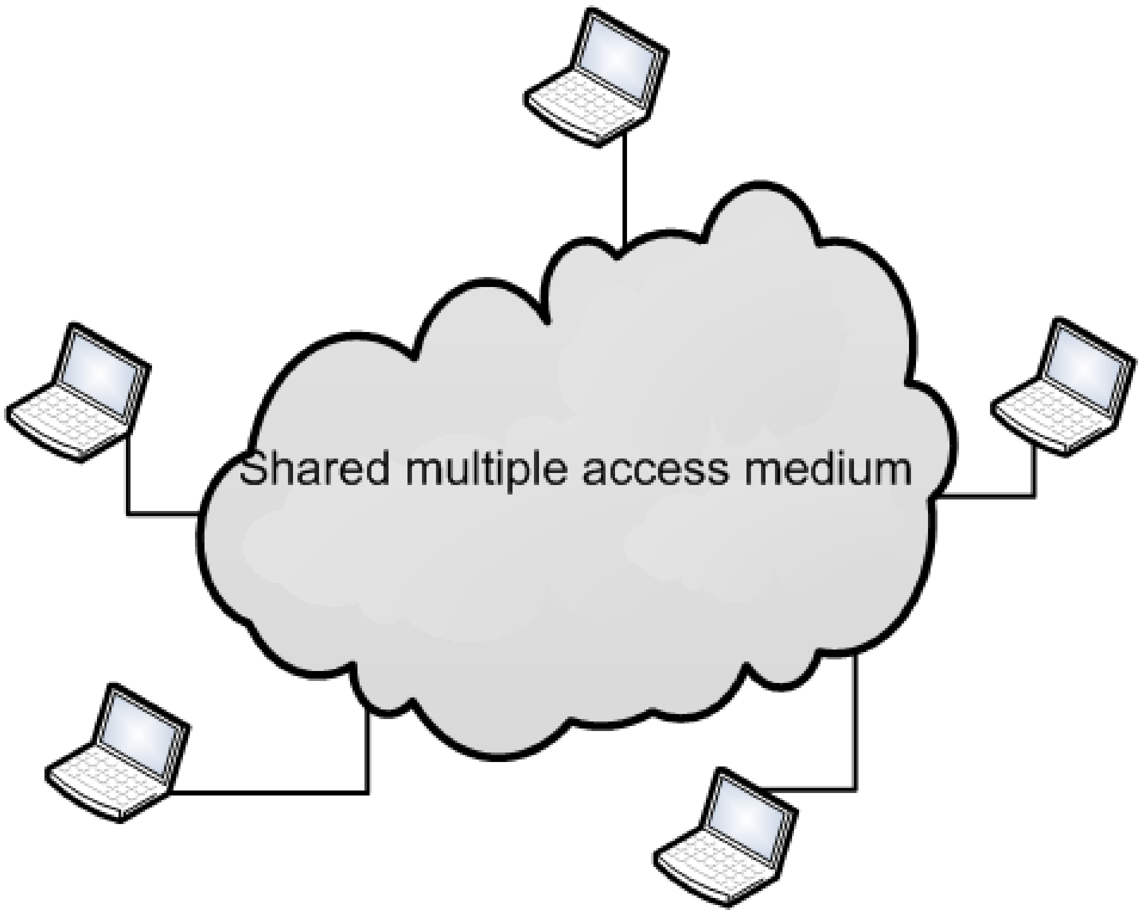
Multiple Radio Access

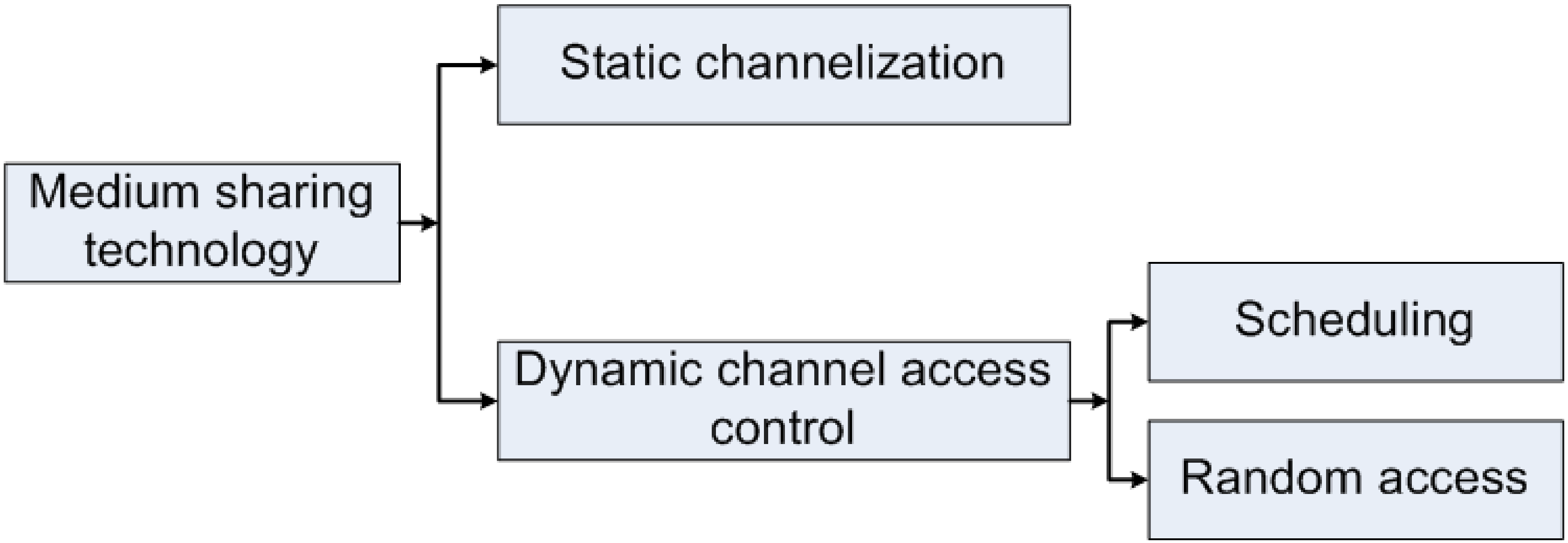
Typical Scenario



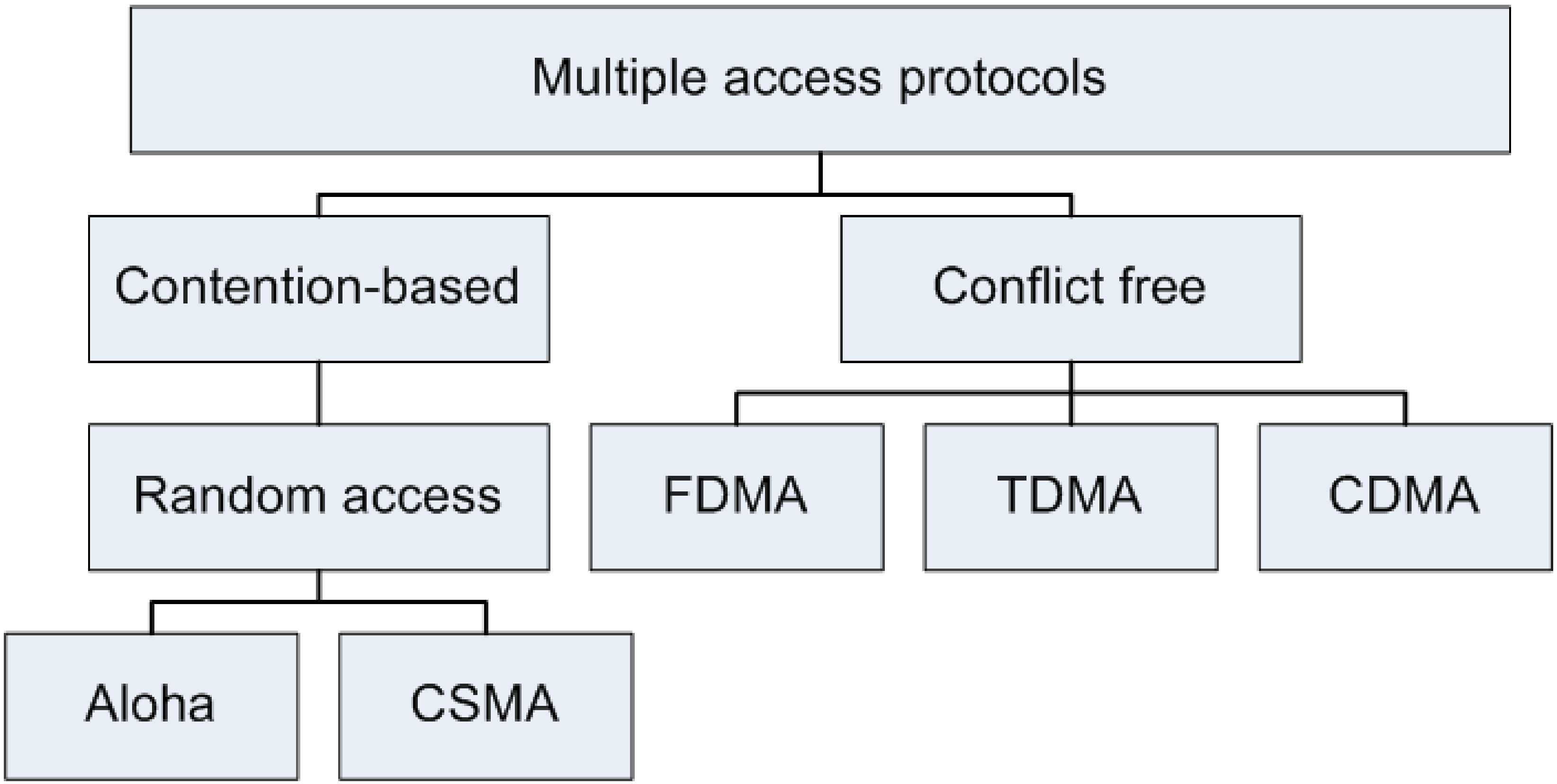
Multiple Access Issues

- 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?
- Contention protocols resolve a collision after it occurs
- Collision-free protocols (e.g., a bit-map protocol and binary countdown) ensure that a collision never occur

Medium-Sharing Techniques



Multiple Radio Access Protocols

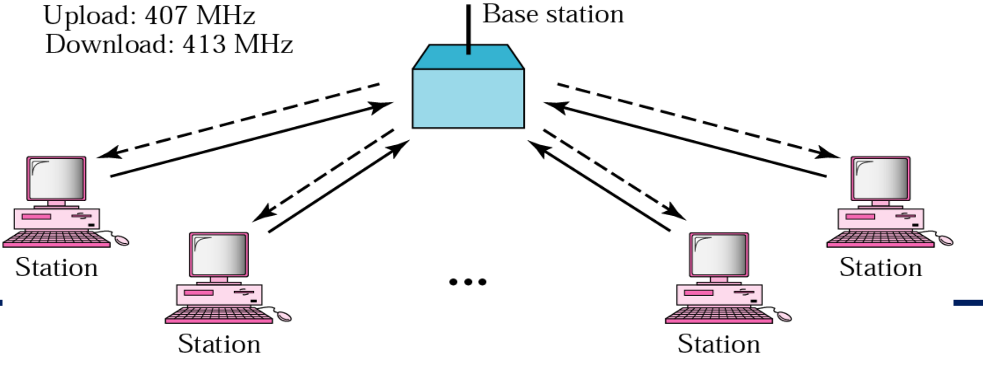


Contention-Based Protocols

