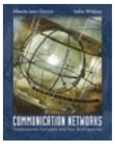
Chapter 6
Medium Access Control and Local Area Networks



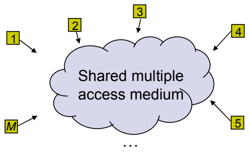
Medium Access Control
Multiple Access Communications
Channelization, Scheduling & Random Access
Local Area Networks, LAN Protocols, LAN Bridges

Switched vs. Broadcast Net's

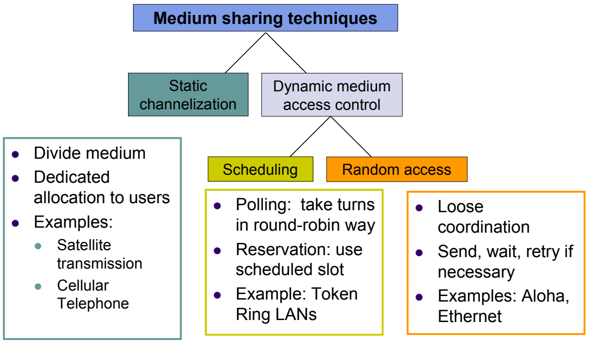
- Switched Net's:
  - provides interaction between users
  - Requires routing tables to direct info
  - Requires hierarchical addressing schemes to
    - 1) scale to a v. large size;
    - 2) to make routing task easier
- Broadcast nets:
  - Much simpler
  - Routing is not needed: all info is received by all users
  - Nonhierarchical addressing scheme is sufficient
  - Requires medium access control (MAC) protocol to orchestrate transmission from various users

Multiple Access Communications

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



Approaches to Media Sharing



Medium sharing techniques

Static channelization

Dynamic medium access control

Scheduling

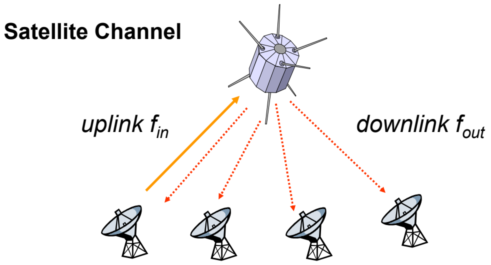
Random access

- Divide medium
- Dedicated allocation to users
- Examples:
  - Satellite transmission
  - Cellular Telephone

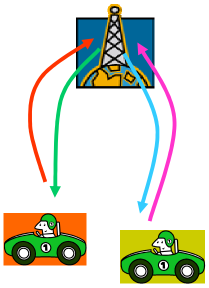
- Polling: take turns in round-robin way
- Reservation: use scheduled slot
- Example: Token Ring LANs

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

Channelization: Satellite



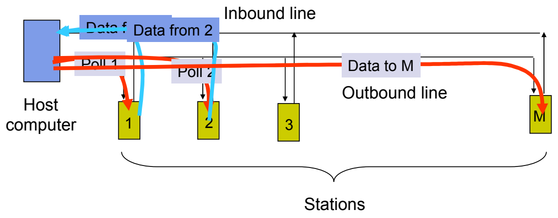
Channelization: Cellular



uplink f_1 ; downlink f_2

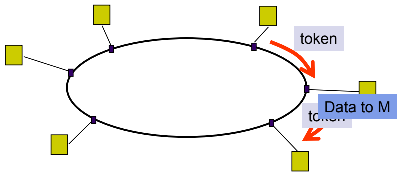
uplink f_3 ; downlink f_4

Scheduling: Polling



Scheduling: Token-Passing

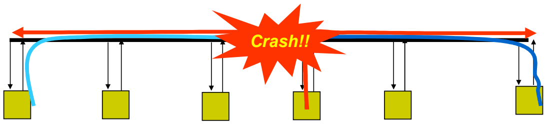
Ring networks



Station that holds token transmits into ring

Random Access

Multitapped Bus



Transmit when ready

Transmissions can occur; need retransmission strategy

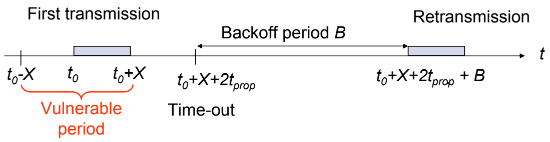
Chapter 6

Medium Access Control Protocols and Local Area Networks

Random Access

ALOHA

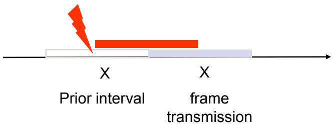
- Wireless link to provide data transfer between main campus & remote campuses of University of Hawaii
- Simplest solution: just do it
  - A station transmits whenever it has data to transmit
  - If more than one frames are transmitted, they interfere with each other (collide) and are lost
  - If ACK 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 "other" transmission during vulnerable period leads to collision
- Success if no new arrivals during period of 2X seconds

