# Chapter 6

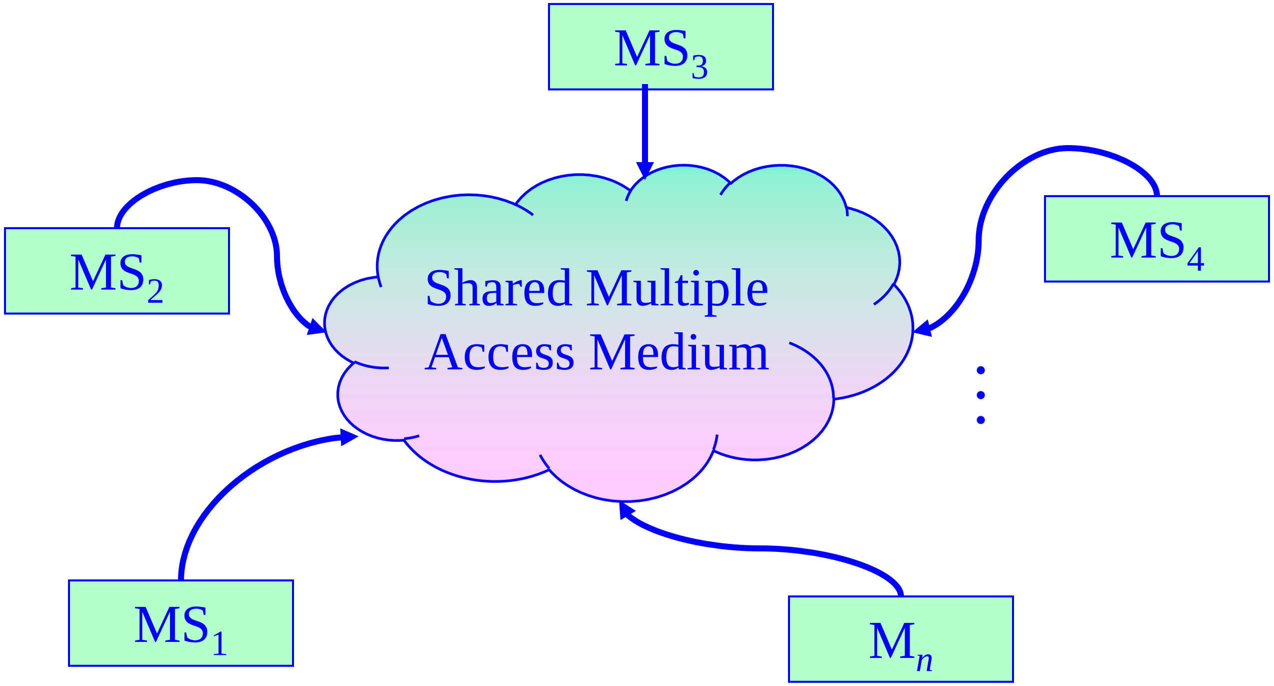
# Multiple Radio Access for Control Channels

# 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

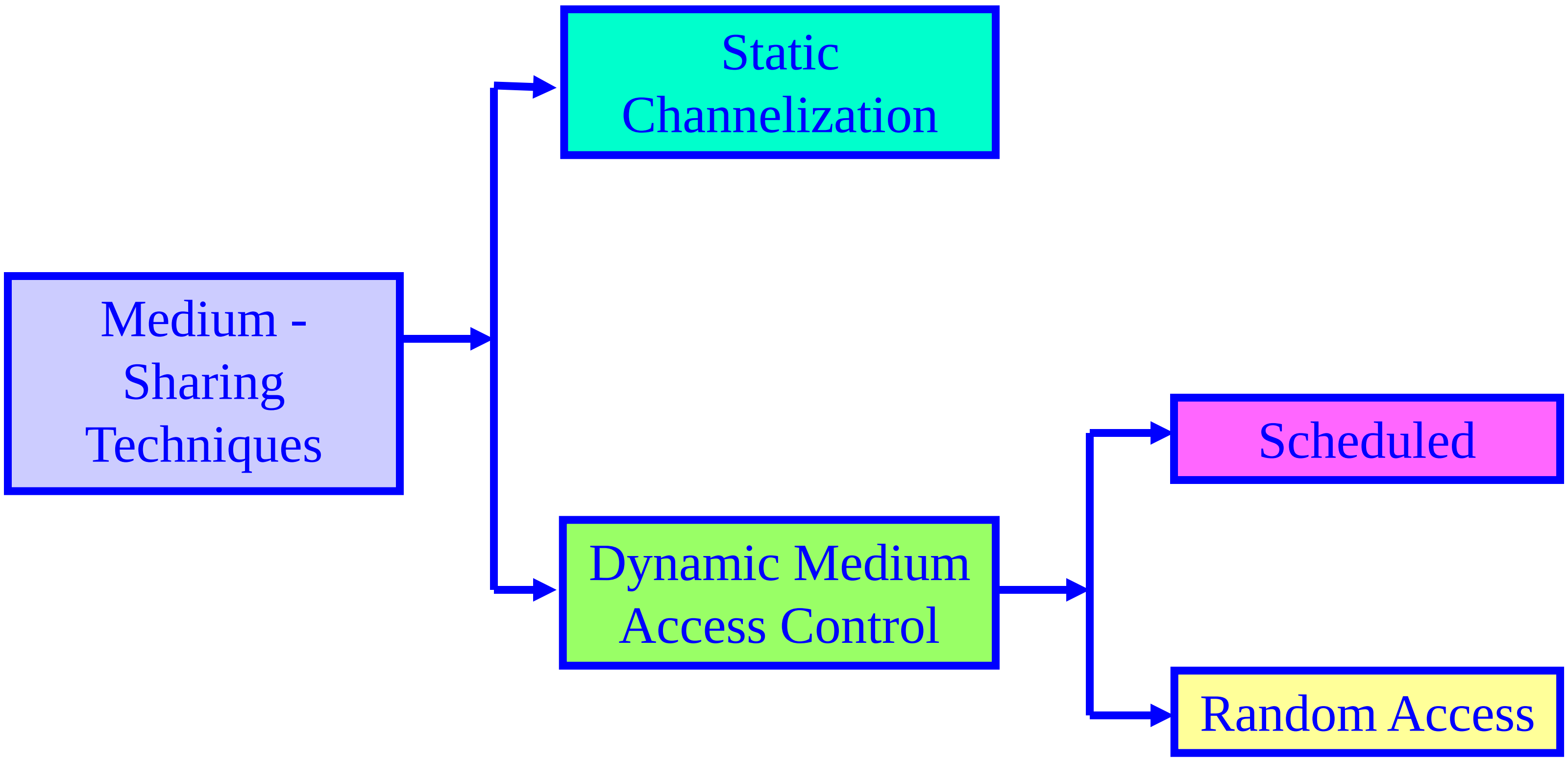
- Multiple access control channels
  - Each Mobile Station (MS) is attached to a transmitter or receiver which communicates via a channel shared by other nodes
  - Transmission from any MS is received by other MSs



