CSE3213 Computer Network I

Medium Access Control Protocols
(Ch. 6.1 – 6.3)

Course page:
http://www.cse.yorku.ca/course/3213

Slides modified from Alberto Leon-Garcia and Indra Widjaja

Chapter Overview

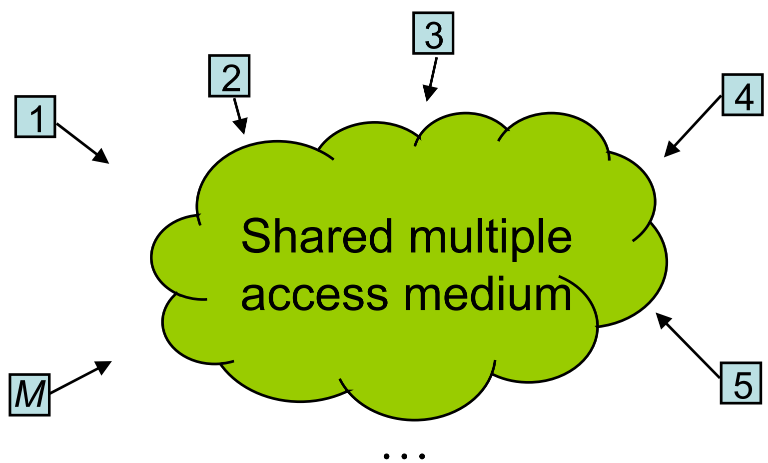
- **Broadcast Networks**
  - All information sent to all users
  - No routing
  - Shared media
  - Radio
    - Cellular telephony
    - Wireless LANs
  - Copper & Optical
    - Ethernet LANs
    - Cable Modem Access

- ***Medium Access Control***
  - To coordinate access to shared medium
  - Data link layer since direct transfer of frames
- ***Local Area Networks***
  - High-speed, low-cost communications between co-located computers
  - Typically based on broadcast networks
  - Simple & cheap
  - Limited number of users

Multiple Access Communications

Multiple Access Communications

- Shared media basis for broadcast networks
  - Inexpensive: radio over air; copper or coaxial cable
  - M users communicate by broadcasting into medium
- Key issue: How to share the medium?



Approaches to Media Sharing

Medium sharing techniques

Static channelization

- Partition medium
- Dedicated allocation to users
- Satellite transmission
- Cellular Telephone

Dynamic medium access control

Scheduling

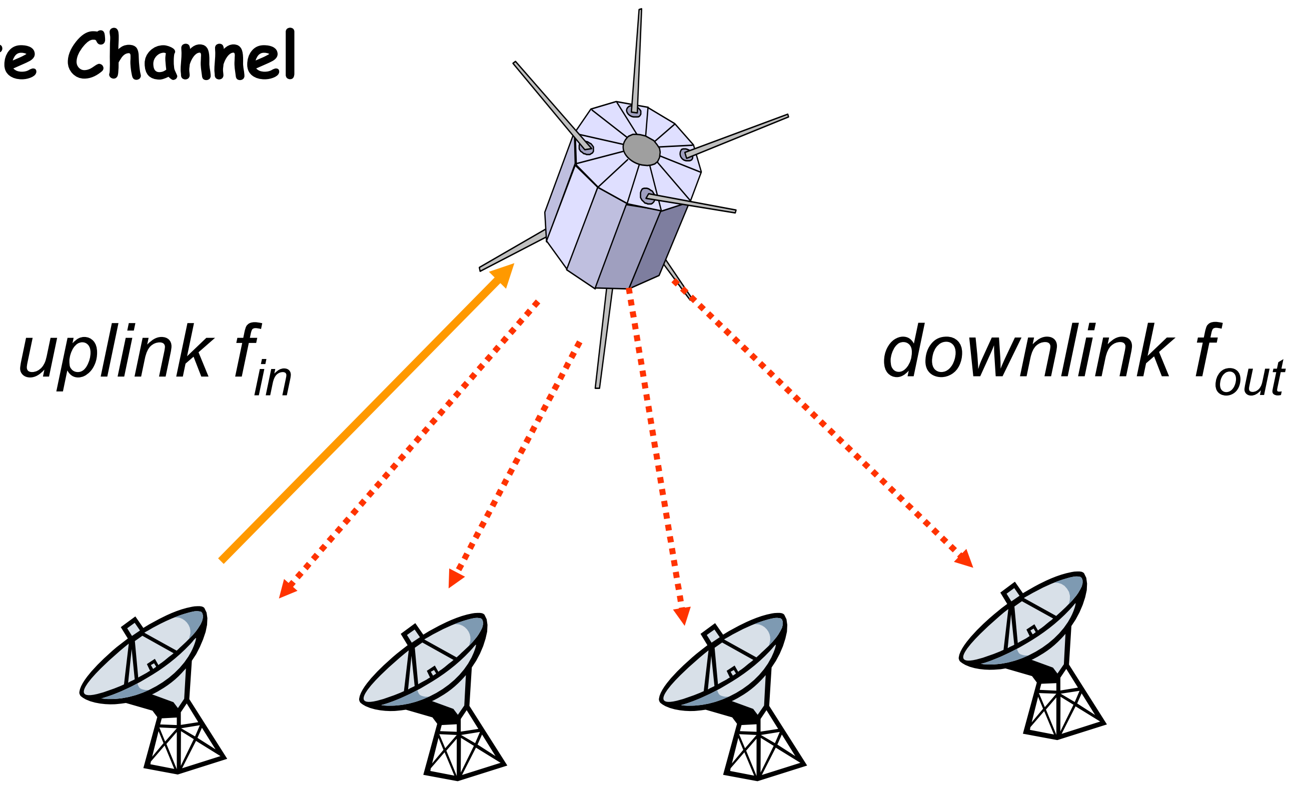
- Polling: take turns
- Request for slot in transmission schedule
- Token ring
- Wireless LANs

