Chapter 6

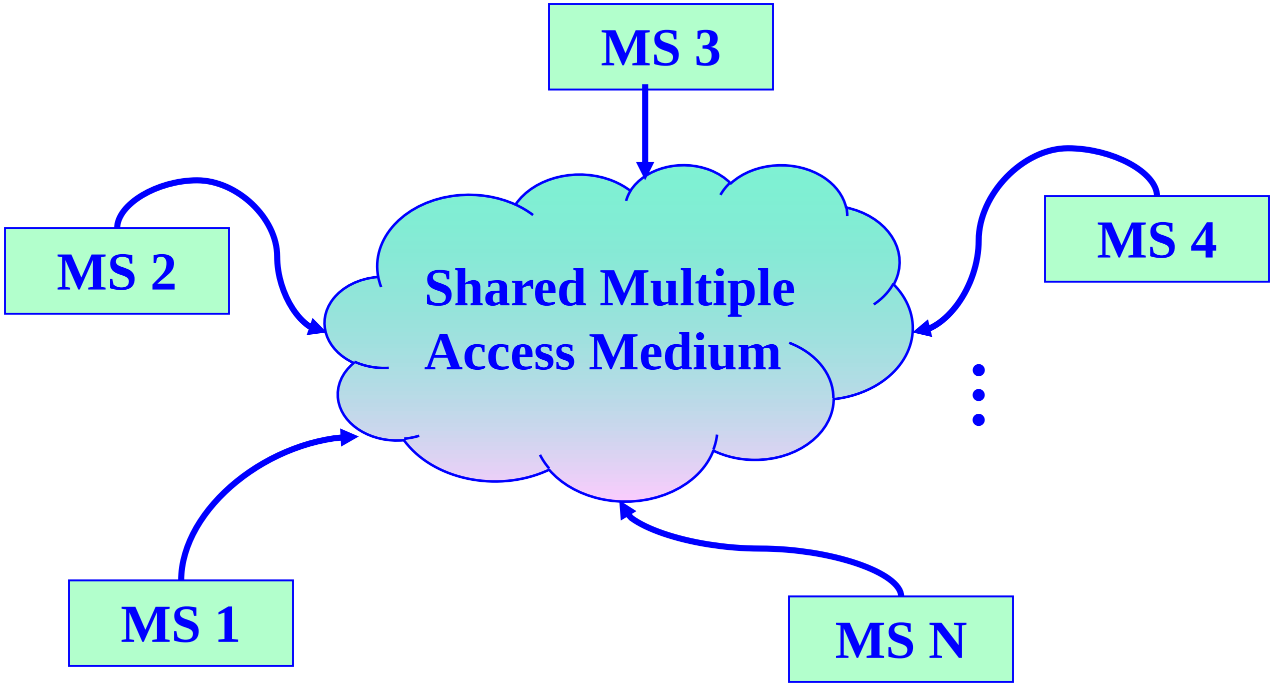
Multiple Radio Access

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

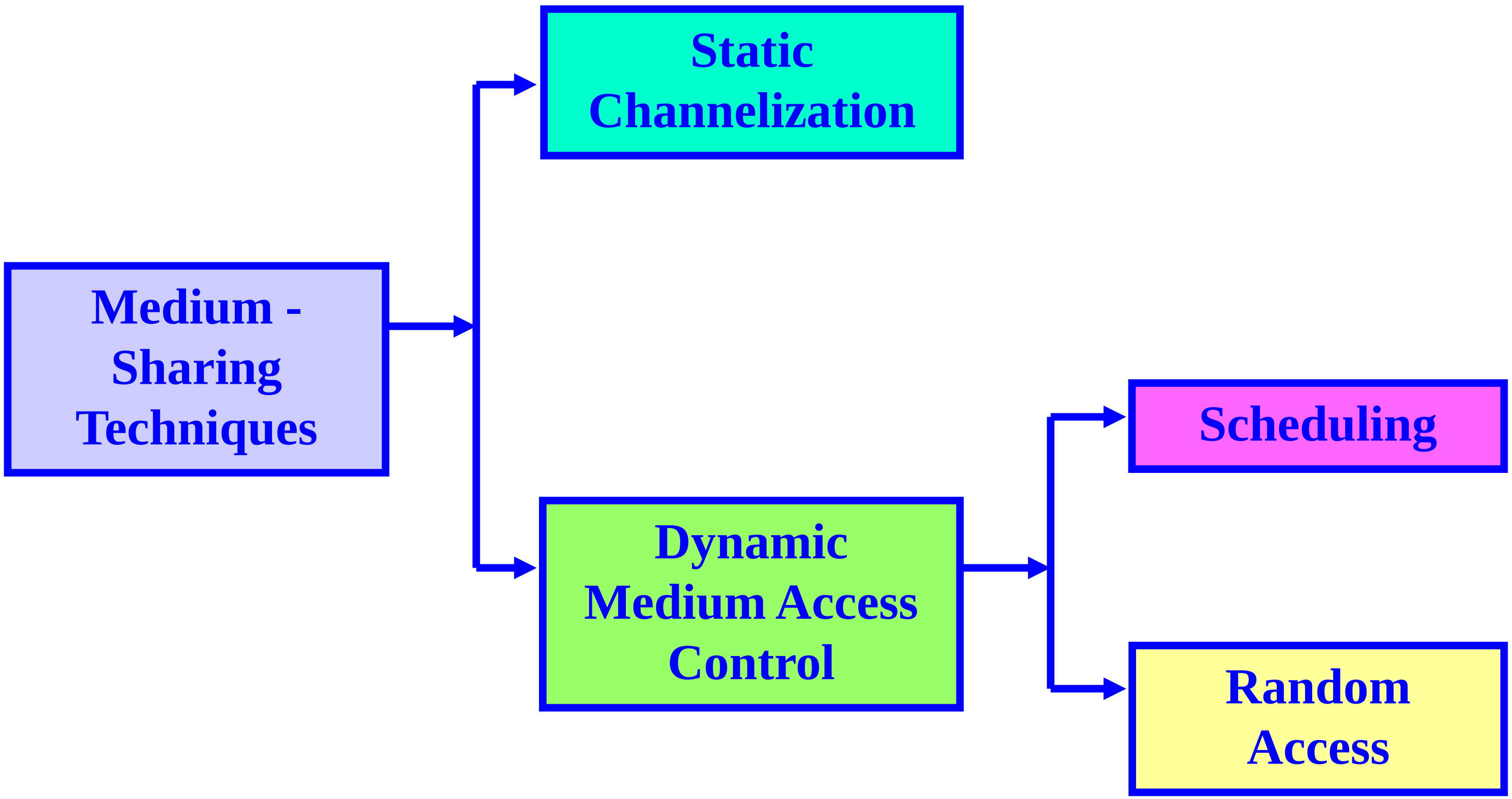
- Multiple access control channels
  - ✓ Each Mobile Station (MS) is attached to a transmitter/receiver which communicates via a channel shared by other nodes
  - ✓ Transmission from any MS is received by other MSs



