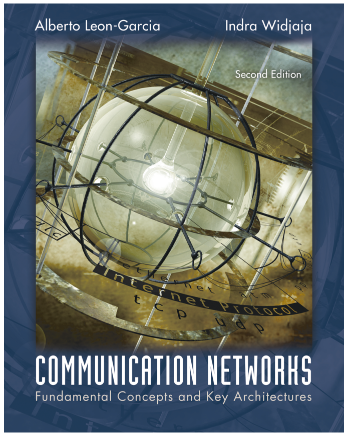
Chapter 6
Medium Access Control Protocols and Local Area Networks



Part I: Medium Access Control

Part II: Local Area Networks

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

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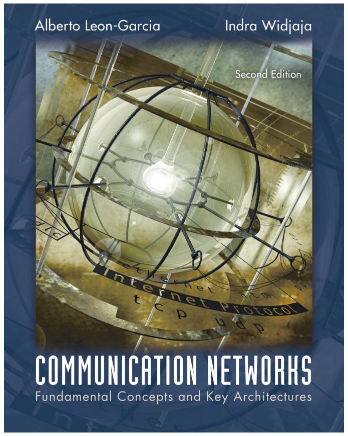

Part I: Medium Access Control

Multiple Access Communications
Random Access
Scheduling
Channelization
Delay Performance

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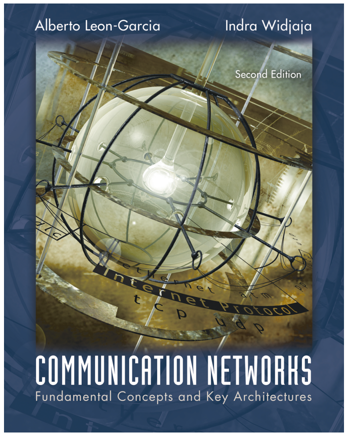
Medium Access Control Protocols and Local Area Networks



Part II: Local Area Networks

Overview of LANs

Ethernet

Token Ring and FDDI

802.11 Wireless LAN

LAN Bridges

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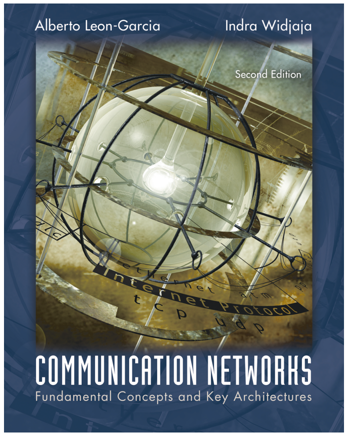
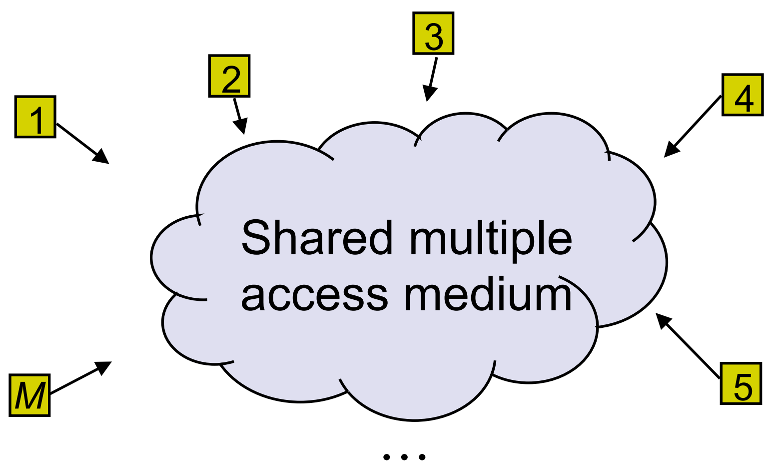
Medium Access Control Protocols and Local Area Networks



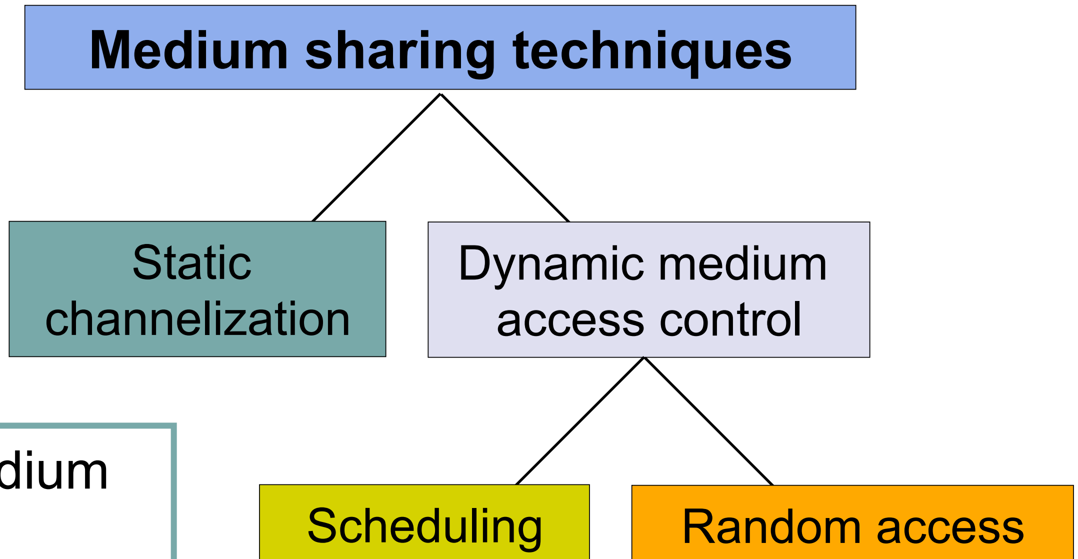
Multiple Access Communications

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



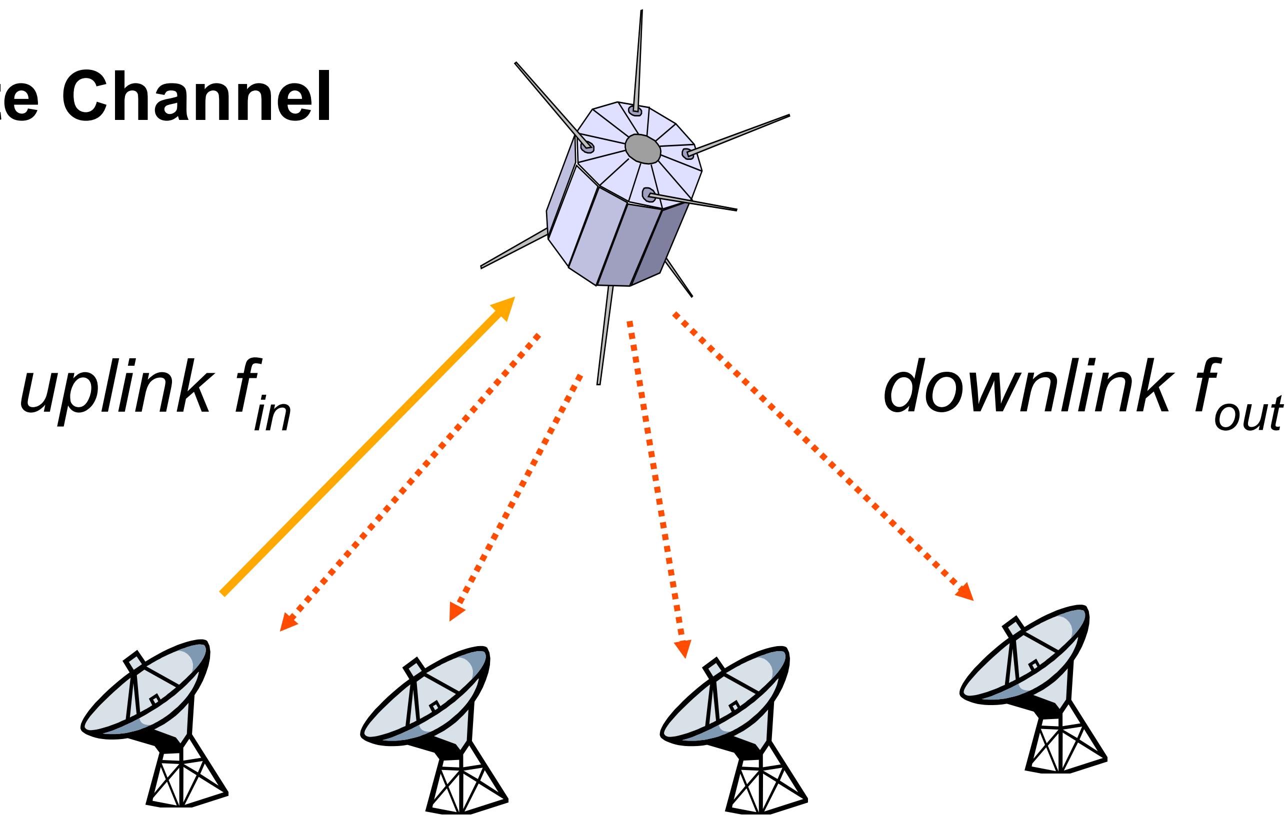
- Partition medium
- Dedicated allocation to users
- Satellite transmission
- Cellular Telephone

