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LECTURE 5
MULTIPLE ACCESS AND LOCAL AREA NETWORKS

Topics

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- Multiple access: CSMA/CD, CSMA/CA, token passing, channelization
- LAN: characteristics, basic principles
- Protocol architecture
- Topologies
- LAN Systems: Ethernet
- Extending LANs: repeater, bridge, router
- Virtual LANs

Link Layer Services

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- *framing, link access:*
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
  - "MAC" addresses used in frame headers to identify source, dest
    - different from IP address!
- *reliable delivery between adjacent nodes*
  - we learned how to do this already !
  - seldom used on low bit-error link (fiber, some twisted pair)
  - wireless links: high error rates
    - Q: why both link-level and end-end reliability?

Link Layer Services (more)

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- *flow control:*
  - pacing between adjacent sending and receiving nodes
- *error detection:*
  - errors caused by signal attenuation, noise.
  - receiver detects presence of errors:
    - signals sender for retransmission or drops frame
- error correction:
  - receiver identifies *and corrects* bit error(s) without resorting to retransmission
- *half-duplex and full-duplex*
  - with half duplex, nodes at both ends of link can transmit, but not at same time

Where is the link layer implemented?

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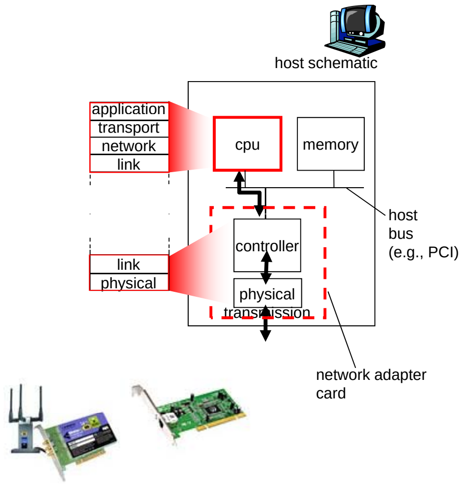
- in each and every host
- link layer implemented in “adaptor” (aka *network interface card* NIC)
  - Ethernet card, PCMCI card, 802.11 card
  - implements link, physical layer
- attaches into host’s system buses
- combination of hardware, software, firmware



Communication on LANs

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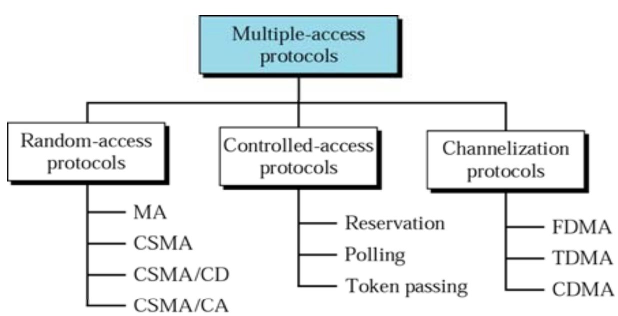
- Goal: simple and cheap solution
- Characteristics
  - small area, limited number of users, all nodes can communicate directly
  - short and long sessions
- The use of shared medium and broadcast transmission
  - simple network elements, simple network management
- Property of LANs
  - propagation time << frame transmission time
    - ($T_{pr} << T_{tr}$)
  - if a station transmits, all other will soon know about it

Multiple Access



- How to access a shared media in a controlled fashion

Multiple Access protocols

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- single shared broadcast channel
- two or more simultaneous transmissions by nodes: interference
  - collision if node receives two or more signals at the same time

multiple access protocol

- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

Ideal Multiple Access Protocol

Broadcast channel of rate R bps

1. when one node wants to transmit, it can send at rate R.
2. when M nodes want to transmit, each can send at average rate R/M
3. fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. simple

MAC Protocols: a taxonomy

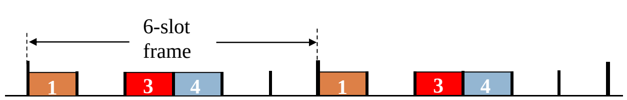
Three broad classes:

- Channel Partitioning
  - divide channel into smaller "pieces" (time slots, frequency, code)
  - allocate piece to node for exclusive use
- Random Access
  - channel not divided, allow collisions
  - "recover" from collisions
- "Taking turns"
  - nodes take turns, but nodes with more to send can take longer turns