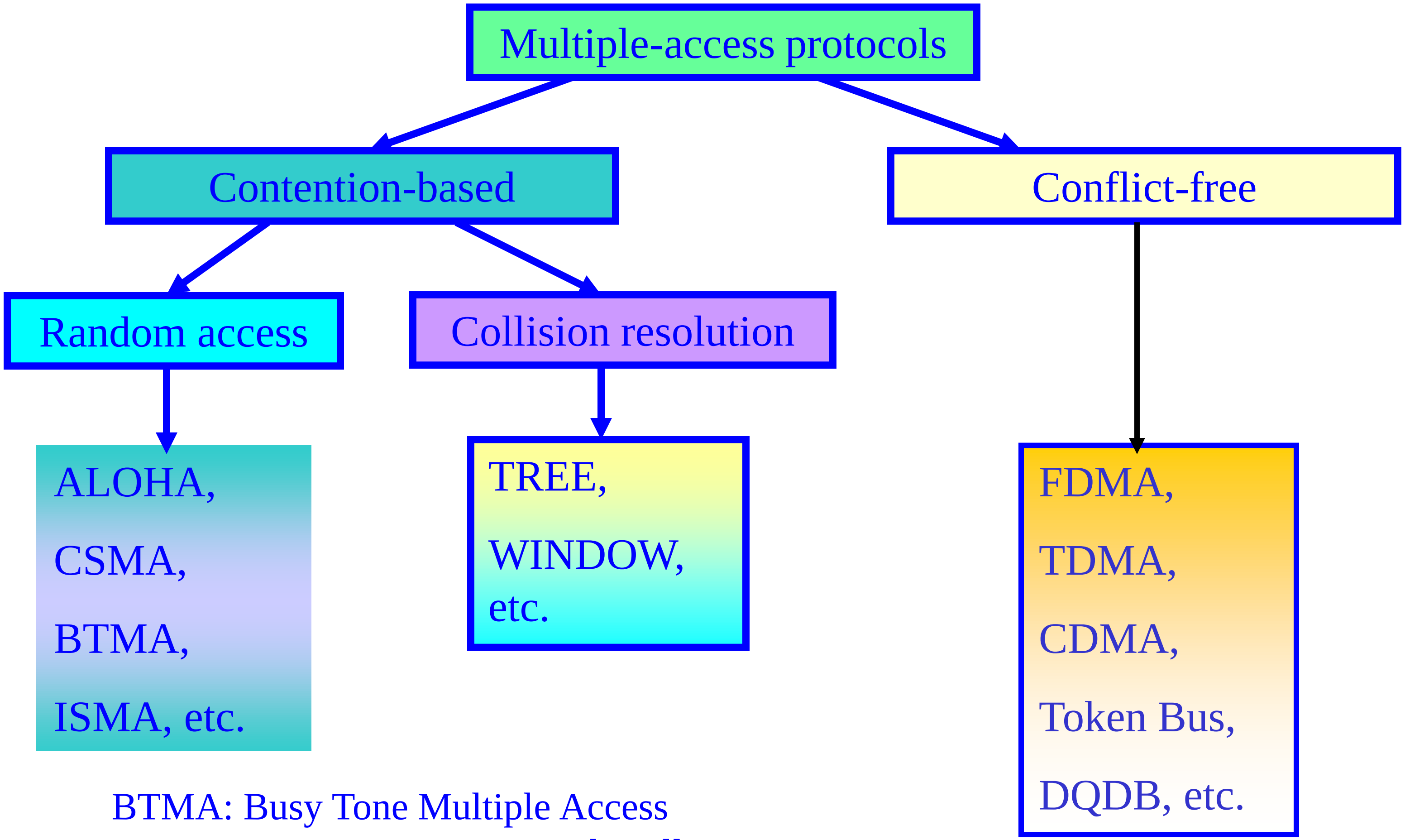
# Introduction (Cont'd)

- 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



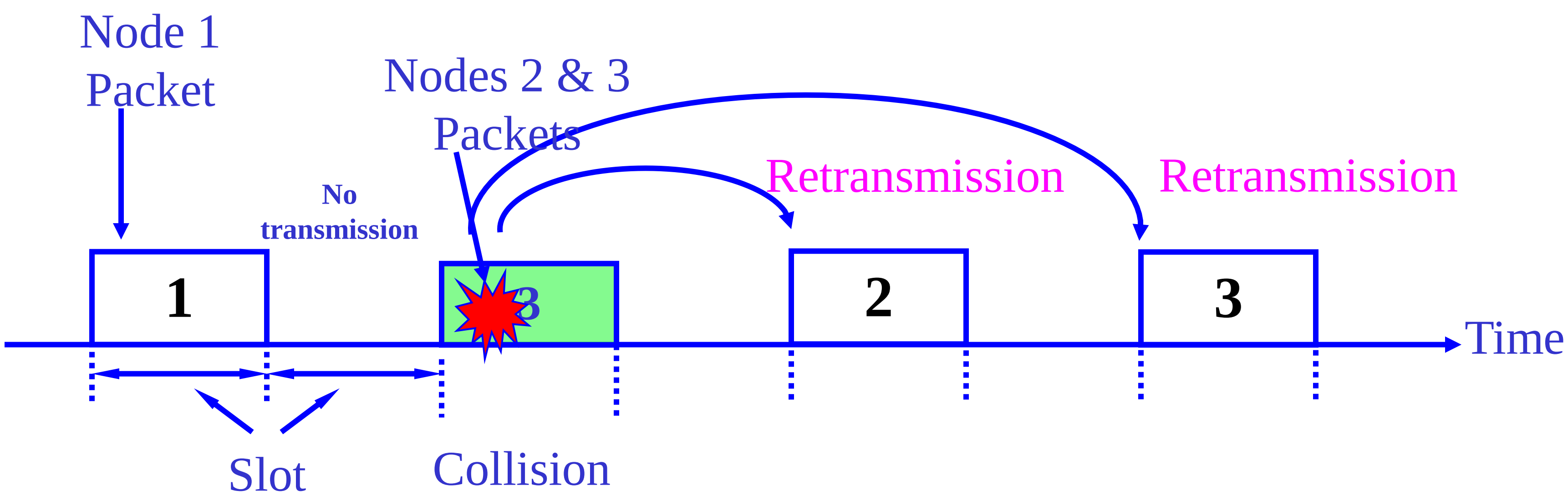

BTMA: Busy Tone Multiple Access
ISMA: Internet Streaming Media Alliance

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

# 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

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

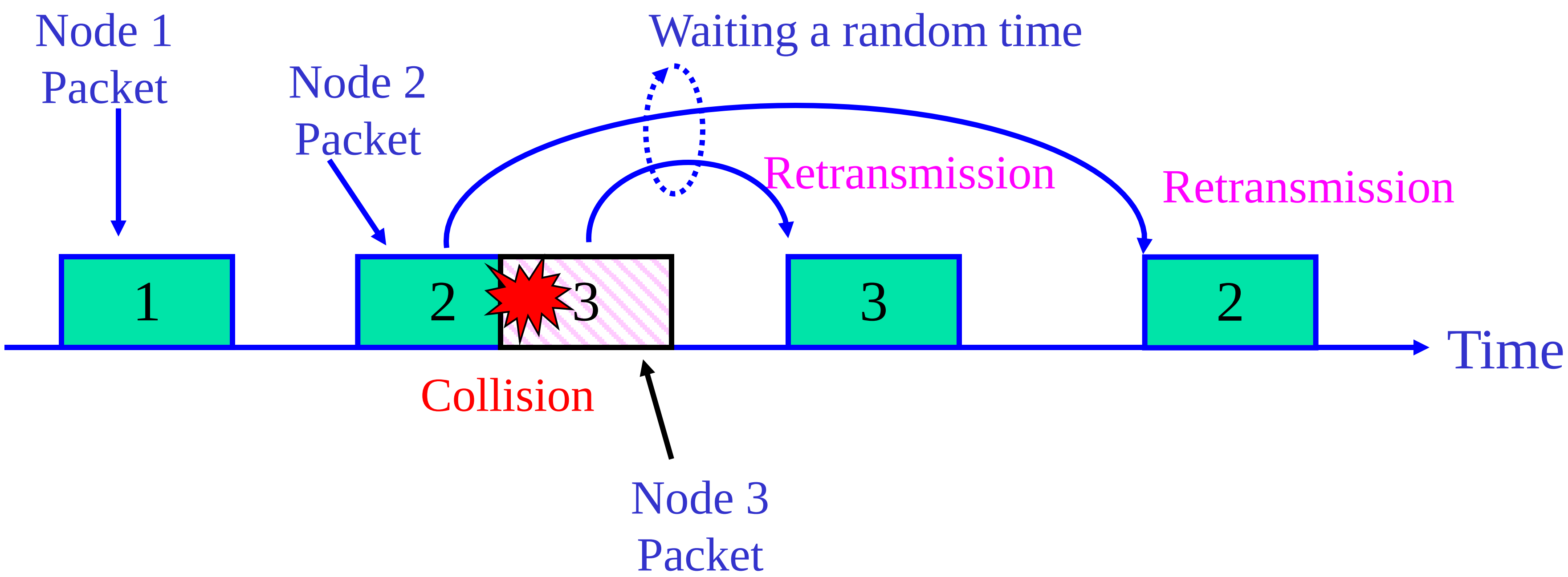
- Differentiating $S_{th}$ with respect to $G$ and equating to zero gives