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

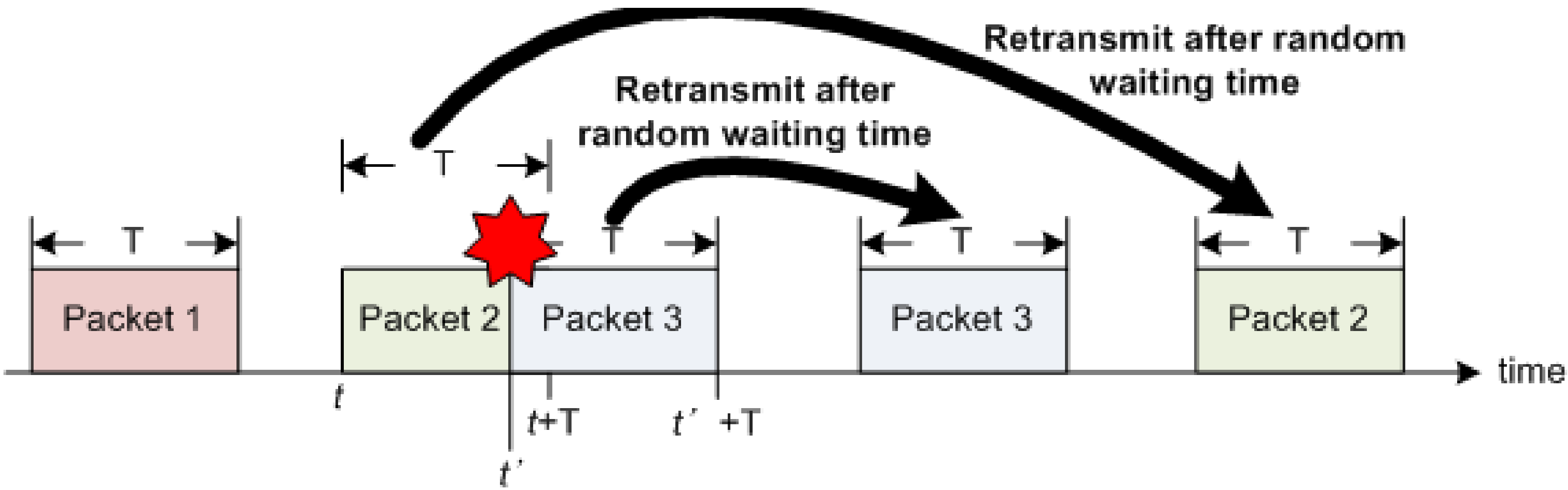
Pure ALOHA (1/4)

- The earliest random-access method
- Two rules
  - Multiple access: a station sends a frame when it has a frame to send
  - Acknowledgment: the station waits for an ACK after its transmission
    - Allotted time: 2 times the max propagation delay
    - Retransmission if needed



Pure ALOHA (2/4)

- The maximum utilization of the channel is only about **18%** because of the rising of the number of collisions



Pure ALOHA (3/4)