Random access

- Loose coordination
- Send, wait, retry if necessary
- Aloha
- Ethernet

Channelization: Satellite

Satellite Channel

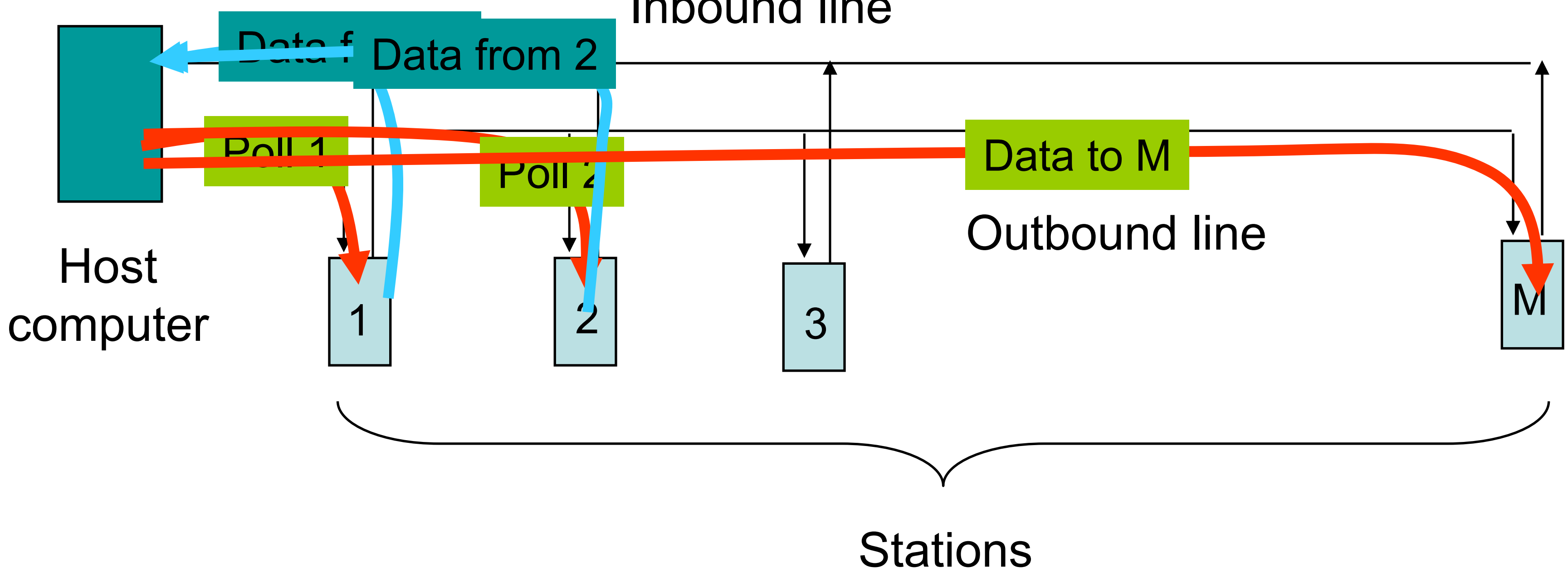


Channelization: Cellular

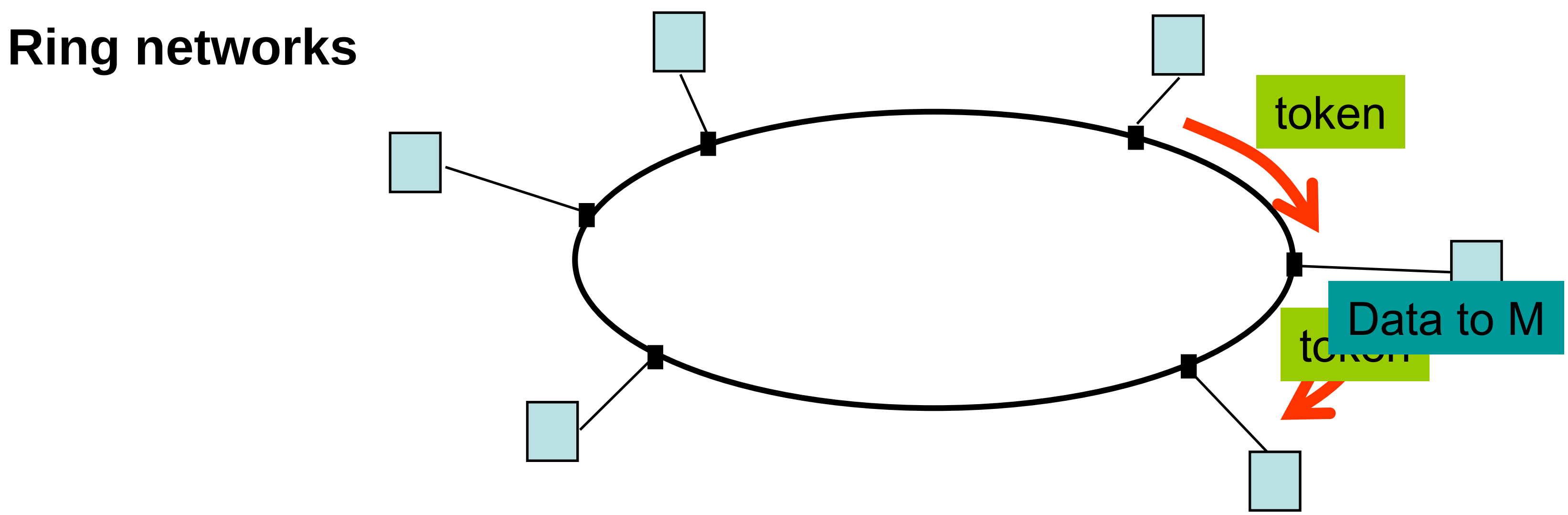
uplink f_1 ; downlink f_2

uplink f_3 ; downlink f_4

Scheduling: Polling



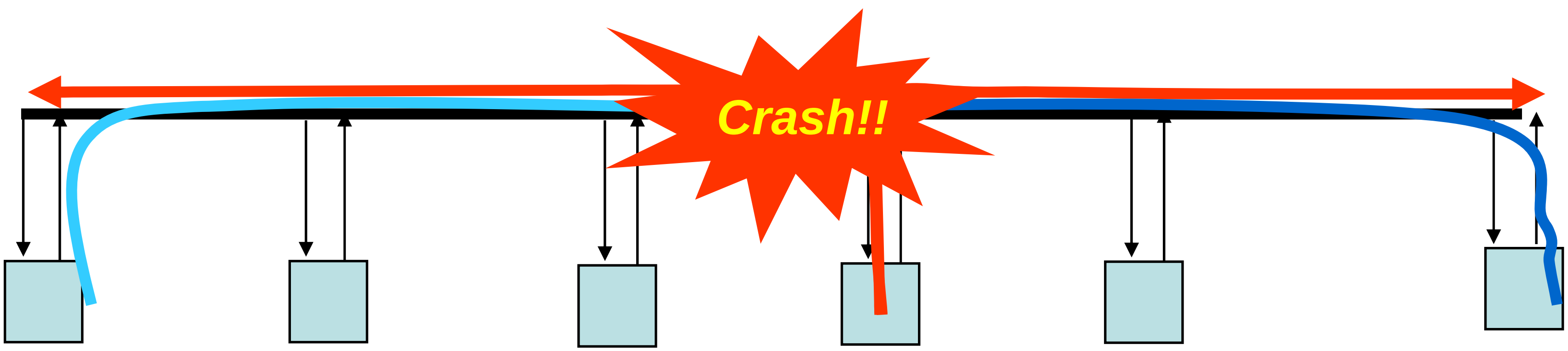
Scheduling: Token-Passing



Station that holds token transmits into ring

Random Access

Multitapped Bus

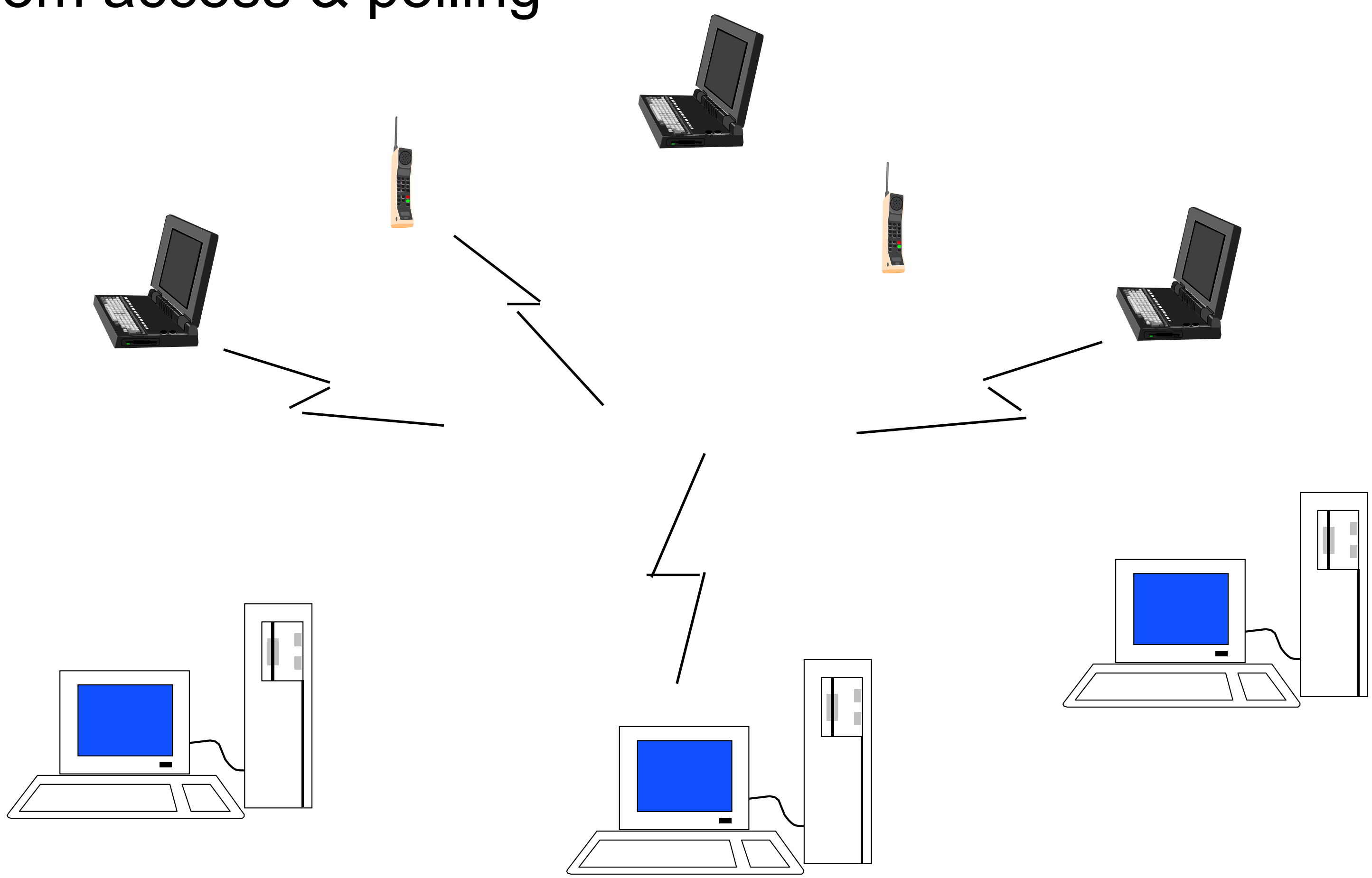


Transmit when ready

Transmissions can occur; need retransmission strategy

Wireless LAN

AdHoc: station-to-station
Infrastructure: stations to base station
Random access & polling



Selecting a Medium Access Control

- Applications
  - What type of traffic?
  - Voice streams? Steady traffic, low delay/jitter
  - Data? Short messages? Web page downloads?
  - Enterprise or Consumer market? Reliability, cost
- Scale
  - How much traffic can be carried?
  - How many users can be supported?
- Current Examples:
  - Design MAC to provide wireless DSL-equivalent access to rural communities
  - Design MAC to provide Wireless-LAN-equivalent access to mobile users (user in car travelling at 130 km/hr)

Delay-Bandwidth Product

- *Delay-bandwidth* product key parameter
  - Coordination in sharing medium involves using bandwidth (explicitly or implicitly)
  - Difficulty of coordination commensurate with delay-bandwidth product
- Simple two-station example
  - Station with frame to send listens to medium and transmits if medium found idle
  - Station monitors medium to detect collision
  - If collision occurs, station that begin transmitting earlier retransmits (propagation time is known)

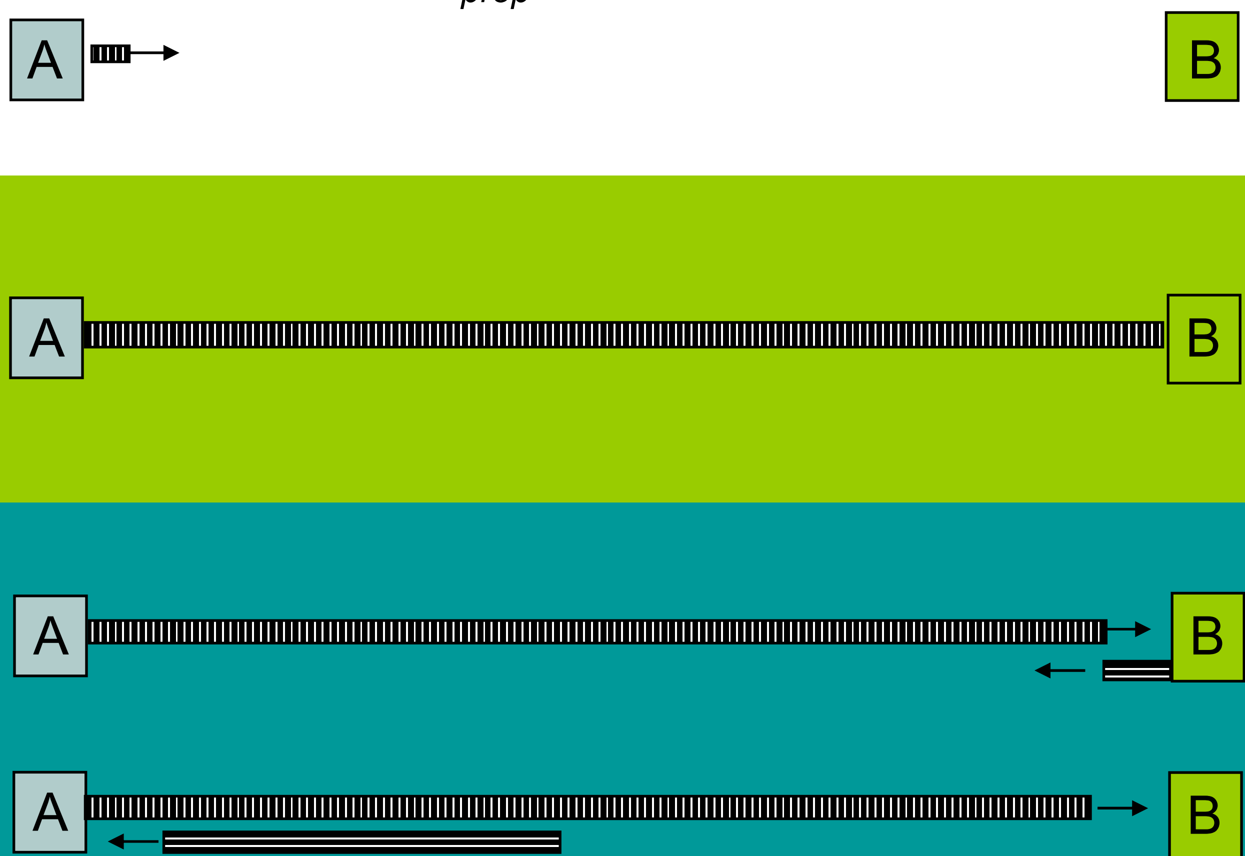
Two-Station MAC Example

Two stations are trying to share a common medium

Distance d meters

$t_{prop} = d / \nu$ seconds

A transmits at $t = 0$



Case 1

B does not transmit before $t = t_{prop}$ & A captures channel

Case 2

B transmits before $t = t_{prop}$ and detects collision soon thereafter

A detects collision at $t = 2\, t_{prop}$

Efficiency of Two-Station Example

- Each frame transmission requires $2t_{prop}$ of quiet time
  - Station B needs to be quiet t_{prop} before *and* after time when Station A transmits
  - R transmission bit rate
  - L bits/frame

$$Efficiency = \rho_{\max} = \frac{L}{L + 2t_{prop}R} = \frac{1}{1 + 2t_{prop}R/L} = \frac{1}{1+2a}$$

$$MaxThroughput = R_{eff} = \frac{L}{L/R + 2t_{prop}} = \frac{1}{1+2a}R \text{ bits/second}$$