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

- The Maximum throughput of ALOHA is

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

# Pure ALOHA



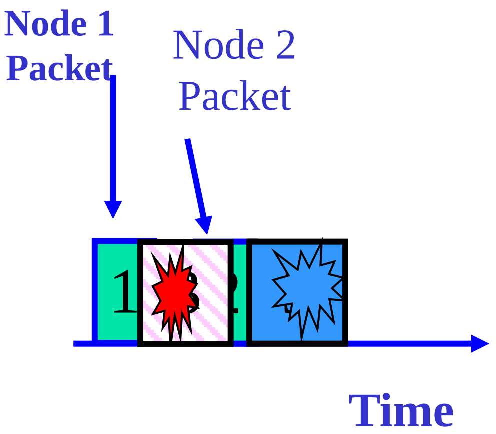

Collision mechanism in ALOHA

# 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 $\boldsymbol{g}$ is the packet rate of the traffic




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

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

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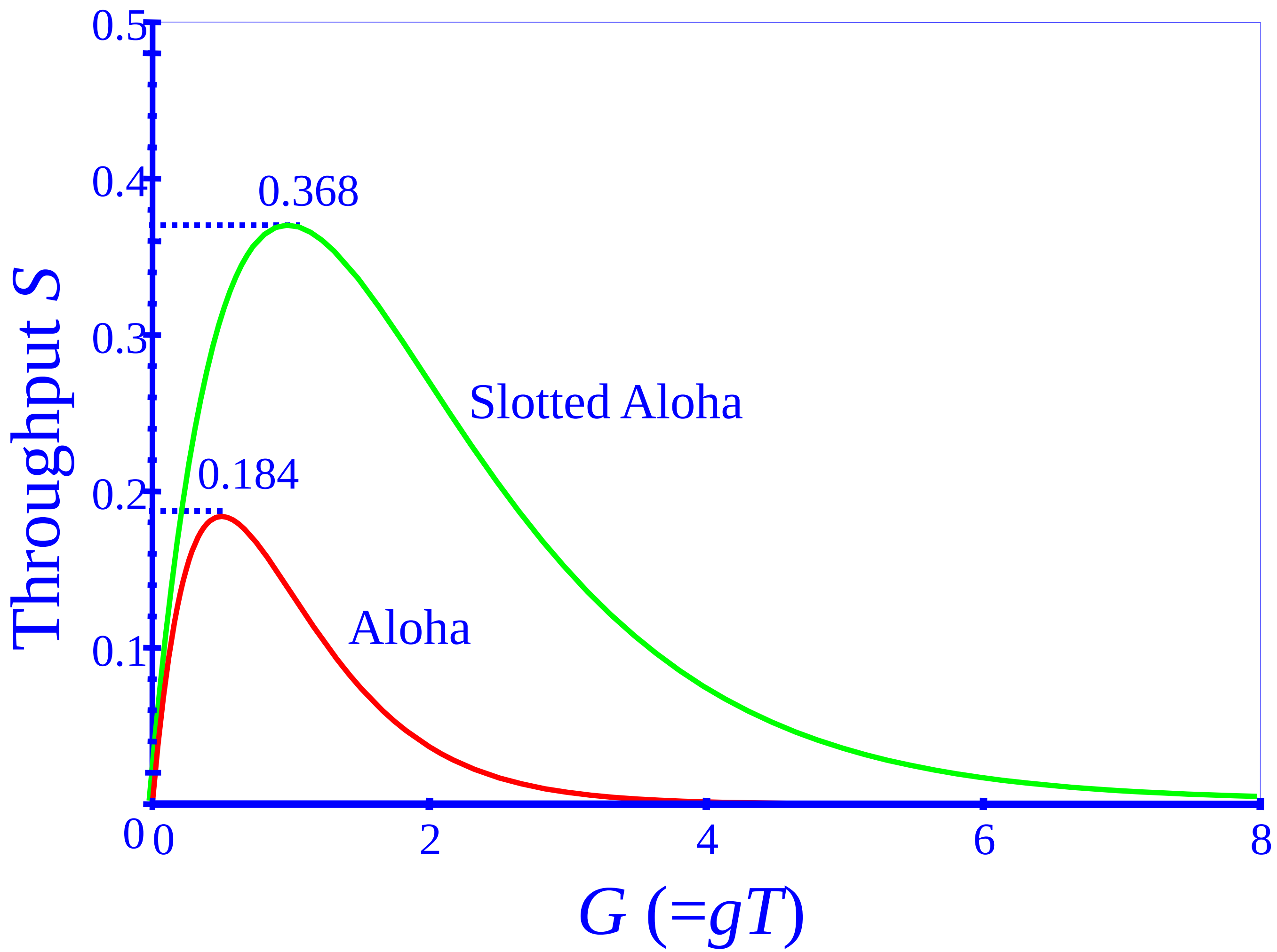
- Differentiating $S_{th}$ with respect to $G$ and equating to zero gives

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

- The Maximum throughput of ALOHA is

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

# 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)

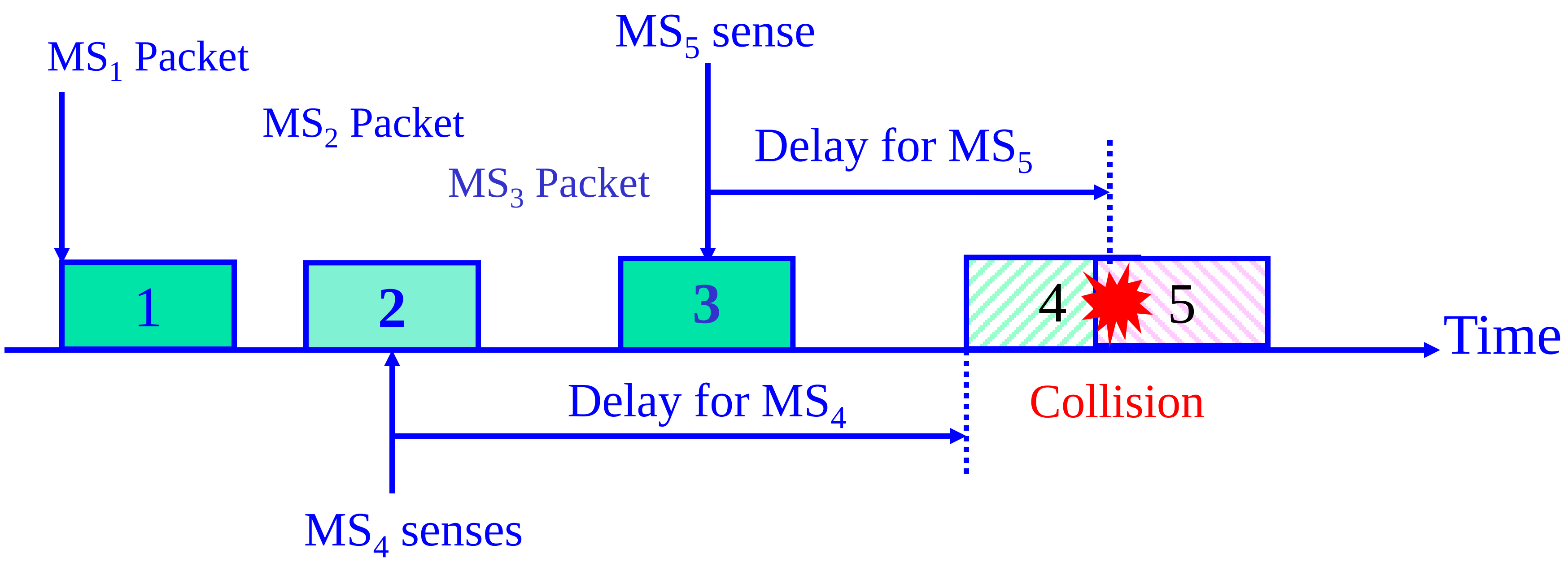
# Contention Protocols (Cont'd)