- Successfully transmitted: no other packets scheduled for transmission between the instants $t-T$ and $t+T$
- Assume fixed packet delivery time T
- Poisson packet arrival with rate λ
- Considering retransmission, the rate of scheduling is g
- The probability of successful transmission P_s is

$$P_s = \frac{e^{-g(2T)}(g(2T)^0)}{0!} = e^{-2gT}$$

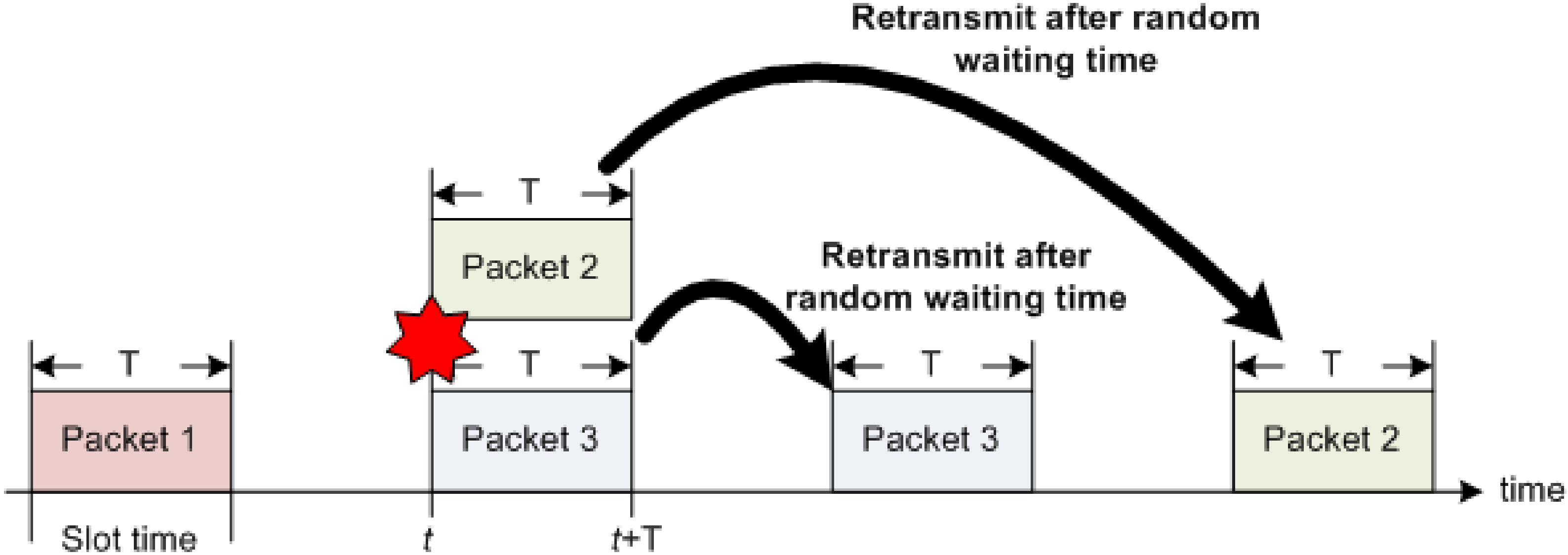
Pure ALOHA (4/4)

- Define the throughput as the fraction of time during which the useful information is carried on the channel
- Define $G = gT$
- Throughput $S_{th} = gTe^{-2gT} = Ge^{-2G}$
- To find max throughput S_{th}^{max}
- $$\frac{\mathrm{d}S_{th}}{\mathrm{d}G} = -2Ge^{-2G} + e^{-2G} = 0$$

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

Slotted ALOHA (1/3)

- Slot time = frame transmission time
- Need one synchronization mechanism
- Improve the maximum utilization to about **37%**



Slotted ALOHA (2/3)

$$P_s = \frac{e^{-gT}(gT)^0}{0!} = e^{-gT}$$

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

$$G = gT \rightarrow S_{th} = Ge^{-G}$$

$$\frac{\mathrm{d}S_{th}}{\mathrm{d}G} = e^{-G} - Ge^{-G} = 0$$

$$G = 1$$

$$S_{th}^{max} = \frac{1}{e} = 0.368$$

Slotted ALOHA (3/3)

- Performance comparison

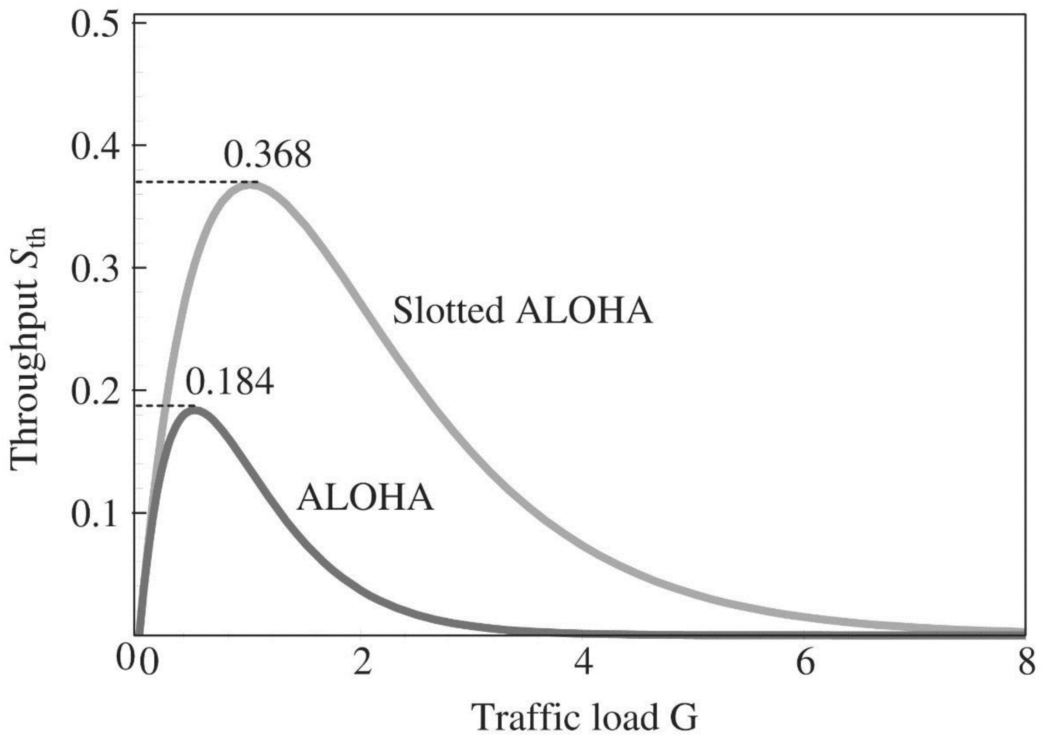
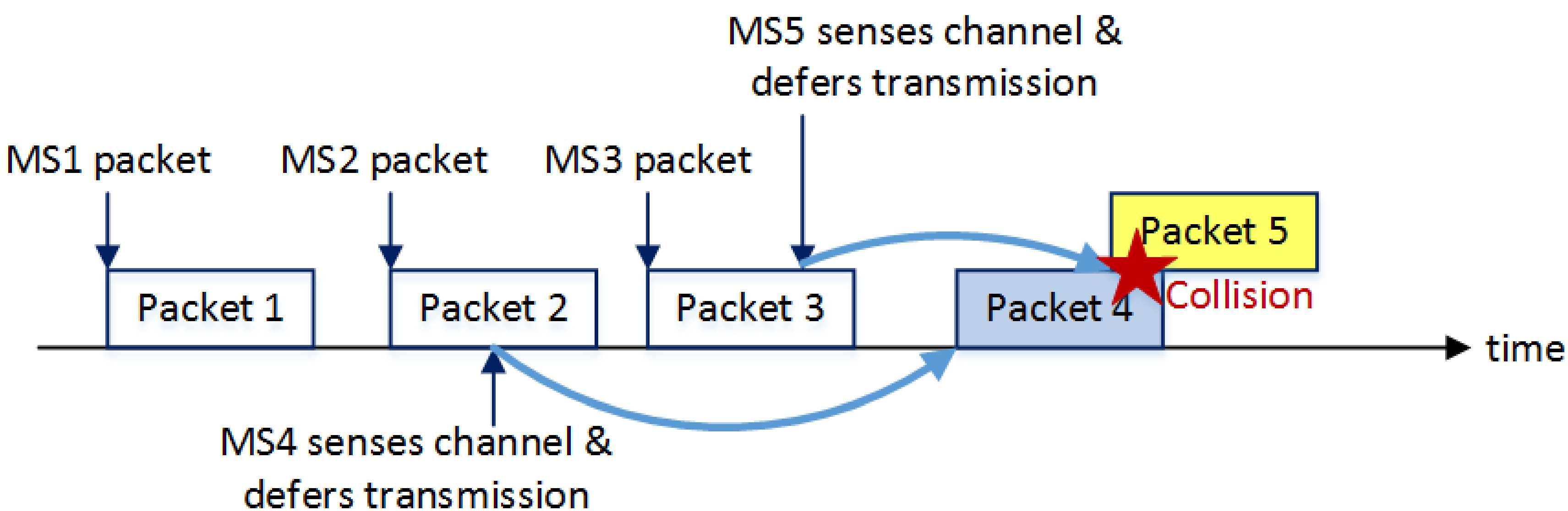


Figure 6.6 Throughputs of pure ALOHA and slotted ALOHA.