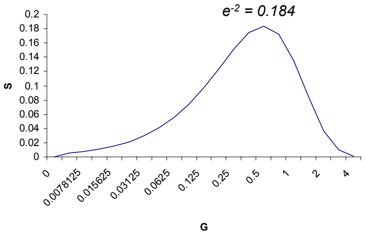
Abramson's Assumption

- *What is probability of no arrivals in the vulnerable period?*
- Abramson assumption: Effect of backoff algorithm is that frame arrivals are equally likely to occur at any point in time
- *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

$$P_{success} = P[0 \text{ arrivals in 2X seconds}] =$$
$$= P[0 \text{ arrivals in 2n intervals}]$$
$$= (1-\text{p})^{2\text{n}} = (1-\frac{G}{n})^{2n} \rightarrow e^{-2G} \text{ as n} \rightarrow \infty$$

Throughput of ALOHA

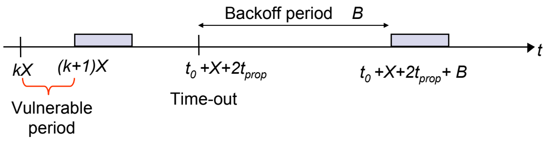
$$S = GP_{success} = Ge^{-2G}$$



- 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

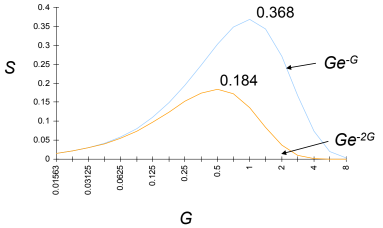
- Time is slotted in X seconds slots
- Stations synchronized to frame times
- Stations transmit frames in first slot after frame arrival
- Backoff intervals in multiples of slots



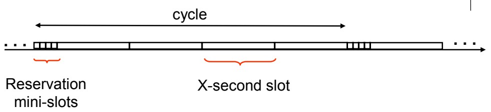
Only frames that arrive during prior X seconds collide

Throughput of Slotted ALOHA

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



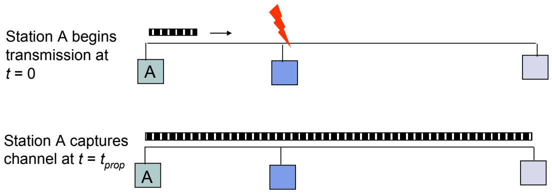
Application of Slotted Aloha



- 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

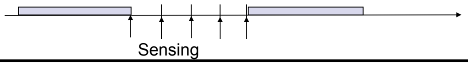
Carrier Sensing Multiple Access (CSMA)

- 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)
  - If t_{prop} <X, we gain compared to ALOHA & slotted ALOHA
  - If t_{prop} >X, no gain compared to ALOHA & slotted ALOHA



CSMA Options

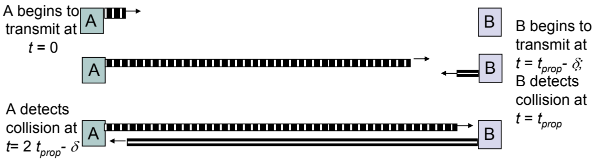
- Transmitter behavior when busy channel is sensed
  - 1-persistent CSMA (most greedy)
    - Start transmission as soon as the channel becomes idle
    - Low delay and low efficiency
  - Non-persistent CSMA (least greedy)
    - Wait a backoff period, then sense carrier again
    - High delay and high 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



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 by detecting collision and aborting transmission

CSMA/CD reaction time



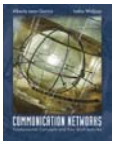
It takes 2 t_{prop} to find out if channel has been captured

CSMA-CD Application: Ethernet

- First Ethernet LAN standard used CSMA-CD
  - 1-persistent Carrier Sensing
  - R = 10 Mbps
  - Slot time: 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)

Chapter 6

Medium Access Control Protocols and Local Area Networks



Scheduling

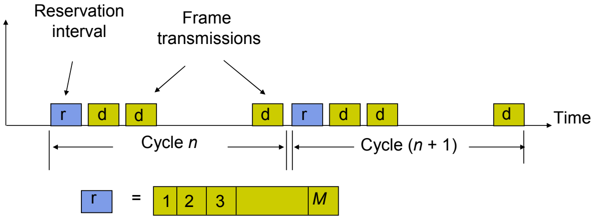
Scheduling for Medium Access Control

- 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

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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

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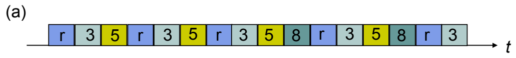
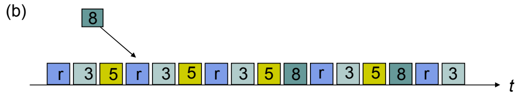
Example

- Initially stations 3 & 5 have reservations to transmit frames



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



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

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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

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Chapter 6
Medium Access Control Protocols and Local Area Networks

Channelization

Why Channelization?