Normalized Delay-Bandwidth Product

$$a = \frac{t_{prop}}{L/R}$$

Propagation delay (t_{prop})

Time to transmit a frame (L/R)

Typical MAC Efficiencies

Two-Station Example:

$$Efficiency = \frac{1}{1+2a}$$

CSMA-CD (Ethernet) protocol:

$$Efficiency = \frac{1}{1+6.44a}$$

Token-ring network

$$Efficiency = \frac{1}{1+a'}$$

a'= latency of the ring (bits)/average frame length

- If $a<<1$, then efficiency close to 100%
- As a approaches 1, the efficiency becomes low

Typical Delay-Bandwidth Products

Distance	10 Mbps	100 Mbps	1 Gbps	Network Type
1 m	3.33×10^{-02}	3.33×10^{-01}	3.33×10^{0}	Desk area network
100 m	3.33×10^{01}	3.33×10^{02}	3.33×10^{03}	Local area network
10 km	3.33×10^{02}	3.33×10^{03}	3.33×10^{04}	Metropolitan area network
1000 km	3.33×10^{04}	3.33×10^{05}	3.33×10^{06}	Wide area network
100000 km	3.33×10^{06}	3.33×10^{07}	3.33×10^{08}	Global area network

- Max size Ethernet frame: 1500 bytes = 12000 bits
- Long and/or fat pipes give large a

MAC protocol features

- Delay-bandwidth product
- Efficiency
- Transfer delay
- Fairness
- Reliability
- Capability to carry different types of traffic
- Quality of service
- Cost

MAC Delay Performance

- Frame transfer delay
  - From first bit of frame arrives at source MAC
  - To last bit of frame delivered at destination MAC
- Throughput
  - Actual transfer rate through the shared medium
  - Measured in frames/sec or bits/sec
- Parameters

  R bits/sec & L bits/frame

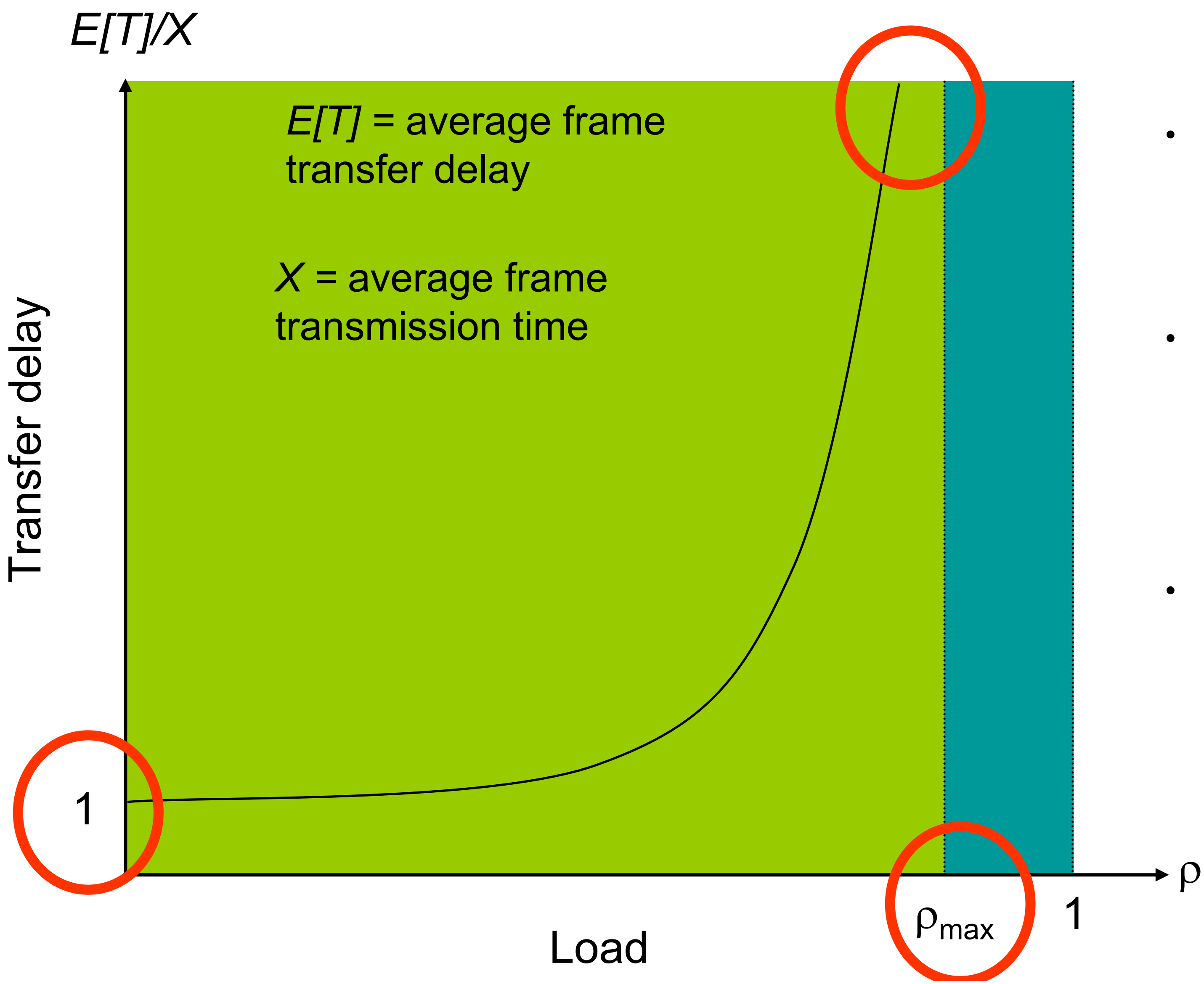
  $X=L/R$ seconds/frame

  λ frames/second average arrival rate

  Load $\rho = \lambda X$, rate at which "work" arrives

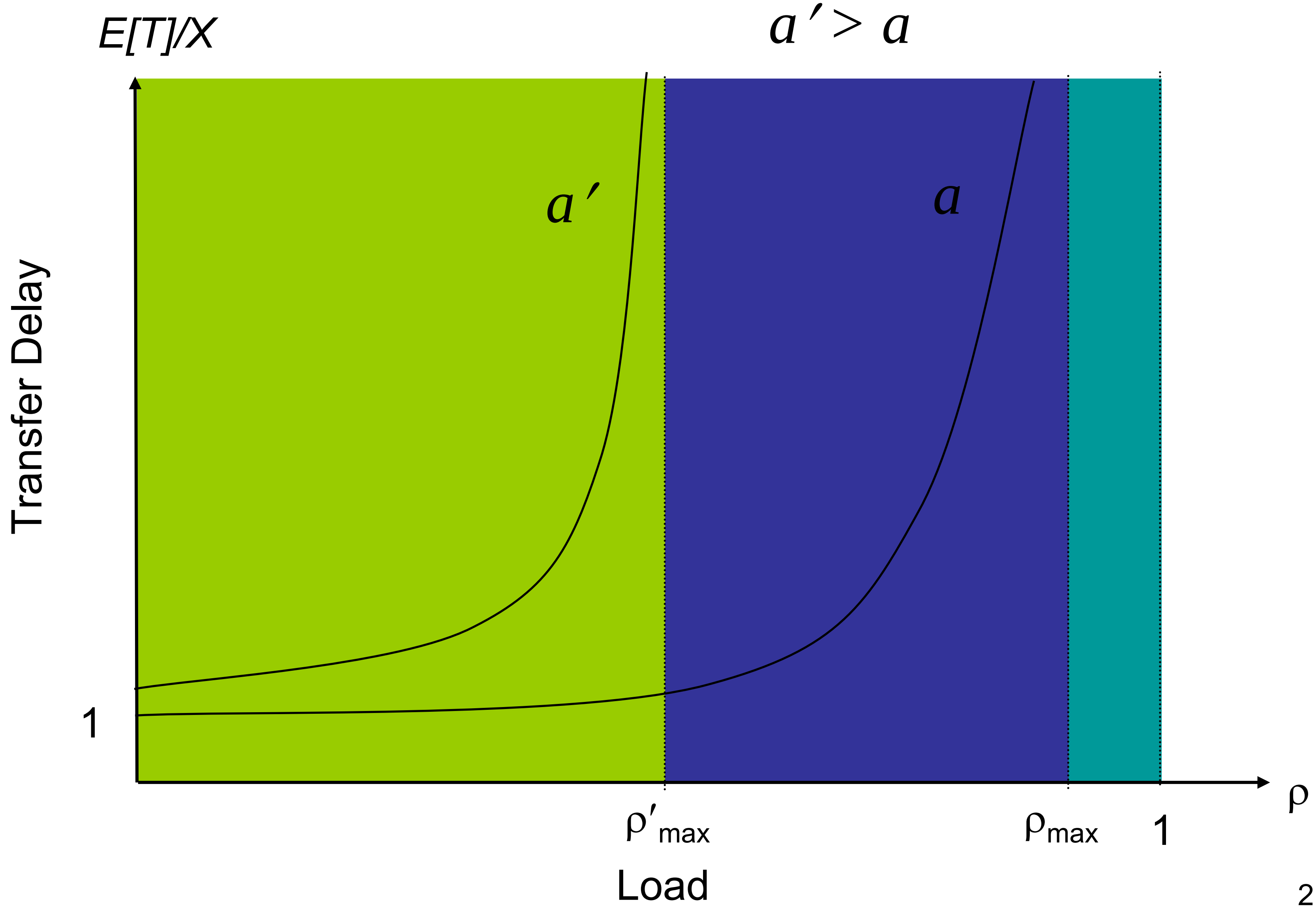
  Maximum throughput (@100% efficiency): R/L fr/sec

Normalized Delay versus Load



- At low arrival rate, only frame transmission time
- At high arrival rates, increasingly longer waits to access channel
- Max efficiency typically less than 100%