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

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

Channelization: Satellite

Satellite Channel

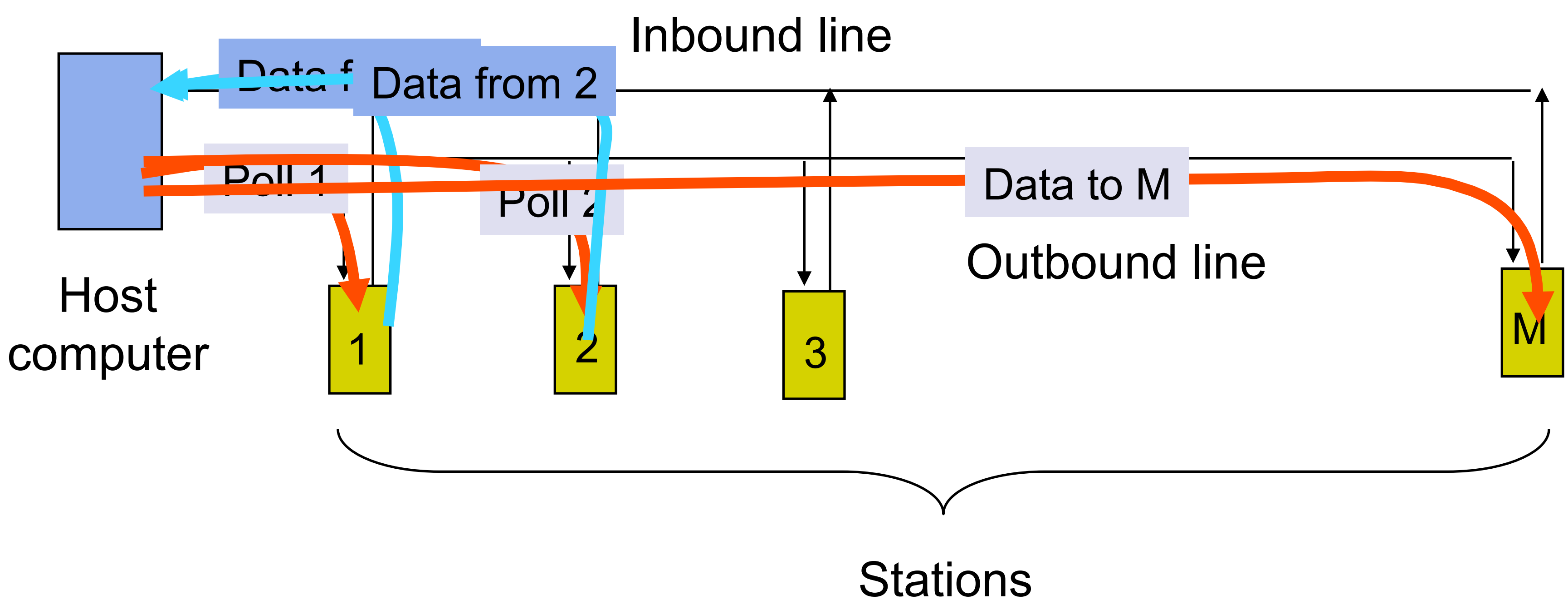


Channelization: Cellular

uplink f_1 ; *downlink f_2*

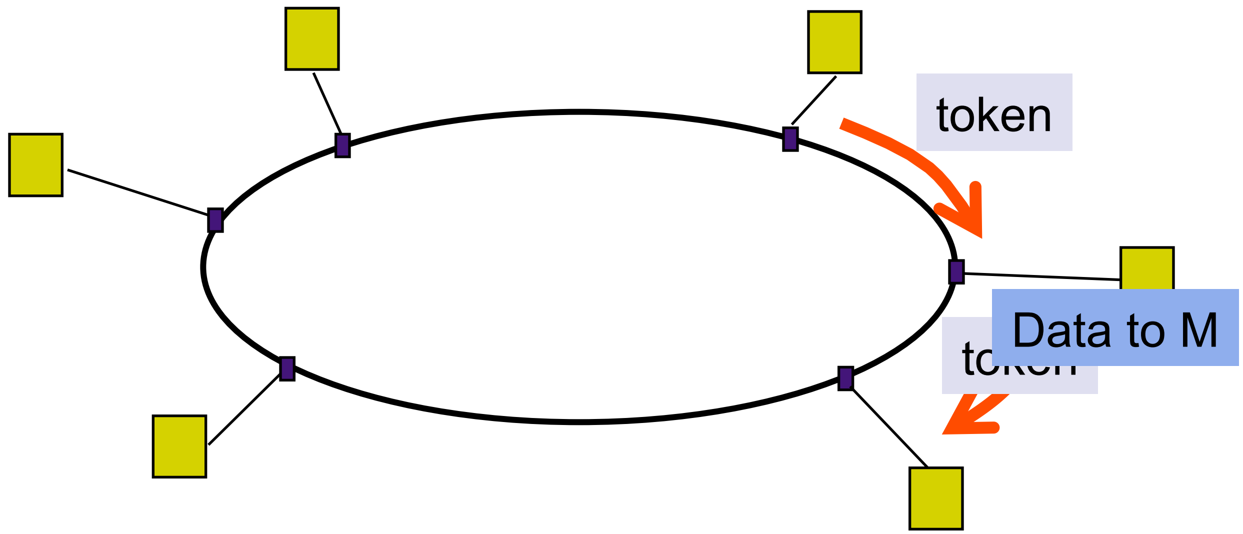
uplink f_3 ; *downlink f_4*

Scheduling: Polling



Scheduling: Token-Passing

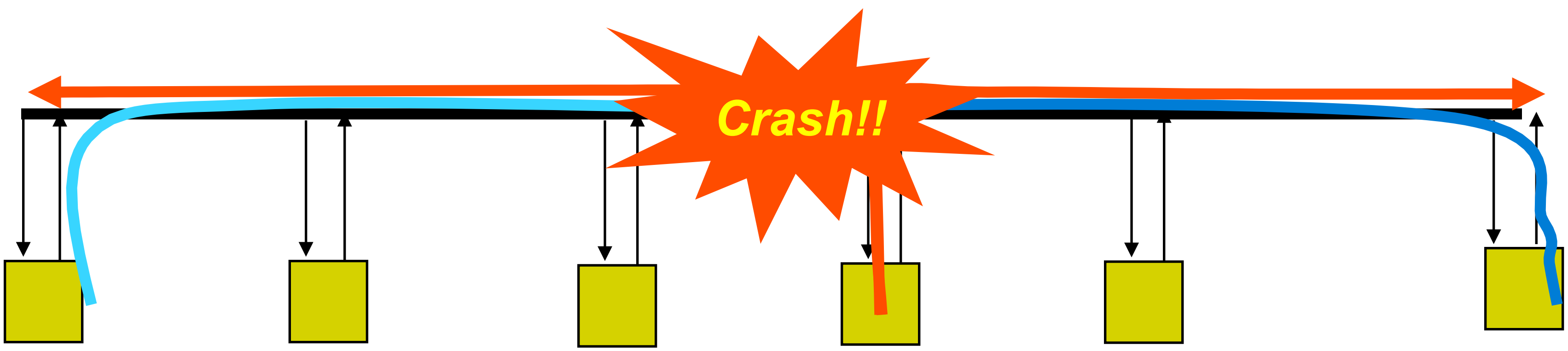
Ring networks



Station that holds token transmits into ring

Random Access

Multitapped Bus

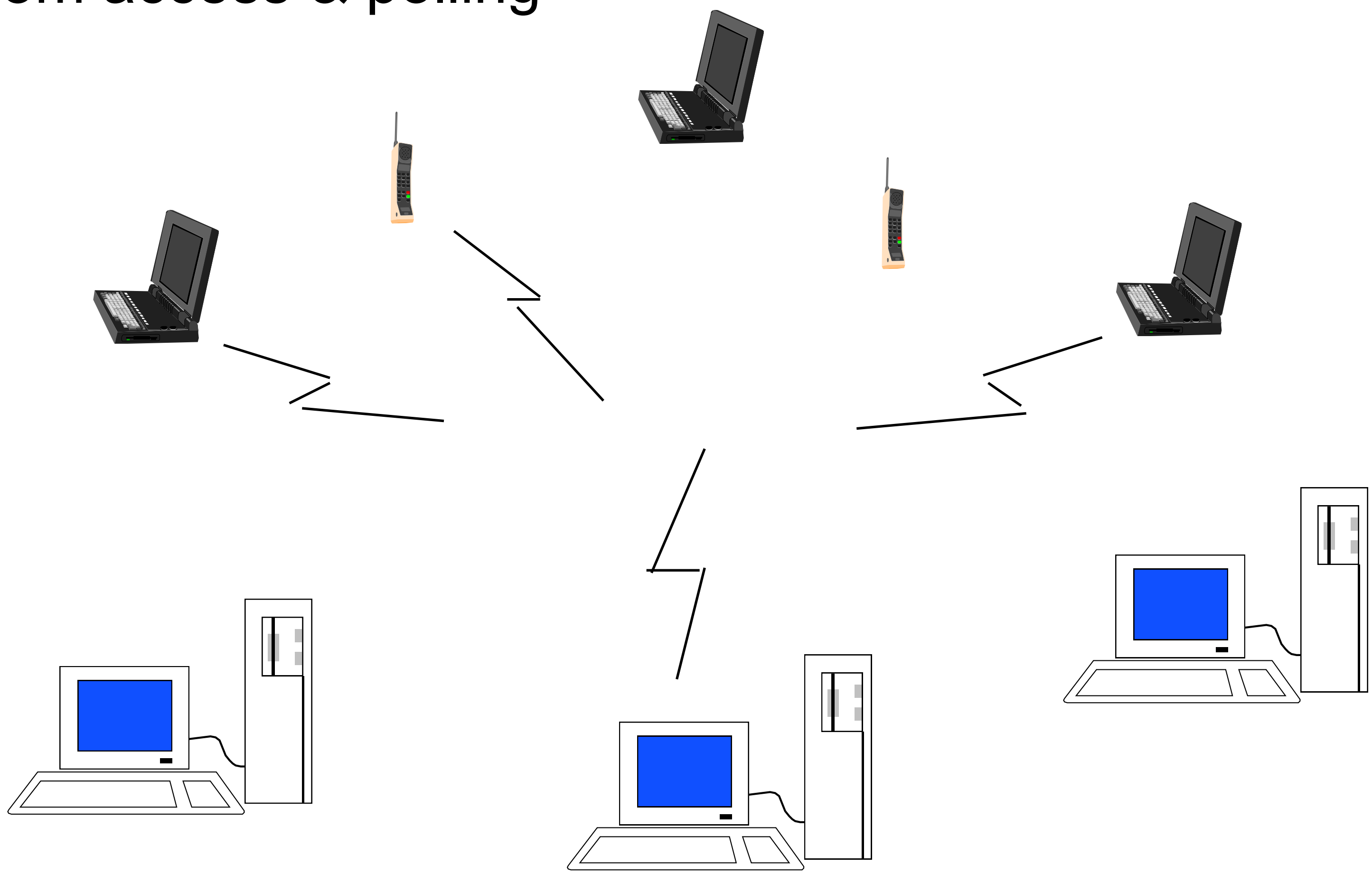


Transmit when ready

Transmissions can occur; need retransmission strategy

Wireless LAN

Ad Hoc: station-to-station
Infrastructure: stations to base station
Random access & polling



Selecting a Medium Access Control

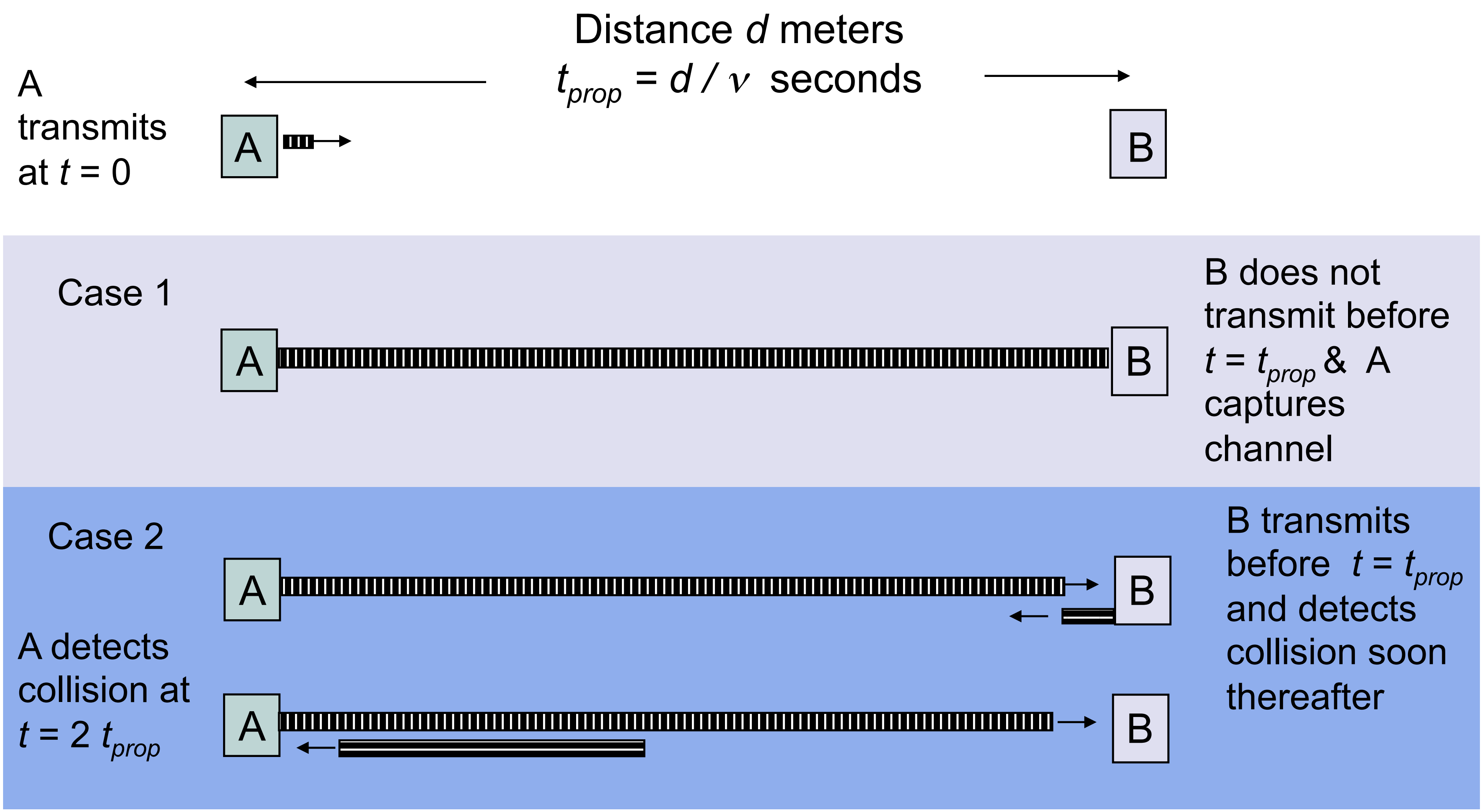
- Applications
  - What type of traffic?
  - Voice streams? Steady traffic, low delay/jitter
  - Data? Short messages? Web page downloads?
  - Enterprise or Consumer market? Reliability, cost
- Scale
  - How much traffic can be carried?
  - How many users can be supported?
- Current Examples:
  - Design 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



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 $a \ll 1$, 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

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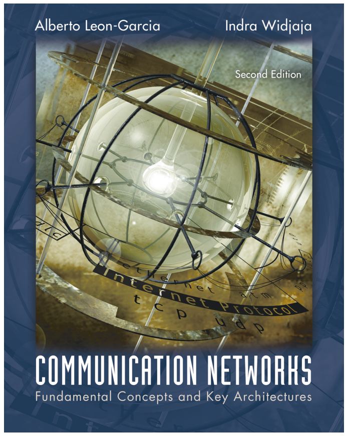
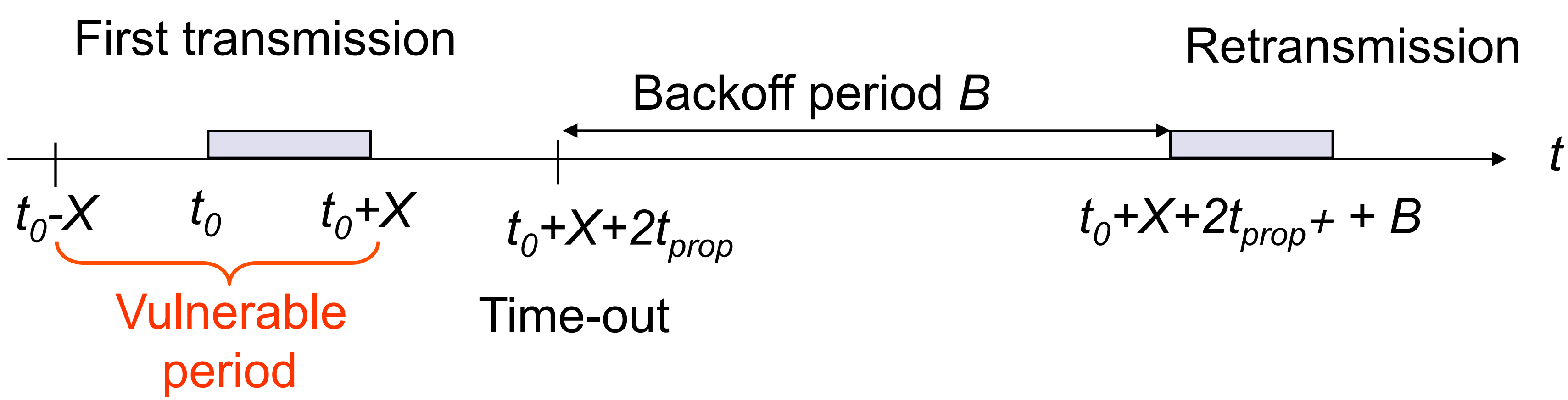


Random Access

ALOHA

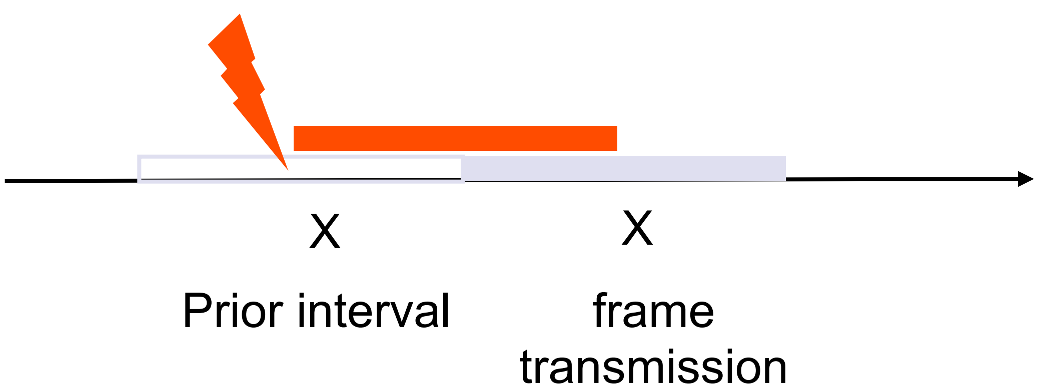
- Wireless link to provide data transfer between main campus & remote campuses of University of Hawaii
- Simplest solution: just do it
  - A station transmits whenever it has data to transmit
  - If more than one frames are transmitted, they interfere with each other (collide) and are lost
  - If ACK 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

Abramson's Assumption

- *What is probability of no arrivals in vulnerable period?*
- Abramson assumption: Effect of backoff algorithm is that frame arrivals are equally likely to occur at any time interval
- *G* is avg. # arrivals per *X* seconds
- Divide *X* into *n* intervals of duration $\Delta = X/n$
- *p* = probability of arrival in Δ interval, then