- **CSMA (Carrier Sense Multiple Access)**
  - Improvement: Start transmission only if no transmission is ongoing
- **CSMA/CD (CSMA with Collision Detection: for wired system)**
  - 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**

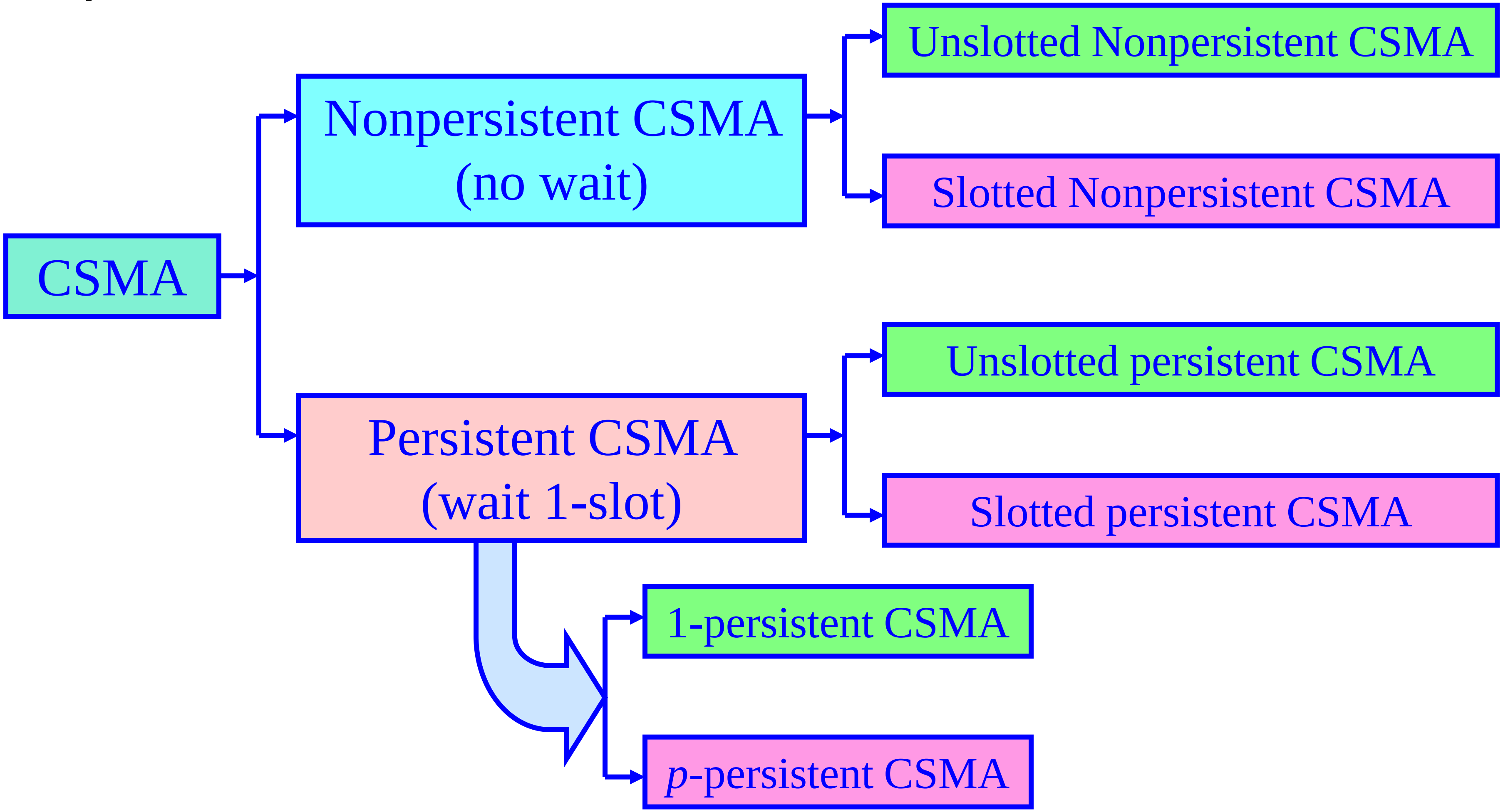
# CSMA (Carrier Sense Multiple Access)

- 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



# *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 ($1-p$)

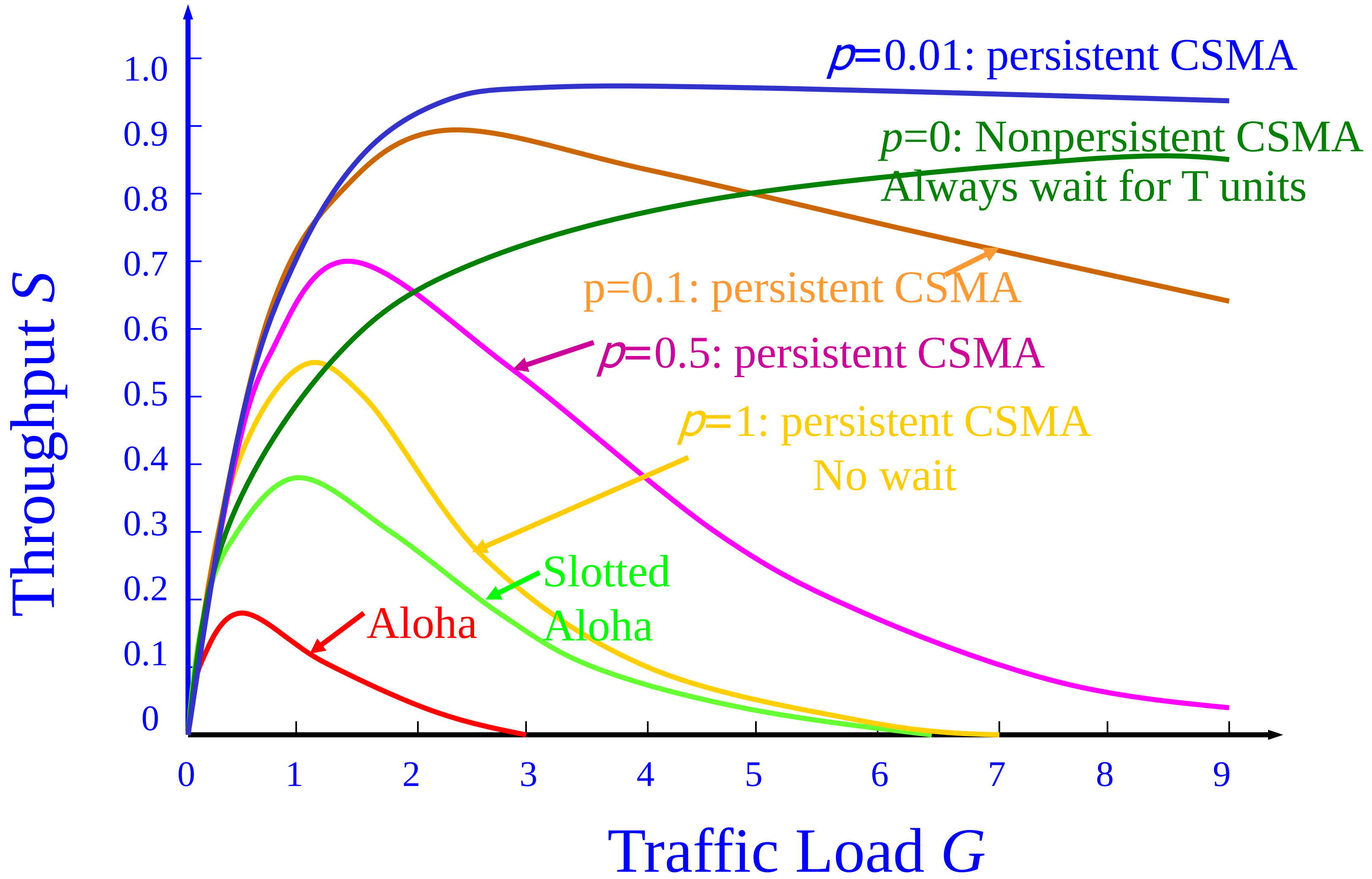
Special case of $p=0$: non-persistent and $p=1$:1-persistent