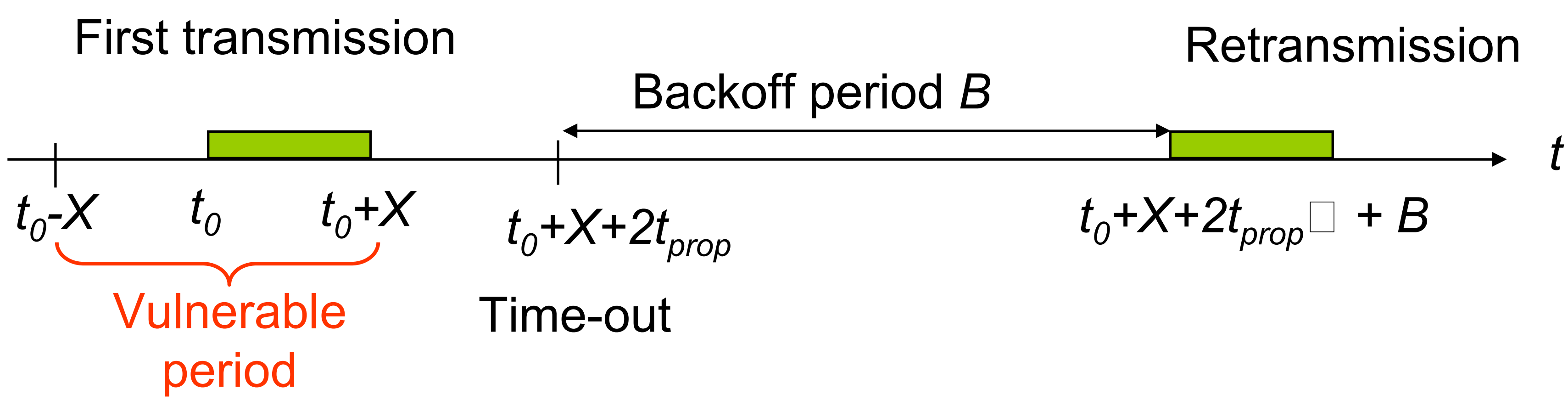
Dependence on Rt_{prop}/L



Random Access

ALOHA

- Wireless link to provide data transfer between main campus & remote campuses of University of Hawaii
- Simplest solution: just do it
  - A station transmits whenever it has data to transmit
  - If more than one frames are transmitted, they interfere with each other (collide) and are lost
  - If ACK not received within timeout, then a station picks random backoff time (to avoid repeated collision)
  - Station retransmits frame after backoff time



ALOHA Model

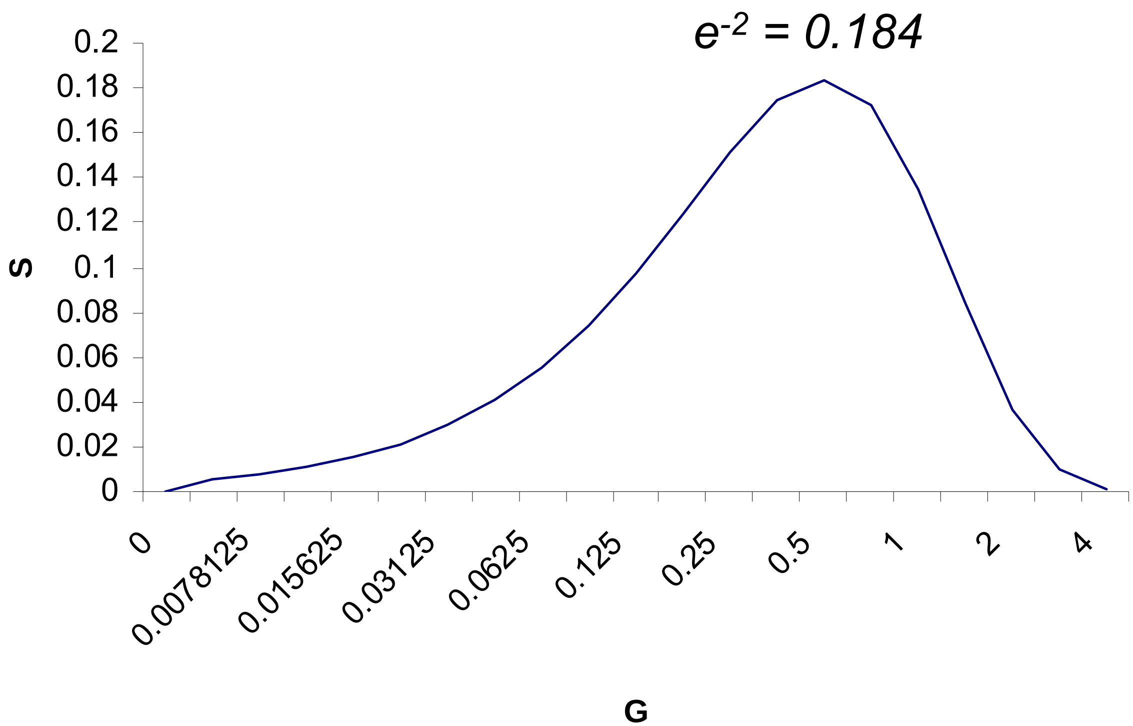
- Definitions and assumptions
  - *X* frame transmission time (assume constant)
  - *S*: throughput (average # successful frame transmissions per *X* seconds)
  - *G*: load (average # transmission attempts per X sec.)
  - $P_{success}$: probability a frame transmission is successful

$$S = GP_{success}$$

- *Any transmission that begins during vulnerable period leads to collision*
- *Success if no arrivals during 2X seconds*

Throughput of ALOHA

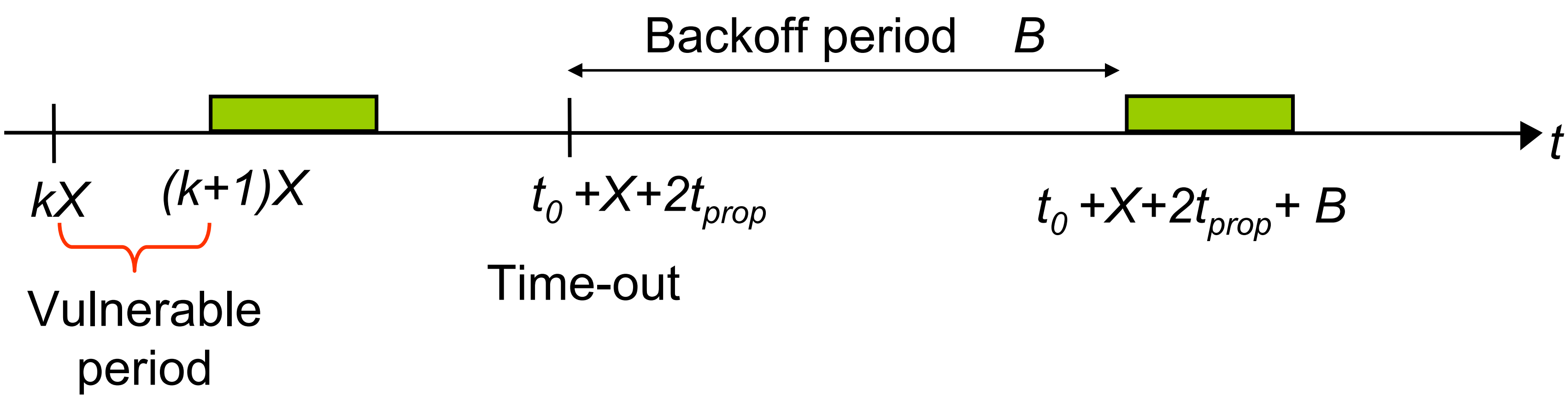
$$S = GP_{success} = Ge^{-2G}$$



- Collisions are means for coordinating access
- Max throughput is ρ_{max}= 1/2*e* *(18.4%)*
- Bimodal behavior:
  - Small *G*, S≈*G*
  - Large *G*, S↓0
- Collisions can snowball and drop throughput to zero

Slotted ALOHA

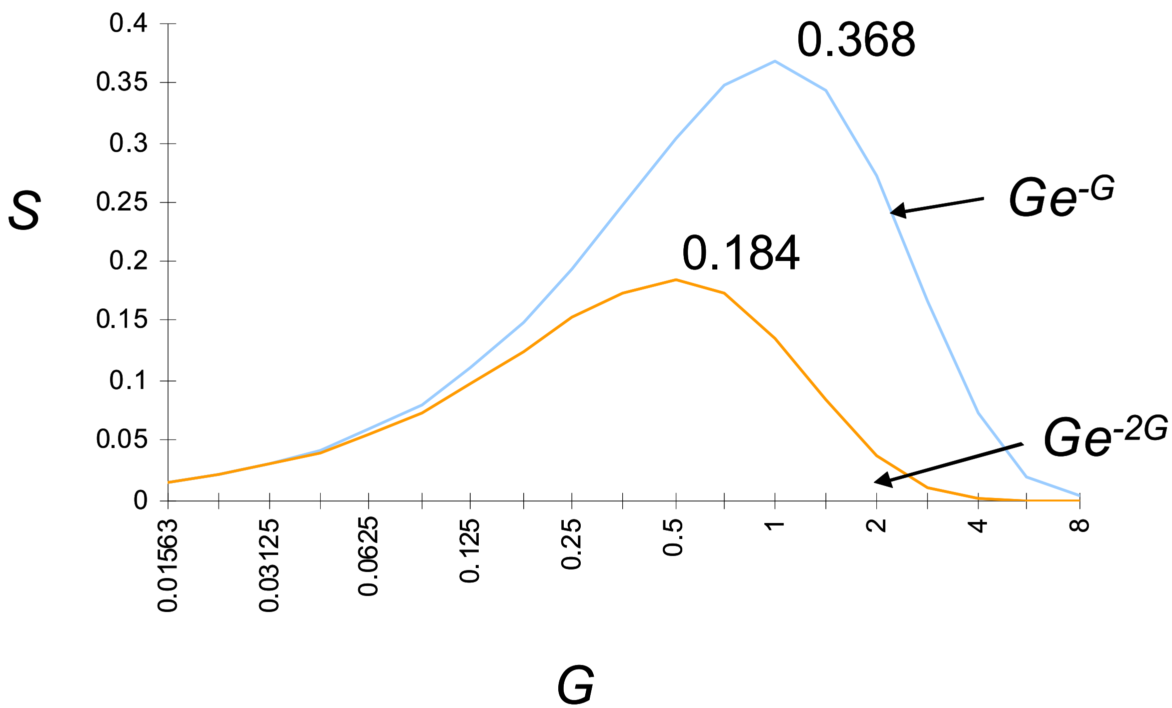
- Time is slotted in X seconds slots
- Stations synchronized to frame times
- Stations transmit frames in first slot after frame arrival
- Backoff intervals in multiples of slots