  $G = n\,p$ since there are *n* intervals in *X* seconds

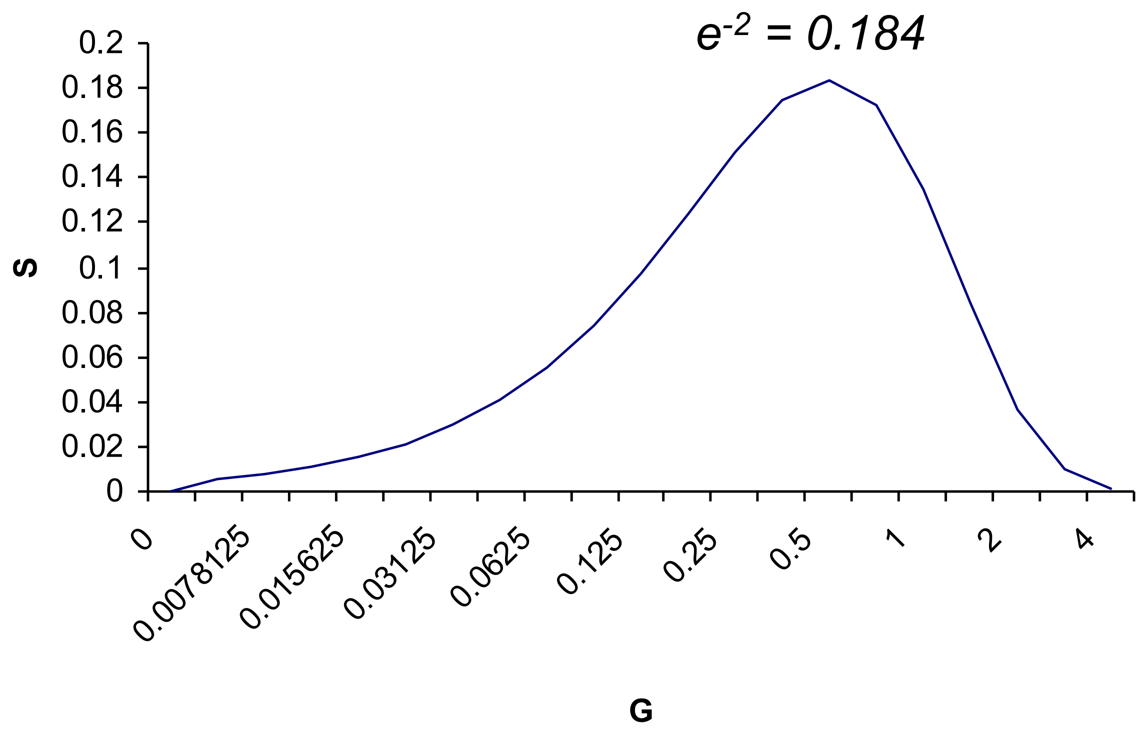
$$P_{success} = P[0 \text{ arrivals in 2X seconds}] =$$

$$= P[0 \text{ arrivals in 2n intervals}]$$

$$= (1 - \text{p})^{2\text{n}} = (1 - \frac{G}{n})^{2n} \rightarrow e^{-2G} \quad \text{as n} \rightarrow \infty$$

Throughput of ALOHA

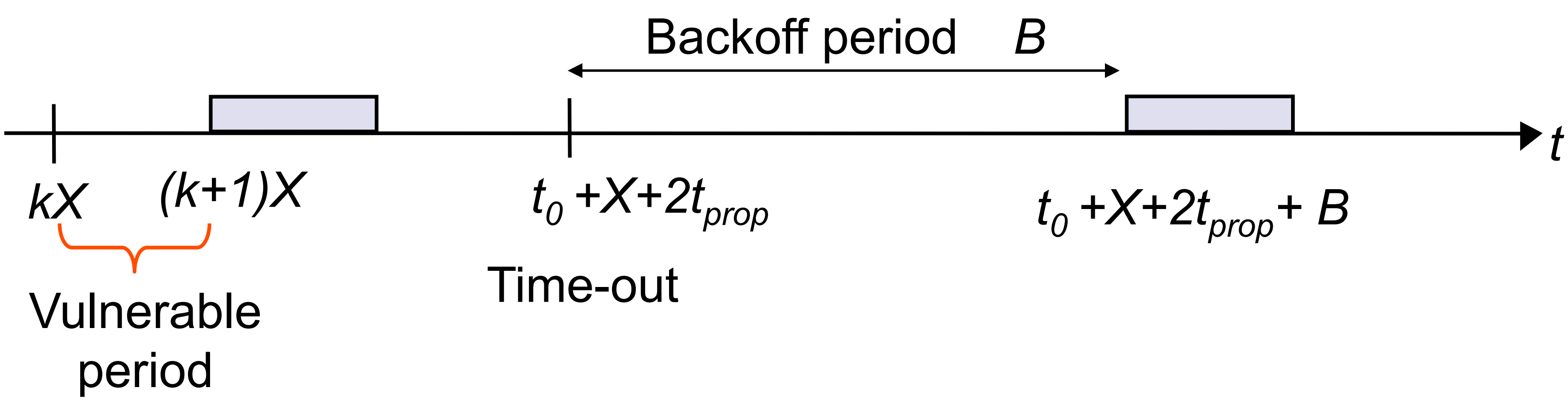
$$S = GP_{success} = Ge^{-2G}$$



- 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

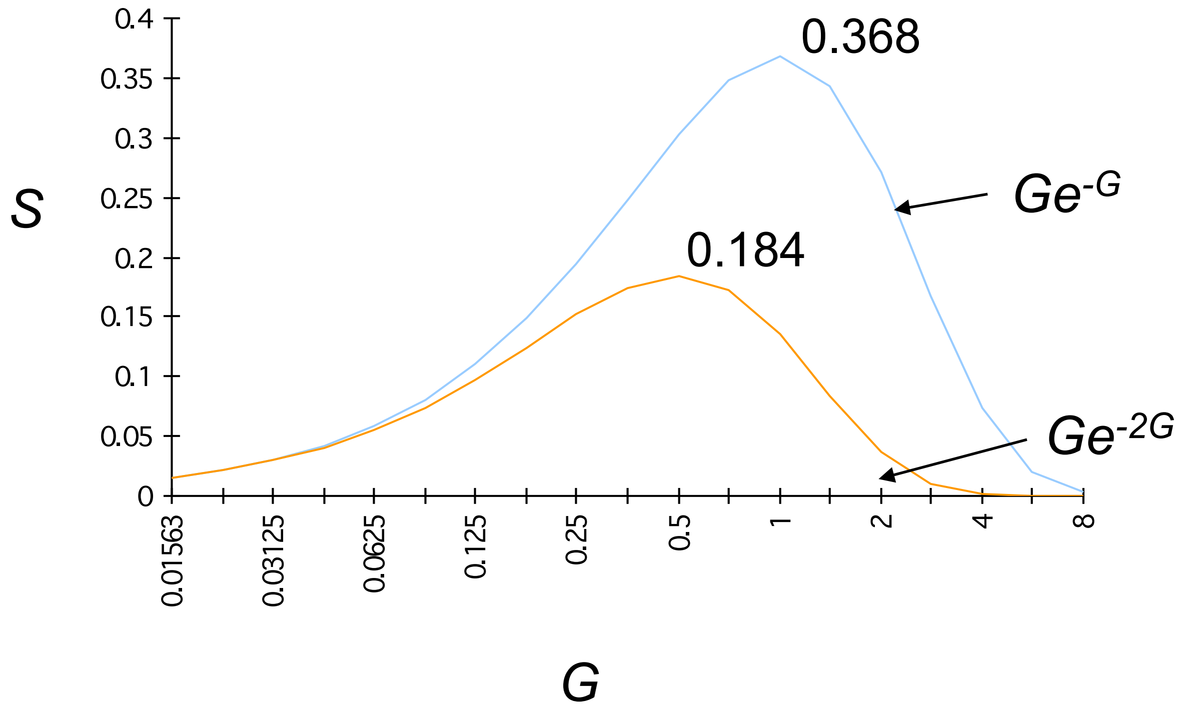
- Time is slotted in X seconds slots
- Stations synchronized to frame times
- Stations transmit frames in first slot after frame arrival
- Backoff intervals in multiples of slots



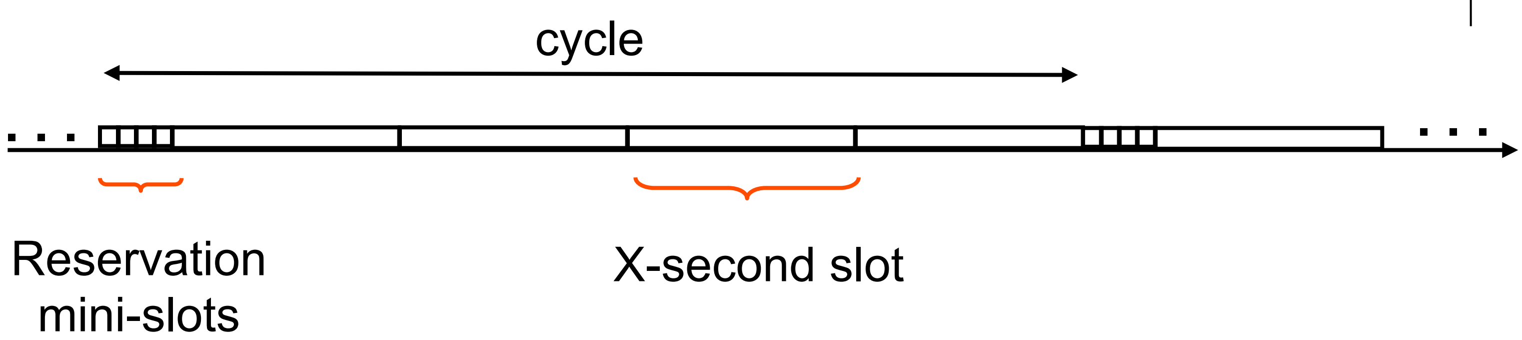
Only frames that arrive during prior X seconds collide

Throughput of Slotted ALOHA

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



Application of Slotted Aloha

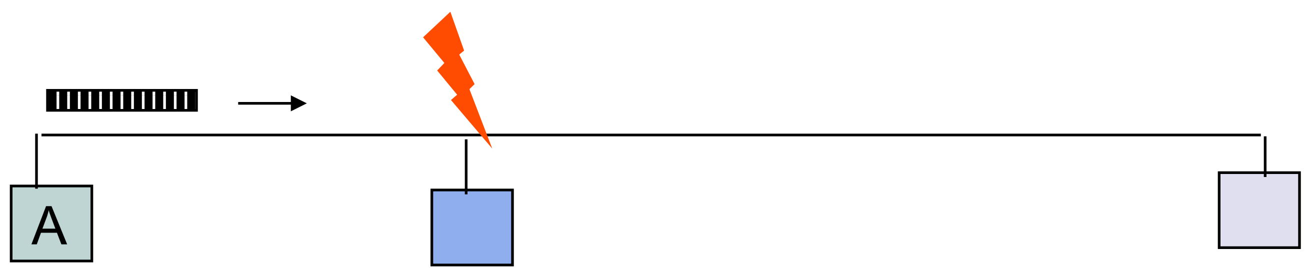


- Reservation protocol allows a large number of stations with infrequent traffic to reserve slots to transmit their frames in future cycles
- Each cycle has mini-slots allocated for making reservations
- Stations use slotted Aloha during mini-slots to request slots

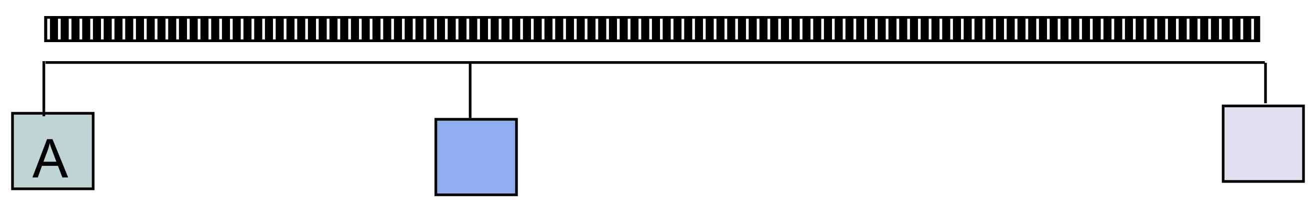
Carrier Sensing Multiple Access (CSMA)