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

  - $p=0$: non-persistent (**no wait**) and $p=1$: 1-persistent CSMA (**wait**)
  - A good tradeoff between non-persistent 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 (no wait):**

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

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:

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

# 1-persistent CSMA Protocols

**1-persistent CSMA Protocol (wait):**

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 without wait

- 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

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

# 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 $Np \leq 1$ 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, $Np \leq 1$. Throughput $S$ as:

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

where $G$ is offered traffic rate

α=τ/T= propagation delay/packet transmission time

where $P_s^{'}, P_s, \overline{t'}, \overline{t}$ and $\pi_0$ are given by the following equations:

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

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

# $p$-persistent CSMA Protocol

**Where:**

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

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

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

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

# 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 (only wired medium):**

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)

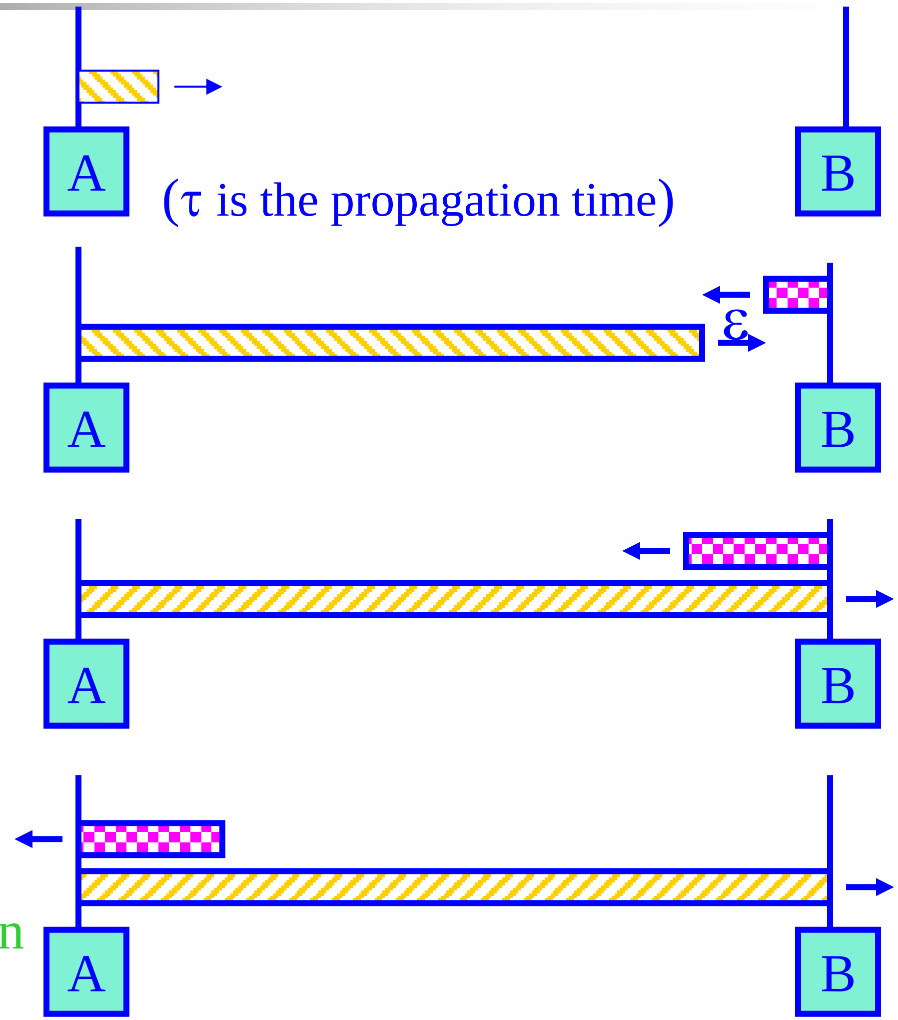
$T_0$ — A begins transmission

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

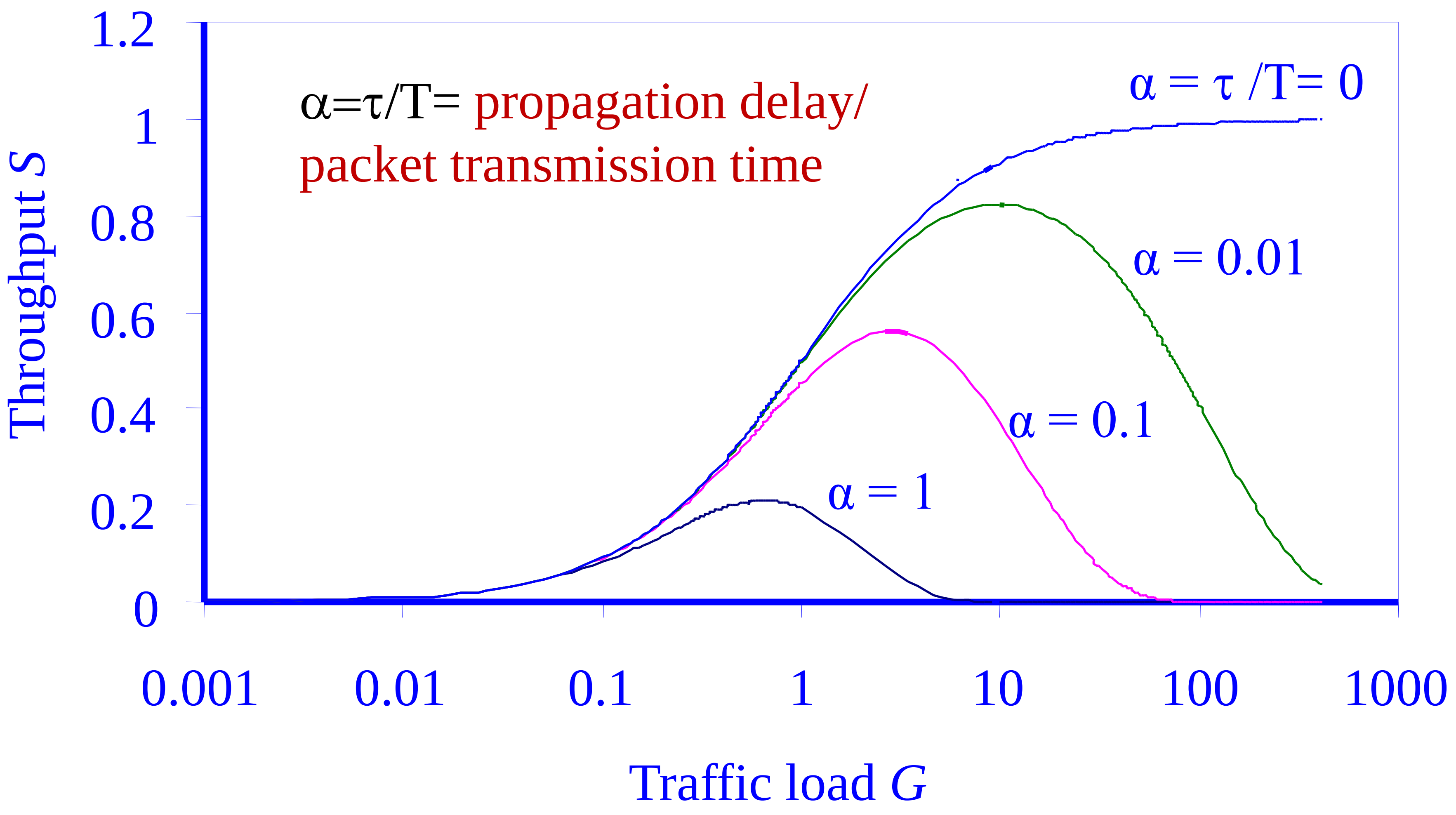
$T_0+\tau+\tau_{cd}$ — B detects collision

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

Time



# Throughput of Slotted Nonpersistent CSMA/CD



# Example of CSMA/CD

**Example 6.1:** Consider building a CSMA/CD network running at 2 Gbps over a 4 km long cable without any repeater and the travel spread of the signal in the cable is $2x10^5$ km/s, find the minimum frame size?