- Channelization
    - Semi-static bandwidth allocation of portion of shared medium to a given user
- Highly efficient for constant-bit rate traffic
- Preferred approach in
    - Cellular telephone networks
    - Terrestrial & satellite broadcast radio & TV

Why not Channelization?

- Inflexible in allocation of bandwidth to users with different requirements
- Inefficient for bursty traffic
- Does not scale well to large numbers of users
    - Average transfer delay increases with number of users M
- Instead, a Dynamic MAC will be much better in handling bursty traffic

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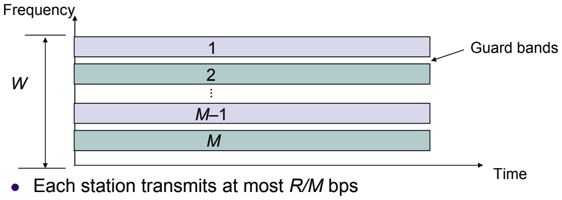
Channelization Approaches

- *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
    - Telephony Transmission (T1/E1, etc), Wireless cellular networks (e.g., GSM)
- *Code Division Multiple Access* (CDMA)
    - Pseudo-random spreading codes allocated to users
    - 2G/3G wireless cellular networks

Channelization: FDMA

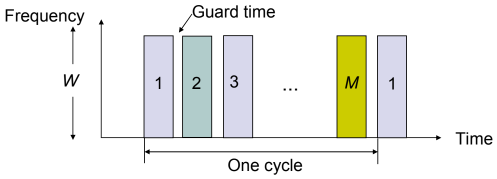
- Divide channel into *M* frequency bands
- Each station transmits and listens on assigned bands



- Each station transmits at most *R/M* bps
- Good for stream traffic; Used in connection-oriented systems
- Inefficient for bursty traffic

Channelization: TDMA

- Dedicate 1 slot per station in transmission cycles
- Stations transmit data burst at full channel bandwidth



- Each station transmits at R bps 1/M of the time
- Excellent for stream traffic; Used in connection-oriented systems
- Inefficient for bursty traffic due to waisted dedicated slots

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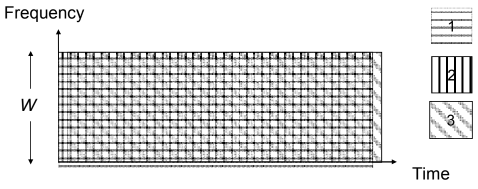
Guard-bands & Guard-intervals

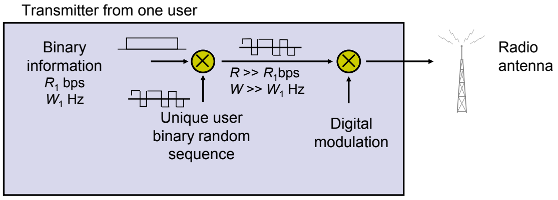
- FDMA
  - Frequency bands must be non-overlapping to prevent interference
  - Guardbands for separation; but this is overhead
- TDMA
  - Stations must be synchronized to common clock
  - Guard-intervals: time gaps between transmission bursts from different stations to prevent collisions; which is a form of waisted 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!

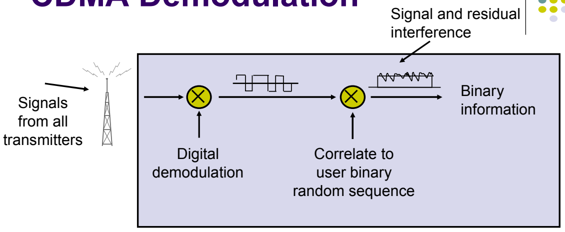


CDMA Spread Spectrum Signal



- User information mapped into: +1 or -1 for T sec.
- Multiply user information by pseudo- random binary pattern of G “chips” of +1’s and -1’s
- Resulting spread spectrum signal occupies G times more bandwidth: $W = GW_1$
- Modulate the spread signal by sinusoid at appropriate f_c

CDMA Demodulation



- Recover spread spectrum signal
- Synchronize to and multiply spread signal by ***same*** pseudo-random binary pattern used at the transmitter
- In absence of other transmitters & noise, we should recover the original +1 or -1 of user information
- Other transmitters using different codes appear as residual noise

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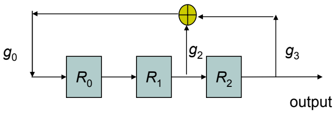
Pseudorandom pattern generator

- Feedback shift register with appropriate feedback taps can be used to generate pseudorandom sequence