CSMA (Carrier Sense Multiple Access) (1/3)

- 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)

CSMA (2/3)


MS5 senses channel &
defers transmission
MS1 packet
MS2 packet
MS3 packet
Packet 5
Packet 1
Packet 2
Packet 3
Packet 4
Collision
time
MS4 senses channel &
defers transmission

CSMA (3/3)

- Throughput: S_{th}
- Offered traffic: G
- Packet transmission time: $T(=1)$
- Propagation delay: t_p
- Define $\alpha = \dfrac{t_p}{T}$
- Unslotted nonpersistent CSMA: $S_{th} = \dfrac{Ge^{-\alpha G}}{G(1+2\alpha)+e^{-\alpha G}}$
- Slotted nonpersistent CSMA: $S_{th} = \dfrac{\alpha Ge^{-\alpha G}}{(1-e^{-\alpha G})+\alpha}$

Unslotted nonpersistent CSMA (1/3)

- CDF of idle period

$$P(I \le x) = 1 - P(I > x) = 1 - P(\text{no packet arrivals in } x \text{ sec})$$
$$= 1 - \frac{(gx)^0}{0!}e^{-gx} = 1 - e^{-gx}$$

- Mean idle time

$$\bar{I} = \int_0^\infty x f_I(x)dx = \frac{1}{g} \quad \text{, where } f_I(x) = ge^{-gx}$$

- Useful mean busy period

$$\bar{U} = T \times P(\text{successful transmission})$$

Unslotted nonpersistent CSMA (2/3)

$$P(\text{successful transmission}) = P(\text{no arrivals in } \tau \text{ sec}) = e^{-g\tau}$$

$$\bar{U} = T \times e^{-g\tau}$$

- Mean busy period

$$B = T + \tau + y$$

$$\tau = \text{max end-to-end delay (constant)}$$

$$y = \text{time lag of the last transmission (random)}$$

$$E[B] = T + \tau + E[y]$$

Unslotted nonpersistent CSMA (3/3)

$$E[y] = 0 \times P(y=0) + \int_{0^+}^{\tau} t \times f_y(t)dt$$

$$= 0 \times e^{-g\tau} + \int_{0^+}^{\tau} t \times g e^{-g(\tau - t)} dt = \tau - \frac{1 - e^{-g\tau}}{g}$$

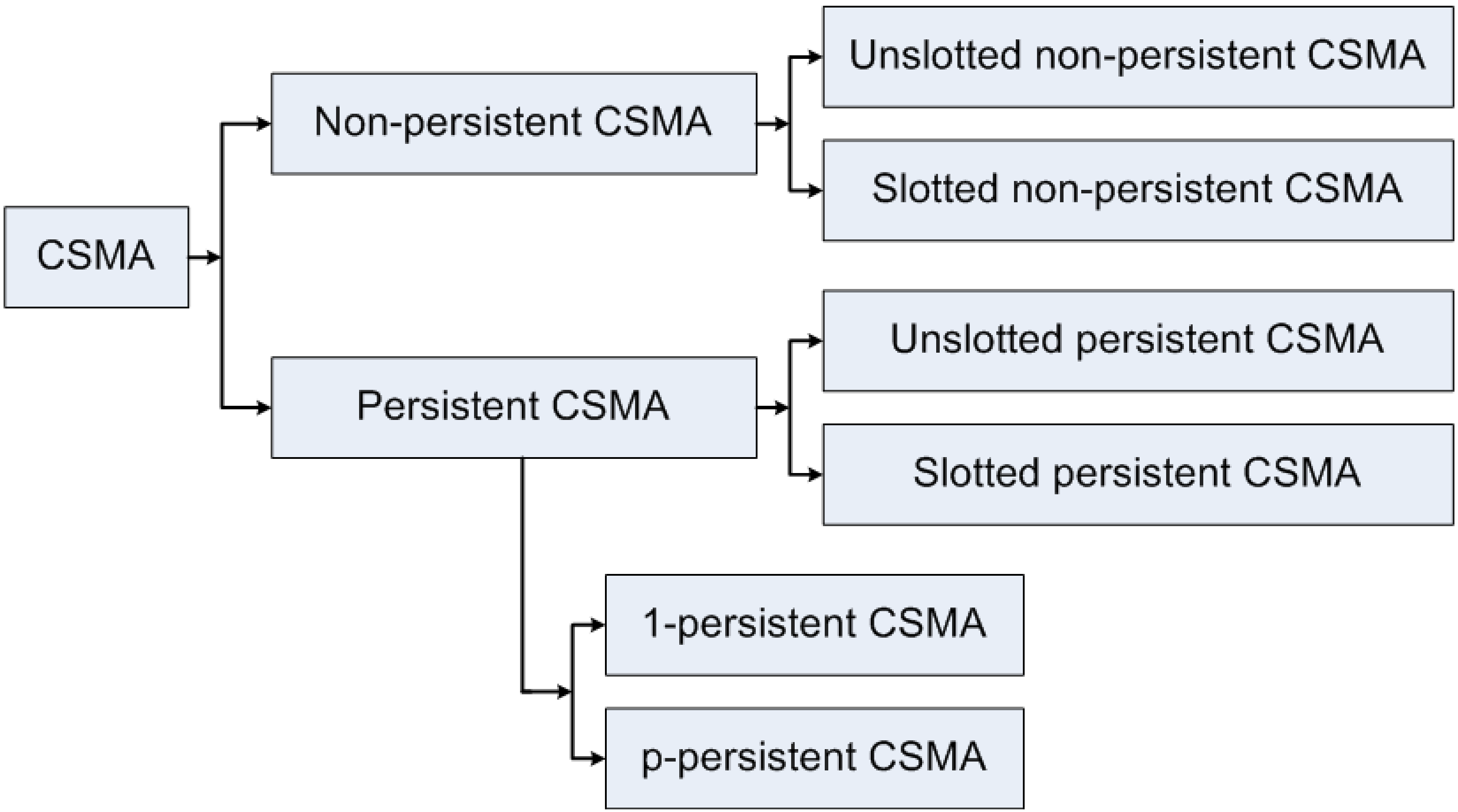
$$\bar{B} = T + \tau + (\tau - \frac{1 - e^{-g\tau}}{g}) = T + 2\tau - \frac{1 - e^{\tau}}{g}$$

- Normalized system throughput

$$S = \frac{\bar{U}}{\bar{B} + \bar{I}} = \frac{gT \times e^{-\alpha g T}}{gT(1 + 2\alpha) + e^{-\alpha g T}} \qquad \alpha = \frac{\tau}{T}$$

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

Kinds of CSMA



CSMA (1/4)

- Carrier sense multiple access
- A station wishing to transmit first listens to the medium.
  - If the medium is in use, the station must wait.
  - It the medium is idle, the station may transmit.
- After transmitting, the station must wait for an ACK within a reasonable amount of time.
- The maximum utilization depends on the length of the frame and on the propagation time.
- The longer the frames or the shorter the propagation time, the higher the utilization.
- Need an algorithm to specify what a station should do if the medium is found busy (we have three as described following).