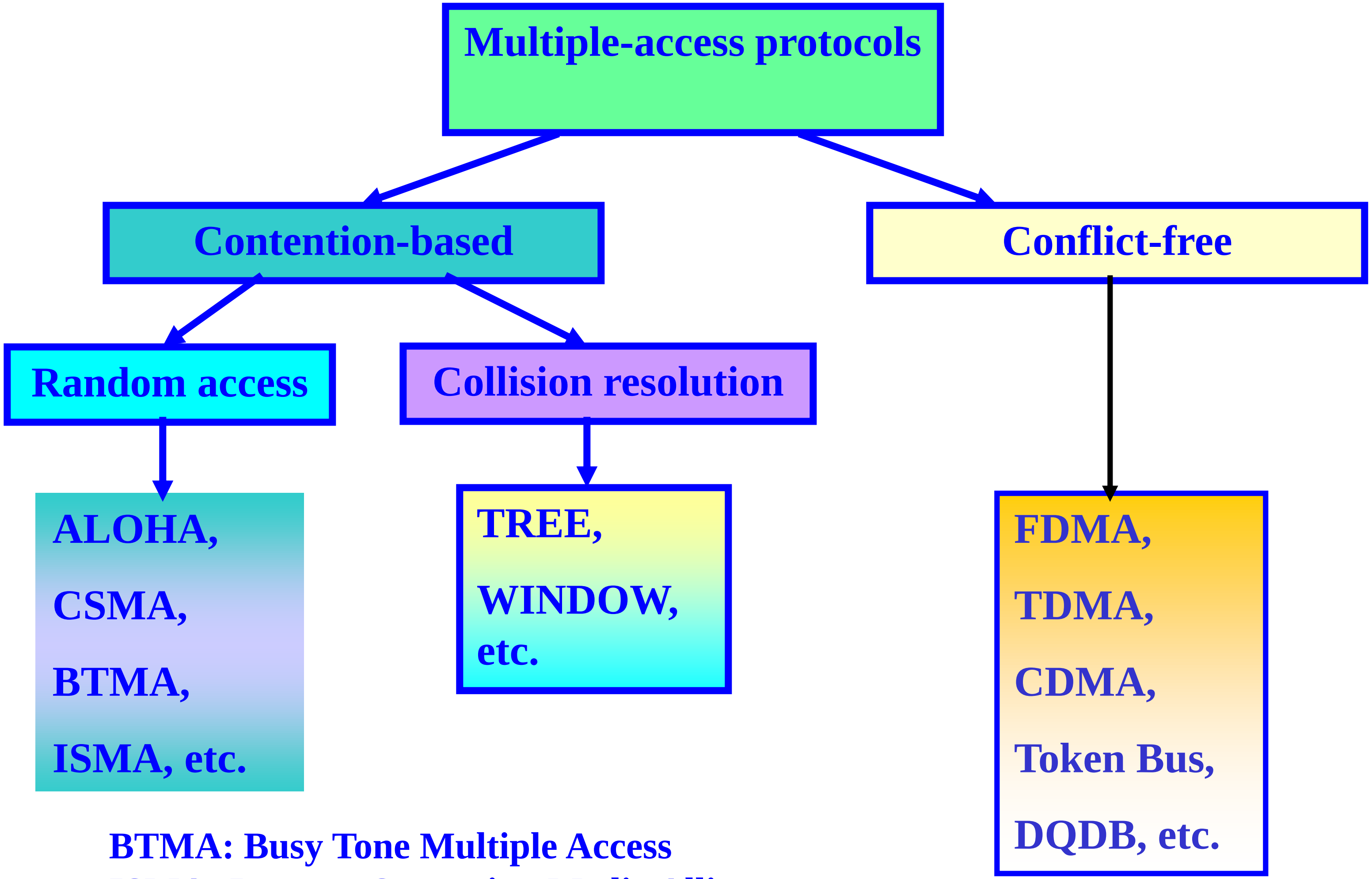
Introduction (Cont'd)

- 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 ensure that a collision can never occur

Channel Sharing Techniques



Classification of Multiple Access Protocols



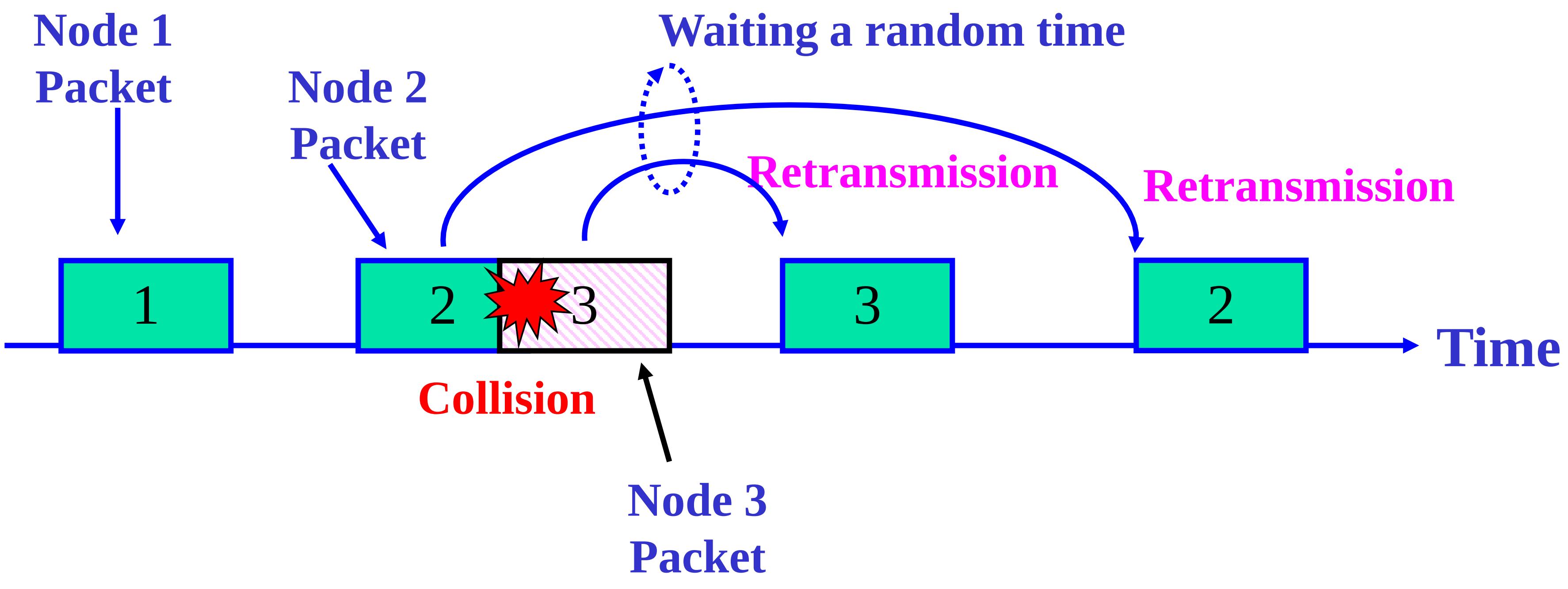
BTMA: Busy Tone Multiple Access
ISMA: Internet Streaming Media Alliance

DQDB: Distributed Queue Dual Bus

Contention-based Protocols

- ALOHA
  - 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

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 2*T***

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

where g is the packet rate of the traffic

- **The throughput S_{th} of pure Aloha as:** $S_{th} = gTe^{-2gT}$

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

$$S_{th} = Ge^{-2G}$$

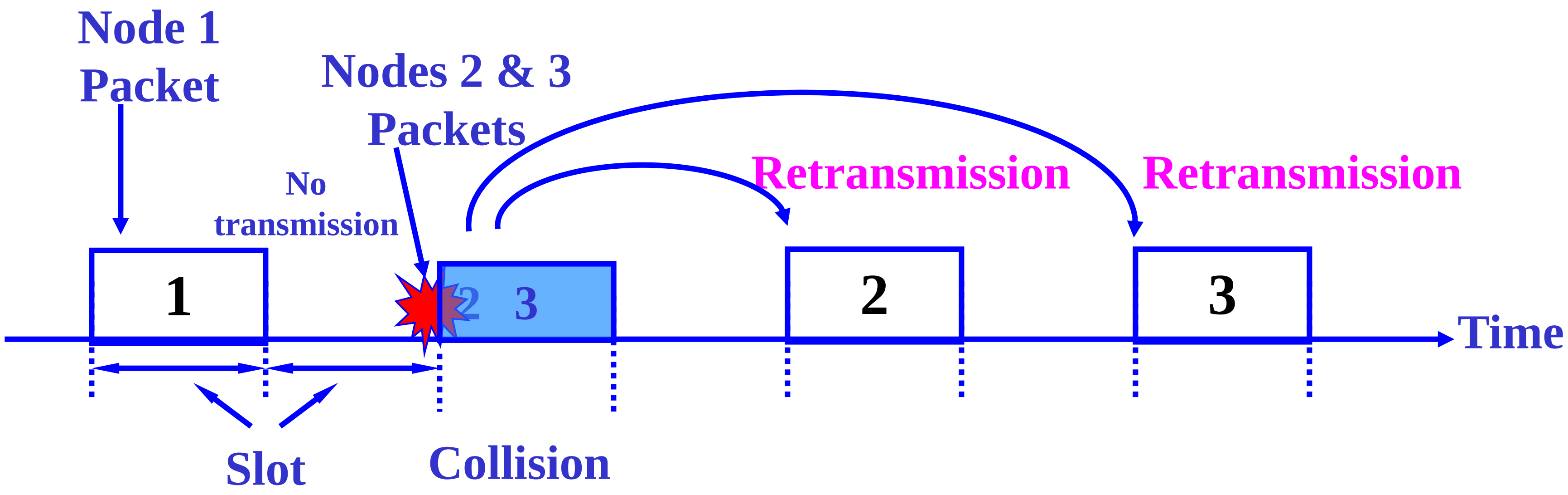
- **Differentiating S_{th} with respect to *G* and equating to zero gives**