Only frames that arrive during prior X seconds collide

Throughput of Slotted ALOHA

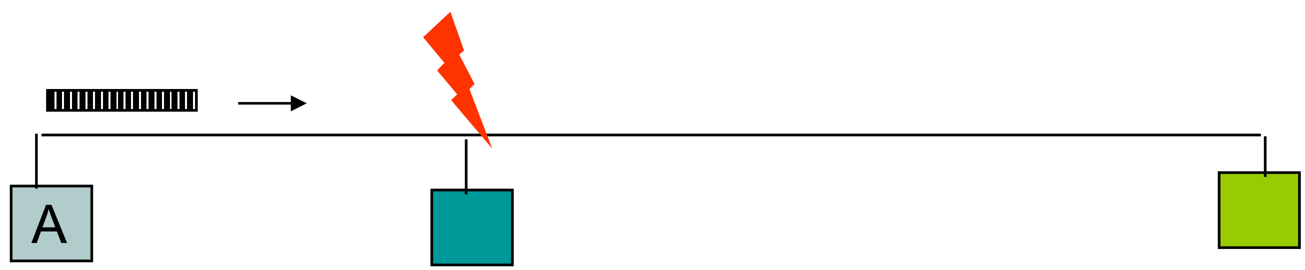
$$S = GP_{success} = GP[\text{no arrivals in X seconds}]$$
$$= GP[\text{no arrivals in n intervals}]$$
$$= G(1-p)^n = G(1-\frac{G}{n})^n \to Ge^{-G}$$



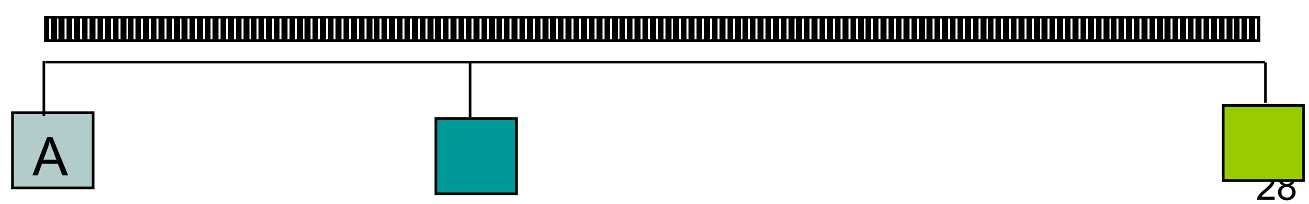
Carrier Sensing Multiple Access (CSMA)

- A station senses the channel before it starts transmission
  - If busy, either wait or schedule backoff (different options)
  - If idle, start transmission
  - Vulnerable period is reduced to t_{prop} (due to *channel capture* effect)
  - When collisions occur they involve entire frame transmission times
  - If t_{prop} >X (or if a>1), no gain compared to ALOHA or slotted ALOHA

Station A begins transmission at $t = 0$

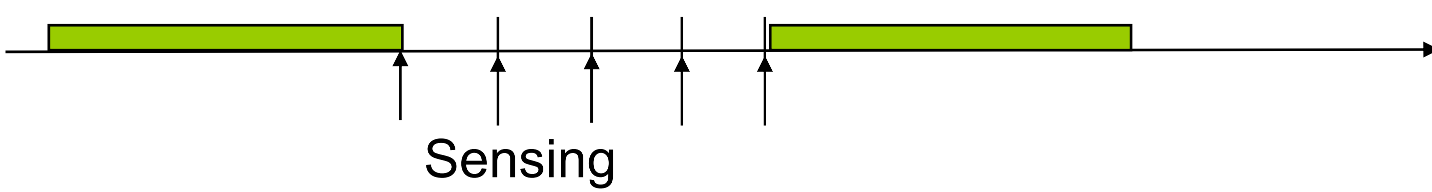


Station A captures channel at $t = t_{prop}$

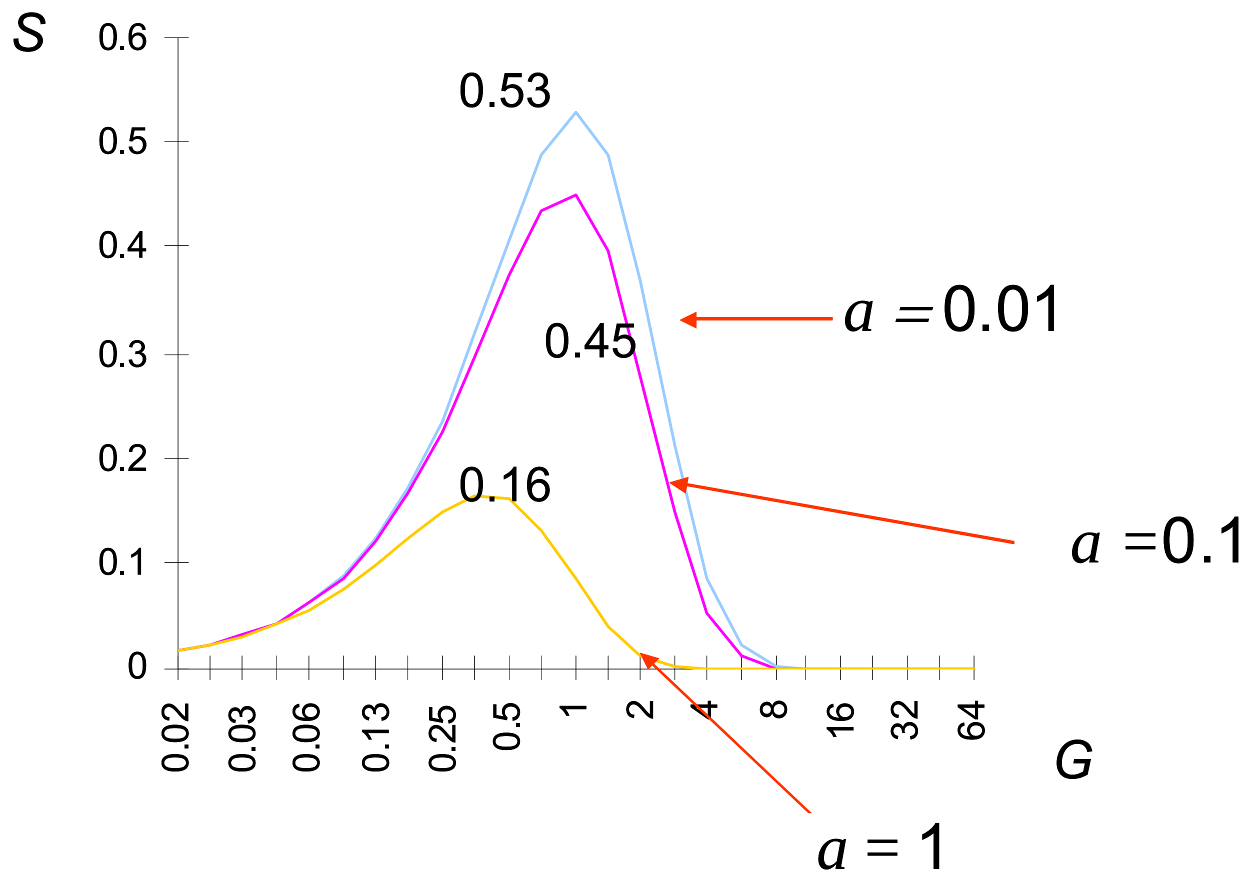


CSMA Options

- Transmitter behavior when busy channel is sensed
  - 1-persistent CSMA (most greedy)
    - Start transmission as soon as the channel becomes idle
    - Low delay and low efficiency
  - Non-persistent CSMA (least greedy)
    - Wait a backoff period, then sense carrier again
    - High delay and high efficiency
  - p-persistent CSMA (adjustable greedy)
    - Wait till channel becomes idle, transmit with prob. p; or wait one mini-slot time & re-sense with probability 1-*p*
    - Delay and efficiency can be balanced