- 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 $t = 0$

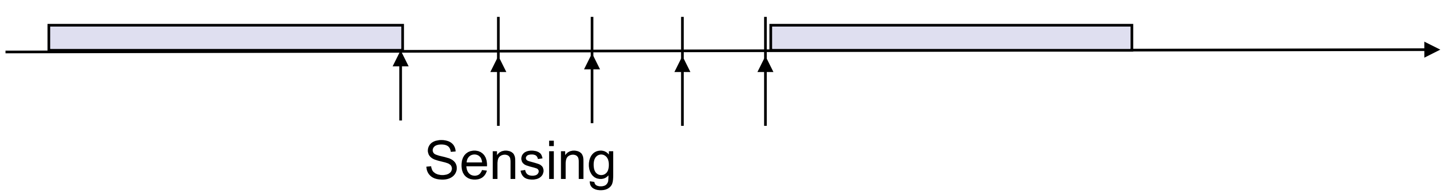


Station A captures channel at $t = t_{prop}$

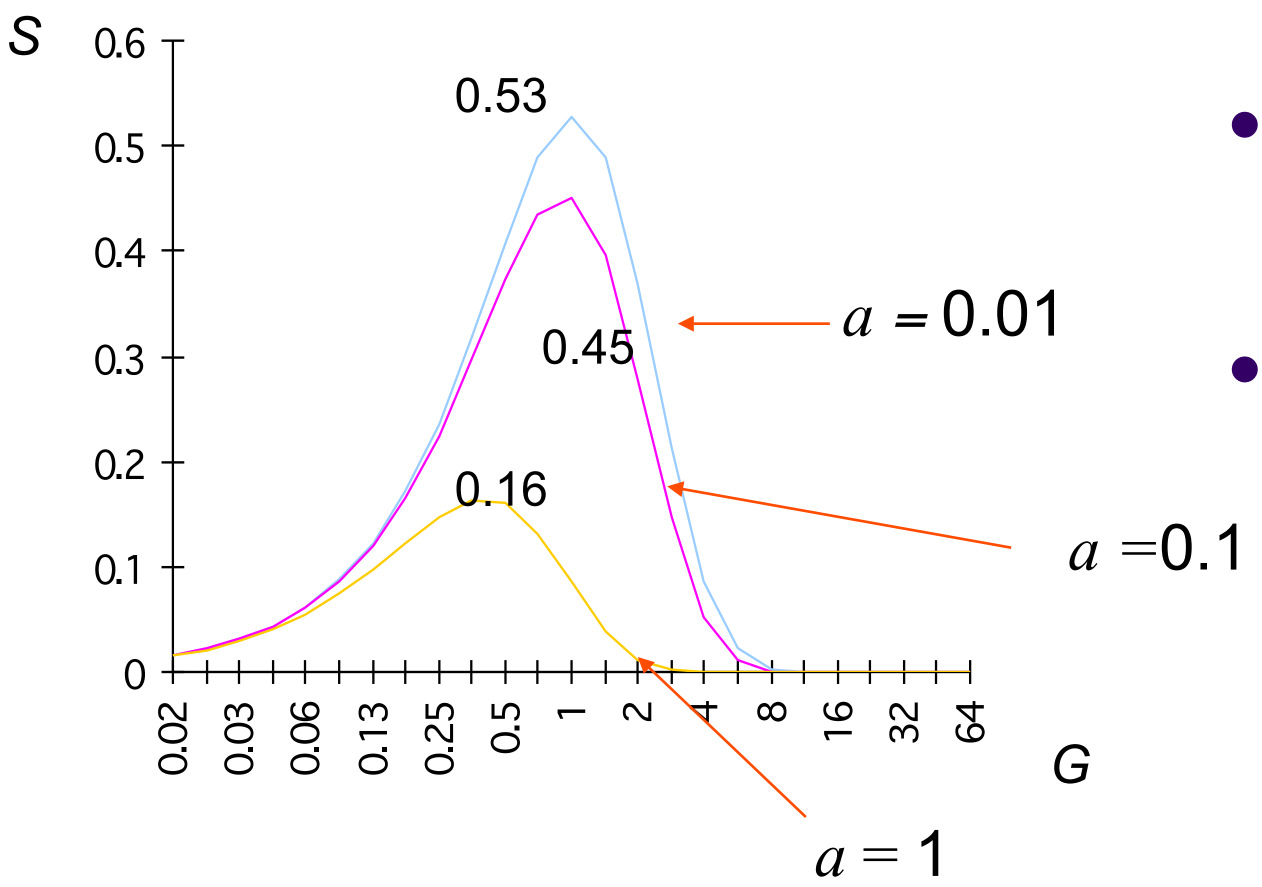


CSMA Options

- 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

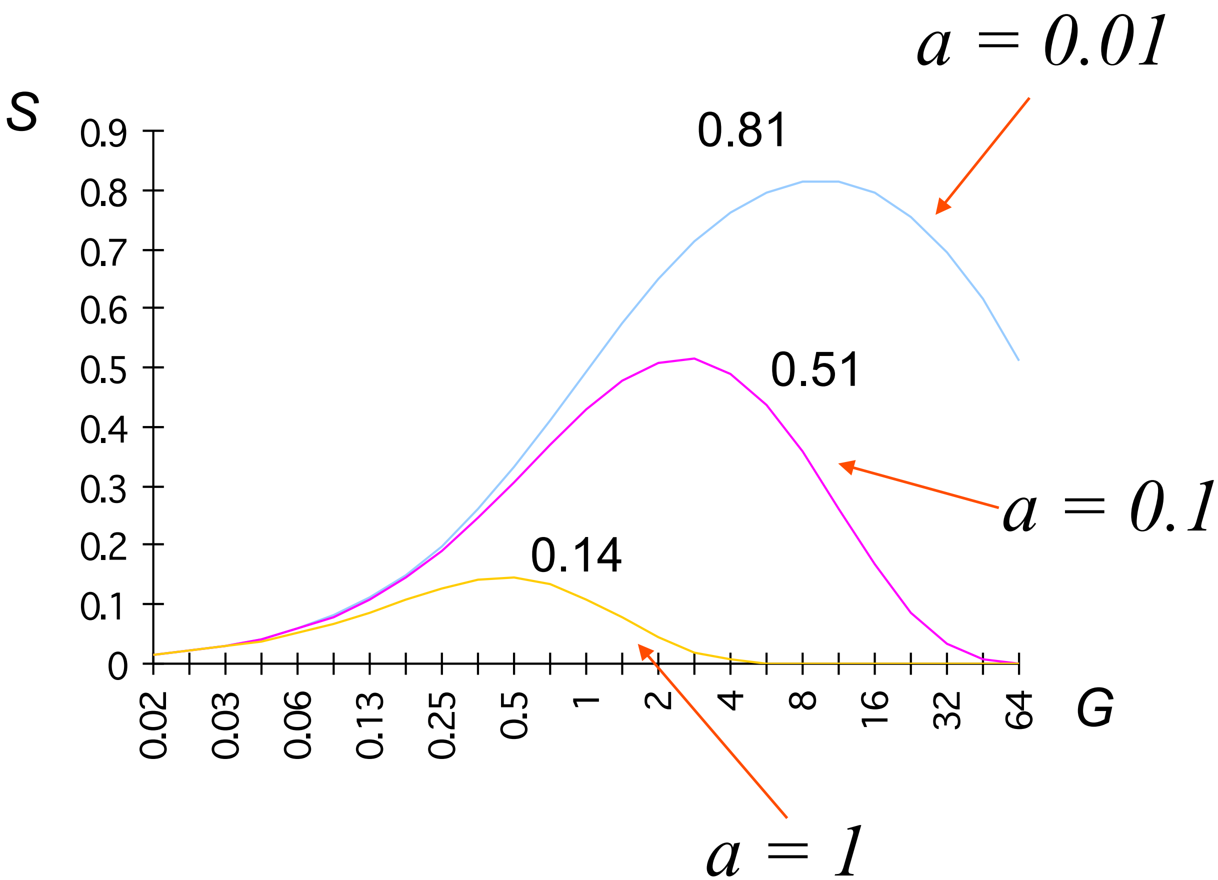


1-Persistent CSMA Throughput



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

Non-Persistent CSMA Throughput

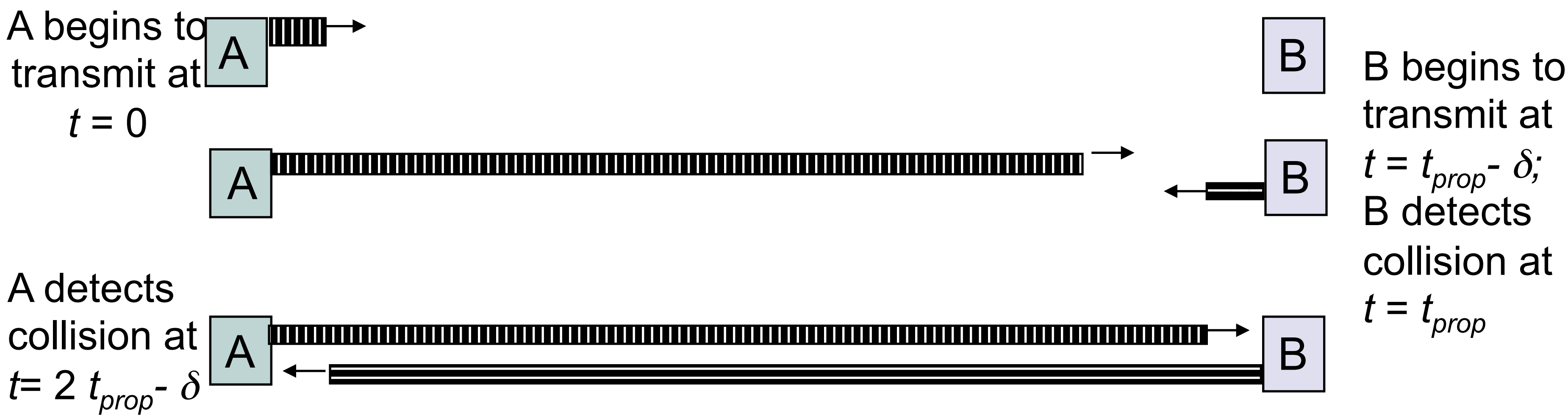


- Higher maximum throughput than 1-persistent for small a
- Worse than Aloha for $a > 1$

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

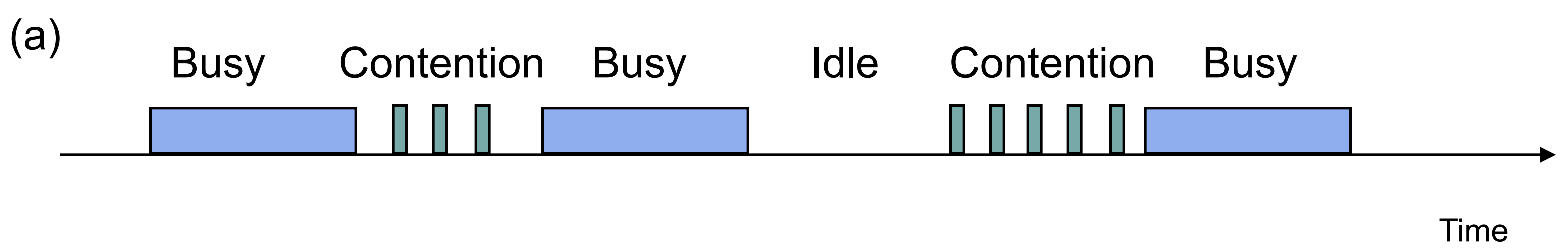
CSMA/CD reaction time



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.



Contention Resolution

- How long does it take to resolve contention?
- Contention is resolved ("success') if exactly 1 station transmits in a slot:

$$P_{success} = np(1-p)^{n-1}$$

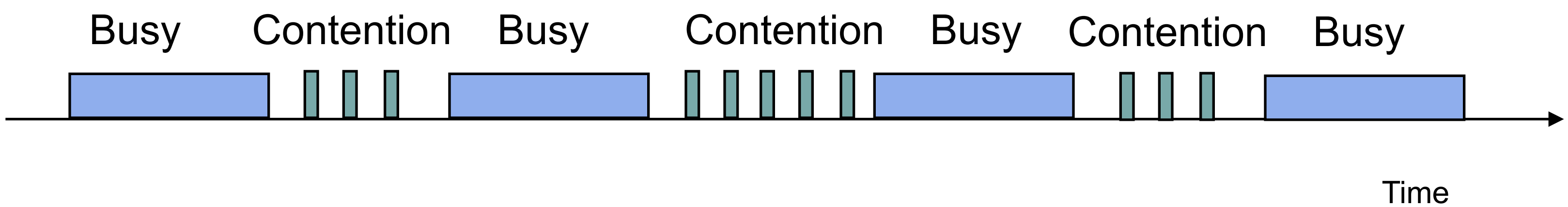
- By taking derivative of $P_{success}$ we find max occurs at p=1/n

$$P_{success}^{\max} = n\frac{1}{n}(1-\frac{1}{n})^{n-1} = (1-\frac{1}{n})^{n-1} \rightarrow \frac{1}{e}$$

- On average, $1/P^{max} = e = 2.718$ time slots to resolve contention

$$\textit{Average Contention Period} = 2t_{prop}e \textit{ seconds}$$

CSMA/CD Throughput



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

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

- where:

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

  $a = t_{prop}/X$

  ν meters/sec. speed of light in medium

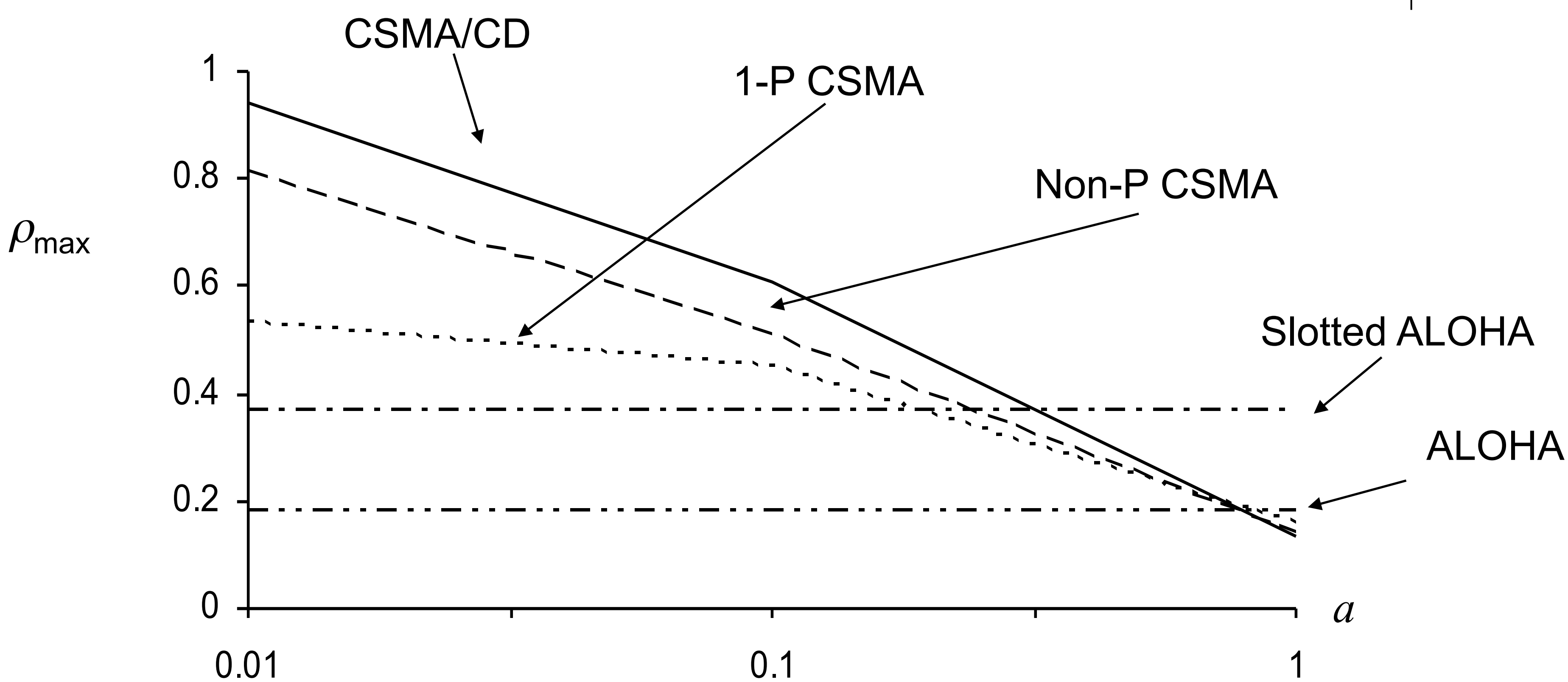
  d meters is diameter of system

  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

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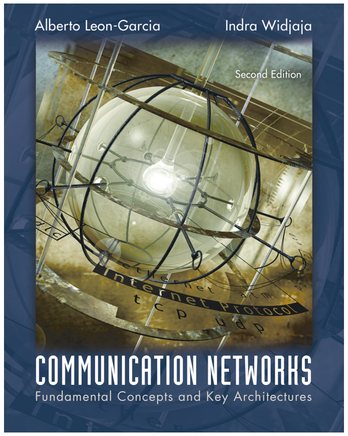