For a 4 km long cable, the round-trip propagation time of the signal is:

$$t = \frac{2x4\ km}{2x10^3\ km/s} = 40\mu s$$

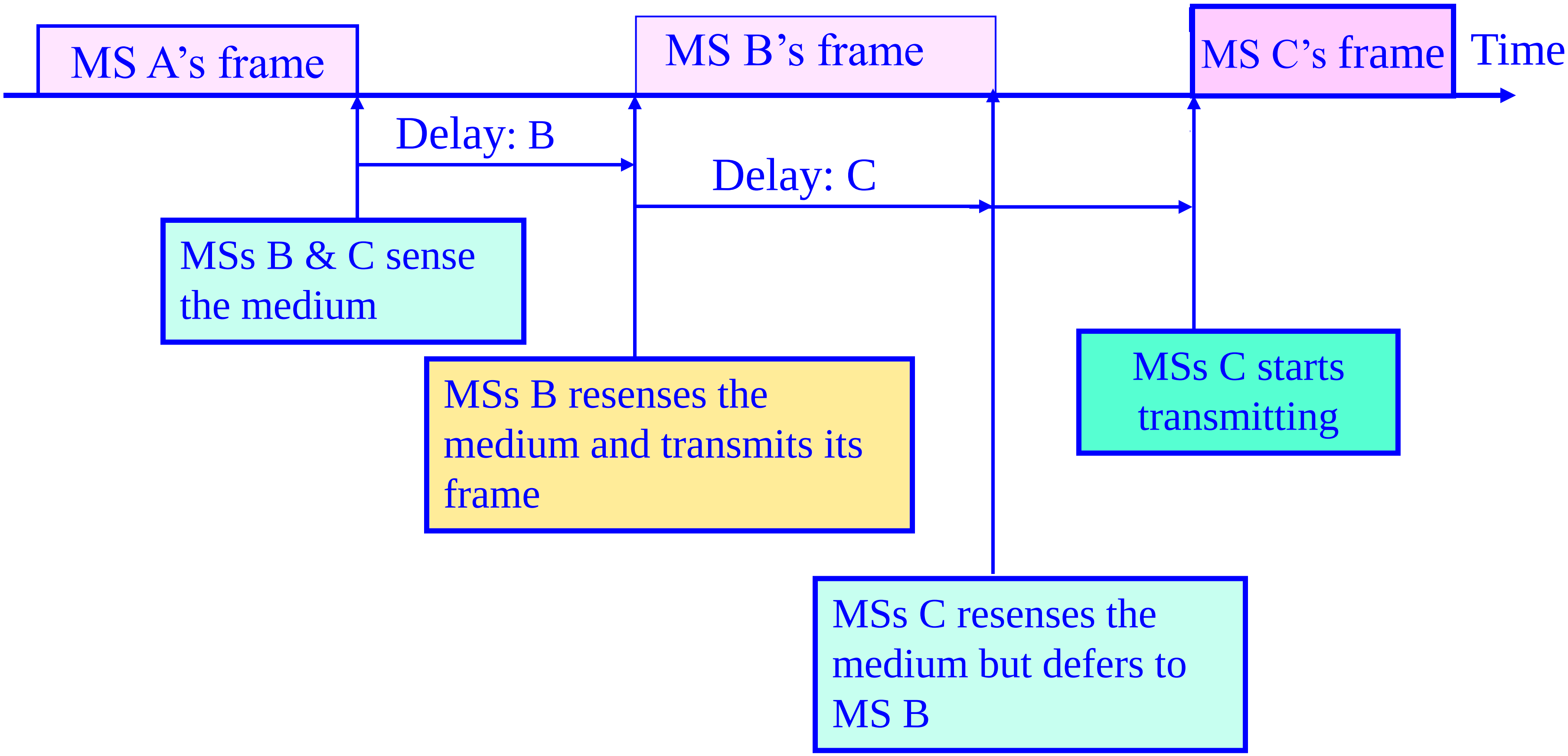
To make CSMA/CD work, it must transmit an entire frame in this interval. For a CSMA/CD network running at 2 Gbps, it can propagate 2000 bits per 1 μs. Therefore, the minimum frame size is:

Minimum Frame Size=2000 bits/μsx20μs=$4x10^4$ bits

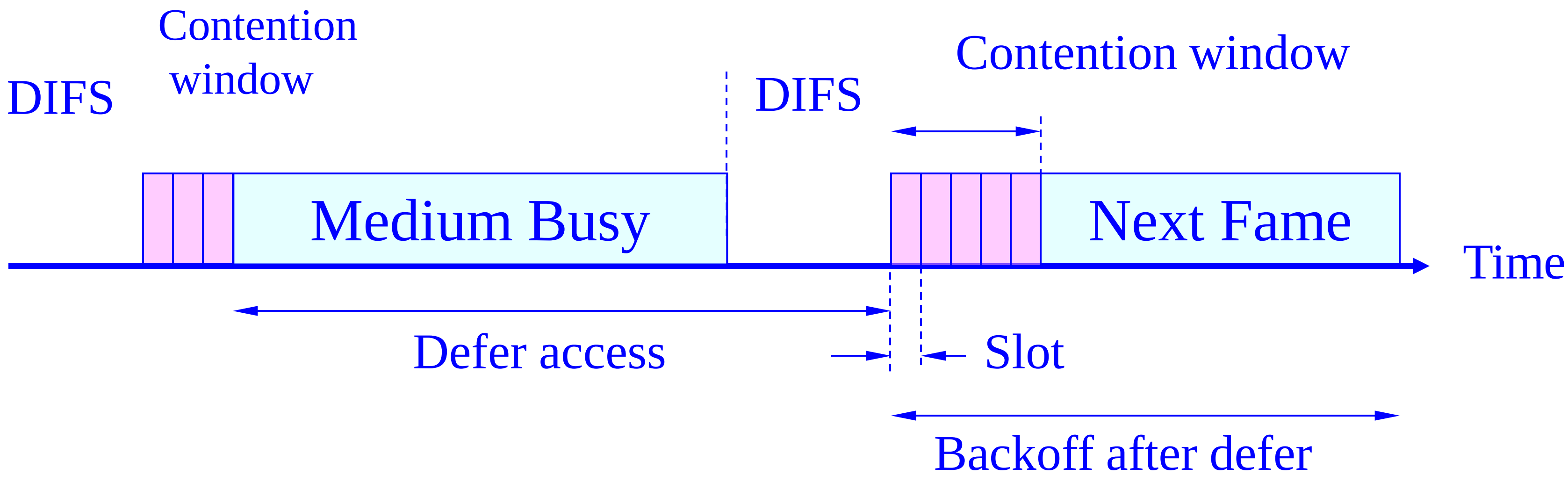
# CSMA/CA (CSMA with Collision Avoidance)

- 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)