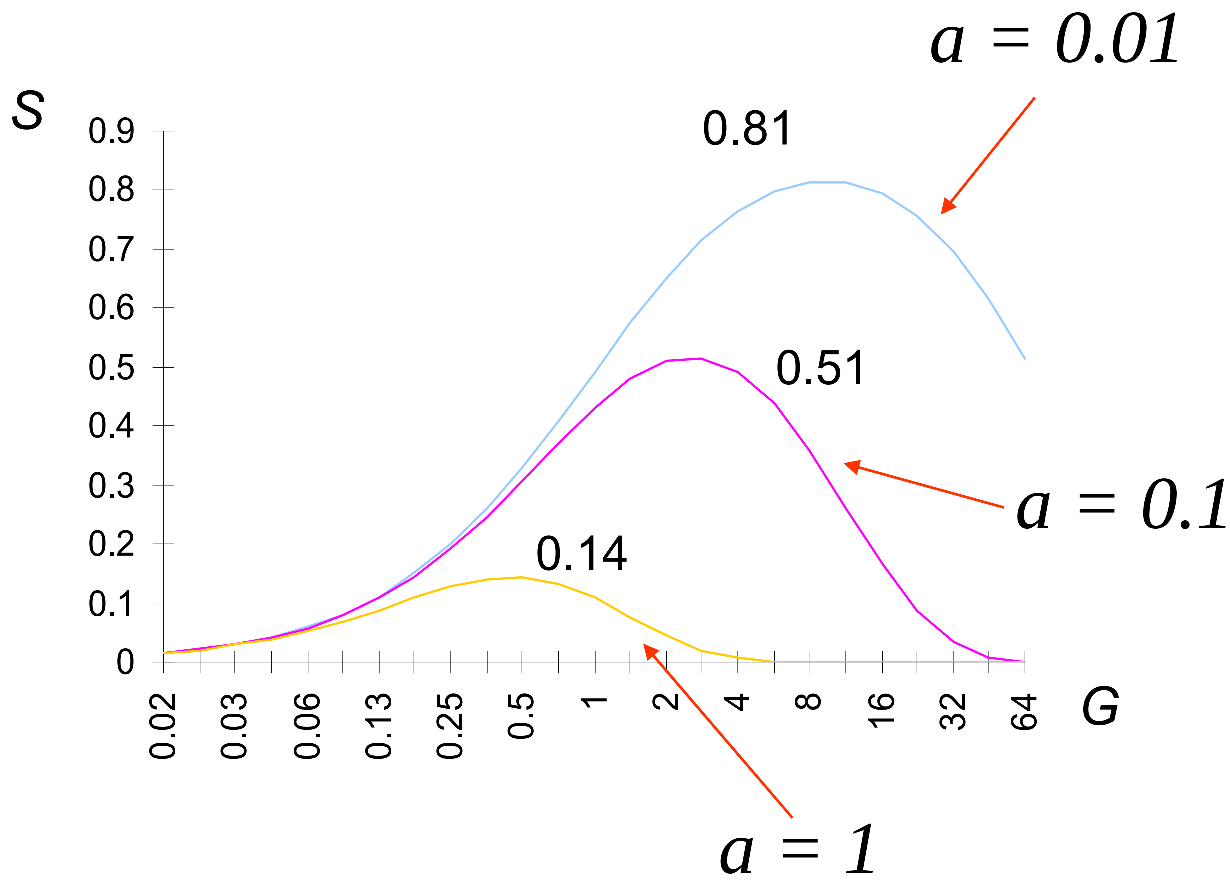


1-Persistent CSMA Throughput



- Better than Aloha & slotted Aloha for small a
- Worse than Aloha for $a > 1$

Non-Persistent CSMA Throughput

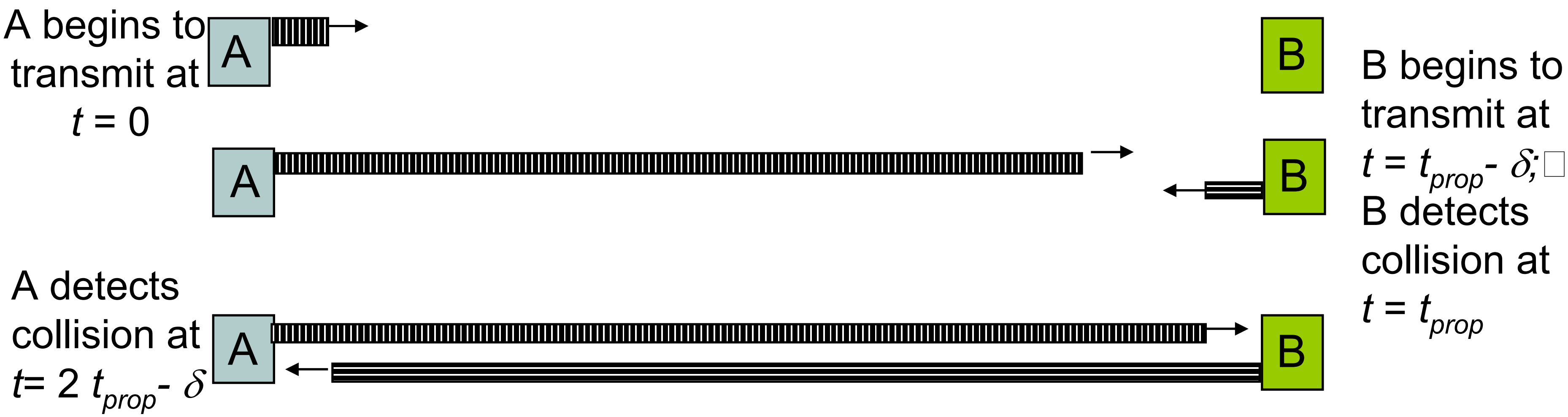


- Higher maximum throughput than 1-persistent for small a
- Worse than Aloha for $a > 1$

CSMA with Collision Detection (CSMA/CD)

- Monitor for collisions & abort transmission
  - Stations with frames to send, first do carrier sensing
  - After beginning transmissions, stations continue listening to the medium to detect collisions
  - If collisions detected, all stations involved stop transmission, reschedule random backoff times, and try again at scheduled times
- In CSMA collisions result in wastage of X seconds spent transmitting an entire frame
- CSMA-CD reduces wastage to time to detect collision and abort transmission

CSMA/CD reaction time

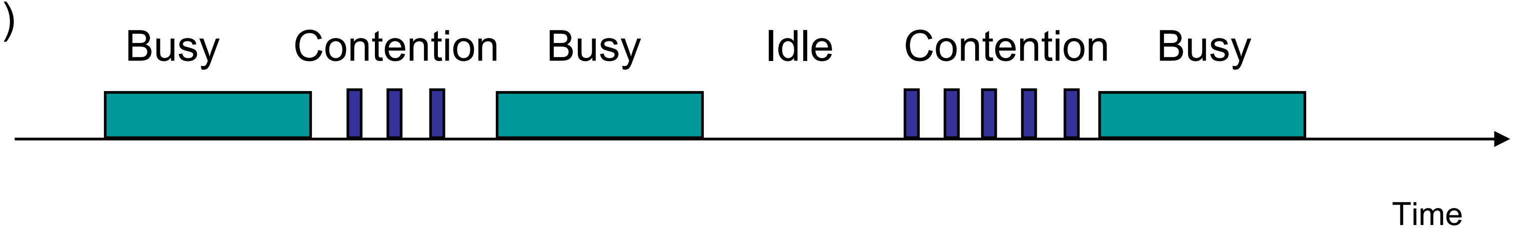


It takes 2 t_{prop} to find out if channel has been captured

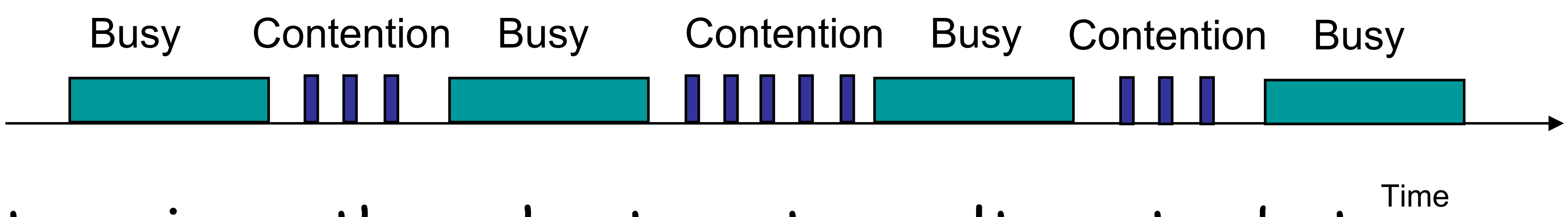
CSMA-CD Model

- Assumptions
  - Collisions can be detected and resolved in $2t_{prop}$
  - Time slotted in $2t_{prop}$ slots during contention periods
  - Assume n busy stations, and each may transmit with probability p in each contention time slot
  - Once the contention period is over (a station successfully occupies the channel), it takes X seconds for a frame to be transmitted
  - It takes t_{prop} before the next contention period starts.

(a)



CSMA/CD Throughput



- At maximum throughput, systems alternates between contention periods and frame transmission times

$$\rho_{\max} = \frac{X}{X + t_{prop} + 2et_{prop}} = \frac{1}{1 + (2e+1)a} = \frac{1}{1 + (2e+1)Rd / \nu L}$$

- where:

  R bits/sec, *L* bits/frame, X=*L/R* seconds/frame

  $a = t_{prop}/X$

  ν meters/sec. speed of light in medium

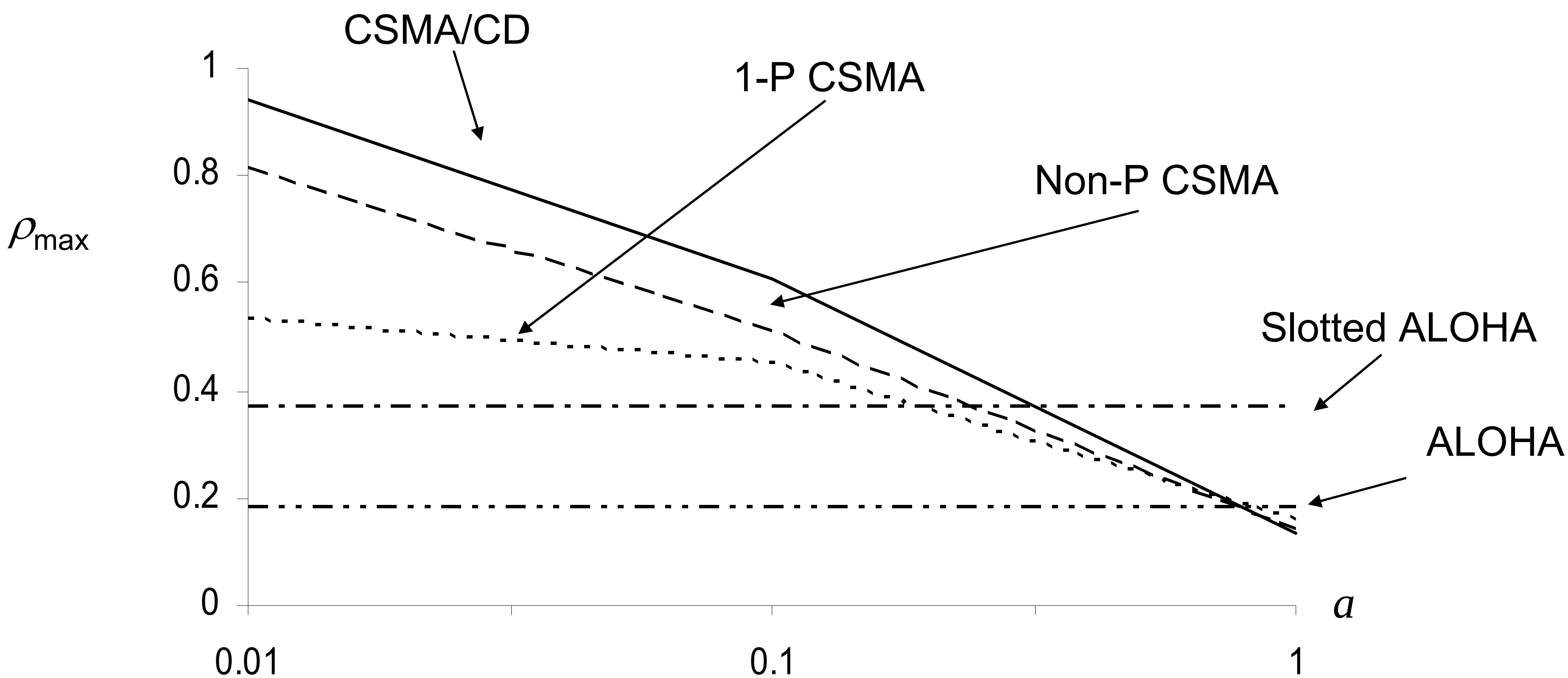
  d meters is diameter of system

  2*e*+1 = 6.44

CSMA-CD Application: Ethernet

- First Ethernet LAN standard used CSMA-CD
  - 1-persistent Carrier Sensing
  - R = 10 Mbps
  - t_{prop} = 51.2 microseconds
    - 512 bits = 64 byte slot
    - accommodates 2.5 km + 4 repeaters
  - Truncated Binary Exponential Backoff
    - After nth collision, select backoff from $\{0, 1, \ldots, 2^k - 1\}$, where k=min(n, 10)

Throughput for Random Access MACs



- For small a: CSMA-CD has best throughput
- For larger a: Aloha & slotted Aloha better throughput

Carrier Sensing and Priority Transmission

- Certain applications require faster response than others, e.g. ACK messages
- Impose different interframe times
  - High priority traffic sense channel for time τ_1
  - Low priority traffic sense channel for time $\tau_2 > \tau_1$
  - High priority traffic, if present, seizes channel first
- This priority mechanism is used in IEEE 802.11 wireless LAN