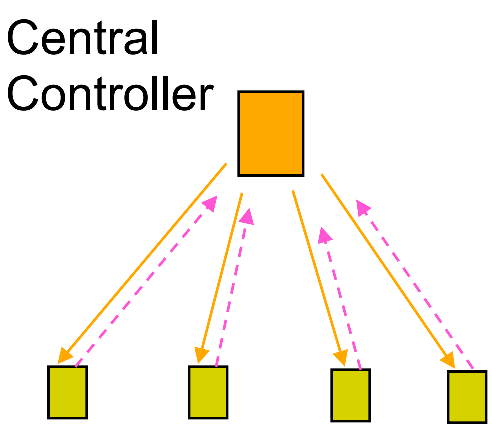
Scheduling

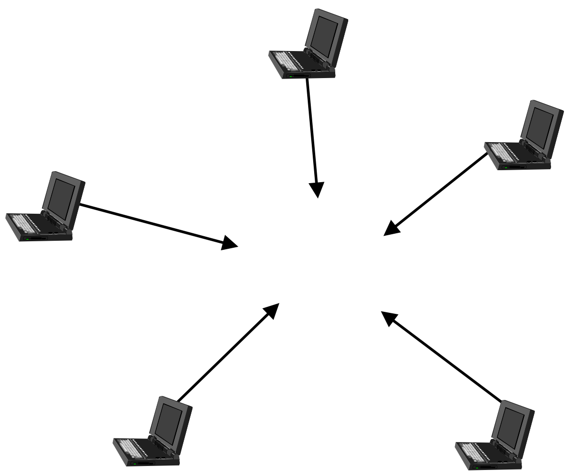
Scheduling for Medium Access Control

- 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

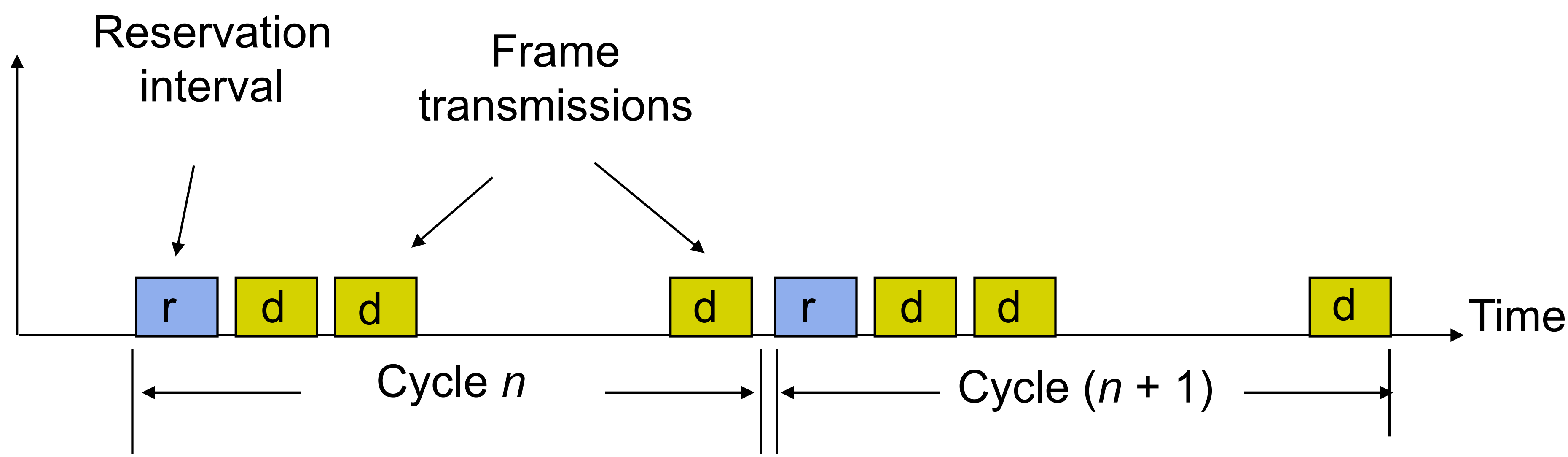
Reservations Systems

- *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



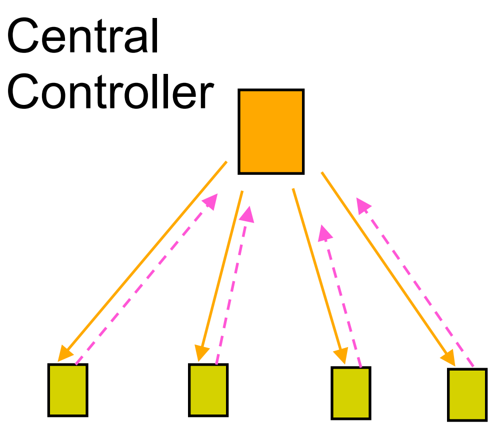
- Transmissions organized into cycles
- Cycle: reservation interval + frame transmissions
- Reservation interval has a minislot for ***each*** station to request reservations for frame transmissions

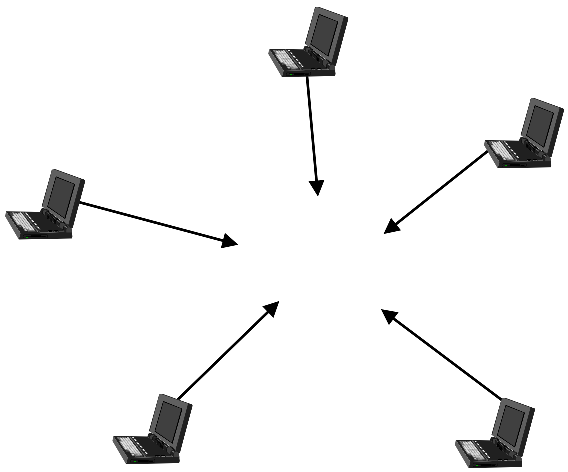
Example: GPRS

- 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

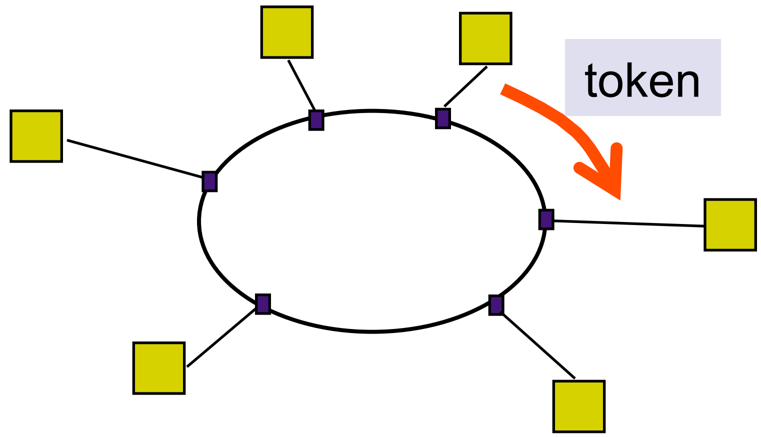
Polling Systems

- *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



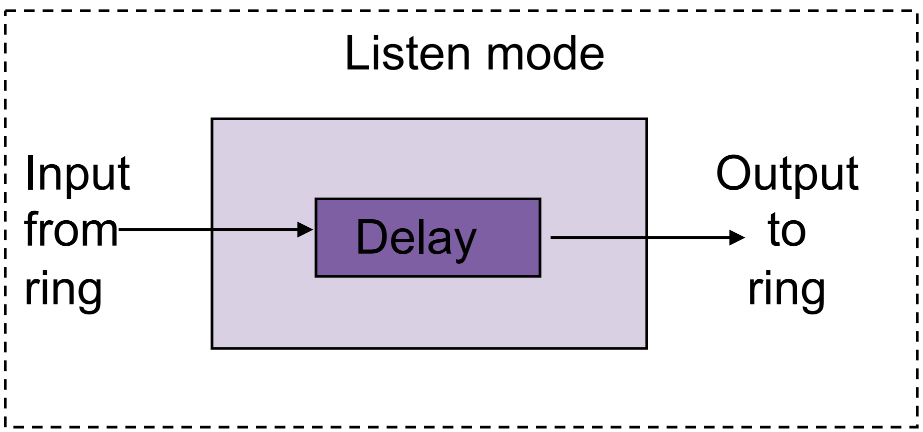


Application: Token-Passing Rings

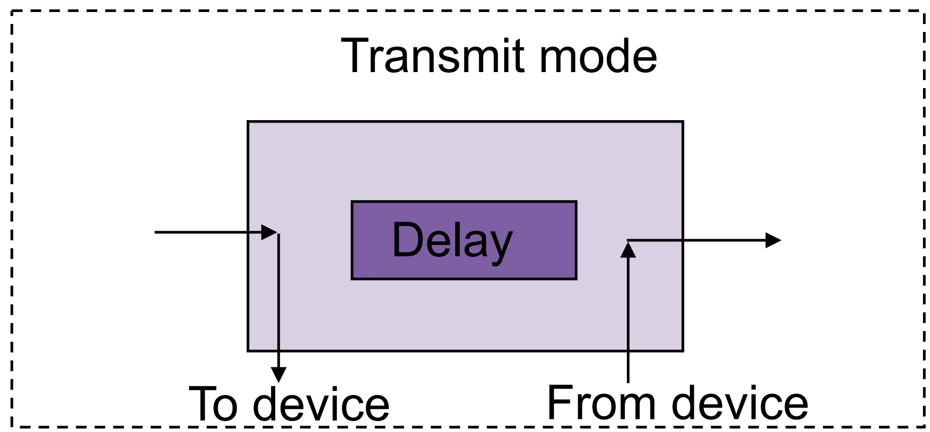


Free Token = Poll

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

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

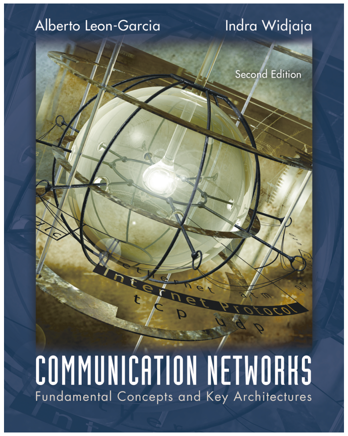
Comparison of MAC approaches

- 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

Chapter 6
Medium Access Control Protocols and Local Area Networks



Channelization

Channelization Approaches

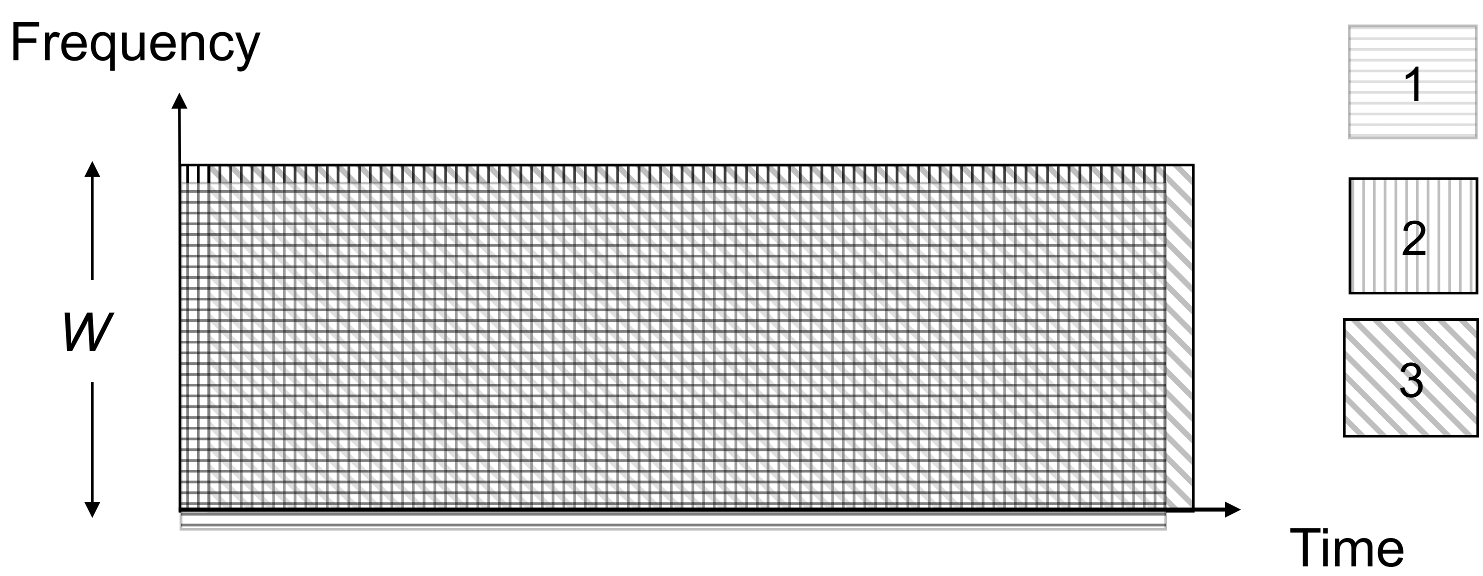
- *Frequency Division Multiple Access* (FDMA)
  - Frequency band allocated to users
  - Broadcast radio & TV, analog cellular phone
- *Time Division Multiple Access* (TDMA)
  - Periodic time slots allocated to users
  - Telephone backbone, GSM digital cellular phone
- *Code Division Multiple Access* (CDMA)
  - Code allocated to users
  - Cellular phones, 3G cellular

Guardbands

- FDMA
  - Frequency bands must be non-overlapping to prevent interference
  - Guardbands ensure separation; form of overhead
- TDMA
  - Stations must be synchronized to common clock
  - Time gaps between transmission bursts from different stations to prevent collisions; form of overhead
  - Must take into account propagation delays

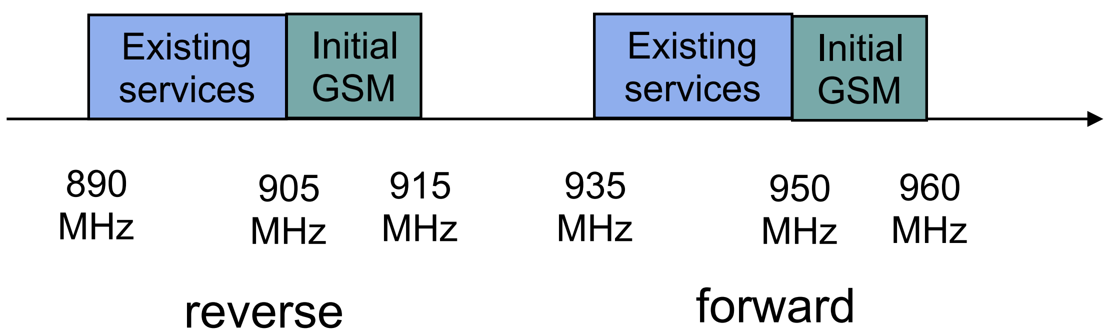
Channelization: CDMA

- Code Division Multiple Access
  - Channels determined by a code used in modulation and demodulation
- Stations transmit over entire frequency band all of the time!