Nonpersistent CSMA Protocol

- A station wishing to transmit listens to the medium and obeys the following rules:
  - Step 1: if the medium is idle, transmit; otherwise, go to the step 2.
  - Step 2: if the medium is busy, wait an amount of time drawn from a probability distribution and repeat step 1.
- (+) Reduce the probability of collisions.
- (–) Waste the capacity.

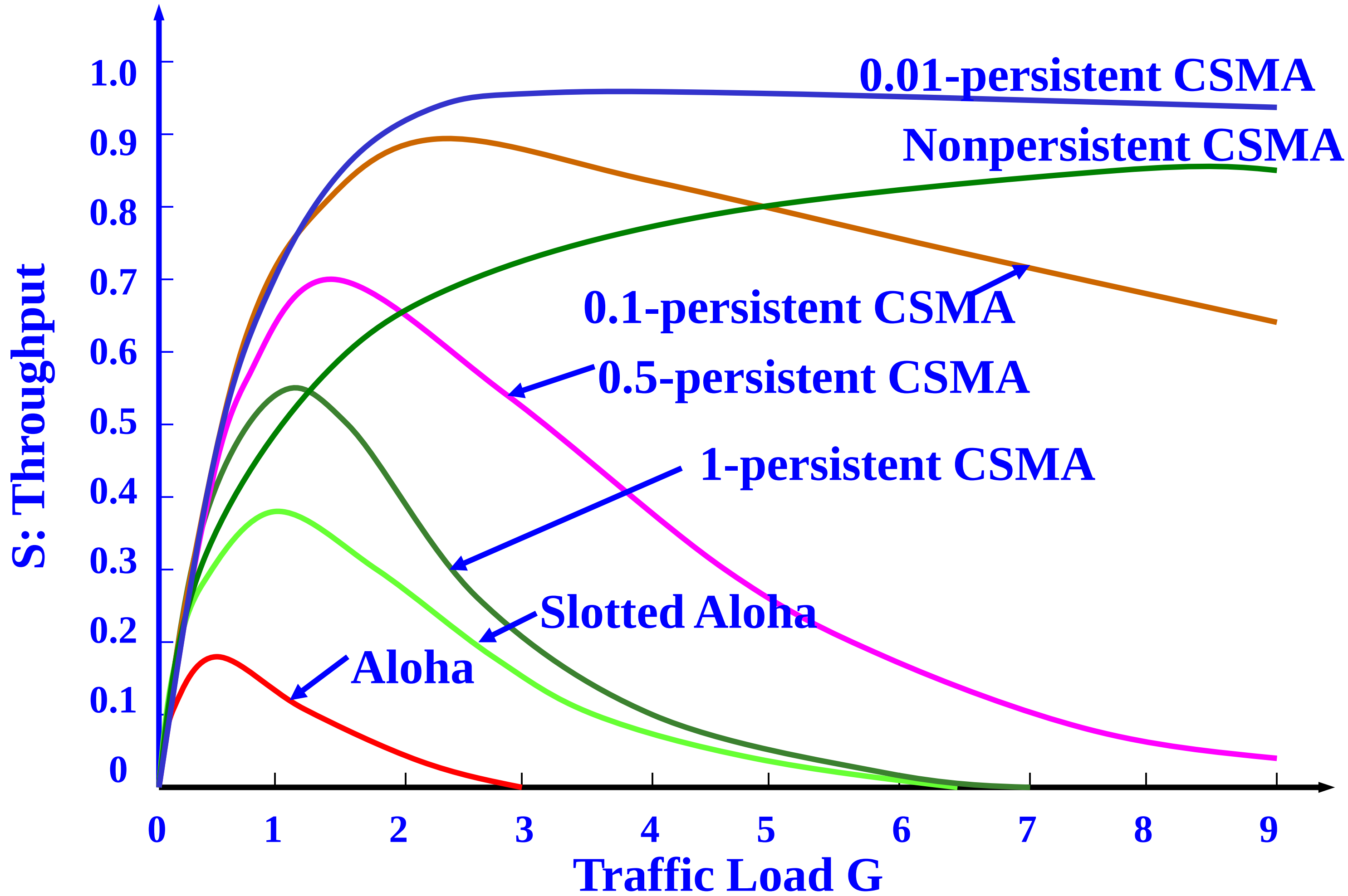
1-Persistent CSMA Protocol

- A station wishing to transmit listens to the medium and obeys the following rules:
  - Step 1: if the medium is idle, transmit; otherwise, go to the step 2.
  - Step 2: if the medium is busy, continue to listen until the channel is sensed idle; then transmit immediately.
- (–) If two or more stations are waiting to transmit, a collision is guaranteed.

p-Persistent CSMA Protocol (1/2)

- A station wishing to transmit listens to the medium and obeys the following rules:
  - Step 1:if the medium is idle, transmit with probability *p*, and delay one time unit with probability (1-*p*). The time unit is typically equal to the maximum propagation delay.
  - Step 2: if the medium is busy, continue to listen until the channel is sensed idle and repeat step 1.
  - Step 3: if transmission is delayed one time unit, repeat step 1.
- How to define *p* value?
  - Assume *n* station have frames to send while a transmission is taking place.
  - The expected number of stations attempting to transmit is *np*.
  - *np* value must be less than 1.
  - Heavy load $\Rightarrow$ small *p*, but stations must wait longer to attempt transmission.

p-Persistent CSMA Protocol (2/2)



CSMA/CD (1/3)

- A station wishing to transmit listens to the medium and obeys the following rules:
  - Step 1: if the medium is idle, transmit; otherwise, go to step 2.
  - Step 2: if the medium is busy, continue to listen until the channel is idle, then transmit immediately.
  - Step 3: if a collision is detected during transmission, transmit a brief jamming signal to assure that all stations know that there has been a collision and then cease transmission.
  - Step 4: after transmitting the jamming signal, wait a random amount of time, then attempt to transmit again (repeat from step 1).
- While colliding $\Rightarrow$ exponential backoff
  - Waiting time = [0, $2^N \times$maximum_propagation_time]
  - Propagation time: the time needed for a bit to reach the end of the network.
  - *N*: the number of attempted transmissions.
- Used in traditional Ethernet.