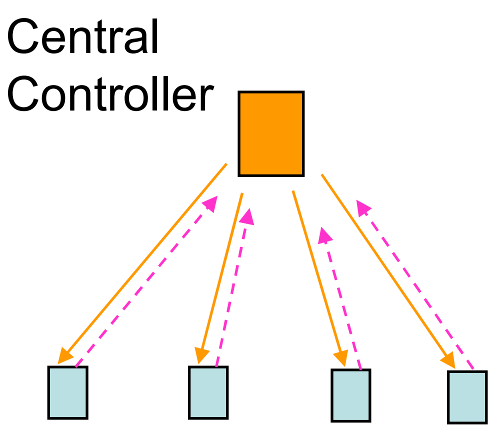
Scheduling

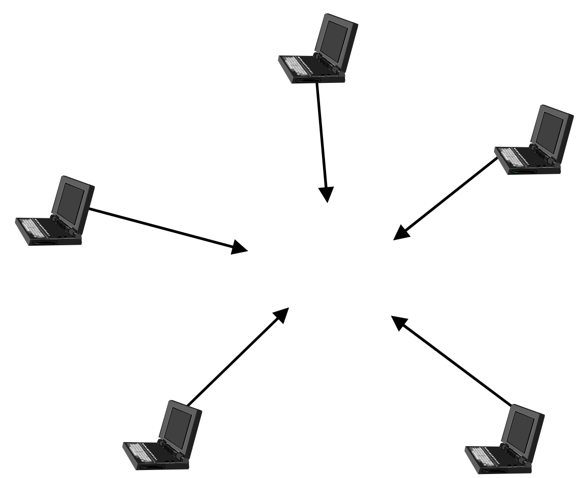
Scheduling for Medium Access Control

- Schedule frame transmissions to avoid collision in shared medium
  - ✓ More efficient channel utilization
  - ✓ Less variability in delays
  - ✓ Can provide fairness to stations
  - ✗ Increased computational or procedural complexity
- Two main approaches
  - Reservation
  - Polling

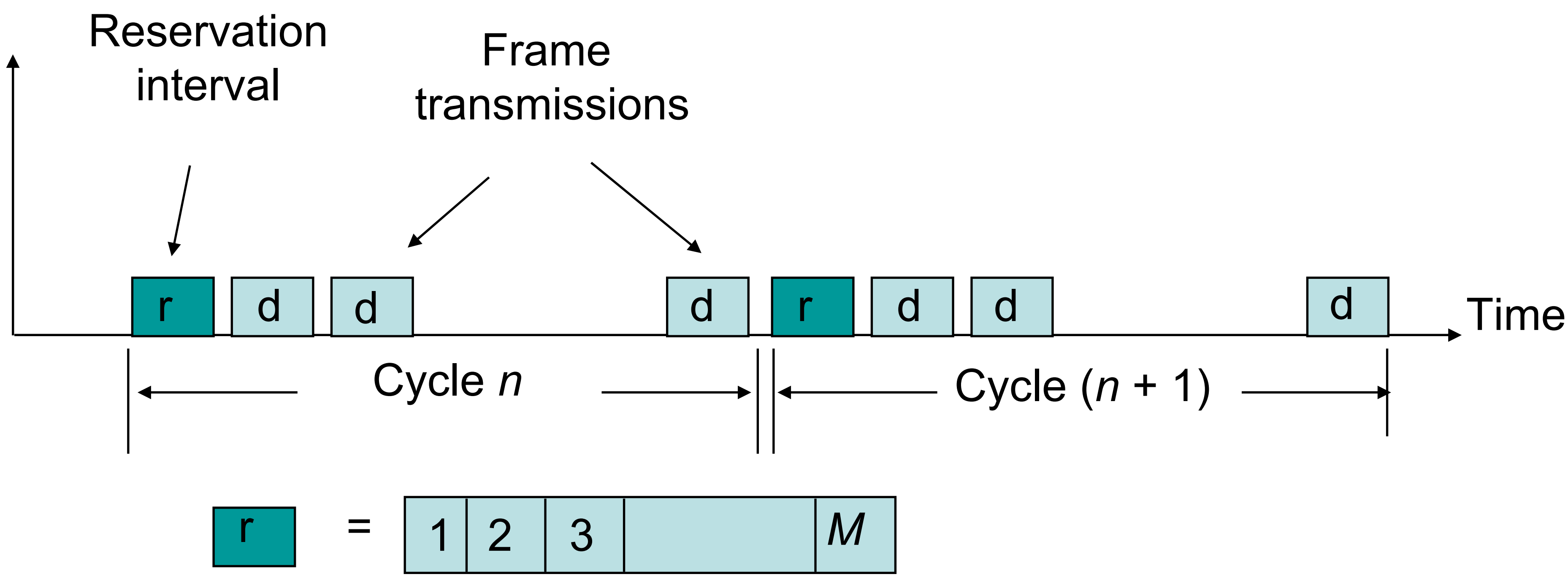
Reservations Systems

- *Centralized systems*: A central controller accepts requests from stations and issues grants to transmit
  - Frequency Division Duplex (FDD): Separate frequency bands for uplink & downlink
  - Time-Division Duplex (TDD): Uplink & downlink time-share the same channel
- *Distributed systems*: Stations implement a decentralized algorithm to determine transmission order





Reservation Systems



- Transmissions organized into cycles
- Cycle: reservation interval + frame transmissions
- Reservation interval has a minislot for ***each*** station to request reservations for frame transmissions

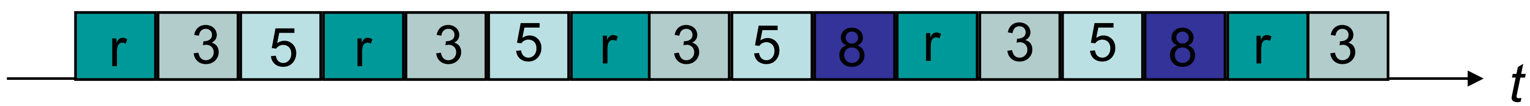
Reservation System Options

- Centralized or distributed system
  - *Centralized systems*: A central controller listens to reservation information, decides order of transmission, issues grants
  - *Distributed systems*: Each station determines its slot for transmission from the reservation information
- Single or Multiple Frames
  - *Single frame reservation*: Only one frame transmission can be reserved within a reservation cycle
  - *Multiple frame reservation*: More than one frame transmission can be reserved within a frame
- Channelized or Random Access Reservations
  - *Channelized (typically TDMA) reservation*: Reservation messages from different stations are multiplexed without any risk of collision
  - *Random access reservation*: Each station transmits its reservation message randomly until the message goes through

Example

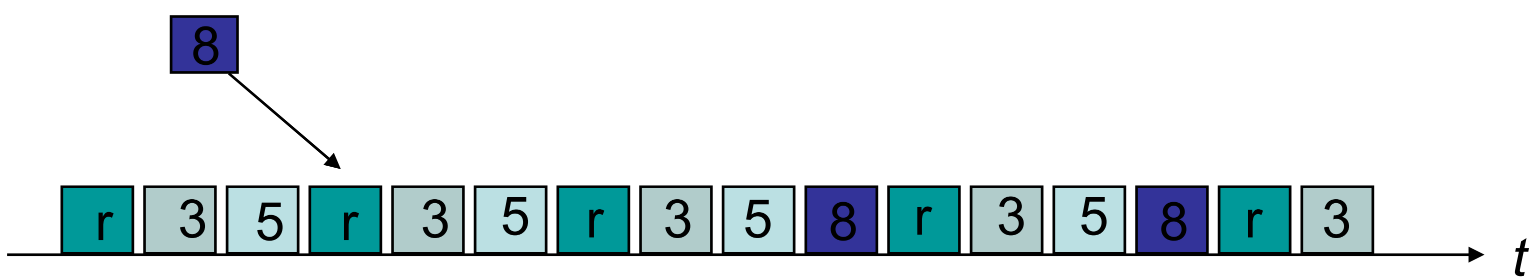
- Initially stations 3 & 5 have reservations to transmit frames

(a)



- Station 8 becomes active and makes reservation
- Cycle now also includes frame transmissions from station 8

(b)



Example: GPRS

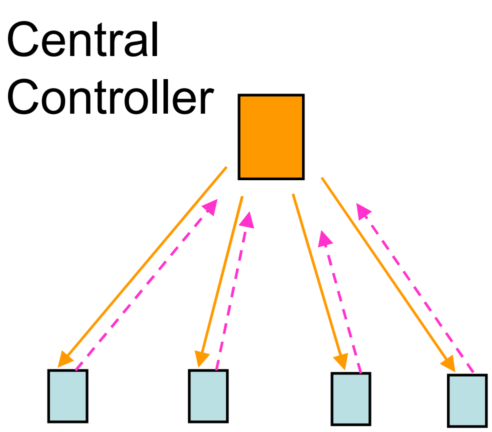
- General Packet Radio Service
  - Packet data service in GSM cellular radio
  - GPRS devices, e.g. cellphones or laptops, send packet data over radio and then to Internet
  - Slotted Aloha MAC used for reservations
  - Single & multi-slot reservations supported

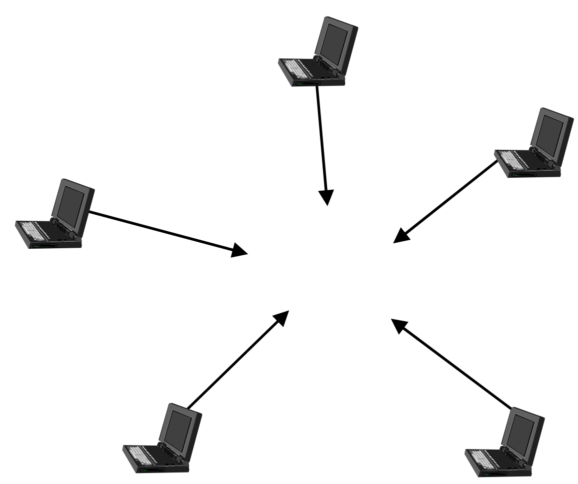
Reservation Systems and Quality of Service

- Different applications; different requirements
  - Immediate transfer for ACK frames
  - Low-delay transfer & steady bandwidth for voice
  - High-bandwidth for Web transfers
- Reservation provide direct means for QoS
  - Stations makes requests per frame
  - Stations can request for persistent transmission access
  - Centralized controller issues grants
    - Preferred approach
  - Decentralized protocol allows stations to determine grants
    - Protocol must deal with error conditions when requests or grants are lost

Polling Systems

- *Centralized polling systems*: A central controller transmits polling messages to stations according to a certain order
- *Distributed polling systems*: A permit for frame transmission is passed from station to station according to a certain order
- A signaling procedure exists for setting up order