Global System for Mobile Communications (GSM)

- European digital cellular telephone system
- 890-915 MHz & 935-960 MHz band
- PCS: 1800 MHz (Europe), 1900 MHz (N.Am.)
- Hybrid TDMA/FDMA
  - Carrier signals 200 kHz apart
  - 25 MHz give 124 one-way carriers



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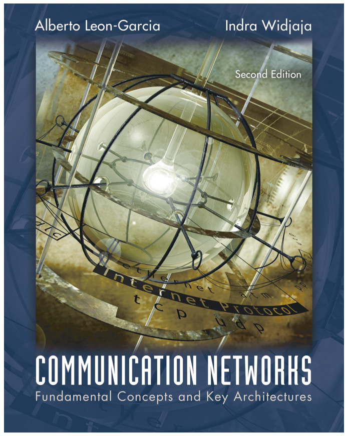
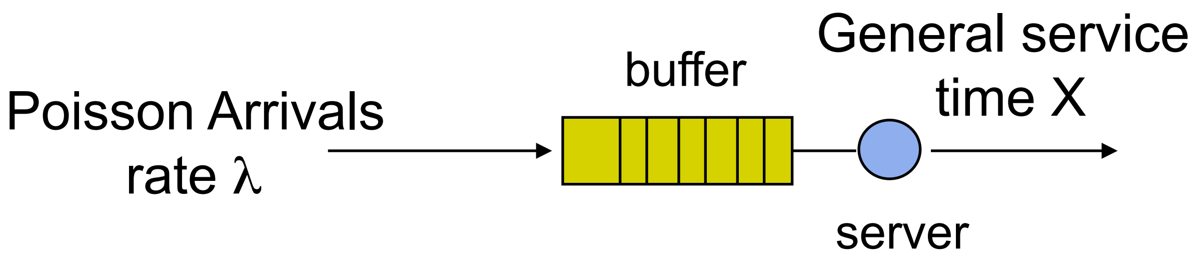


Delay Performance

M/G/1 Queueing Model for Statistical Multiplexer



- Arrival Model
  - Independent frame interarrival times:
  - Average $1/\lambda$
  - Exponential distribution
  - "Poisson Arrivals"
- Infinite Buffer
  - No Blocking
- Frame Length Model
  - Independent frame transmission times X
  - Average $E[X] = 1/\mu$
  - General distribution
  - Constant, exponential,…
- Load $\rho=\lambda/\mu$
  - Stability Condition: $\rho<1$

We will use M/G/1 model as baseline for MAC performance

M/G/1 Performance Results

(From Appendix A)

Total Delay = Waiting Time + Service Time

Average Waiting Time:

$$E[W] = \frac{\rho}{2(1-\rho)}(1 + \frac{\sigma_X^2}{E[X]^2})E[X]$$

Average Total Delay:

$$E[T] = E[W] + E[X]$$

Example: M/D/1

$$E[W] = \frac{\rho}{2(1-\rho)}E[X]$$

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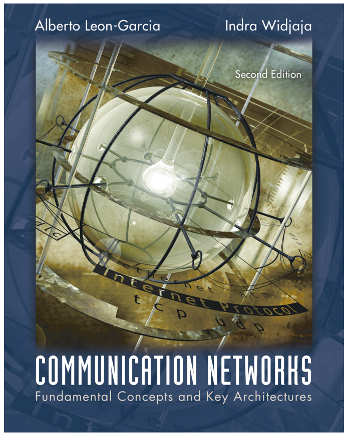
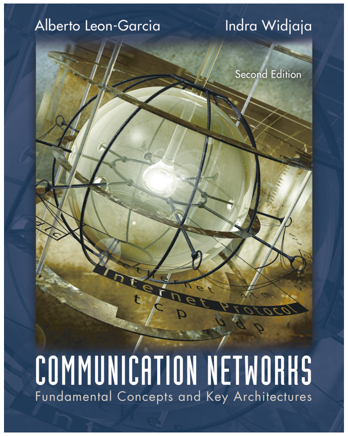


Part II: Local Area Networks

Overview of LANs
Ethernet
Token Ring and FDDI
802.11 Wireless LAN
LAN Bridges

Chapter 6
Medium Access Control Protocols and Local Area Networks



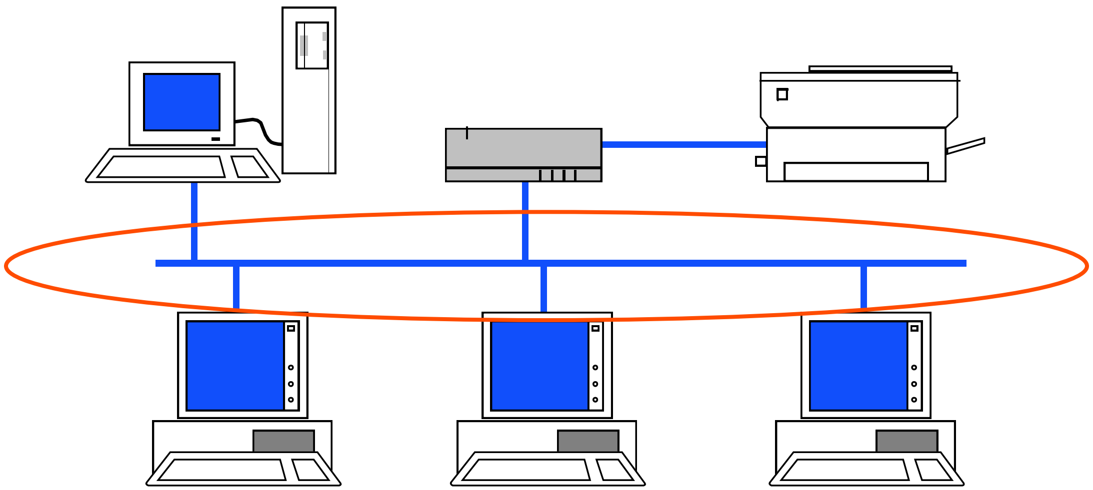
Overview of LANs

What is a LAN?

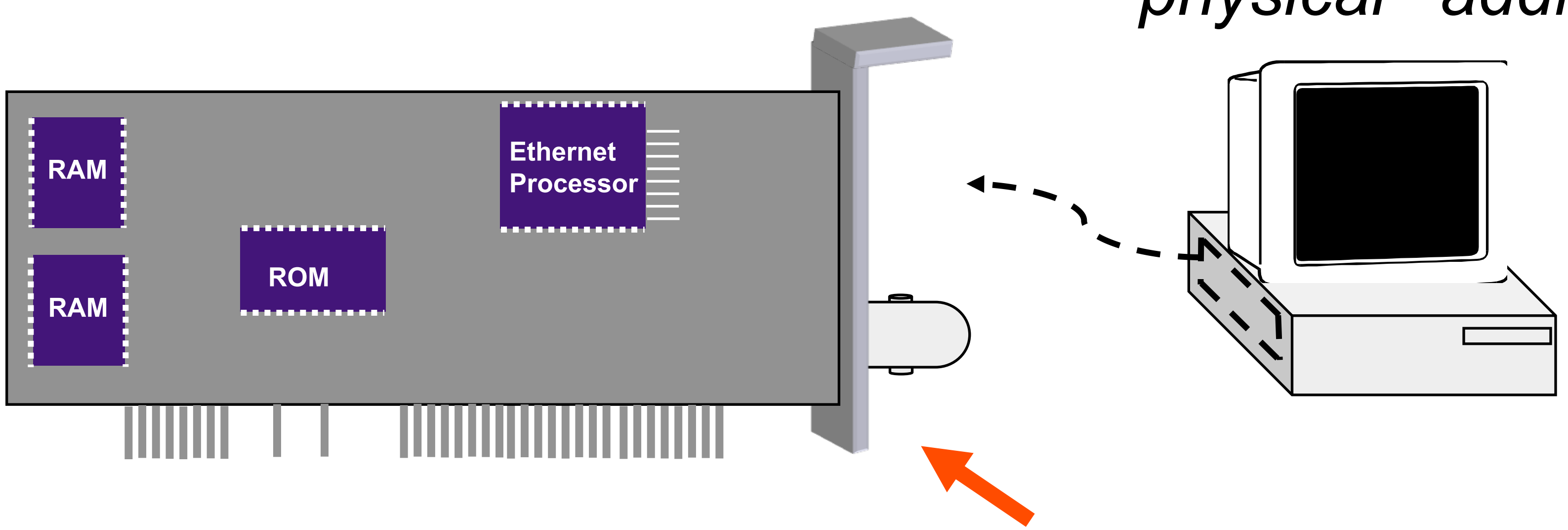
Local area means:

- Private ownership
  - freedom from regulatory constraints of WANs
- Short distance (~1km) between computers
  - low cost
  - very high-speed, relatively error-free communication
  - complex error control unnecessary
- Machines are constantly moved
  - Keeping track of location of computers a chore
  - Simply give each machine a unique address
  - ***Broadcast*** *all messages to all machines in the LAN*
- Need a *medium access control protocol*

Typical LAN Structure



- Transmission Medium
- Network Interface Card (NIC)
- *Unique MAC "physical" address*

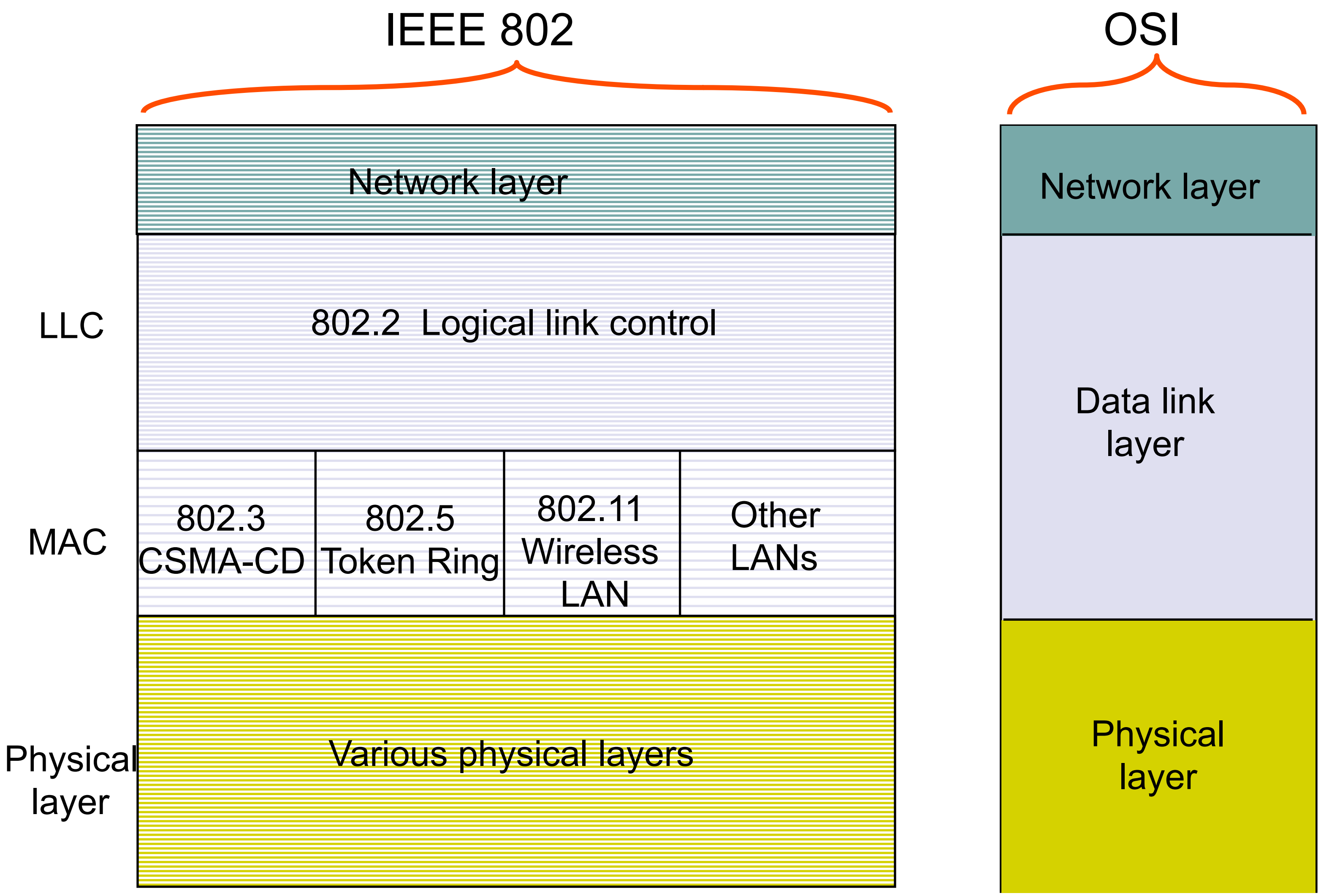


Medium Access Control Sublayer

- In IEEE 802.1, Data Link Layer divided into:

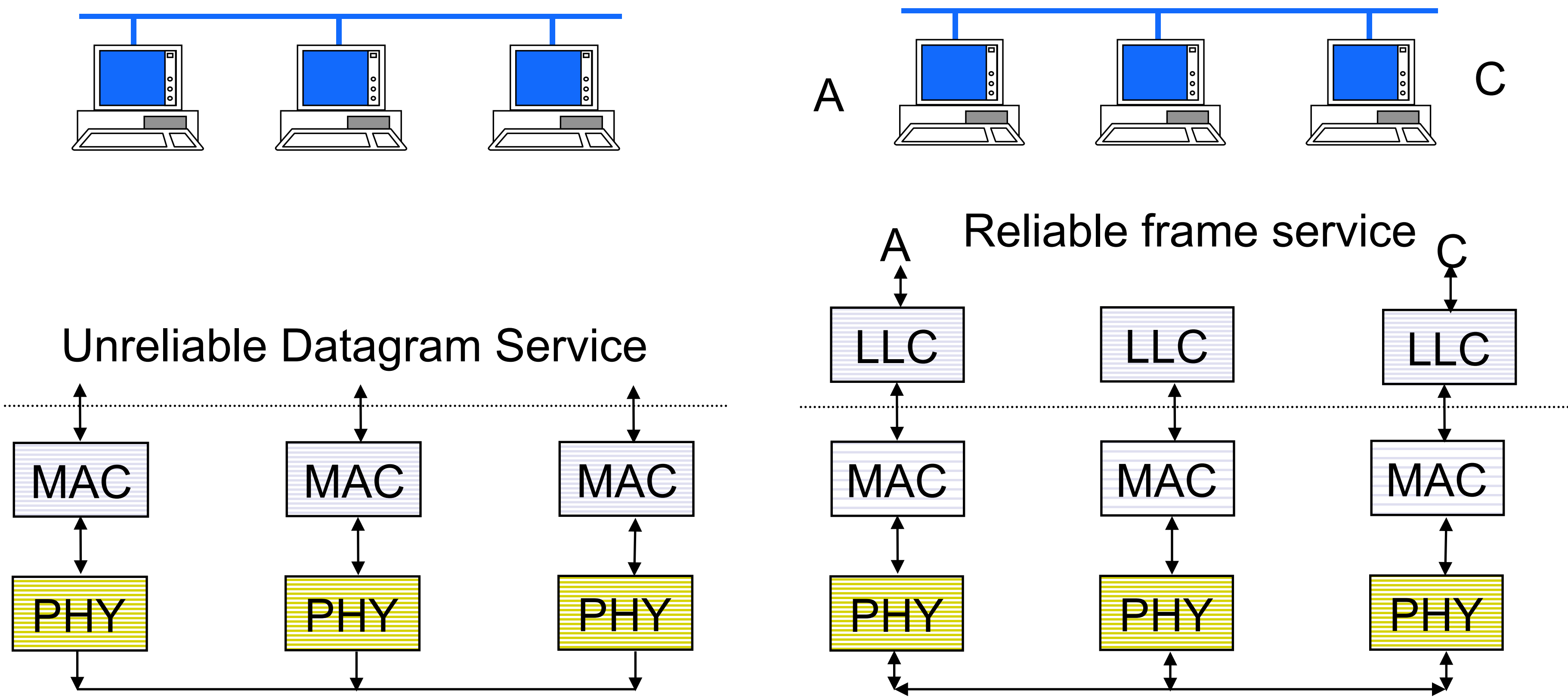
1. Medium Access Control Sublayer
   - Coordinate access to medium
   - Connectionless frame transfer service
   - Machines identified by MAC/physical address
   - Broadcast frames with MAC addresses
2. Logical Link Control Sublayer
   - Between Network layer & MAC sublayer