CSMA/CD (2/3)

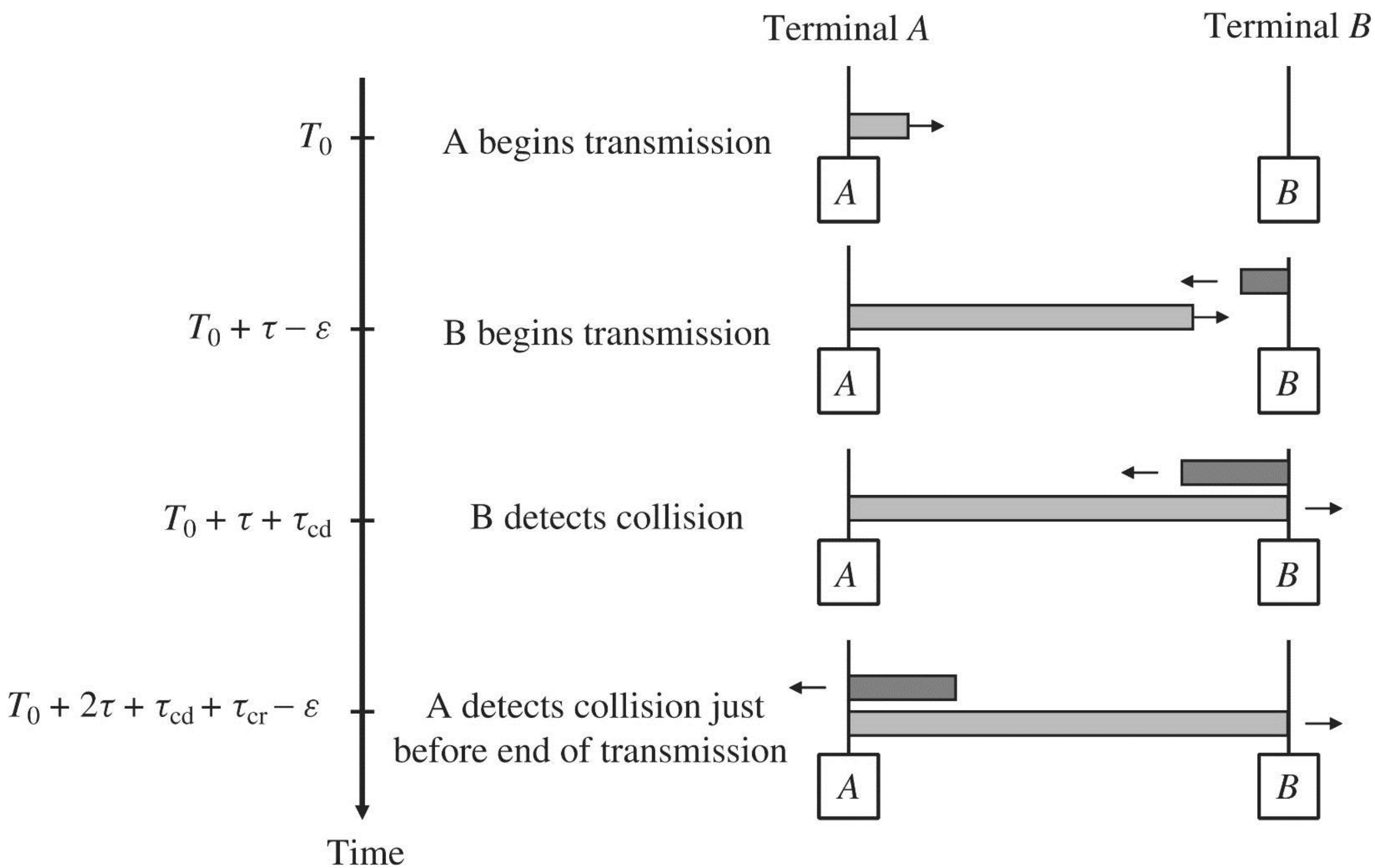


Figure 6.10 Collision mechanism in CSMA/CD.

CSMA/CD (3/3)

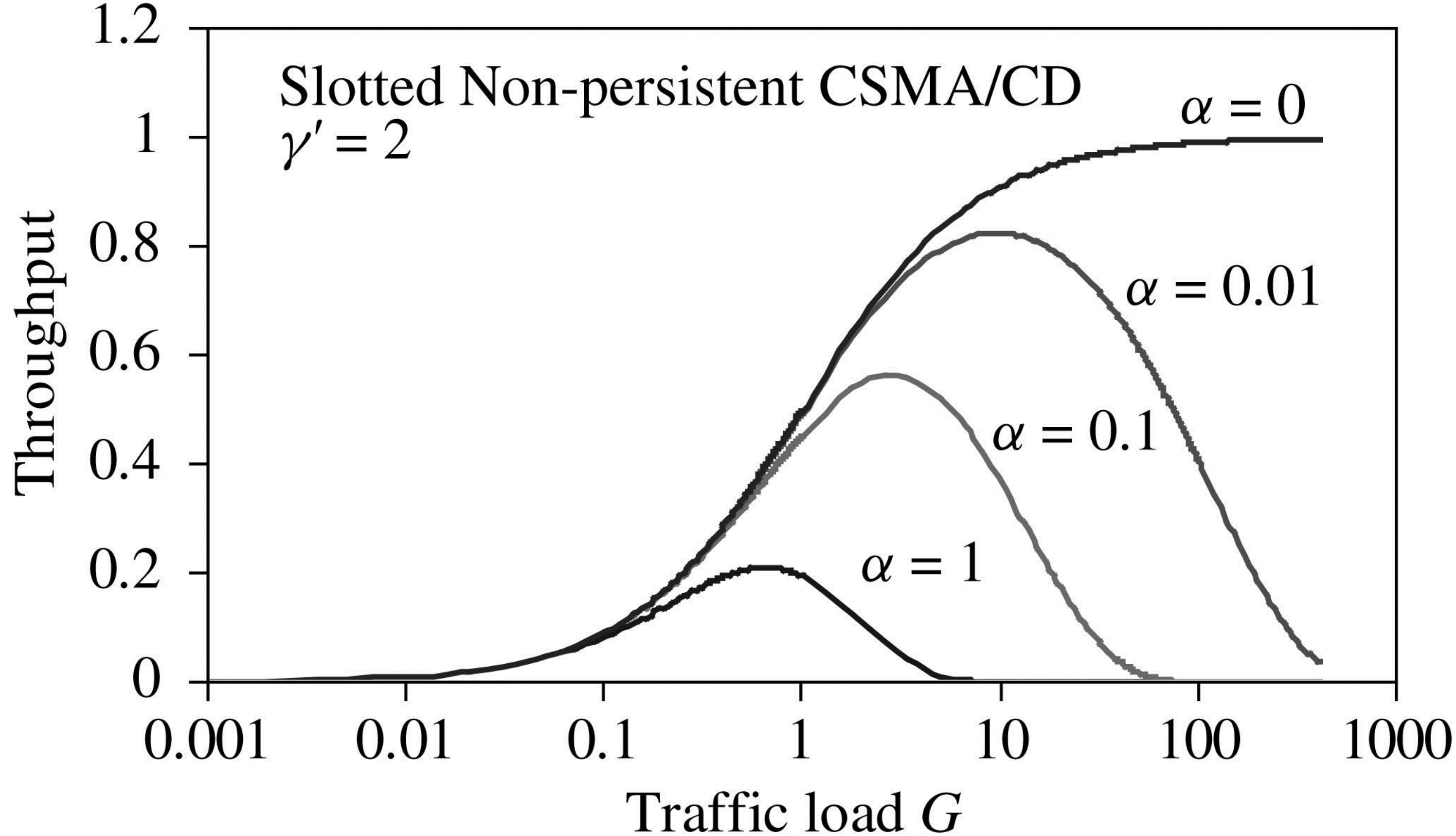


Figure 6.11 Throughput of slotted non-persistent CSMA/CD.