$g(x) = x^3 + x^2 + 1$

The coefficients of a primitive generator polynomial determine the feedback taps

Time	R_0	R_1	R_2
0	1	0	0
1	0	1	0
2	1	0	1
3	1	1	0
4	1	1	1
5	0	1	1
6	0	0	1
7	1	0	0

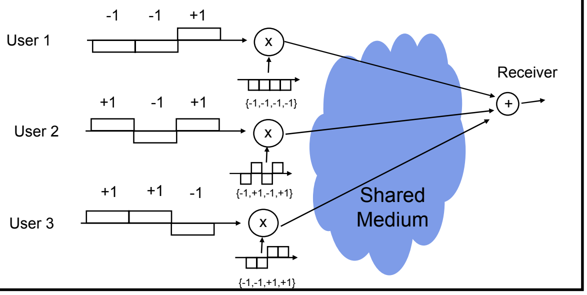
Sequence repeats from here onwards

Channelization in CDMA

- Each channel uses a different pseudorandom code
- Codes should have low cross-correlation
  - If they differ in approximately half the bits the correlation between codes is close to zero and the effect at the output of each other's receiver is small
- As number of users increases, effect of other users on a given receiver increases as additive noise
- CDMA has gradual increase in BER due to noise as number of users is increased
- Interference between channels can be eliminated is codes are selected so they are *orthogonal* and if receivers and transmitters are synchronized
  - Shown in next example

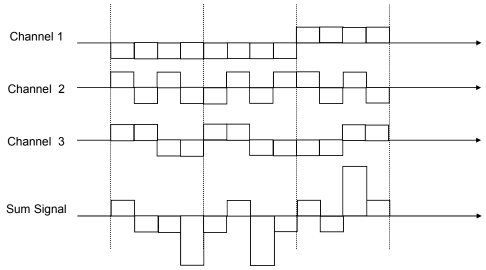
Example: CDMA with 3 users

- Assume three users share same medium
- Users are synchronized & use different 4-bit orthogonal codes: {-1,-1,-1,-1}, {-1, +1,-1,+1}, {-1,-1,+1,+1}, {-1,+1,+1,-1},



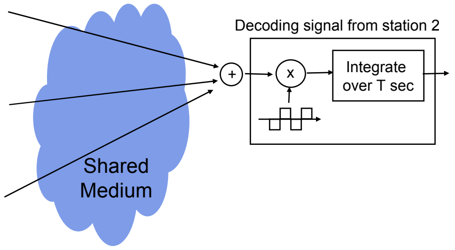
Sum signal is input to receiver

Channel 1: `110 -> +1+1-1 -> (-1,-1,-1,-1),(-1,-1,-1,-1),(+1,+1,+1,+1)`
Channel 2: `010 -> -1+1-1 -> (+1,-1,+1,-1),(-1,+1,-1,+1),(+1,-1,+1,-1)`
Channel 3: `001 -> -1-1+1 -> (+1,+1,-1,-1),(+1,+1,-1,-1),(-1,-1,+1,+1)`
Sum Signal: `(+1,-1,-1,-3),(-1,+1,-3,-1),(+1,-1,+3,+1)`



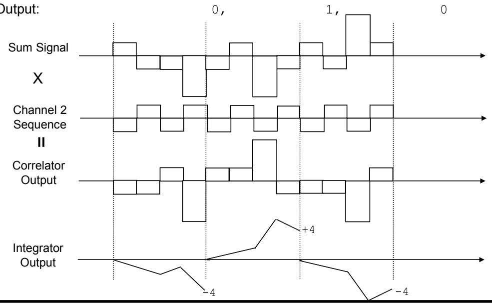
Example: Receiver for Station 2

- Each receiver takes sum signal and integrates by code sequence of desired transmitter
- Integrate over T seconds to smooth out noise



Decoding at Receiver 2

Sum Signal: `(+1,-1,-1,-3),(-1,+1,-3,-1),(+1,-1,+3,+1)`
Channel 2 Sequence: `(-1,+1,-1,+1),(-1,+1,-1,+1),(-1,+1,-1,+1)`
Correlator Output: `(-1,-1,+1,-3),(+1,+1,+3,-1),(-1,-1,-3,+1)`
Integrated Output: `-4, +4, -4`
Binary Output: `0, 1, 0`

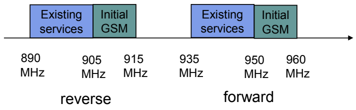


Channelization in Cellular Telephone Networks

- Cellular networks use frequency reuse
  - Band of frequencies reused in other cells that are sufficiently far that interference is not a problem
  - Cellular networks provide voice connections which is steady stream
- FDMA used AMPS in US
- TDMA used in GSM
- CDMA used in IS-95 and UMTS (3G)

Global System for Mobile Communications (GSM)

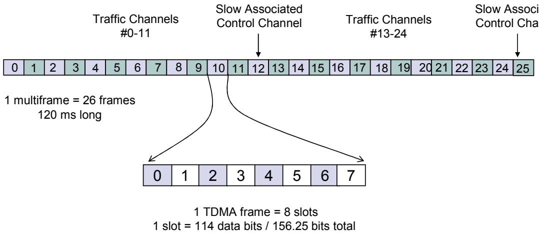
- European digital cellular telephone system
- 890-915 MHz & 935-960 MHz band
- PCS: 1800 MHz (Europe), 1900 MHz (N.Am.)
- Hybrid TDMA/FDMA
  - Carrier signals 200 kHz apart
  - 25 MHz give 124 one-way carriers