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

- **The Maximum throughput of ALOHA is**

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

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**

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

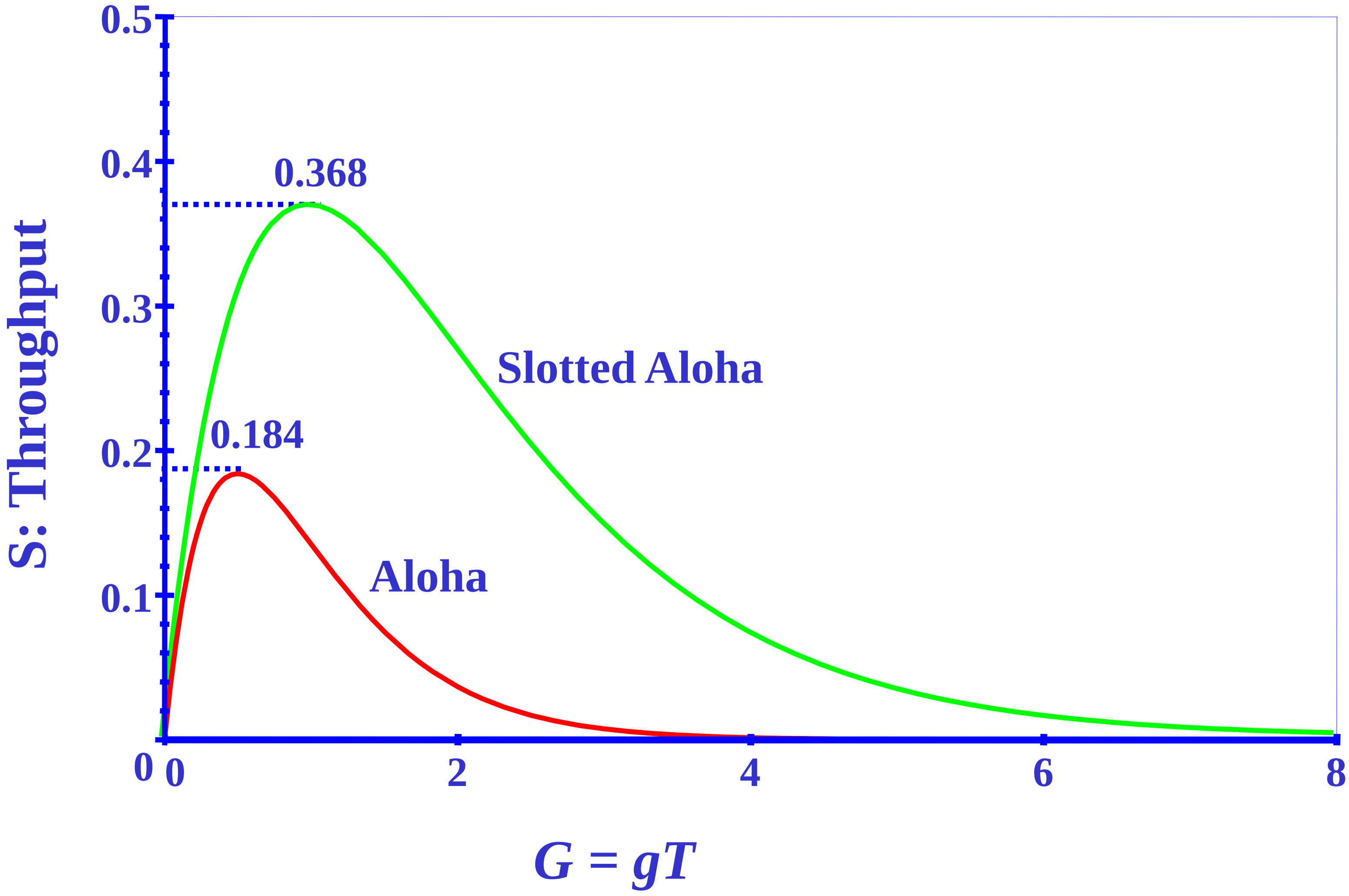
- **Differentiating S_{th} with respect to G and equating to zero gives**

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

- **The Maximum throughput of ALOHA is**

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

Throughput



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

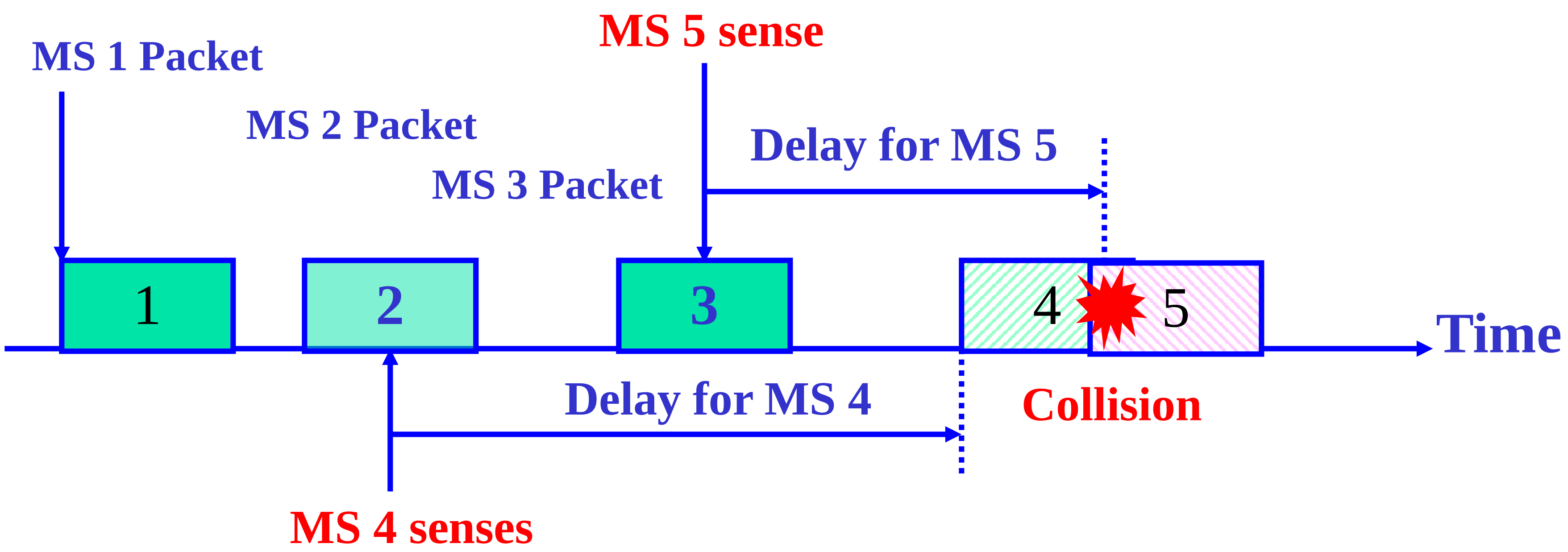
Contention Protocols (Cont'd)

- **CSMA (Carrier Sense Multiple Access)**
  - **Improvement: Start transmission only if no transmission is ongoing**
- **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**

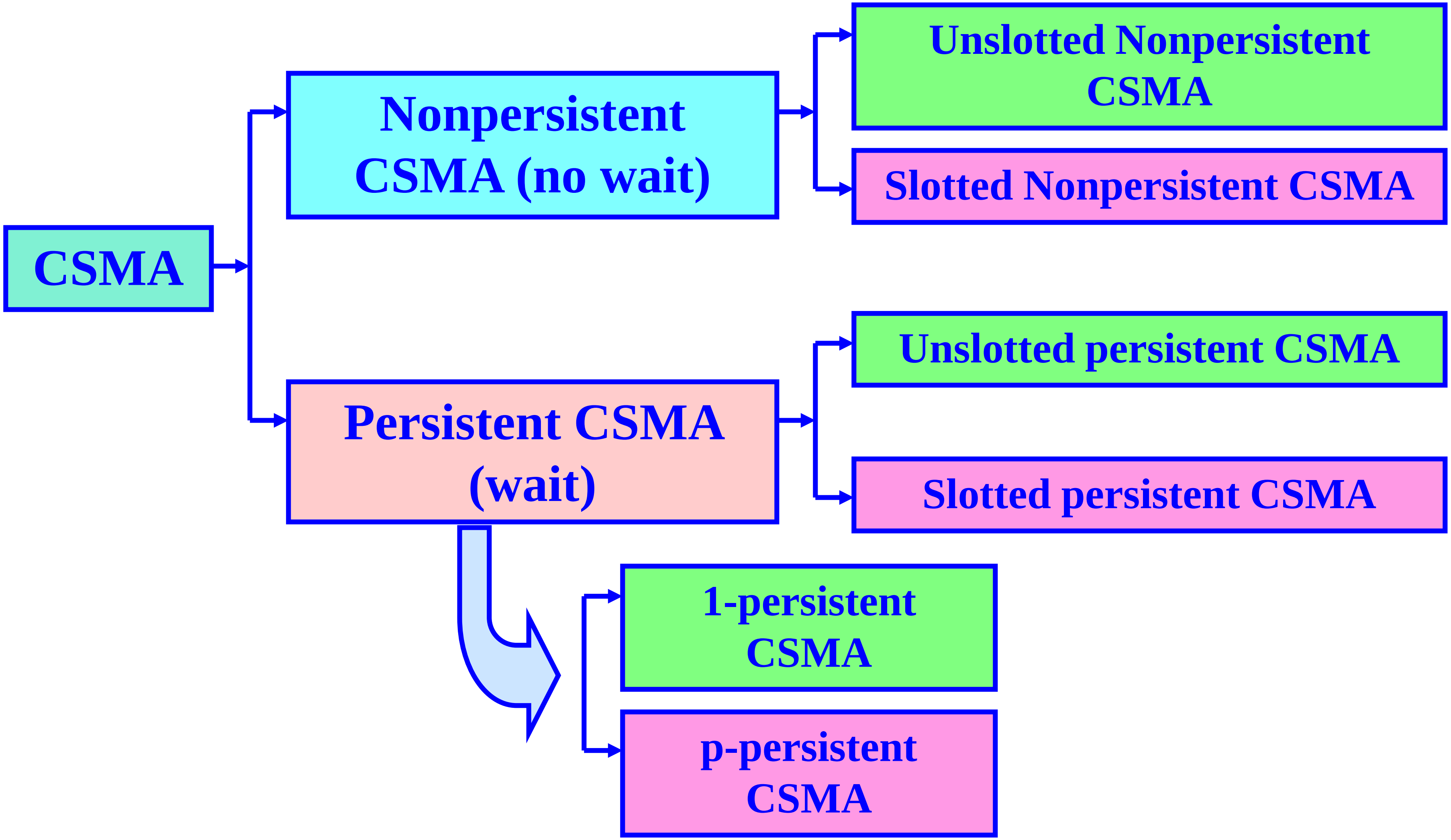
CSMA (Carrier Sense Multiple Access)