CSMA/CA (1/4)

- Adopted by the IEEE 802.11

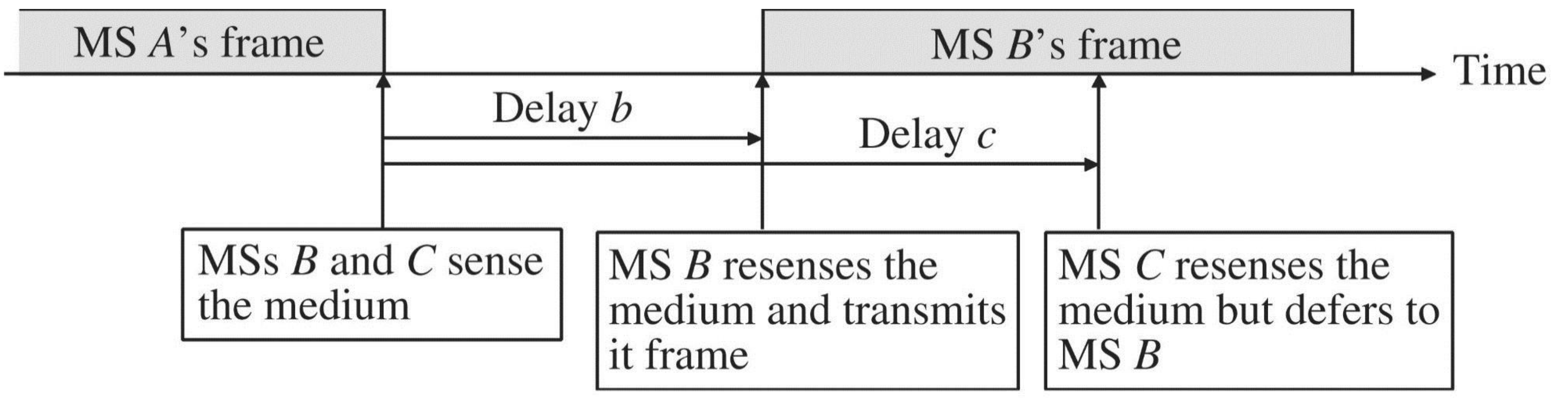


Figure 6.12 A basic collision avoidance scheme.

CSMA/CA (2/4)

- Basic CSMA/CA
  - Differing from CSMA/CD in that there is no collision detection.
  - After finding line idle, the station waits an IFG (interframe gap) amount of time (i.e., DCF InterFrame Space, DIFS, 34 µs in 802.11a, n, ac).
  - It further waits another random amount of time, then sends the frame and sets a timer.

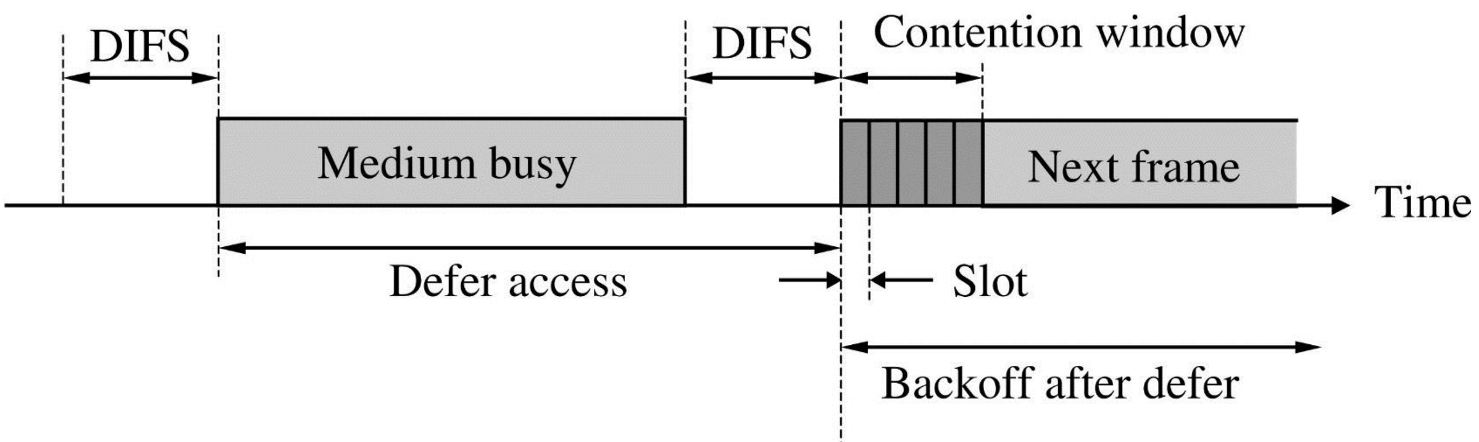


Figure 6.13 Basic CSMA/CA.

CSMA/CA (3/4)

- CSMA/CA with ACK (SIFS: Short InterFrame Spacing, 16μs in 802.11a, n, ac)

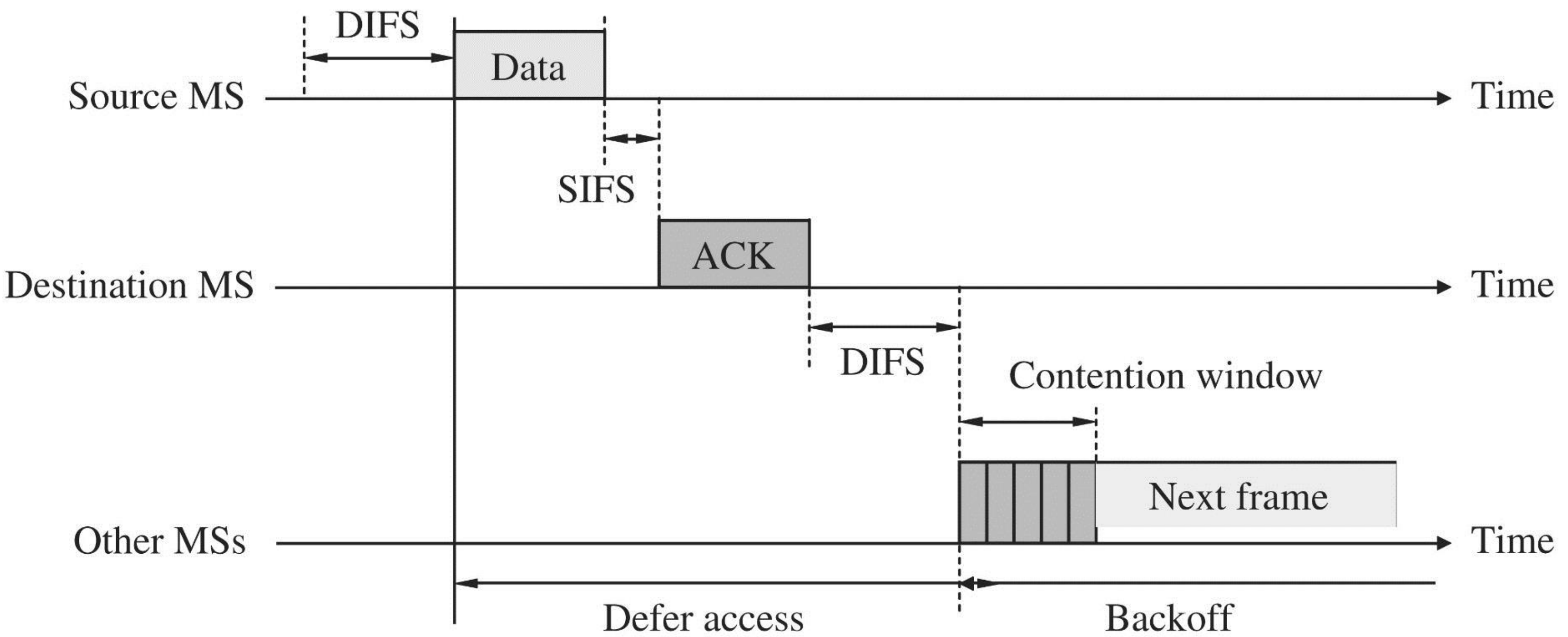


Figure 6.14 CSMA/CA with ACK.