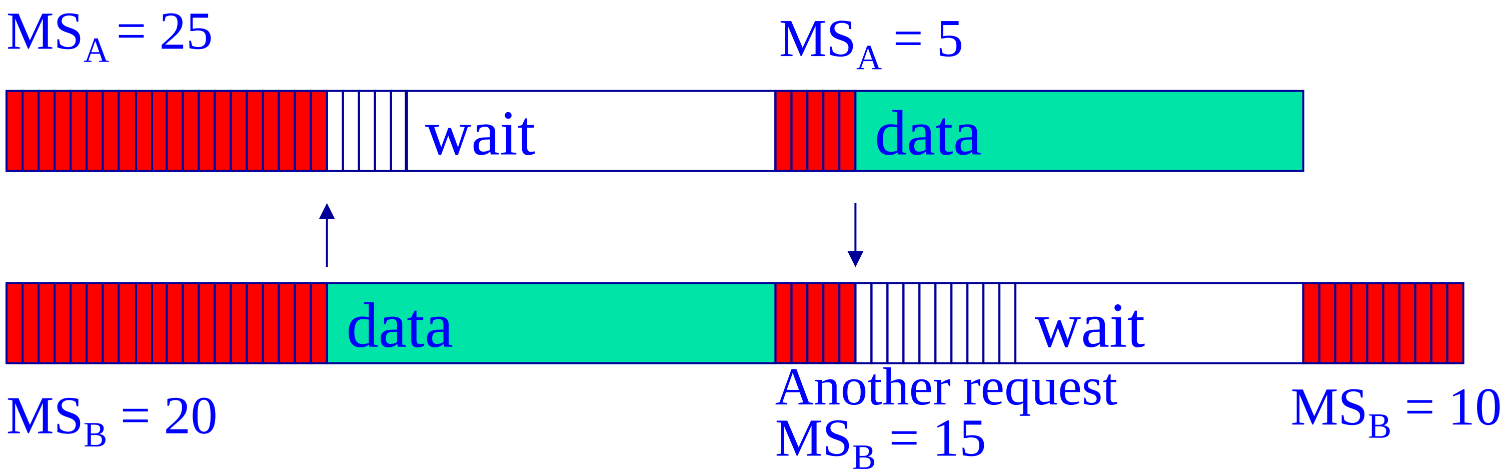


# CSMA/CA Explained




DIFS – Distributed Inter Frame Spacing

# Random Delay helps CSMA/CA



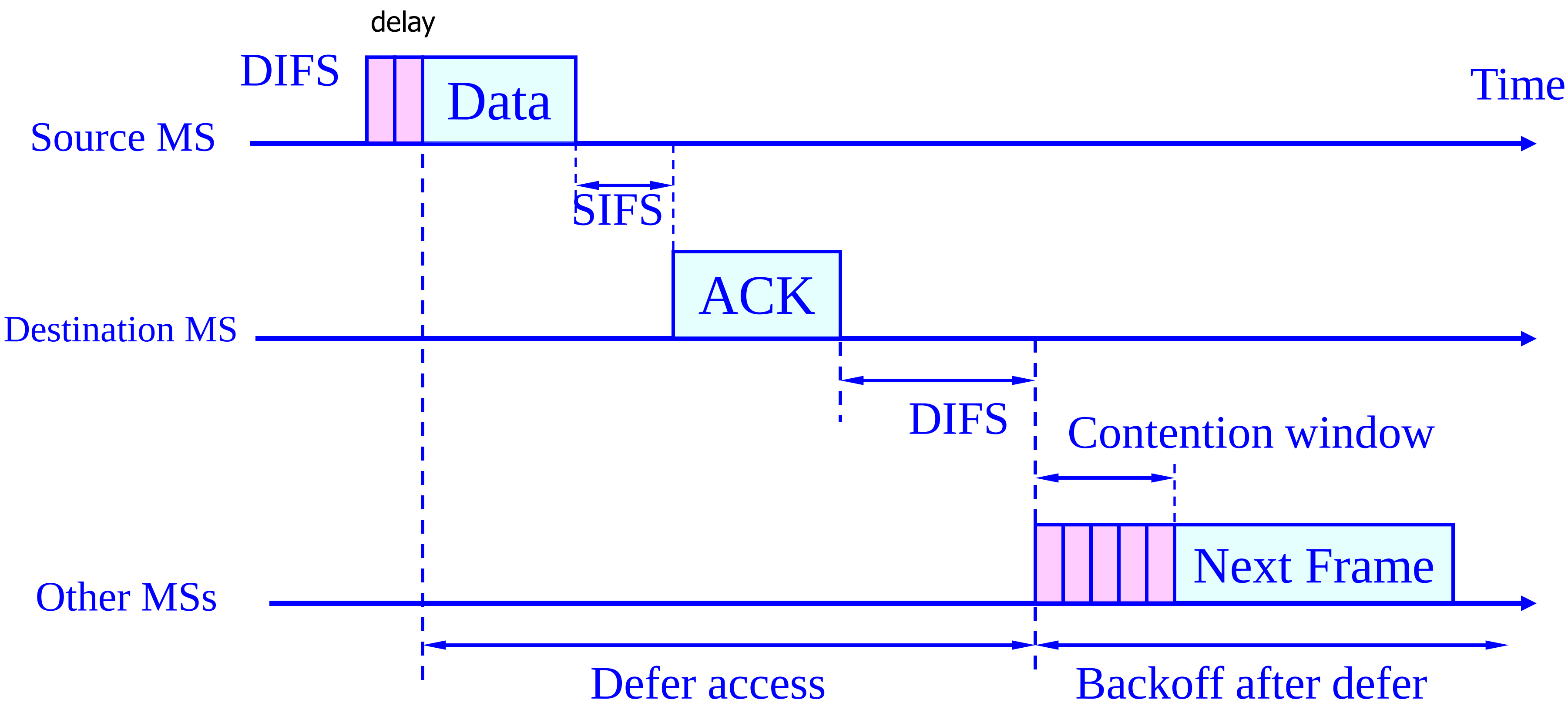

CW = 31, $MS_A$ and $MS_B$ are backoff intervals at nodes A and B

- $MS_A$ 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
- 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

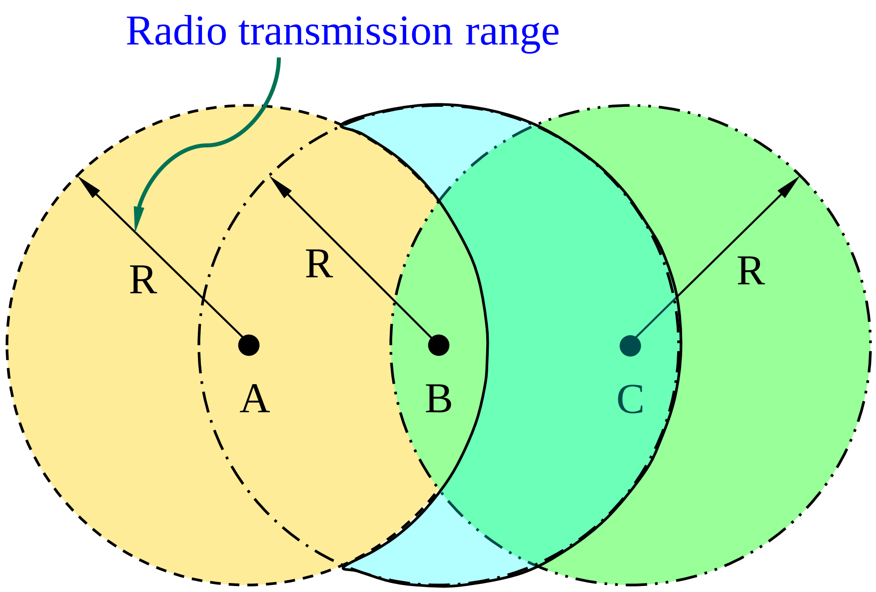
- Immediate Acknowledgements from receiver upon reception of data frame without any need for sensing the medium
- ACK frame transmitted after time interval SIFS (*Short Inter-Frame Space*) (*SIFS* < *DIFS*)
- Receiver transmits ACK without sensing the medium
- If ACK is lost, retransmission done