- **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)**

Collision Mechanism in CSMA



Kinds of CSMA



Nonpersistent CSMA Protocols

- **Nonpersistent CSMA Protocol:**
  - ✓ **Step 1: If the medium is idle, transmit immediately**
  - ✓ **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**
- **For unslotted nonpersistent CSMA, the throughput is given by:**

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

- **For slotted nonpersistent CSMA, the throughput is given by:**

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

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

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

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

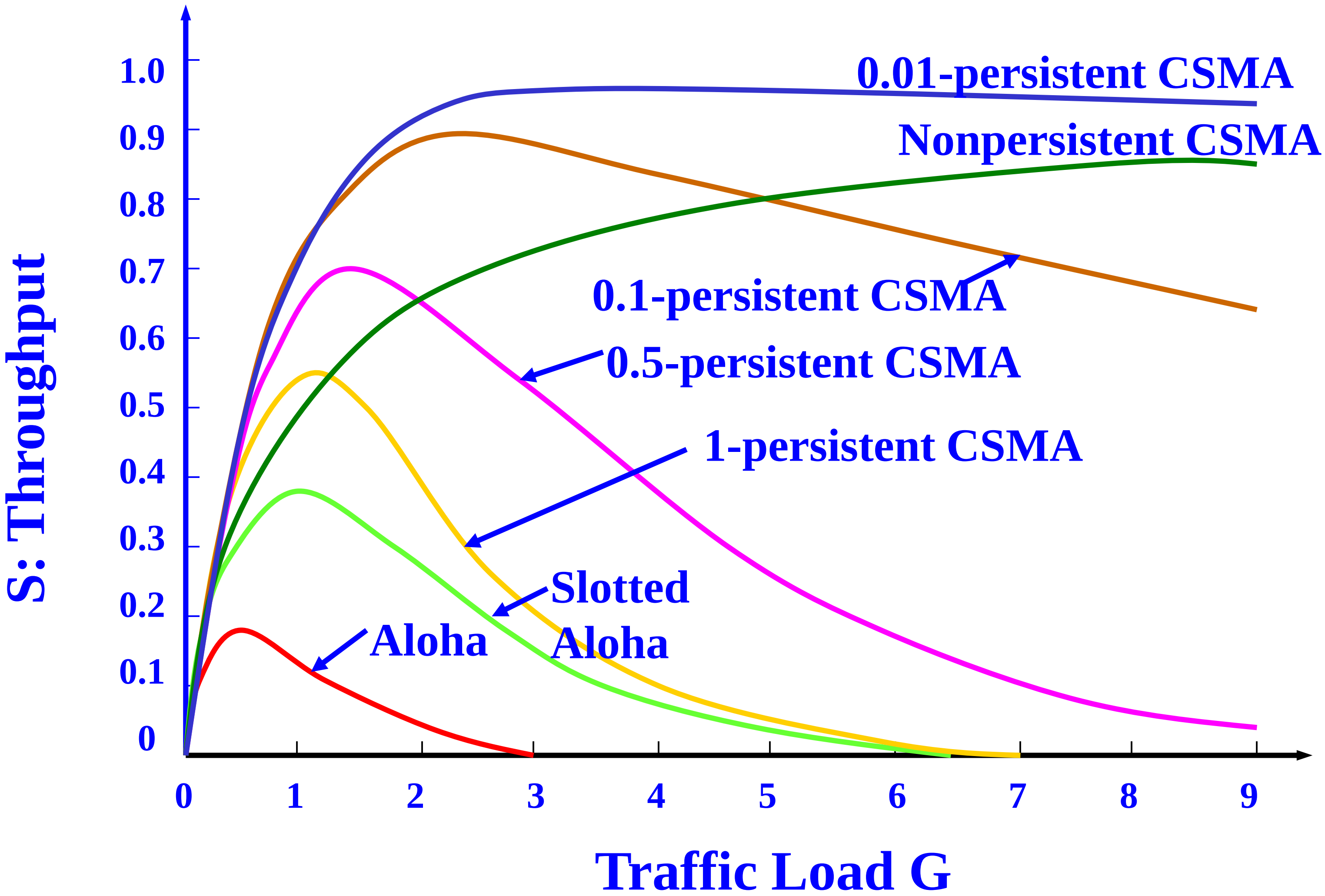
- **For slotted 1-persistent CSMA, the throughput is given by:**

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

p-persistent CSMA Protocols

- ***p*-persistent CSMA Protocol (time is slotted):**
  - **Step 1: If the medium is idle, transmit with probability *p*, or delay the transmission with probability (1 - *p*) until the next slot**
  - **Step 2: If the medium is busy, waits until the next slot and continue to listen until medium becomes idle, then go to Step 1**
- **A good tradeoff between nonpersistent and 1-persistent CSMA**

Throughput



S: Throughput
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01-persistent CSMA
Nonpersistent CSMA
0.1-persistent CSMA
0.5-persistent CSMA
1-persistent CSMA
Slotted Aloha
Aloha
0
1
2
3
4
5
6
7
8
9
Traffic Load G

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 during transmission, cease transmitting (detection not possible by wireless devices)

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

CSMA/CD in Ethernet (Cont'd)