MAC Sub-layer



Logical Link Control Layer

- IEEE 802.2: LLC enhances service provided by MAC



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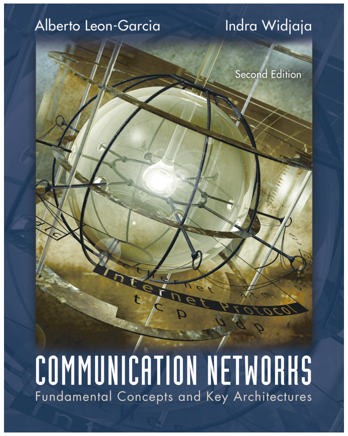
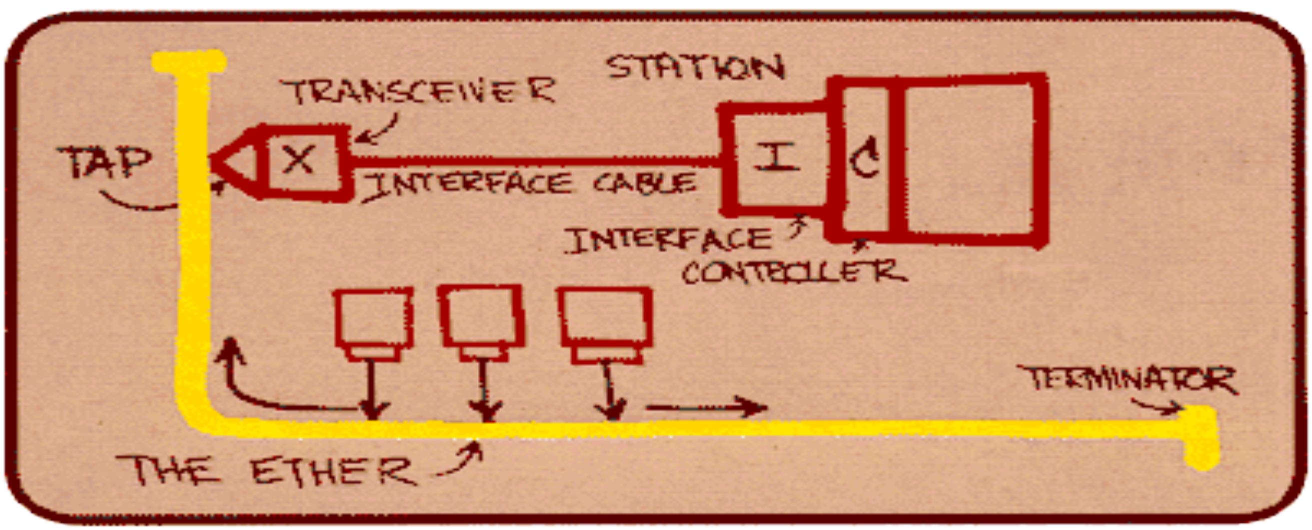


Ethernet

A bit of history…

- 1970 ALOHAnet radio network deployed in Hawaiian islands
- 1973 Metcalf and Boggs invent Ethernet, random access in wired net
- 1979 DIX Ethernet II Standard
- 1985 IEEE 802.3 LAN Standard (10 Mbps)
- 1995 Fast Ethernet (100 Mbps)
- 1998 Gigabit Ethernet
- 2002 10 Gigabit Ethernet
- Ethernet is the dominant LAN standard

Metcalf's Sketch



IEEE 802.3 MAC: Ethernet

MAC Protocol:

- CSMA/CD
- *Slot Time* is the critical system parameter
  - upper bound on time to detect collision
  - upper bound on time to acquire channel
  - upper bound on length of frame segment generated by collision
  - quantum for retransmission scheduling
  - max{round-trip propagation, MAC jam time}
- Truncated binary exponential backoff
  - for retransmission n: $0 < r < 2^k$, where k=min(n,10)
  - Give up after 16 retransmissions

IEEE 802.3 Original Parameters

- Transmission Rate: 10 Mbps
- Min Frame: 512 bits = 64 bytes
- Slot time: 512 bits/10 Mbps = 51.2 μsec
  - 51.2 μsec x $2x10^5$ km/sec =10.24 km, 1 way
  - 5.12 km round trip distance
- Max Length: 2500 meters + 4 repeaters

- *Each x10 increase in bit rate, must be accompanied by x10 decrease in distance*

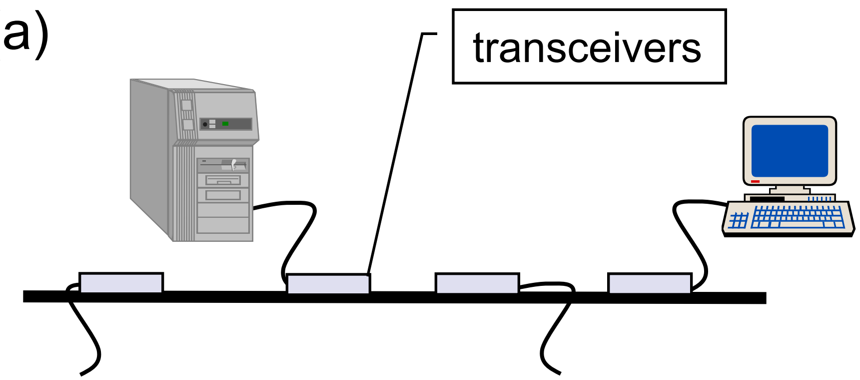
IEEE 802.3 Physical Layer

Table 6.2 IEEE 802.3 10 Mbps medium alternatives

	10base5	10base2	10baseT	10baseFX
Medium	Thick coax	Thin coax	Twisted pair	Optical fiber
Max. Segment Length	500 m	200 m	100 m	2 km
Topology	Bus	Bus	Star	Point-to-point link

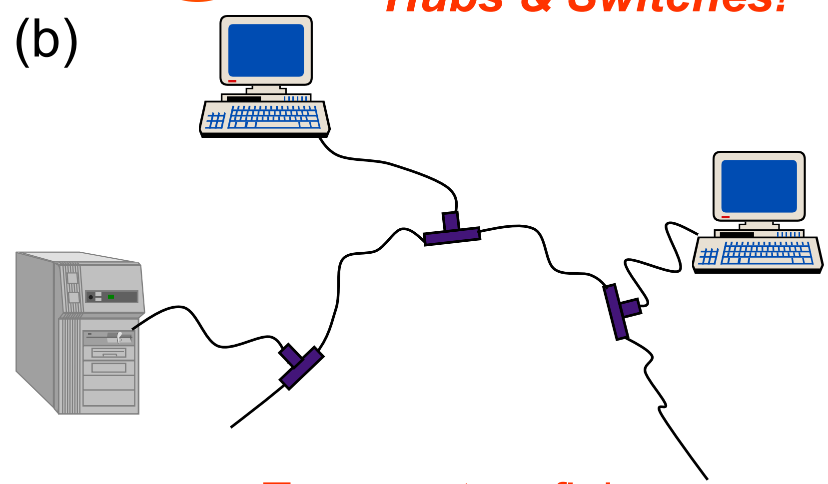
Hubs & Switches!

(a)



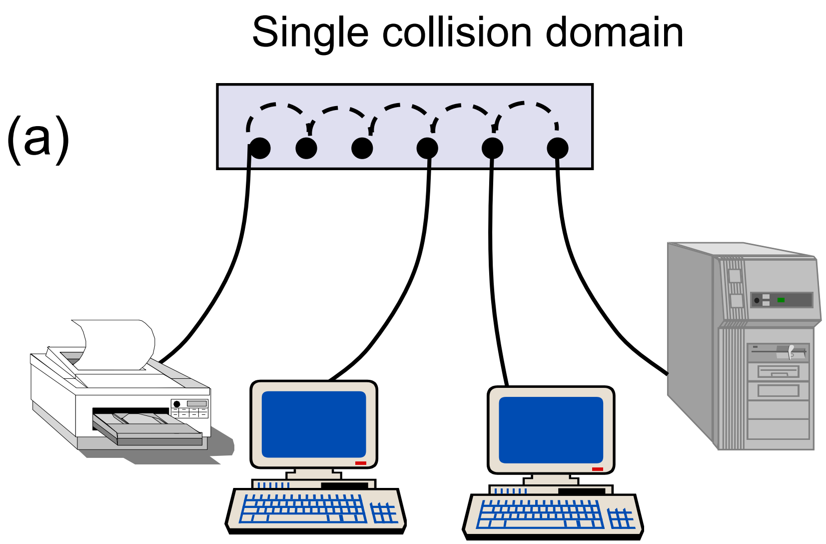
Thick Coax: Stiff, hard to work with

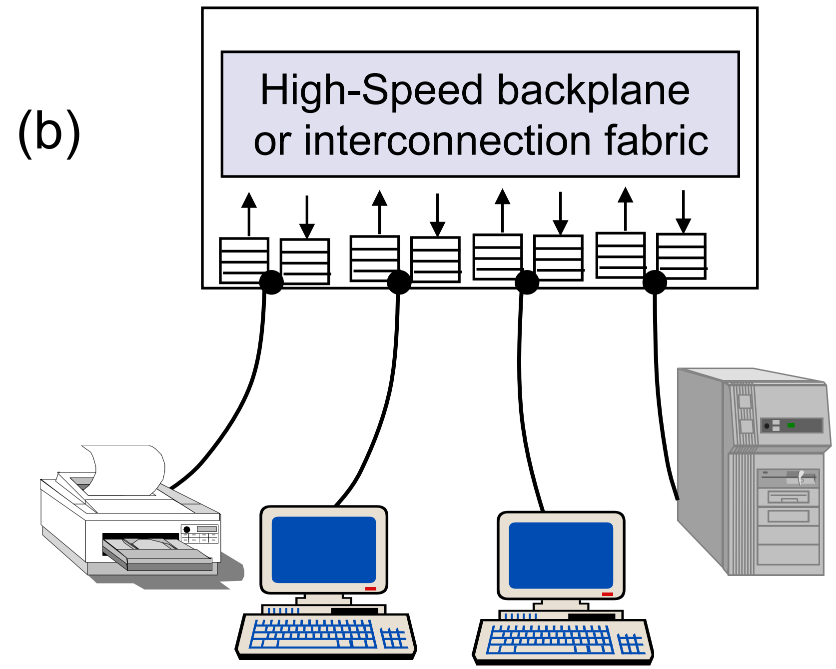
(b)



T connectors flaky

Ethernet Hubs & Switches





Twisted Pair Cheap
Easy to work with
Reliable
Star-topology CSMA-CD

Twisted Pair Cheap
Bridging increases scalability
Separate collision domains
Full duplex operation

Fast Ethernet

Table 6.4 IEEE 802.3 100 Mbps Ethernet medium alternatives

	100baseT4	100baseT	100baseFX
Medium	Twisted pair category 3 UTP 4 pairs	Twisted pair category 5 UTP two pairs	Optical fiber multimode Two strands
Max. Segment Length	100 m	100 m	2 km
Topology	Star	Star	Star

To preserve compatibility with 10 Mbps Ethernet:

- Same frame format, same interfaces, same protocols
- Hub topology only with twisted pair & fiber
- Bus topology & coaxial cable abandoned
- Category 3 twisted pair (ordinary telephone grade) requires 4 pairs
- Category 5 twisted pair requires 2 pairs (most popular)
- Most prevalent LAN today

Gigabit Ethernet

Table 6.3 IEEE 802.3 1 Gbps Fast Ethernet medium alternatives

	1000baseSX	1000baseLX	1000baseCX	1000baseT
Medium	Optical fiber multimode Two strands	Optical fiber single mode Two strands	Shielded copper cable	Twisted pair category 5 UTP
Max. Segment Length	550 m	5 km	25 m	100 m
Topology	Star	Star	Star	Star

- Slot time increased to *512 bytes*
- Small frames need to be extended to 512 B
- Frame bursting to allow stations to transmit burst of short frames
- Frame structure preserved but CSMA-CD essentially abandoned
- Extensive deployment in backbone of enterprise data networks and in server farms

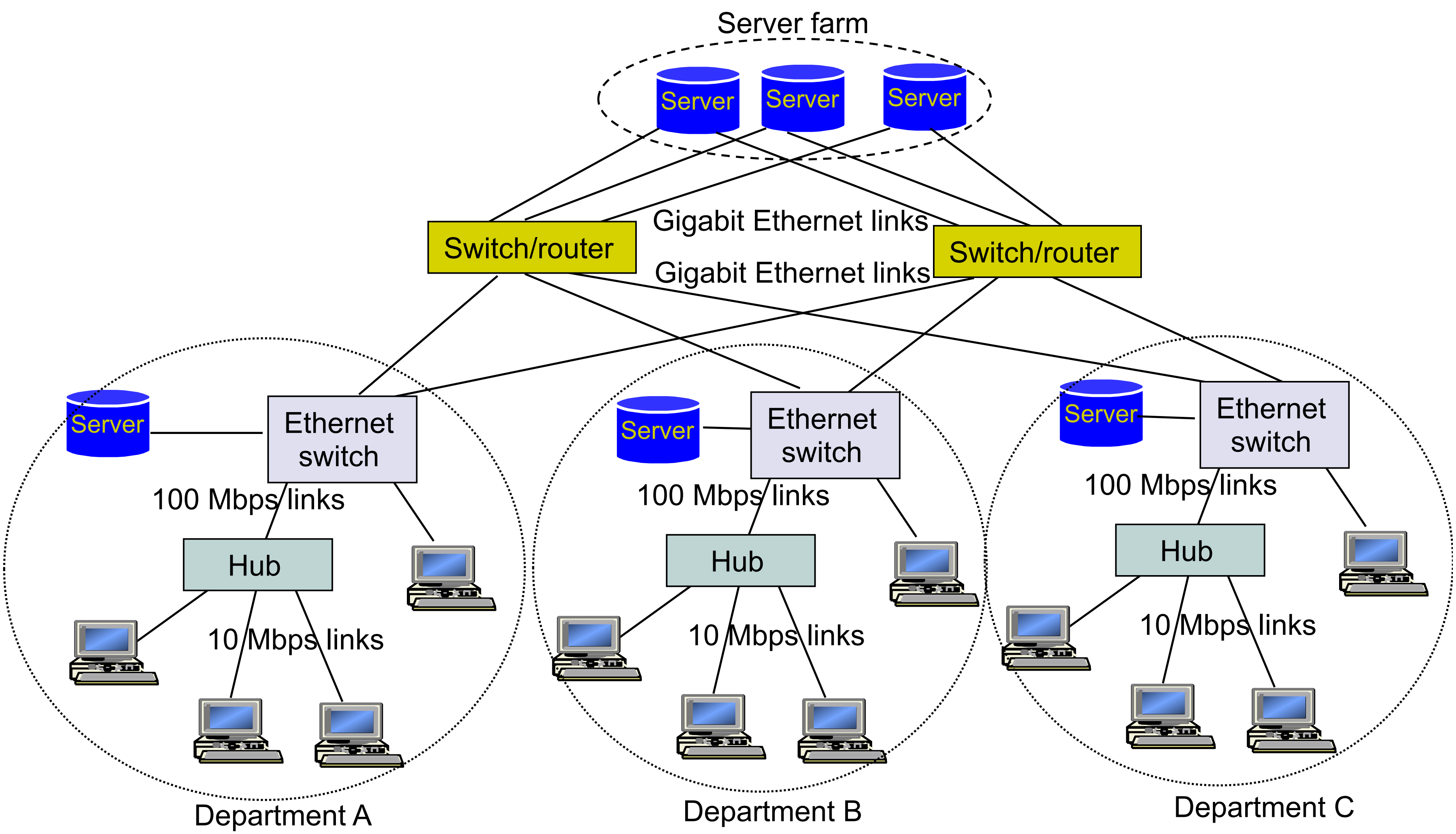
10 Gigabit Ethernet

Table 6.5 IEEE 802.3 10 Gbps Ethernet medium alternatives

	10GbaseSR	10GBaseLR	10GbaseEW	10GbaseLX4
Medium	Two optical fibers Multimode at 850 nm 64B66B code	Two optical fibers Single-mode at 1310 nm 64B66B	Two optical fibers Single-mode at 1550 nm SONET compatibility	Two optical fibers multimode/single-mode with four wavelengths at 1310 nm band 8B10B code
Max. Segment Length	300 m	10 km	40 km	300 m – 10 km