# CSMA/CA/ACK




SIFS – Short Inter Frame Spacing

# Hidden Terminal Problem

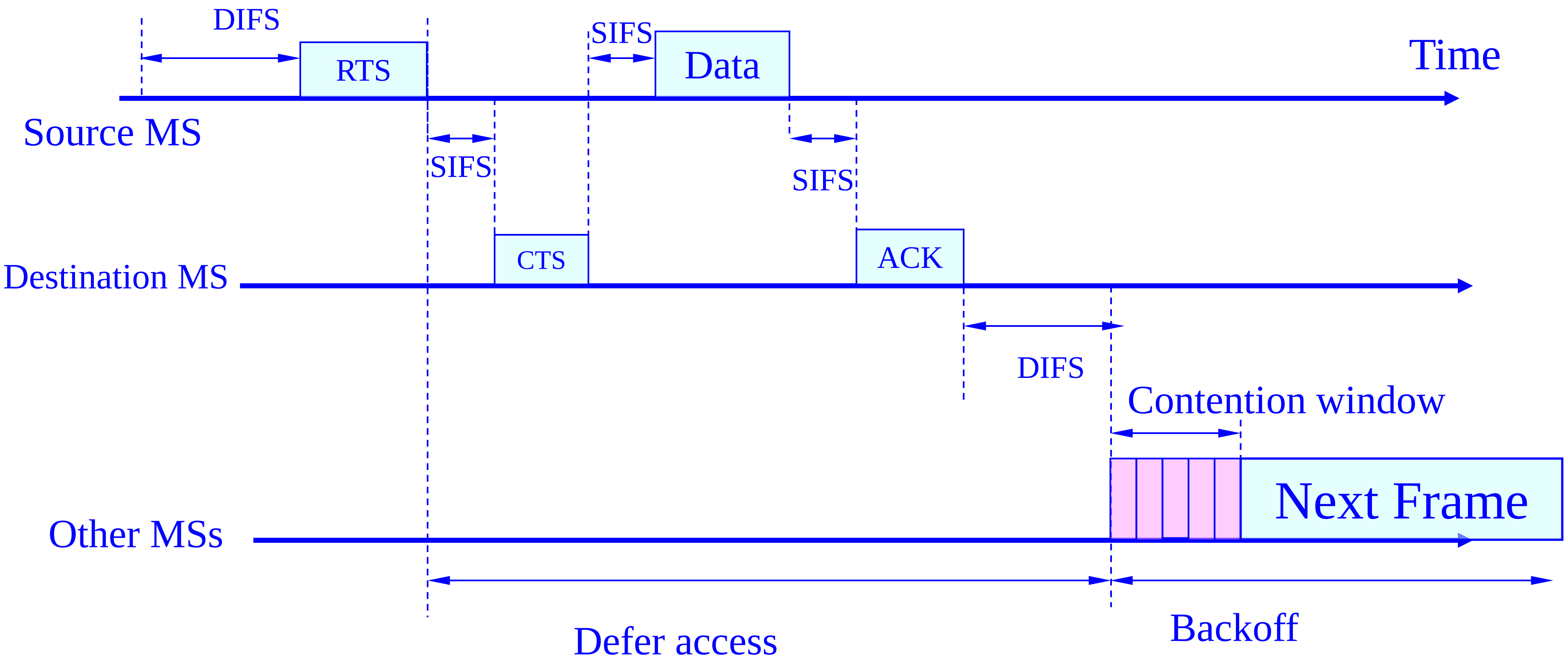



Nodes A and C are hidden with respect to each other

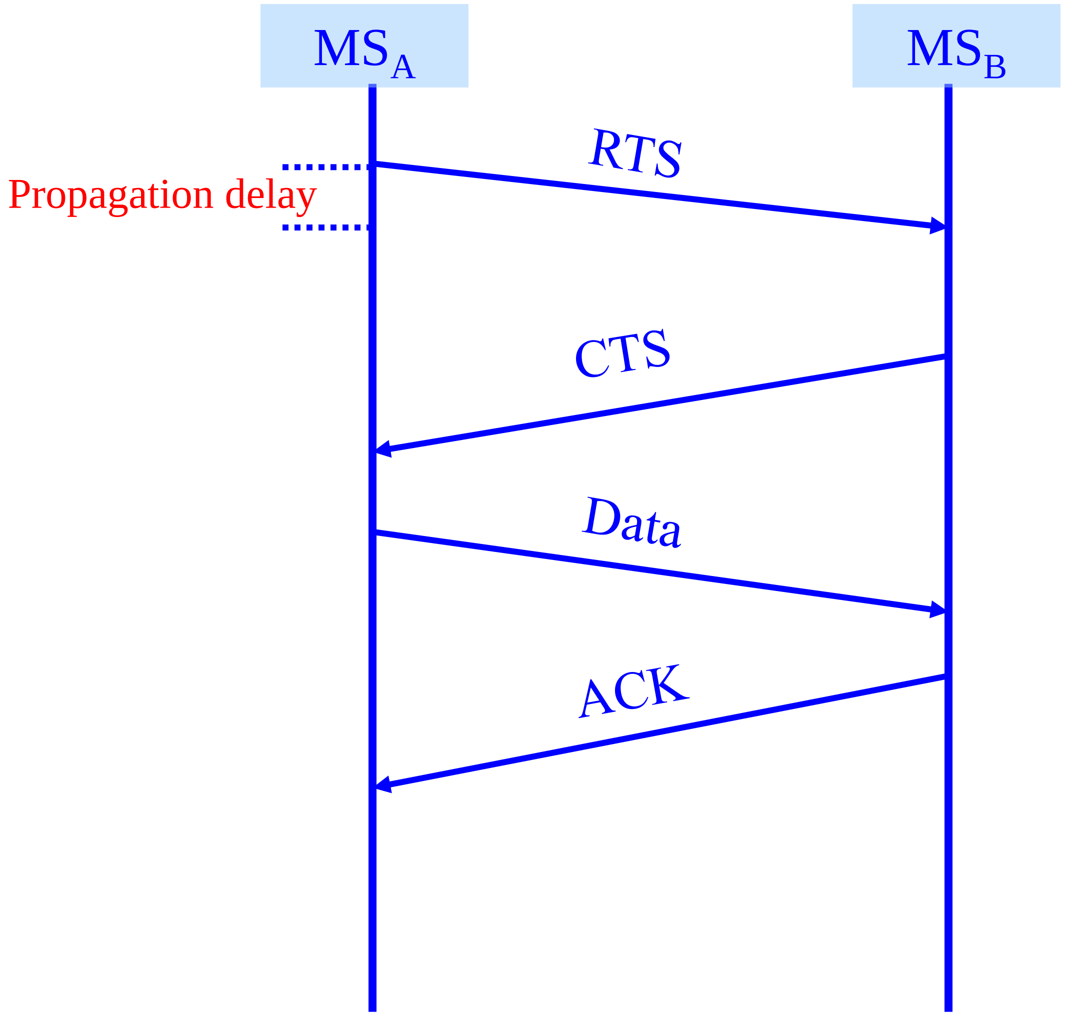
# CSMA/CA with RTS/CTS

- 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

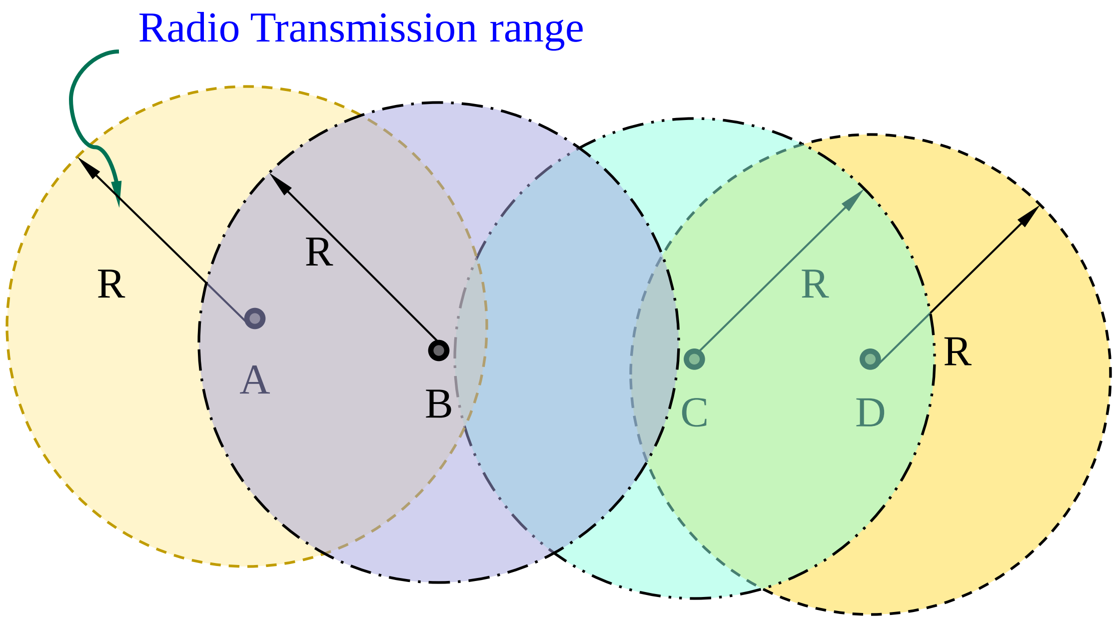


# RTS/CTS




This helps avoid hidden terminal problem in such networks like ad hoc

# Exposed Terminal Problem




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