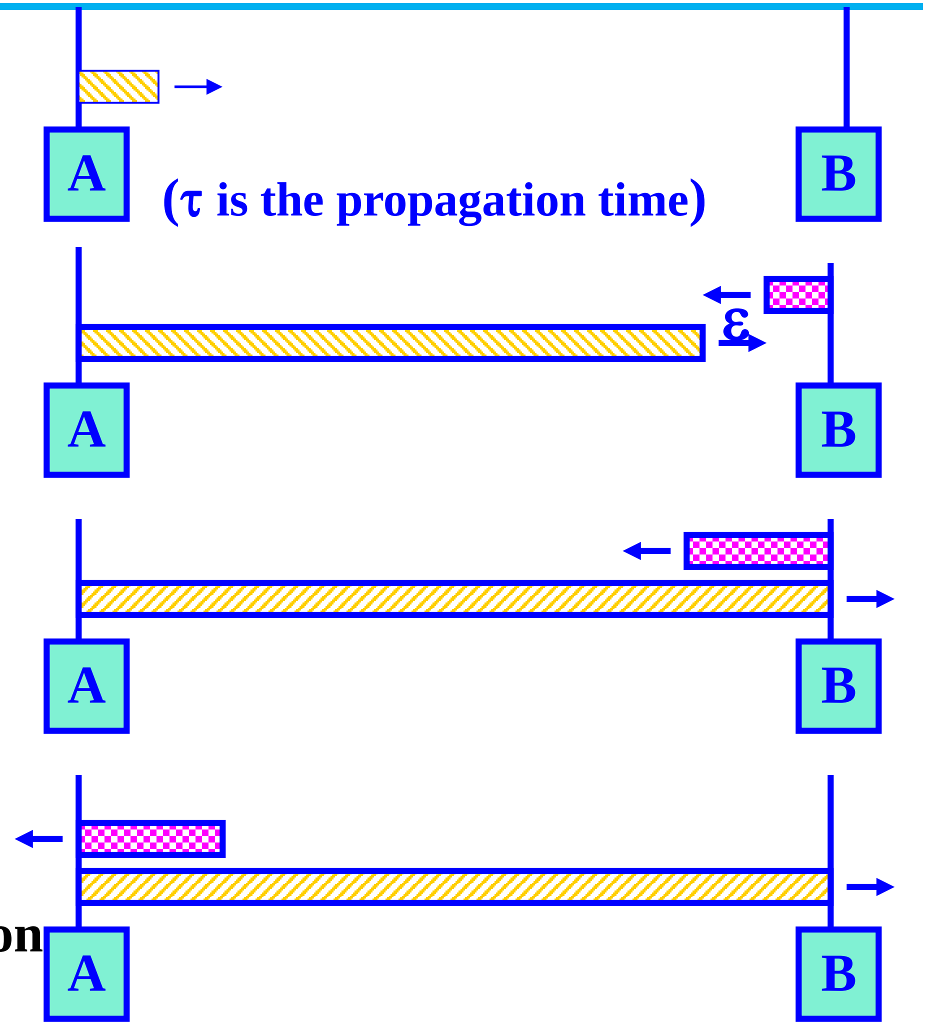
T_0 — **A begins transmission**

$T_0+\tau-\varepsilon$ — **B begins transmission**

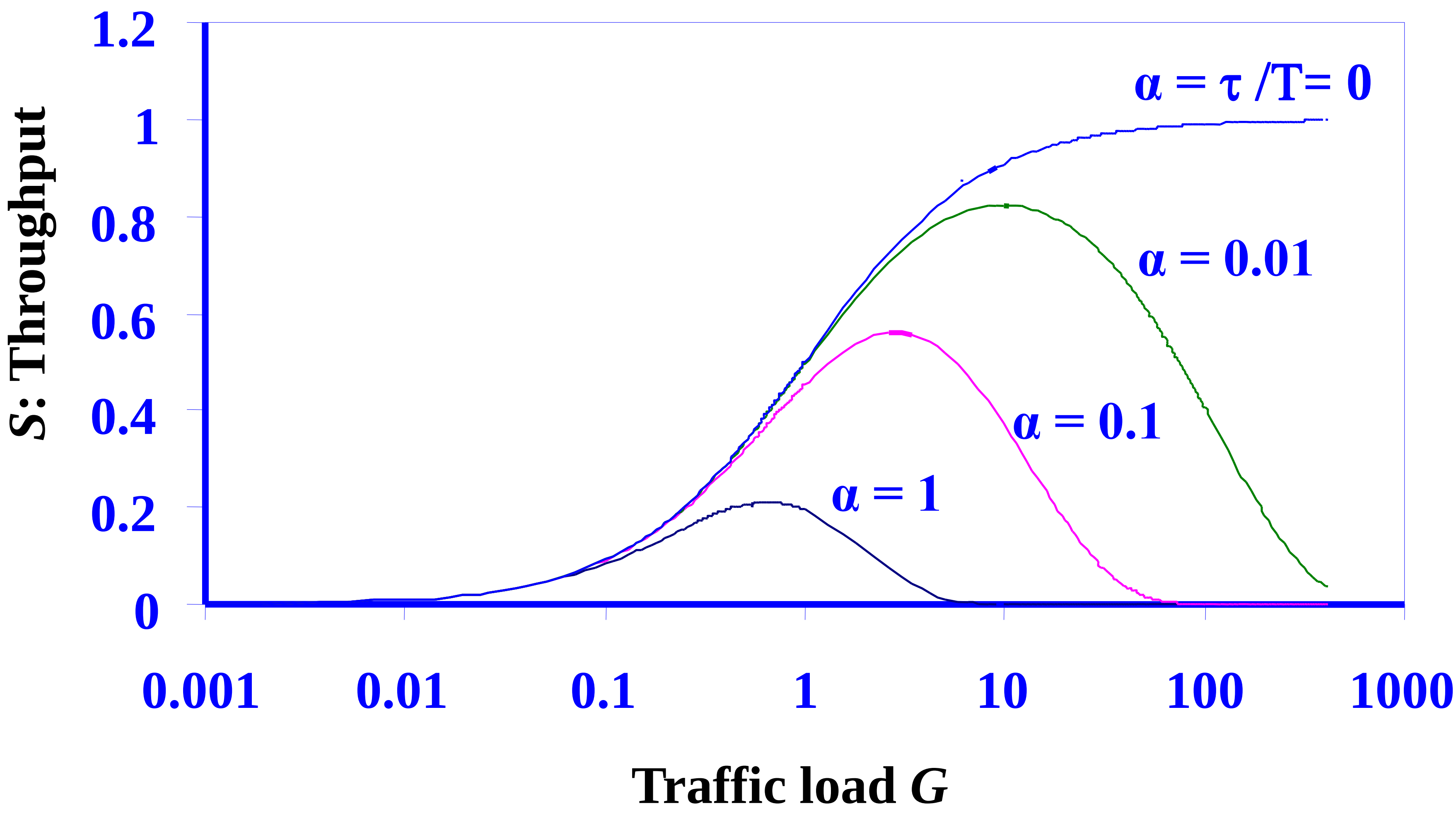
$T_0+\tau+\tau_{cd}$ — **B detects collision**

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

Time



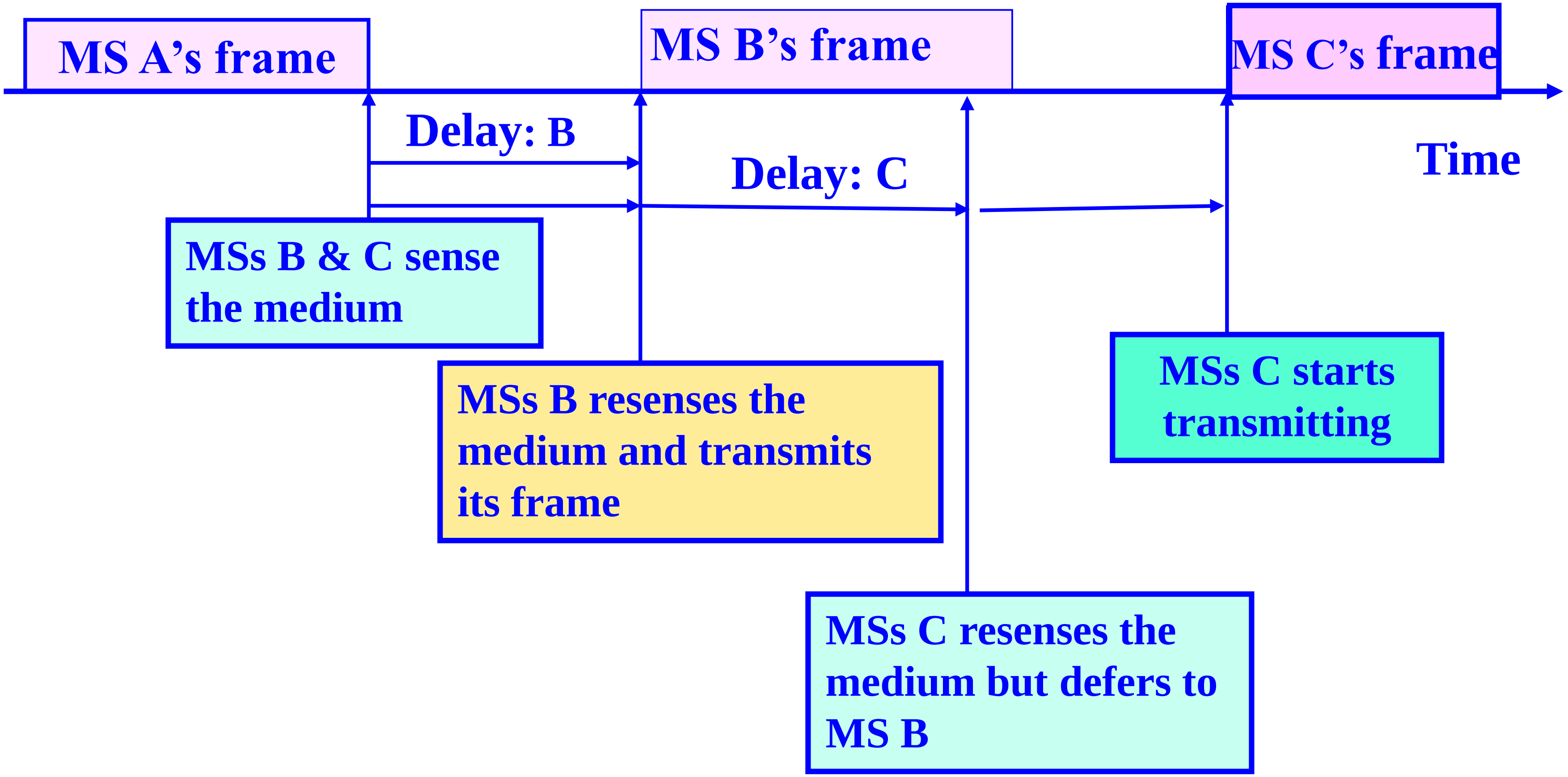
Throughput of slotted non-persistent CSMA/CD