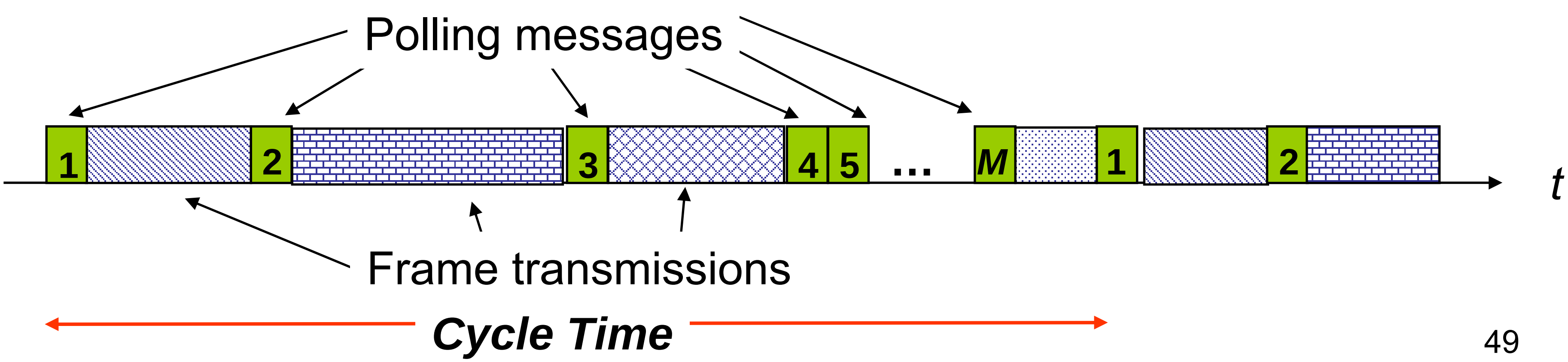


Polling System Options

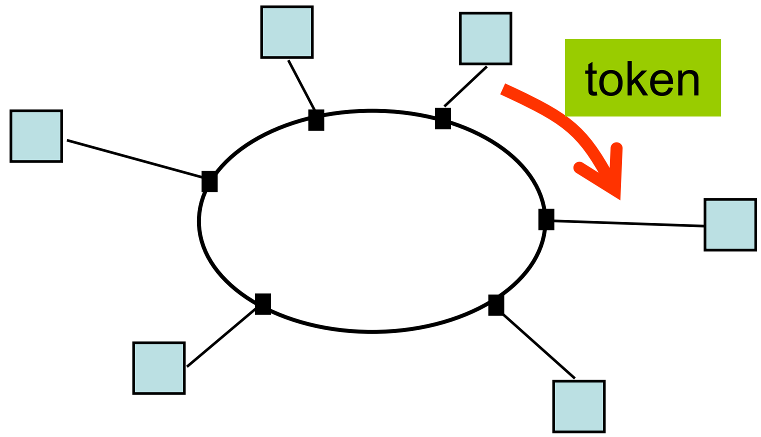
- Service Limits: How much is a station allowed to transmit per poll?
  - *Exhaustive*: until station's data buffer is empty (including new frame arrivals)
  - *Gated*: all data in buffer when poll arrives
  - *Frame-Limited*: one frame per poll
  - *Time-Limited*: up to some maximum time
- Priority mechanisms
  - More bandwidth & lower delay for stations that appear multiple times in the polling list
  - Issue polls for stations with message of priority k or higher

Walk Time & Cycle Time

- Assume polling order is round robin
- Time is "wasted" polling stations
  - Time to prepare & send polling message
  - Time for station to respond
- *Walk time:* from when a station completes transmission to when next station begins transmission
- *Cycle time* is between consecutive polls of a station
- Overhead/cycle = total walk time/cycle time

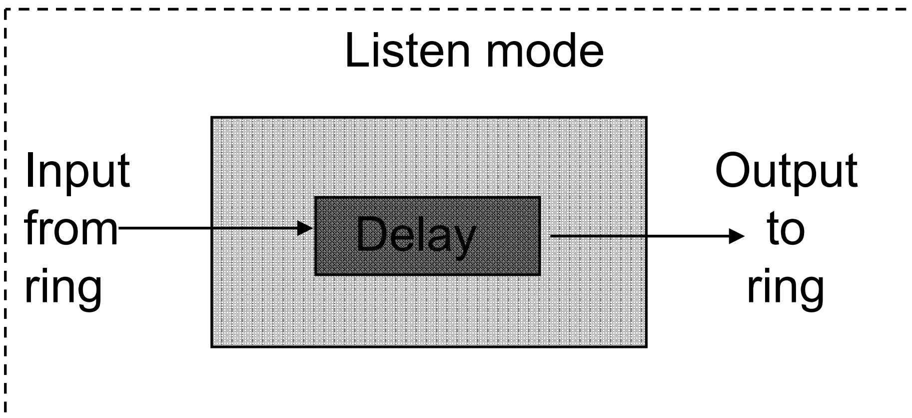


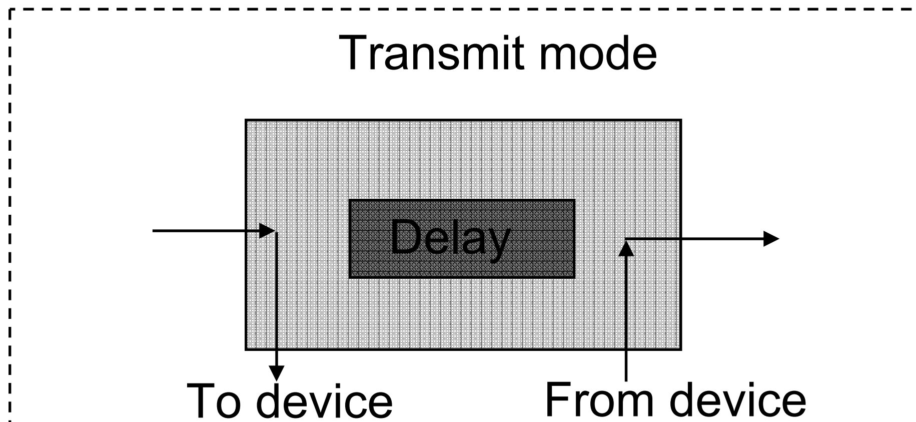
Application: Token-Passing Rings



Free Token = Poll

Frame Delimiter is Token
Free = 01111110
Busy = 01111111



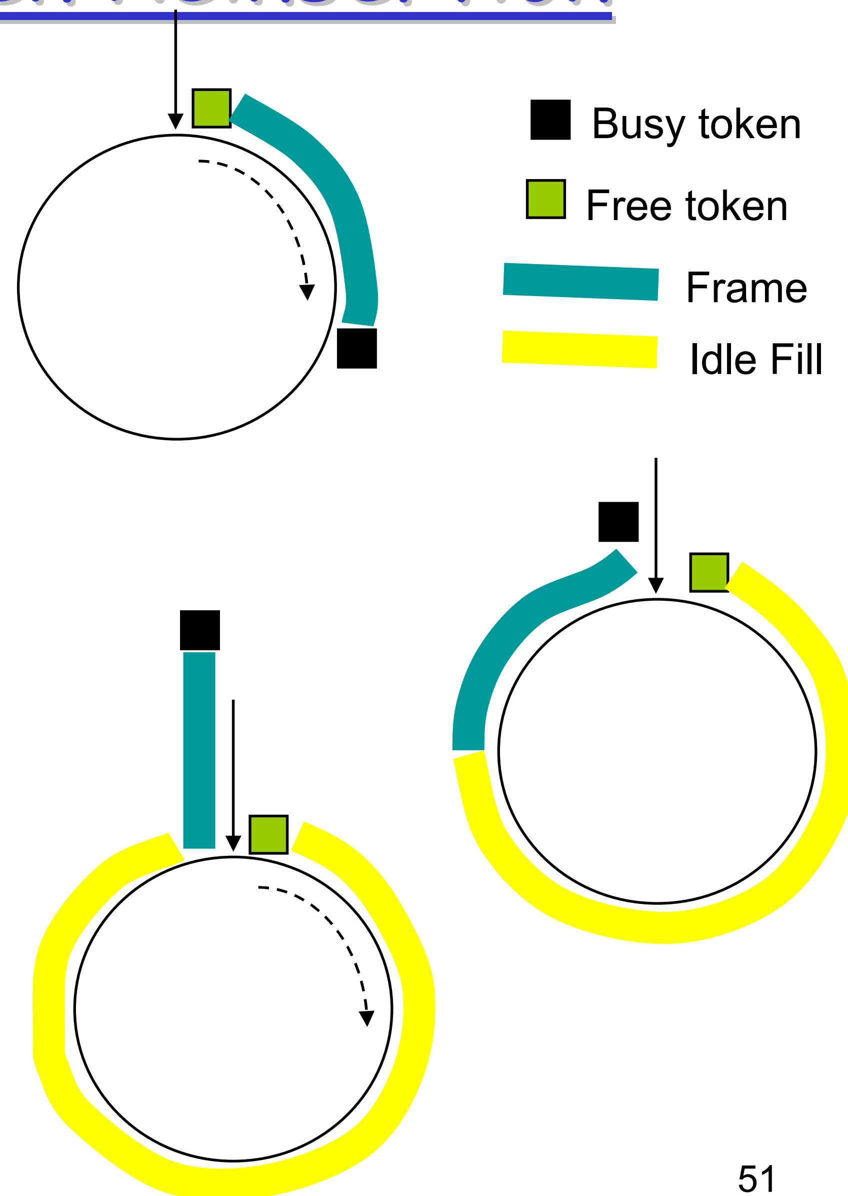


Ready station looks for free token
Flips bit to change free token to busy

Ready station inserts its frames
Reinserts free token when done

Methods of Token Reinsertion

- Ring latency: number of bits that can be simultaneously in transit on ring
- Multi-token operation
  - Free token transmitted immediately after last bit of data frame
- Single-token operation
  - Free token inserted after last bit of the busy token is received back
  - Transmission time at least ring latency
  - If frame is longer than ring latency, equivalent to multi-token operation
- Single-Frame operation
  - Free token inserted after transmitting station has received last bit of its frame
  - Equivalent to attaching trailer equal to ring latency



Application Examples

- Single-frame reinsertion
  - IEEE 802.5 Token Ring LAN @ 4 Mbps
- Single token reinsertion
  - IBM Token Ring @ 4 Mbps
- Multitoken reinsertion
  - IEEE 802.5 and IBM Ring LANs @ 16 Mbps
  - FDDI Ring @ 50 Mbps
- All of these LANs incorporate token priority mechanisms

Comparison of MAC approaches

- Aloha & Slotted Aloha
  - Simple & quick transfer at very low load
  - Accommodates large number of low-traffic bursty users
  - Highly variable delay at moderate loads
  - Efficiency does not depend on a
- CSMA-CD
  - Quick transfer and high efficiency for low delay-bandwidth product
  - Can accommodate large number of bursty users
  - Variable and unpredictable delay

Comparison of MAC approaches

- Reservation
  - On-demand transmission of bursty or steady streams
  - Accommodates large number of low-traffic users with slotted Aloha reservations
  - Can incorporate QoS
  - Handles large delay-bandwidth product via delayed grants
- Polling
  - Generalization of time-division multiplexing
  - Provides fairness through regular access opportunities
  - Can provide bounds on access delay
  - Performance deteriorates with large delay-bandwidth product