CSMA/CA (4/4)

- CSMA/CA with RTS and CTS (help on avoiding the problem of hidden terminal problem)

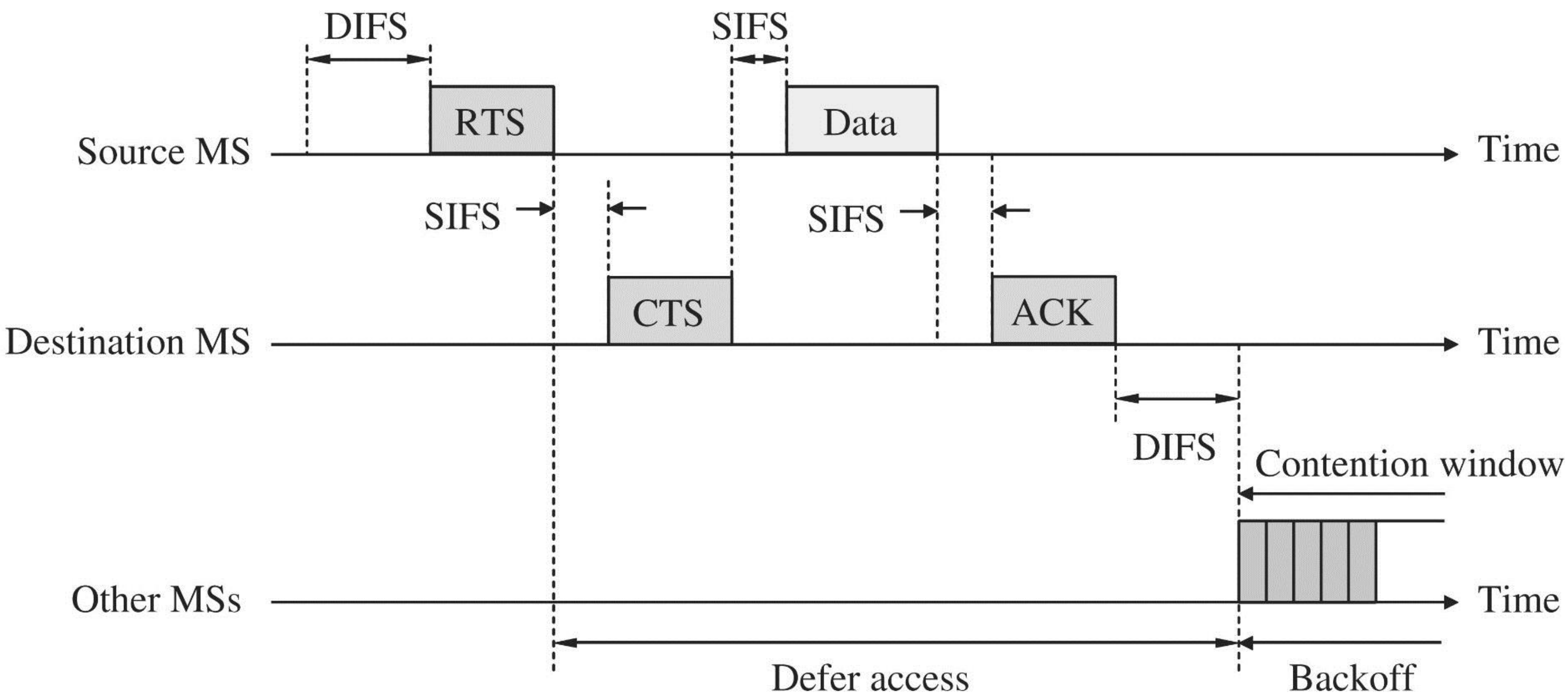
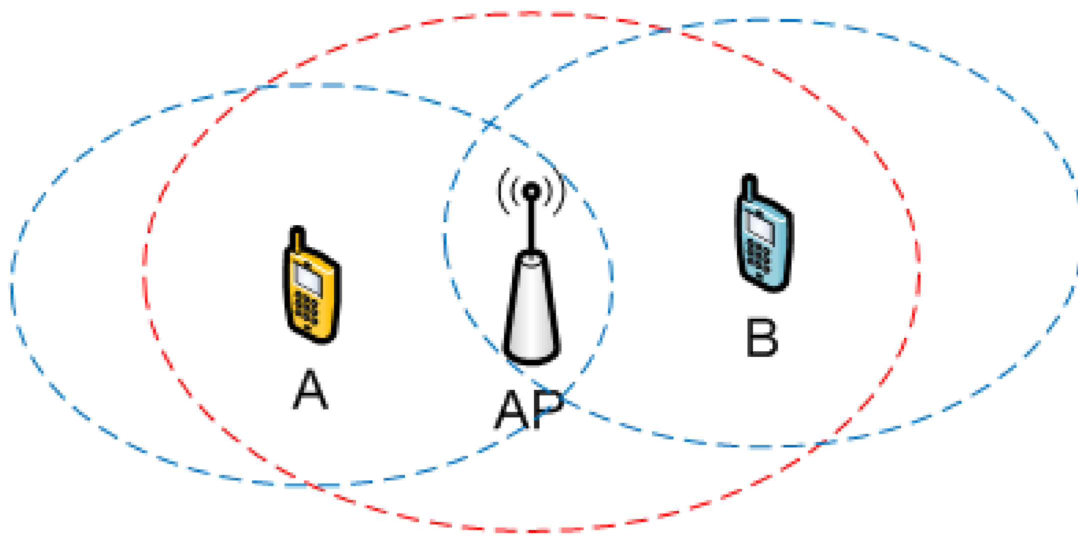


Figure 6.15 CSMA/CA with RTS and CTS.

Hidden Terminal Problem

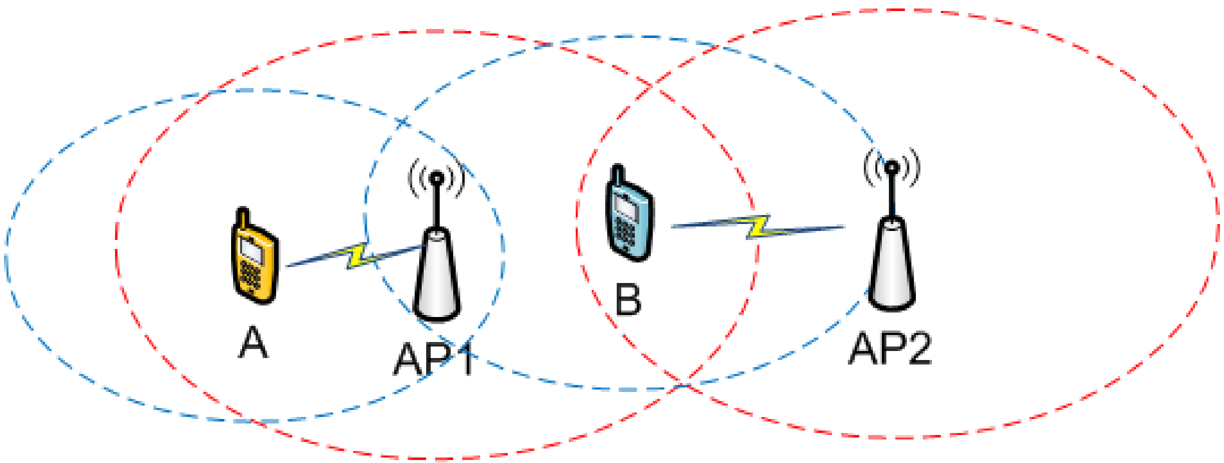
- MS A and MS B simultaneously transmit packets to AP
- Solution: Ready To Send (RTS)/Clear To Send(CTS)
- Either MS A or MS B receive AP's CTS, it defers its transmission



A and B are hidden with respect to each other

Exposed Terminal Problem

- Transmission of AP1 to MS A forces MS B to stop its transmission to AP2
- Solution: RTS/CTS
- MS B can transmit its RTS to AP2 upon receiving only AP1's CTS



Transmission at A force B (exposed) to stop transmission to AP2