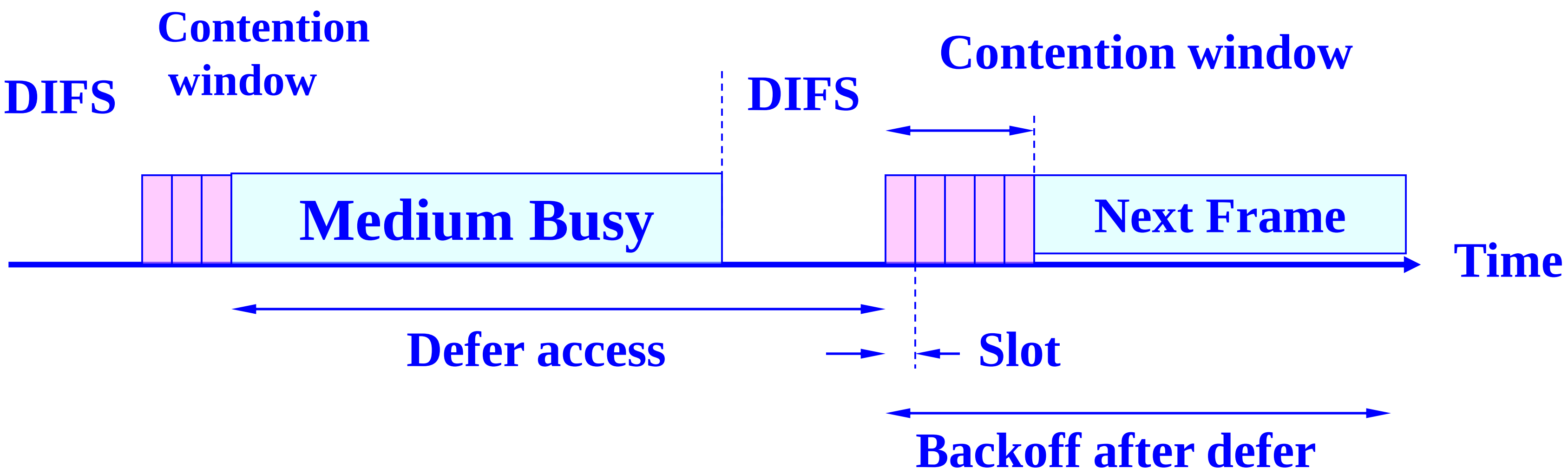
CSMA/CA (CSMA with collision Avoidance) for wireless devices

- 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 + DIFS. The MS can start its transmission when the counter reaches to zero

CSMA/CA (Cont'd) for Wireless Devices

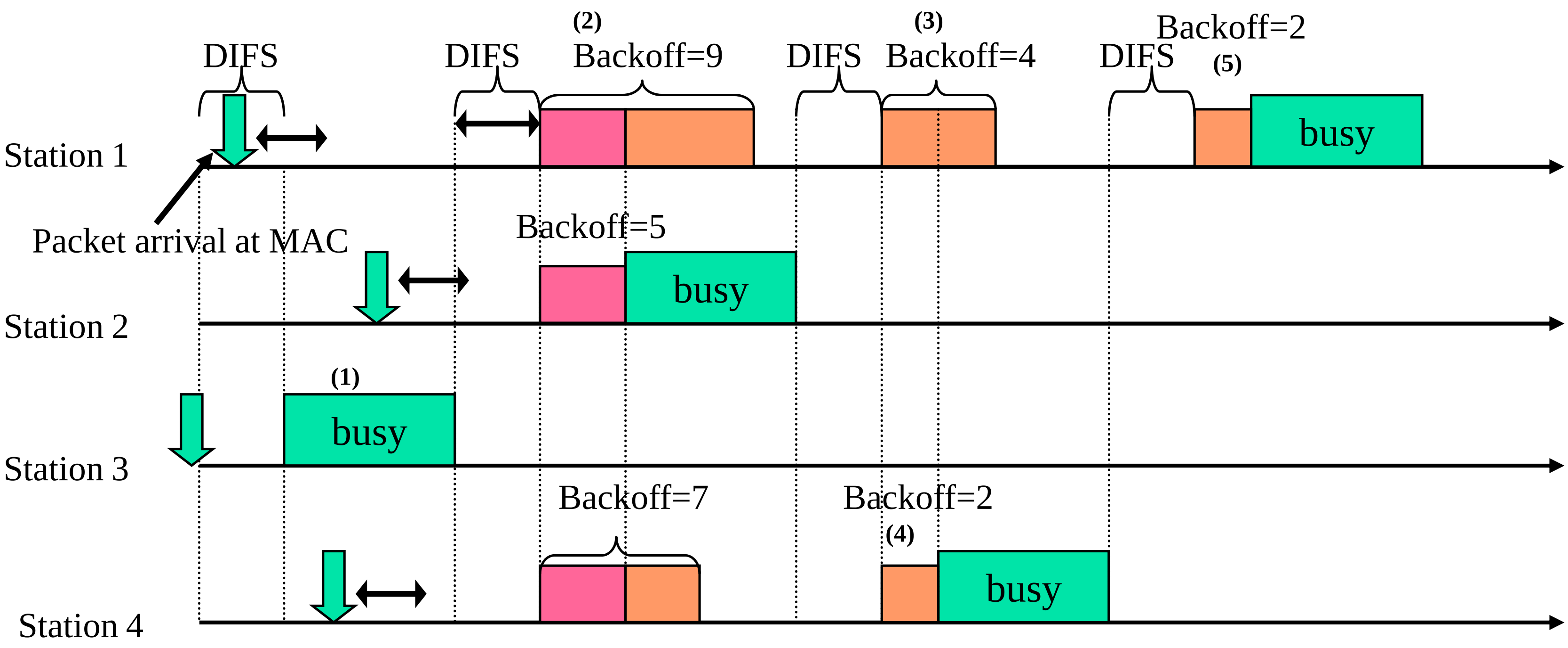


CSMA/CA Explained



DIFS – Distributed Inter Frame Spacing

Example of Backoff Intervals



(1) After packet arrival at MAC, station 3 senses medium free for DIFS, so it starts transmission immediately (without backoff interval).

(2) For station 1, 2, and 4, their DIFS intervals are interrupted by station 3. Thus, backoff intervals for station 1, 2, and 4, are generated randomly (i.e. 9, 5, and 7, respectively).

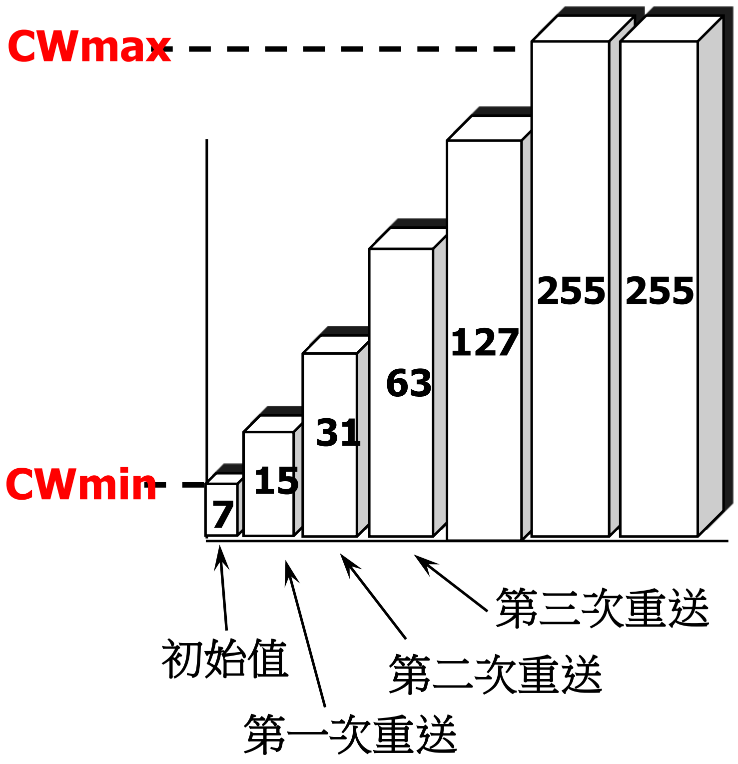
(3) After transmission of station 2, the remaining backoff interval of station 1 is (9-5)=4.

(4) After transmission of station 2, the remaining backoff interval of station 4 is (7-5)=2.

(5) After transmission of station 4, the remaining backoff interval of station 1 is (4-2)=2.