GSM TDMA Structure

- Each carrier signal carries traffic and control channels
- 1 full rate traffic channel = 1 slot in every traffic frame

  24 slots x 114 bits/slot / 120 ms = 22.8 kbps



GSM Spectrum Efficiency

- Error correction coding used in 22.8 kbps to carry 13 kbps digital voice signal
- Frequency reuse of 3 or 4 possible
- 124 carriers x 8 = 992 traffic channels
- Spectrum efficiency for GSM:
  - (992/3)/50MHz = 6.61 calls/cell/MHz

Chapter 6

Medium Access Control Protocols and Local Area Networks

Comparison of MAC Protocols

Performance Analysis

Selecting a MAC Protocol

- 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?

MAC protocol features

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

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 delay-bandwidth product 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

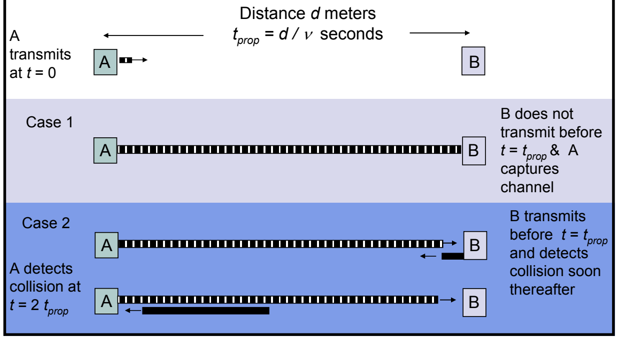
- Reservation
  - On-demand transmission of bursty or steady streams
  - Accommodates large number of low-traffic users with slotted Aloha reservations
  - Can incorporate QoS
  - Handles large delay-bandwidth product via delayed grants
- Polling
  - Generalization of time-division multiplexing
  - Provides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

Delay-Bandwidth Product

- *Delay-bandwidth* product is a key parameter
  - Coordination in sharing medium involves using bandwidth (explicitly or implicitly)
  - Difficulty of coordination related to 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 begun 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 the instant when Station A transmits
  - *R:* transmission bit rate, in bps
  - *L:* # bits/frame, *X* = *L/R* seconds/frame

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

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

Normalized Delay-Bandwidth Product

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

Propagation delay

Time to transmit a frame

Typical MAC Efficiencies

Two-Station Example:

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

Similarly, for CSMA-CD (Ethernet), It can be shown that:

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

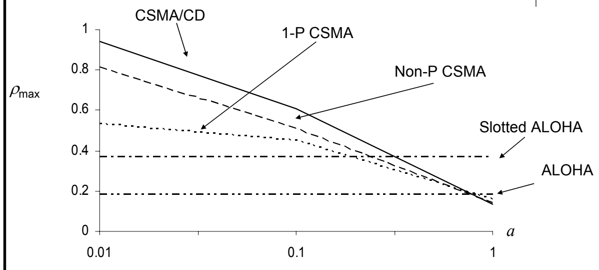
- If $a << 1$, then efficiency close to 100%
- As a approaches 1, the efficiency becomes low

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

Throughput for Random Access MACs



- For small a: CSMA-CD has best throughput
- For large a: Aloha & S-Aloha give better throughput

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

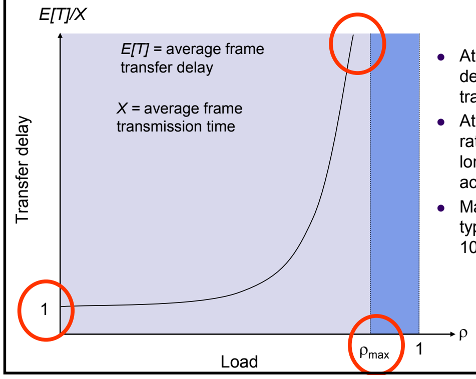
  X=*L/R* seconds/frame

  λ frames/second average arrival rate

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

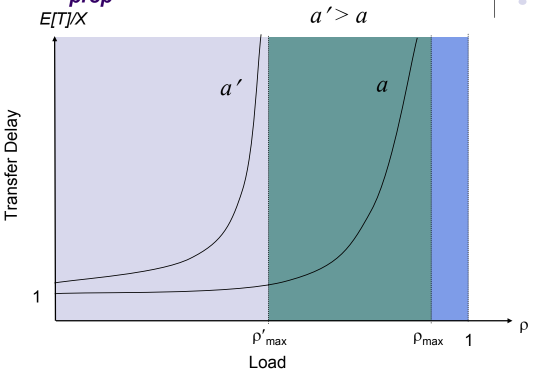
  Maximum throughput (@100% efficiency): *R/L* fr/sec