- Frame structure preserved
- CSMA-CD protocol officially abandoned
- LAN PHY for local network applications
- WAN PHY for wide area interconnection using SONET OC-192c
- Extensive deployment in metro networks anticipated

Typical Ethernet Deployment



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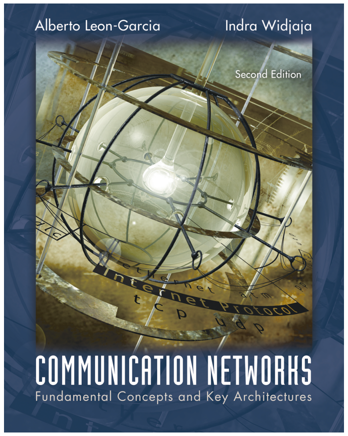

*Token Ring and **FDDI***

IEEE 802.5 Ring LAN

- Unidirectional ring network
- 4 Mbps and 16 Mbps on twisted pair
  - Differential Manchester line coding
- Token passing protocol provides access
  - ✓ Fairness
  - ✓ Access priorities
  - ✗ Breaks in ring bring entire network down
- Reliability by using star topology

Fiber Distributed Data Interface (FDDI)

- Token ring protocol for LAN/MAN
- Counter-rotating dual ring topology
- 100 Mbps on optical fiber
- Up to 200 km diameter, up to 500 stations
- Station has 10-bit "elastic" buffer to absorb timing differences between input & output
- Max frame 40,000 bits
- 500 stations @ 200 km gives ring latency of 105,000 bits
- FDDI has option to operate in multitoken mode

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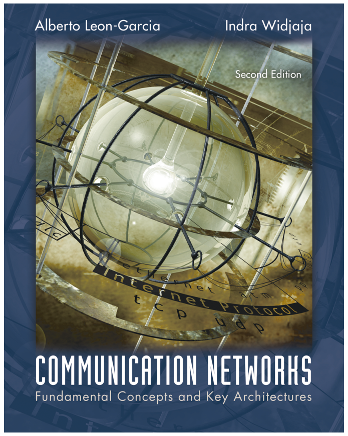
Medium Access Control Protocols and Local Area Networks

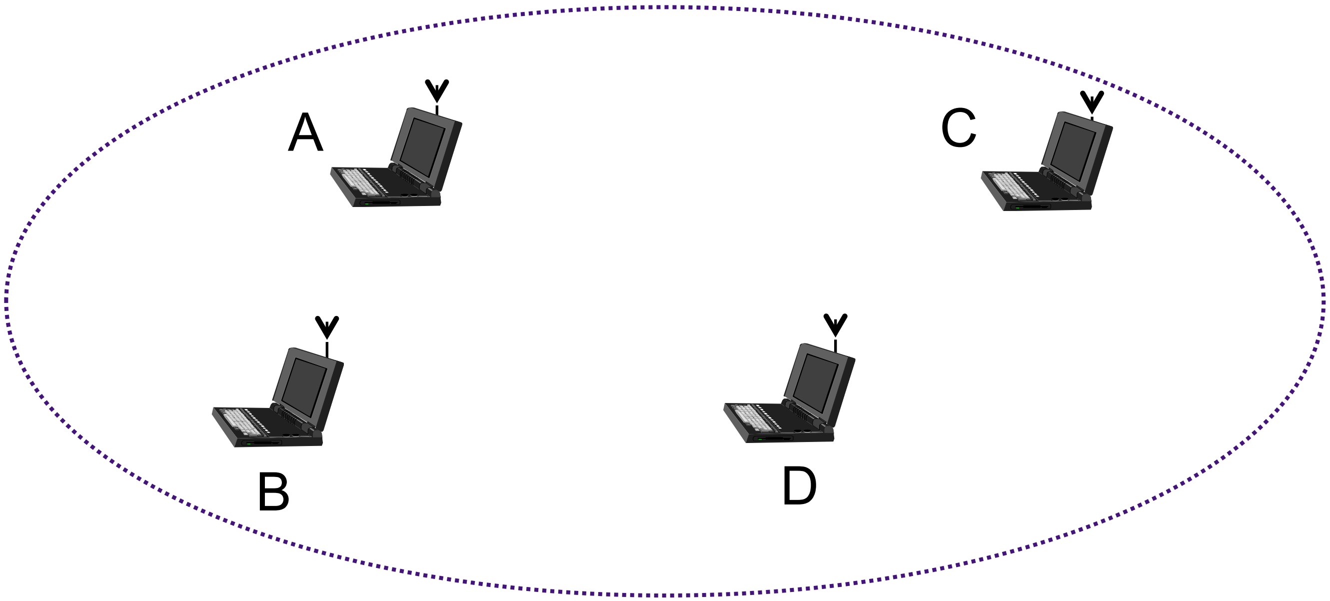


802.11 Wireless LAN

Wireless Data Communications

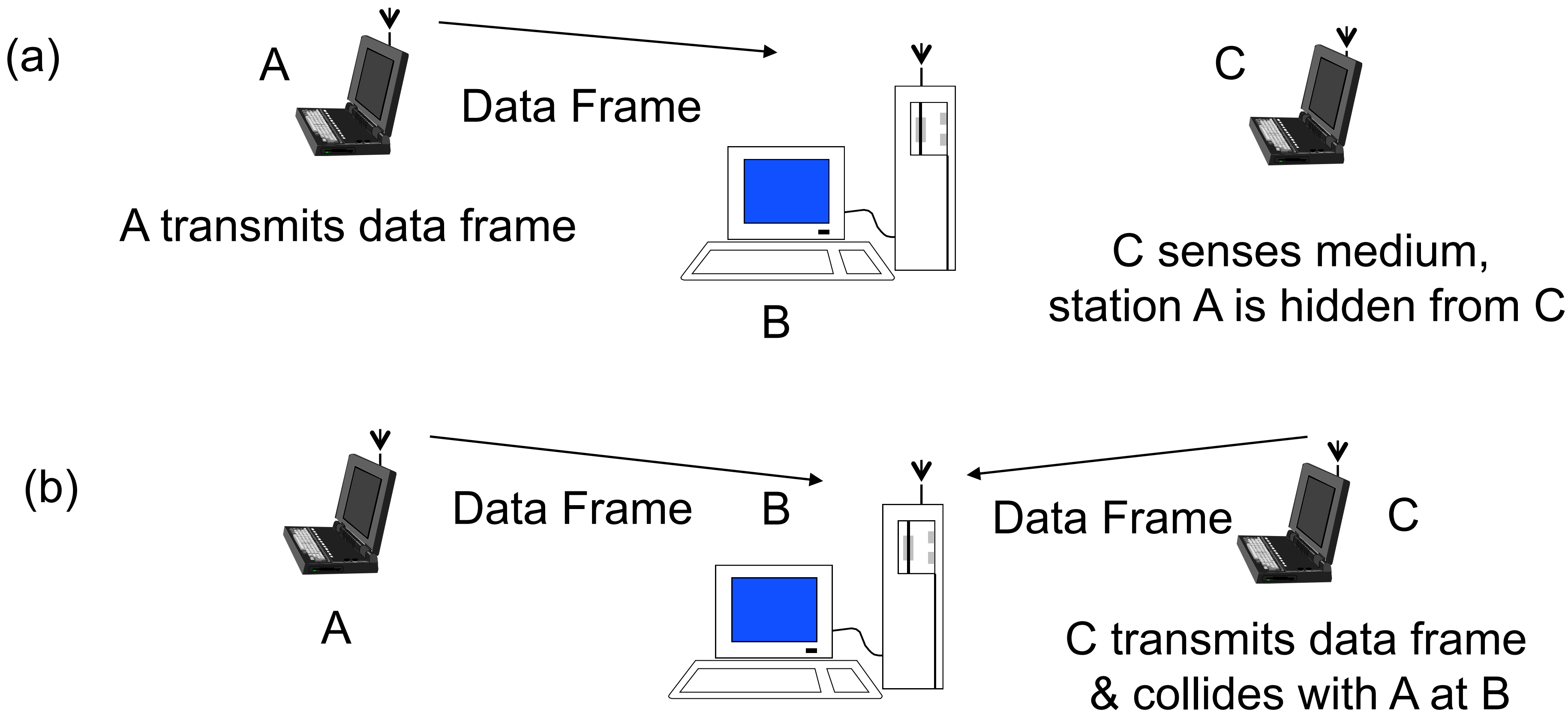
- Wireless communications compelling
  - ✓ Easy, low-cost deployment
  - ✓ Mobility & roaming: Access information anywhere
  - ✓ Supports personal devices
    - ✓ PDAs, laptops, data-cell-phones
  - ✓ Supports communicating devices
    - ✓ Cameras, location devices, wireless identification
  - ✗ Signal strength varies in space & time
  - ✗ Signal can be captured by snoopers
  - ✗ Spectrum is limited & usually regulated

Ad Hoc Communications



- Temporary association of group of stations
  - Within range of each other
  - Need to exchange information
  - E.g. Presentation in meeting, or distributed computer game, or both

Hidden Terminal Problem

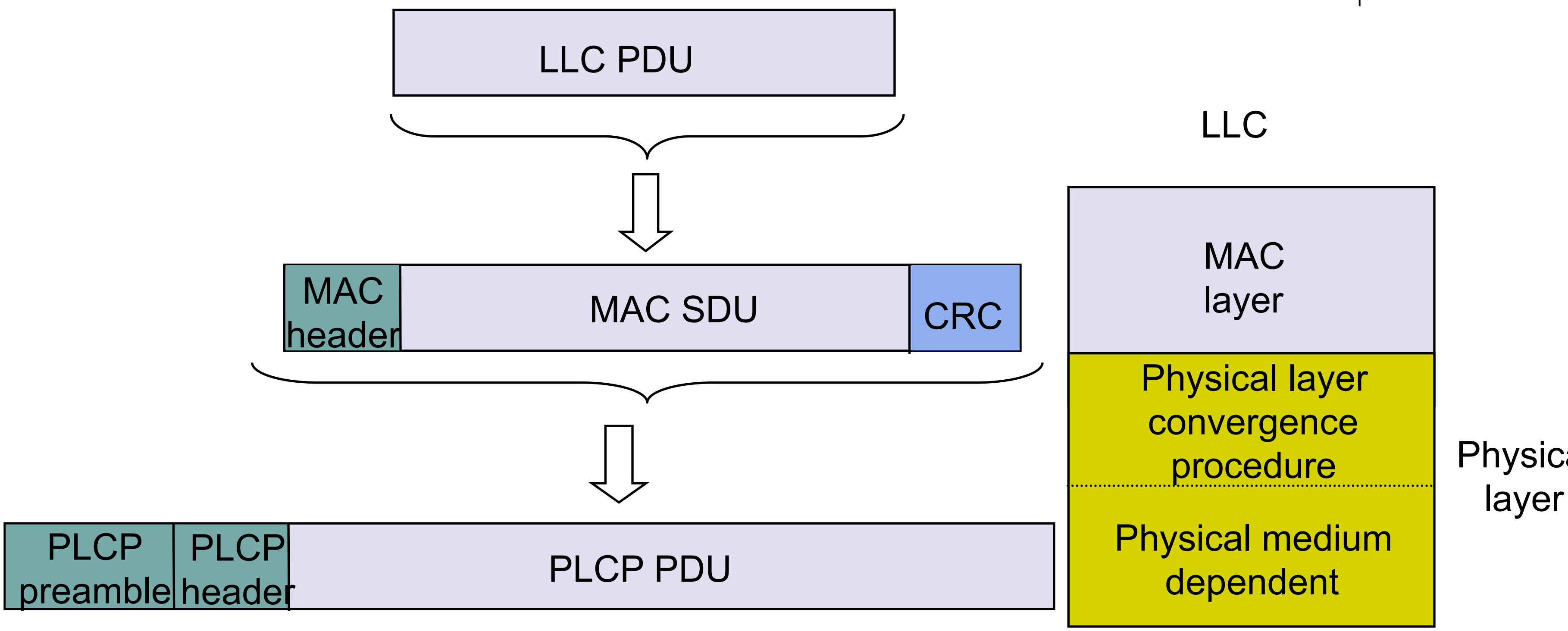


- New MAC: CSMA with *Collision Avoidance*

IEEE 802.11 Wireless LAN

- Stimulated by availability of *unlicensed spectrum*
  - U.S. Industrial, Scientific, Medical (ISM) bands
  - 902-928 MHz, 2.400-2.4835 GHz, 5.725-5.850 GHz
- Targeted wireless LANs @ 20 Mbps
- MAC for high speed wireless LAN
- Ad Hoc & Infrastructure networks
- Variety of physical layers

Physical Layers



- 802.11 designed to
  - Support LLC
  - Operate over many physical layers

IEEE 802.11 Physical Layer Options

	Frequency Band	Bit Rate	Modulation Scheme
802.11	2.4 GHz	1-2 Mbps	Frequency-Hopping Spread Spectrum, Direct Sequence Spread Spectrum
802.11b	2.4 GHz	11 Mbps	Complementary Code Keying & QPSK
802.11g	2.4 GHz	54 Mbps	Orthogonal Frequency Division Multiplexing & CCK for backward compatibility with 802.11b
802.11a	5-6 GHz	54 Mbps	Orthogonal Frequency Division Multiplexing