Random Backoff Time

- Backoff time = CW* Random() * Slot time
  - CW = starts at CWmin, and doubles after each failure until reaching CWmax (e.g., CWmin = 7, CWmax = 255)
  - Random() = (0,1)
  - Slot Time = Transmitter turn on delay + medium propagation delay + medium busy detect response time



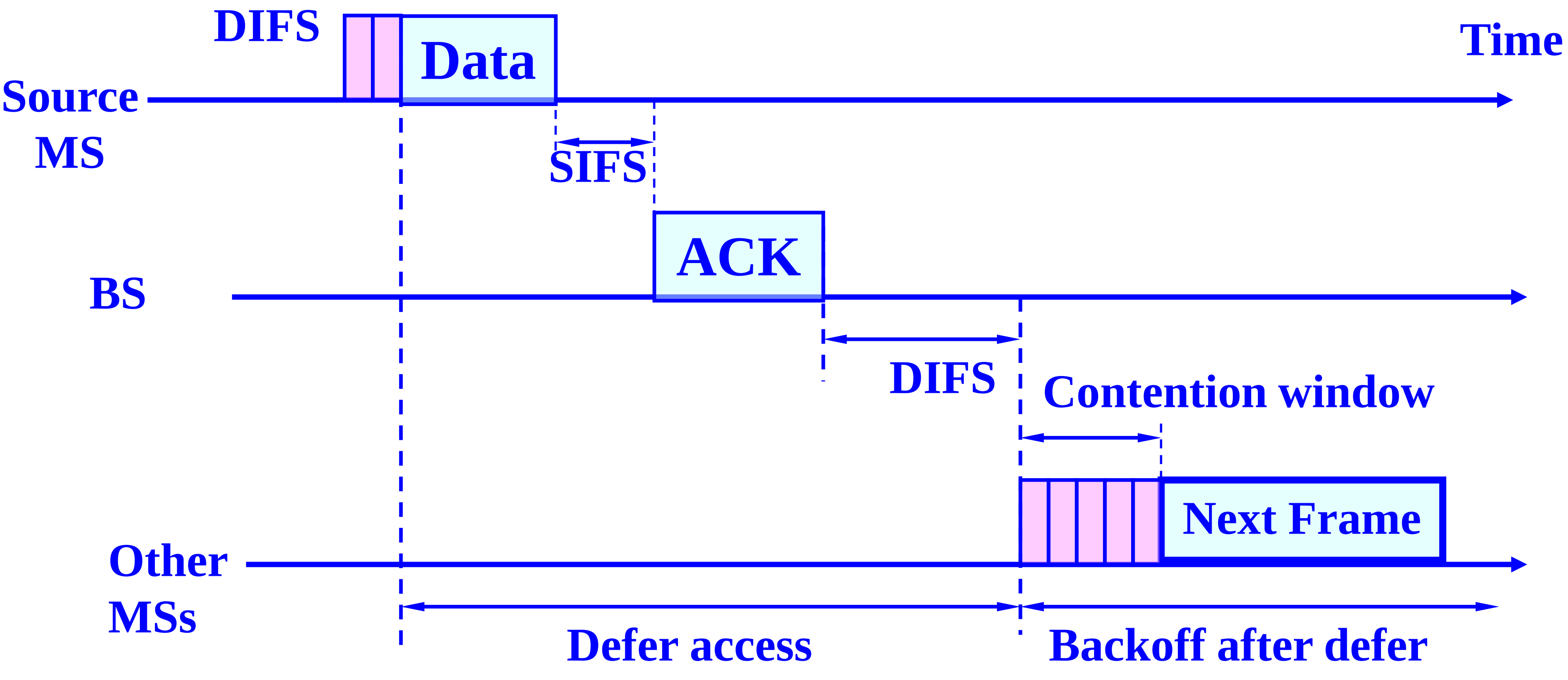
Priority Scheme in MAC

- Priorities of frames are distinguished by the IFS (inter-frame spacing) between two consecutive frames.
- 4 IFS's:
  - SIFS: the highest priority
    - ACK, CTS, the second or subsequent MPDU of a fragmented burst, and to respond to a poll from the PCF.
  - PIFS (PCF-IFS): 2nd highest
    - by PCF to send any of the Contention Free Period frames.
  - DIFS (DCF-IFS): 3nd highest
    - by the DCF to transmit MPDUs or MMPDUs
  - EIFS (Extended-IFS): lowest
    - by the DCF to transmit a frame when previous frame was not received correctly

CSMA/CA with ACK for Ad Hoc Networks

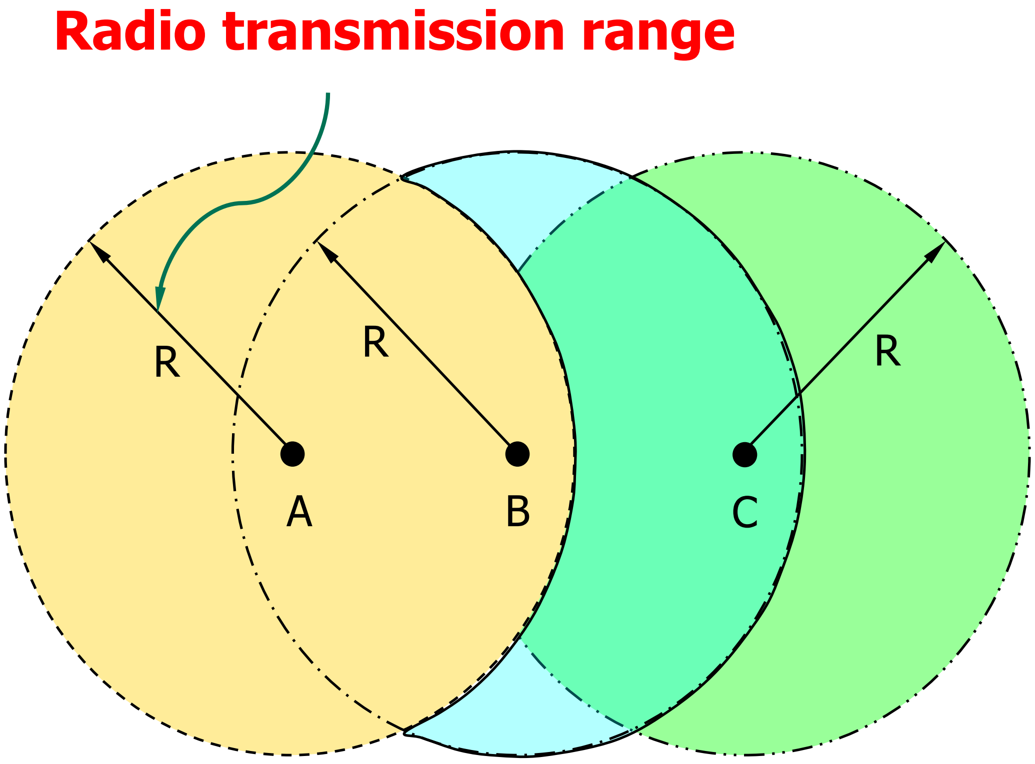
- **Immediate Acknowledgements from receiver upon reception of data frame without any need for sensing the medium**
- **ACK frame transmitted after time interval SIFS (*Short Inter-Frame Space*) (SIFS < DIFS)**
- **Receiver transmits ACK without sensing the medium**
- **If ACK is lost, retransmission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

