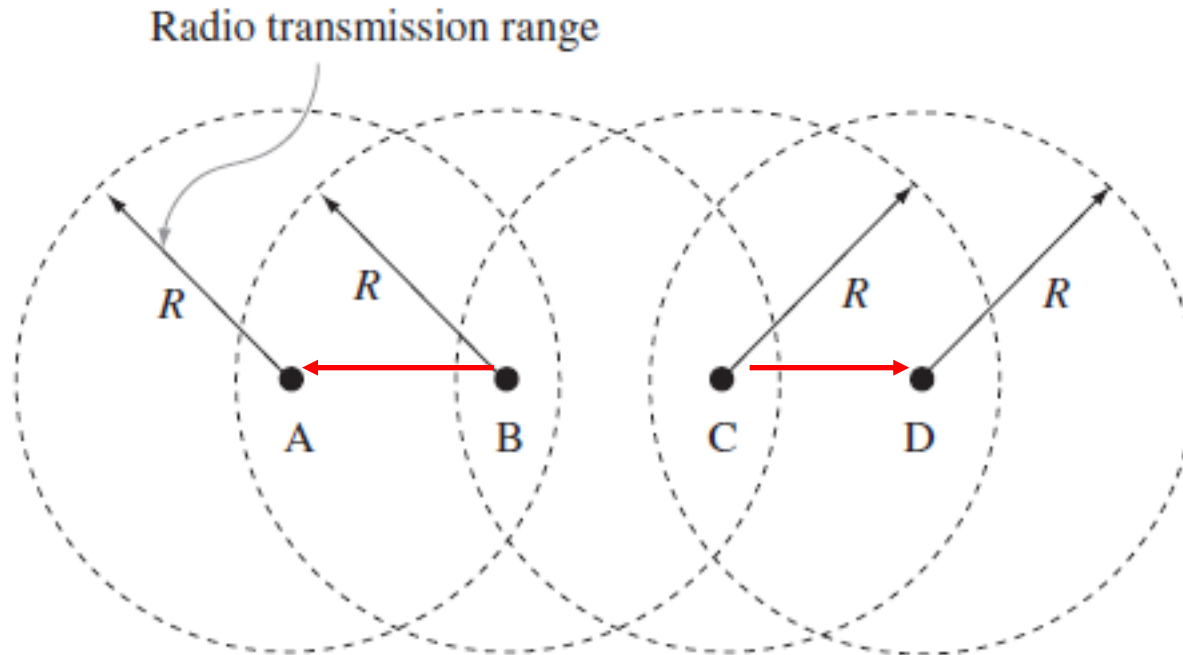


- station can send RTS with reservation parameter after waiting for DIFS (reservation declares amount of time the data packet needs the medium)
- acknowledgement via CTS after SIFS by receiver (if ready to receive)
- sender can now send data at once, acknowledgement via ACK
- other stations store medium reservations distributed via RTS and CTS

RTS/CTS



Exposed Terminal Problem



- CSMA/CA with RTS/CTS (unidirectional) solve hidden terminal problem, BUT create exposed terminal problem
- Transmission B to A forces C (Exposed, delay access hearing RTS from B) to stop transmission to D
(B to A actually do not interfere C to D because D is out of range of B)

HW

P6.2. How does slotted ALOHA improve the throughput as compared to pure ALOHA?

[Hint]

no partial collision 、 reducing the contention period.

Plot figures p.21 and p.23

HW

P6.10. What is the difference between collision detection and collision avoidance?

[Solution]

collision detection : aborts its transmission immediately

collision avoidance : does not abort the transmission but tries to avoid collisions in advance.

6.13. What in your opinion should be the criteria to select the value of the contention window?

[Solution]

the range of values should be more than the number of nodes 、 the traffic load is heavy=>contention window should be large.

light=>contention window should be small.

HW

P6.17. Suppose the propagation delay is α , SIFS is α , DIFS is 3α , and RTS and CTS are 5α , respectively for CSMA/CA with RTS/CTS.

- (a) What is the earliest time for the receiver to send the CTS message?
- (b) If data packet is 100α long, what is the shortest time for the receiver to send the ACK signal?
- (c) Explain why SIFS is kept smaller than DIFS period?
- (d) Can you make SIFS=0?

[Hint] refer to handout figures (add propagation delay)

- (a) $\text{DIFS} + \text{RTS} + \text{propagation delay} + \text{SIFS} = 10\alpha$
- (b) $(a) + \text{CTS} + \text{propagation delay} + \text{SIFS} + \text{data} + \text{propagation delay} + \text{SIFS} = 119\alpha$
- (c) priority to some packets
- (d) turn around time from transmit (receive) mode to receive (transmit) mode, >0