Normalized Delay versus Load



- At low arrival rate, delay is ~ frame transmission time
- At high arrival rate, increasingly long waiting to access channel
- Max efficiency typically less than 100%

Impact of Delay-Bandwidth Product
$a = Rt_{prop}/L$



Chapter 6
Medium Access Control Protocols and Local Area Networks

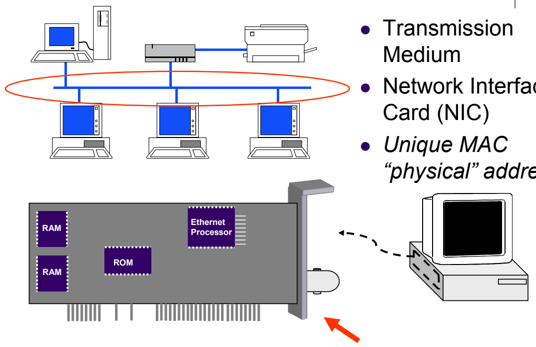
Part II: Local Area Networks
Overview of LANs
MAC Protocols
LAN Bridges

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 is too complex
  - 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



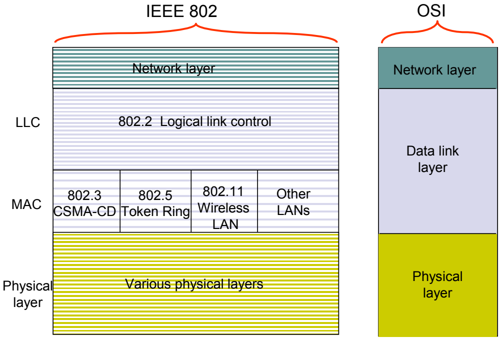
- Transmission Medium
- Network Interface Card (NIC)
- *Unique MAC "physical" address*

Medium Access Control Sublayer

- In IEEE 802.1, Data Link Layer divided into:

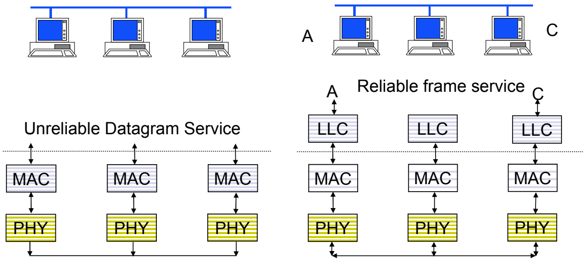
1. Medium Access Control Sublayer
   - Coordinate access to medium
   - Connectionless frame transfer service
   - Machines identified by MAC/physical address
   - Broadcast frames with MAC addresses
2. Logical Link Control Sublayer
   - Between Network layer & MAC sublayer

MAC Sub-layer

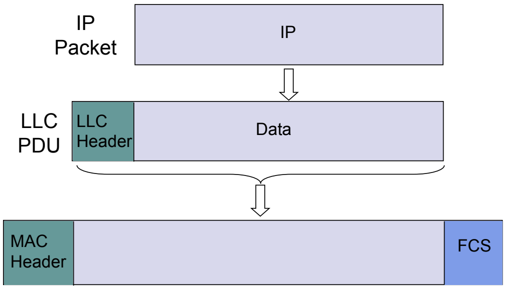


Logical Link Control Layer

- IEEE 802.2: LLC enhances service provided by MAC



Encapsulation of MAC frames



IEEE 802.3 MAC: Ethernet

MAC Protocol:

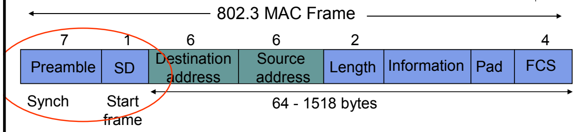
- CSMA/CD
- *Slot Time* is the critical system parameter
  - upper bound on time to detect collision
  - upper bound on time to acquire channel
  - upper bound on length of frame segment generated by collision
  - quantum for retransmission scheduling
  - max{round-trip propagation, MAC jam time}
- Truncated 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 MAC Frame



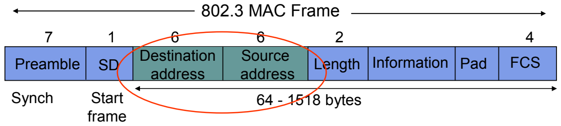
802.3 MAC Frame

7	1	6	6	2			4
Preamble	SD	Destination address	Source address	Length	Information	Pad	FCS
Synch	Start frame						

64 - 1518 bytes

- Every frame transmission begins “from scratch”
- Preamble helps receivers synchronize their clocks to transmitter clock
- 7 bytes of 10101010 generate a square wave
- Start frame byte changes to 10101011
- Receivers look for change in 10 pattern