CSMA/CA/ACK



SIFS – Short Inter Frame Spacing

Hidden Terminal Problem

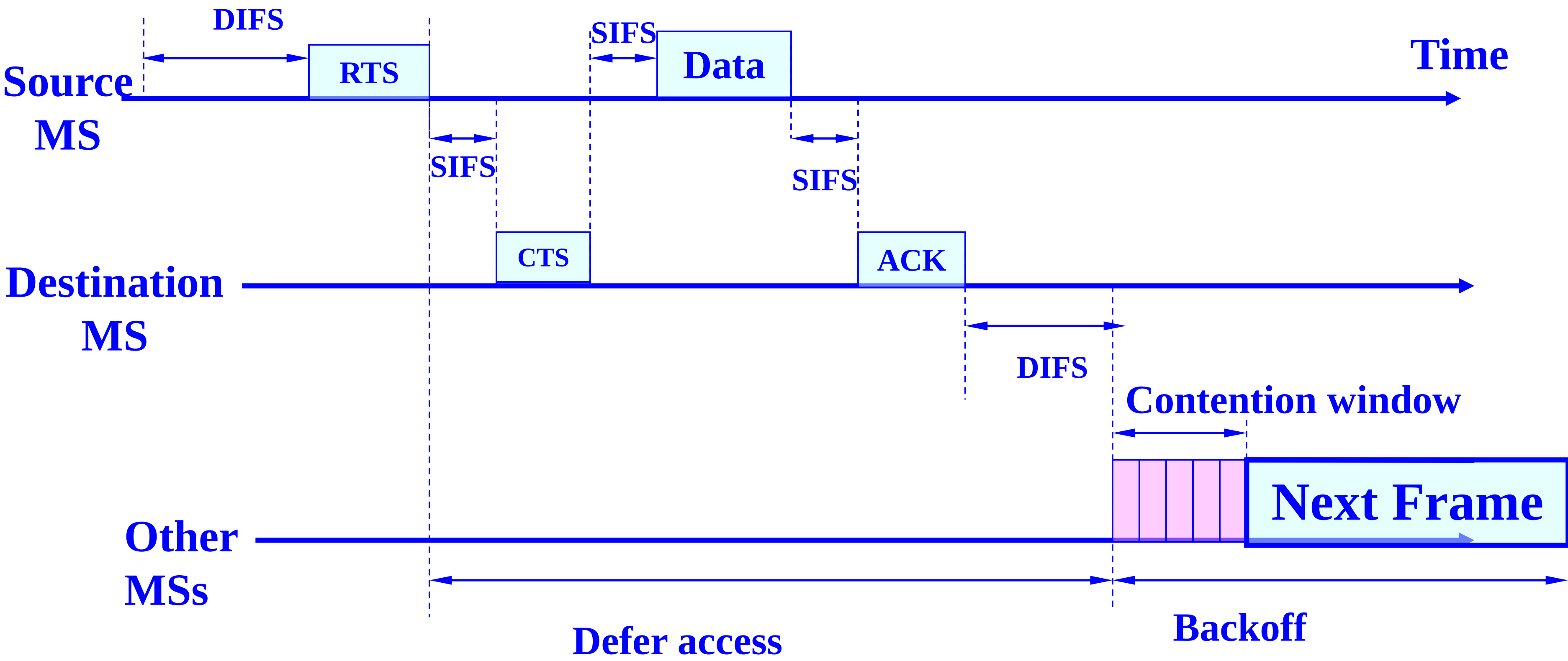


A and C are hidden with respect to each other

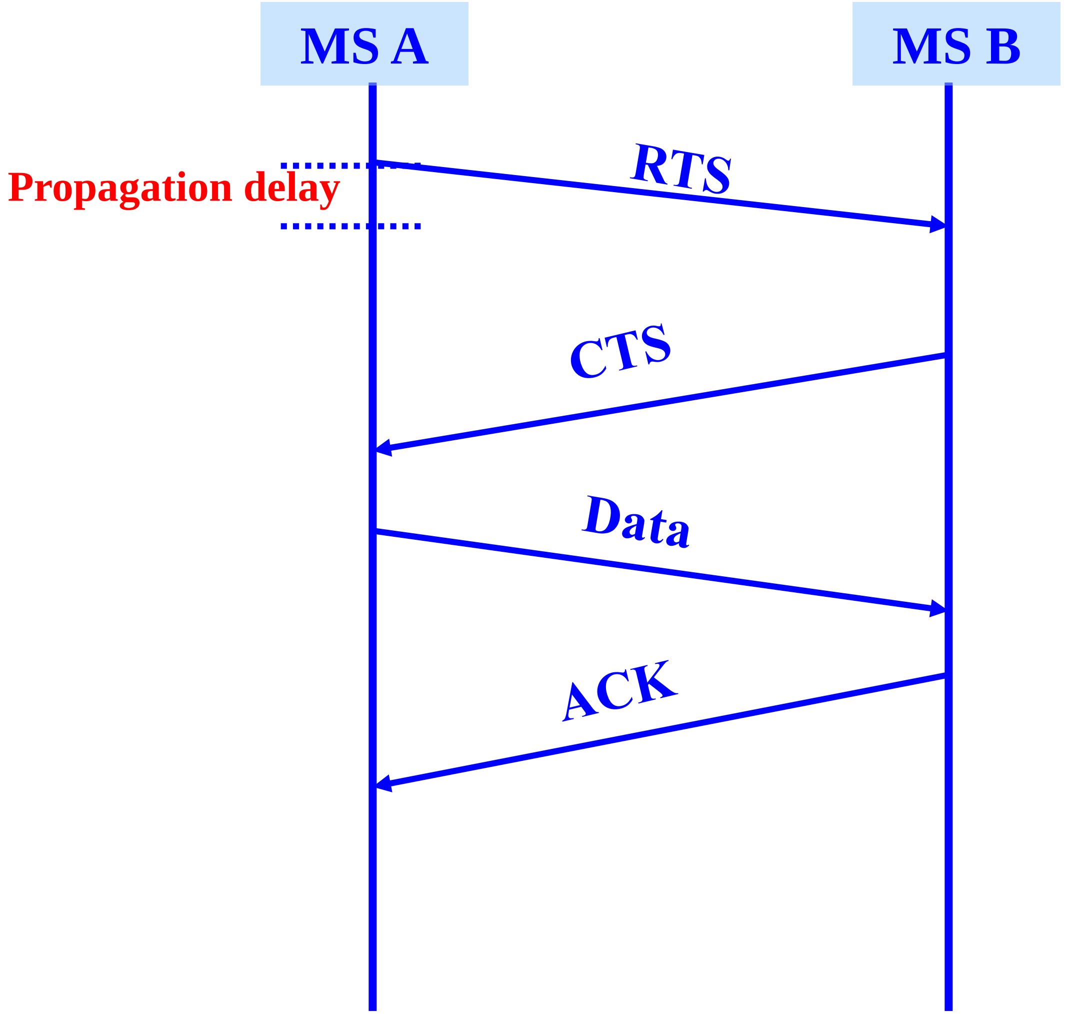
CSMA/CA with RTS/CTS for Hidden Terminal Problem

- 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

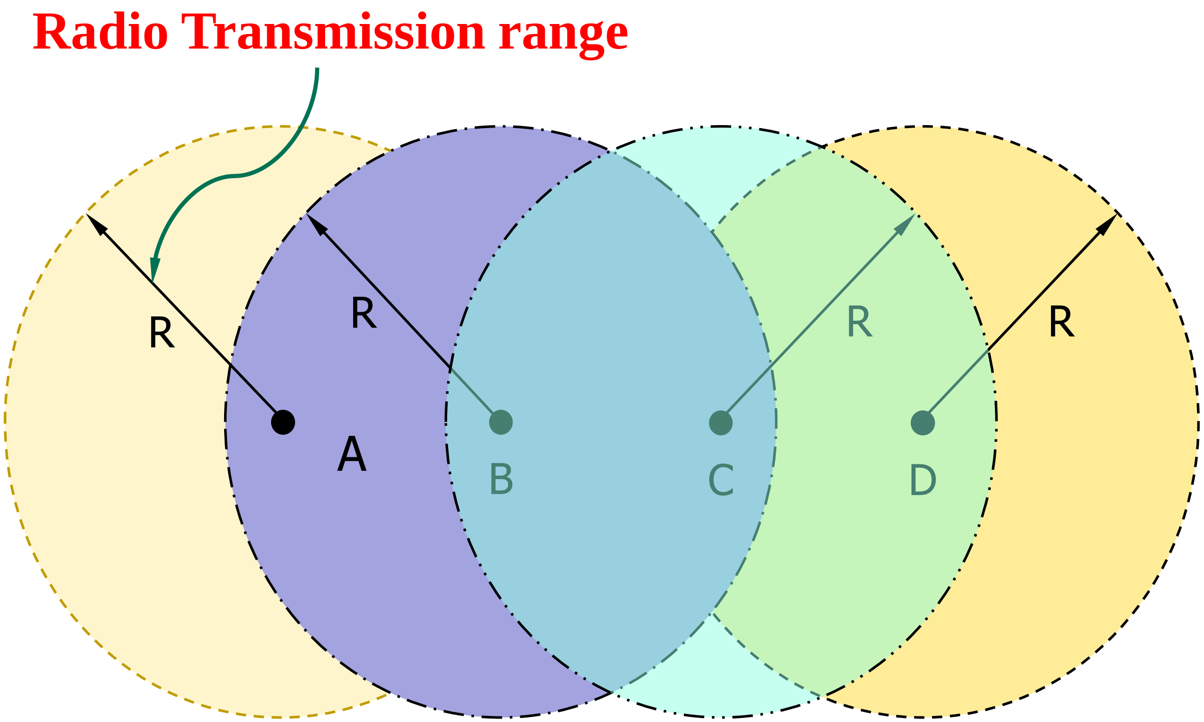


RTS/CTS



This helps avoid hidden terminal problem in Ad hoc networks

Exposed Terminal Problem



Transmission at B forces C (Exposed) to stop transmission to D

Homework

- Problems: 6.2, 6.6, 6.10, 6.13, 6.17
- Experiment 3: Using MATLAB to implement Pure ALOHA, Slotted ALOHA, and CSMA protocols and show their performance.