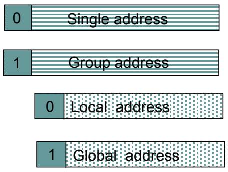
IEEE 802.3 MAC Frame



802.3 MAC Frame

7	1	6	6	2			4
Preamble	SD	Destination address	Source address	Length	Information	Pad	FCS
Synch	Start frame						

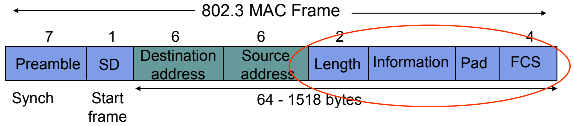
64 - 1518 bytes



0	Single address
1	Group address
0	Local address
1	Global address

- Destination address
  - single address
  - group address
  - broadcast = 111...111
- Addresses
  - local or global
- Global addresses
  - first 24 bits assigned to manufacturer;
  - next 24 bits assigned by manufacturer
  - Cisco 00-00-0C
  - 3COM 02-60-8C

IEEE 802.3 MAC Frame



802.3 MAC Frame

7	1	6	6	2			4
Preamble	SD	Destination address	Source address	Length	Information	Pad	FCS
Synch	Start frame						

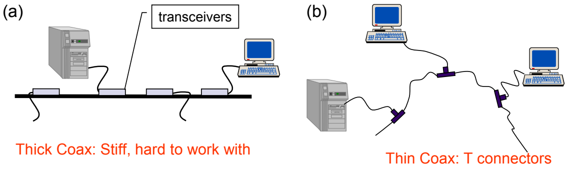
64 - 1518 bytes

- Length: # bytes in information field
  - Max frame 1518 bytes, excluding preamble & SD
  - Max information 1500 bytes: 05DC
- Pad: ensures min frame of 64 bytes
- FCS: CCITT-32 CRC, covers addresses, length, information, pad fields
  - NIC discards frames with improper lengths or failed CRC

IEEE 802.3 Physical Layer

Table 6.2 IEEE 802.3 10 Mbps medium alternatives

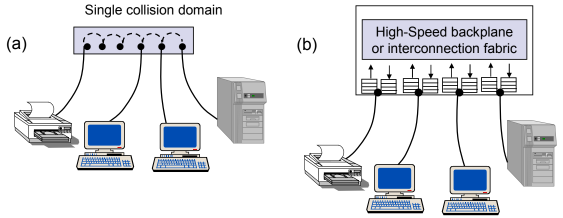
	10base5	**10base2**	**10baseT**	**10baseFX**
Medium	Thick coax	Thin coax	Twisted pair	Optical fiber
Max. Segment Length	500 m	200 m	100 m	2 km
Topology	Bus	Bus	Star	Point-to-point link



Thick Coax: Stiff, hard to work with

Thin Coax: T connectors

Ethernet Hubs & Switches



Hub (or repeater) mode
Twisted Pair cheaper
Easy to work with, Reliable
Star-topology CSMA-CD

Switch (with buffer) mode
Bridging increases scalability
Each port form a separate collision domain
Full duplex operation

Fast Ethernet

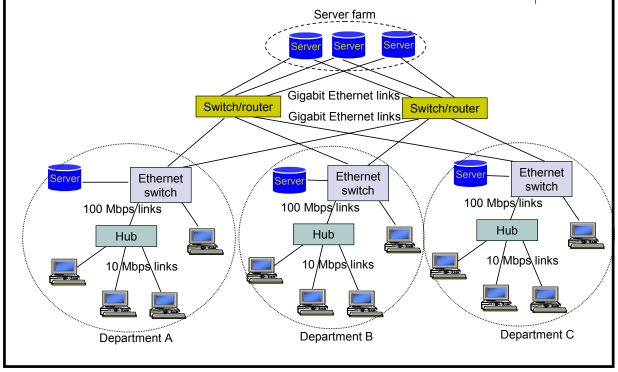
Table 6.4 IEEE 802.3 100 Mbps Ethernet medium alternatives

	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

Typical Ethernet Deployment



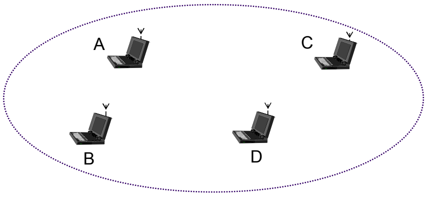
Wireless LANs

- Wireless communication features:
  - ✓ 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

IEEE 802.11 Wireless LAN

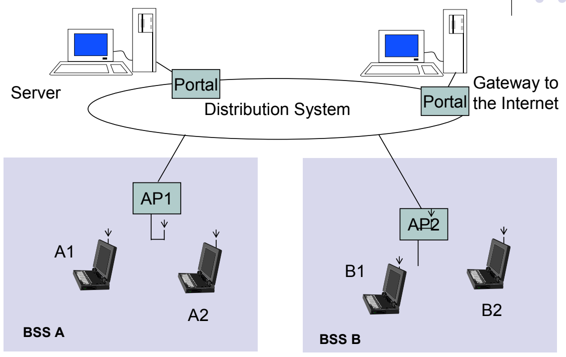
- Stimulated by availability of *unlicensed spectrum*
  - U.S. Industrial, Scientific, Medical (ISM) bands
  - 902-928 MHz, 2.400-2.4835 GHz, 5.725-5.850 GHz
- Targeted wireless LANs @ 20 Mbps
- MAC for high speed wireless LAN
- Ad Hoc & Infrastructure networks
- Variety of physical layers

Ad Hoc Communications



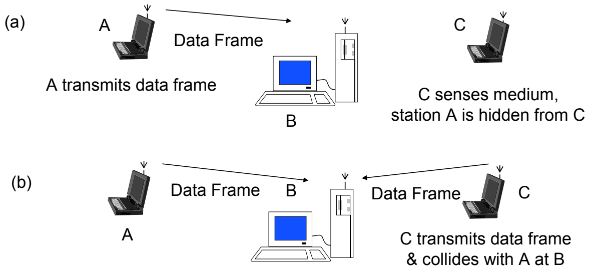
- Temporary association of group of stations
  - Within range of each other
  - Need to exchange information
  - E.g. Presentation in meeting, or distributed computer game, or both

Infrastructure Network



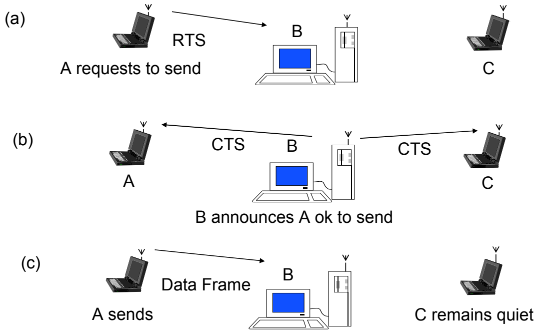
- Permanent Access Points provide access to Internet

Hidden Terminal Problem



- New MAC: CSMA with *Collision Avoidance*

CSMA with Collision Avoidance



IEEE 802.11 Wireless LANs: 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

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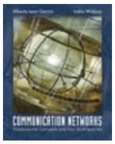
Chapter 6

Medium Access Control Protocols and Local Area Networks



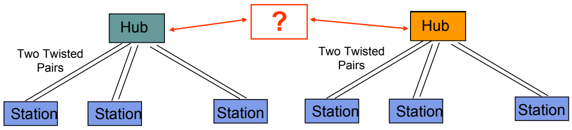
LAN Bridges

Hubs, Bridges & Routers

- Hub: Active central element in a star topology
  - Twisted Pair: inexpensive, easy to install
  - Simple repeater in Ethernet LANs
  - "Intelligent hub": fault isolation, net configuration, statistics
  - Requirements that arise:

User community grows, need to interconnect hubs

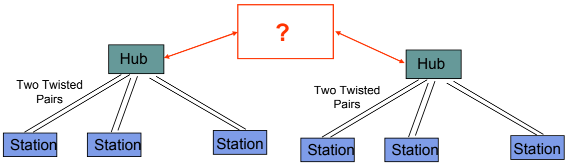
Hubs are for different types of LANs



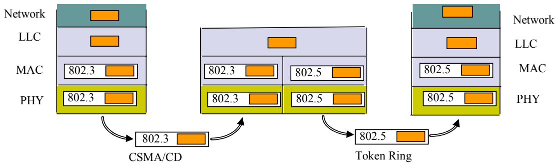
Hubs, Bridges & Routers

- Interconnecting Hubs
  - Repeater: Signal regeneration
    - All traffic appears in both LANs
  - Bridge: MAC address filtering
    - Local traffic stays in own LAN
  - Routers: Internet routing
    - All traffic stays in own LAN

Higher Scalability

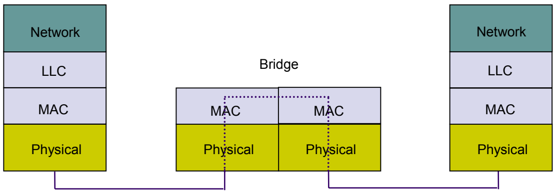


General Bridge Issues



- Operation at data link level implies capability to work with multiple network layers
- However, must deal with
  - Difference in MAC formats
  - Difference in data rates; buffering; timers
  - Difference in maximum frame length

Bridges of Same Type



- Common case involves LANs of same type
- Bridging is done at MAC level

Transparent Bridges

- Interconnection of IEEE LANs with complete transparency
- Use table lookup, and
  - discard frame, if source & destination in same LAN
  - forward frame, if source & destination in different LAN
  - use flooding, if destination unknown
- Use backward learning to build table
  - observe source address of arriving LANs
  - handle topology changes by removing old entries