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

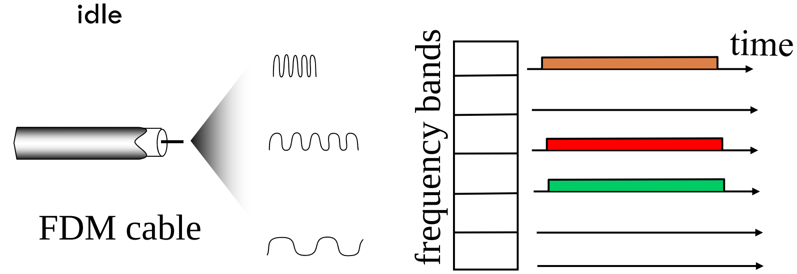
- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle



Channel Partitioning MAC protocols: FDMA

FDMA: frequency division multiple access

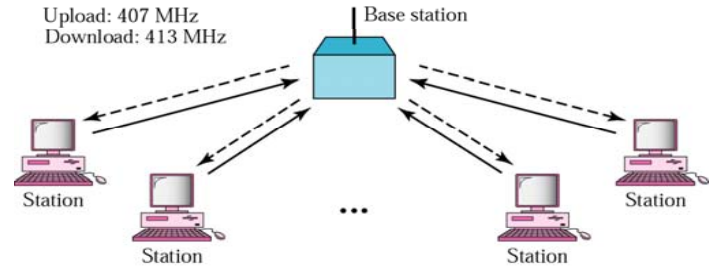
- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle



Random Access Protocols

- When node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes
- two or more transmitting nodes ➜ "collision",
- random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access MAC protocols:
  - slotted ALOHA
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA

MA—Multiple Access



- Aloha
  - Packet radio protocol
  - Random-access method based on acknowledgements and backoffs

Slotted ALOHA

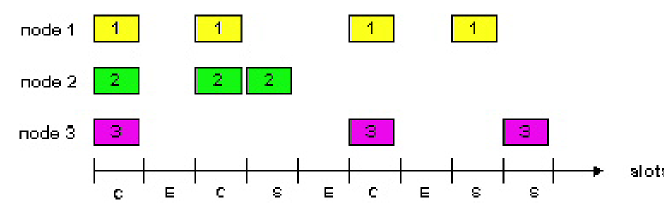
Assumptions:

- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

Operation:

- when node obtains fresh frame, transmits in next slot
  - *if no collision:* node can send new frame in next slot
  - *if collision:* node retransmits frame in each subsequent slot with prob. p until success

Slotted ALOHA



Pros

- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons

- collisions, wasting slots
- idle slots
- nodes may be able to detect collision in less than time to transmit packet
- clock synchronization

Slotted Aloha efficiency

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Efficiency : long-run fraction of successful slots (many nodes, all with many frames to send)

- *suppose:* N nodes with many frames to send, each transmits in slot with probability *p*
- prob that given node has success in a slot = $p(1-p)^{N-1}$
- prob that *any* node has a success = $Np(1-p)^{N-1}$

- max efficiency: find p* that maximizes $Np(1-p)^{N-1}$
- for many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives:

Max efficiency = 1/e = .37

At best: channel used for useful transmissions 37% of time!

!

Pure (unslotted) ALOHA

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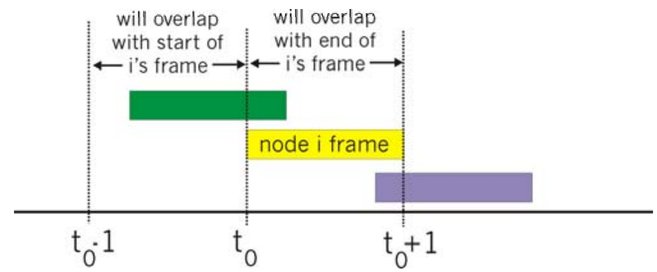
- unslotted Aloha: simpler, no synchronization
- when frame first arrives
  - transmit immediately
- collision probability increases:
  - frame sent at t_0 collides with other frames sent in $[t_0-1,t_0+1]$



Pure Aloha efficiency

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P(success by given node) = P(node transmits) ·

P(no other node transmits in $[p_0-1,p_0]$ ·

P(no other node transmits in $[p_0-1,p_0]$

$= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1}$

$= p \cdot (1-p)^{2(N-1)}$

… choosing optimum p and then letting n -> infty ...

= 1/(2e) = .18

even worse than slotted Aloha!

Aloha Protocol

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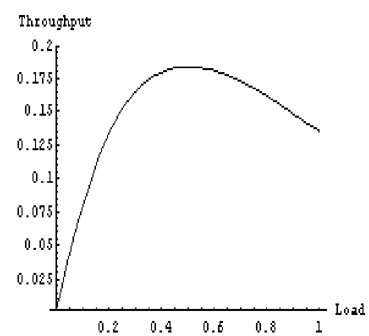

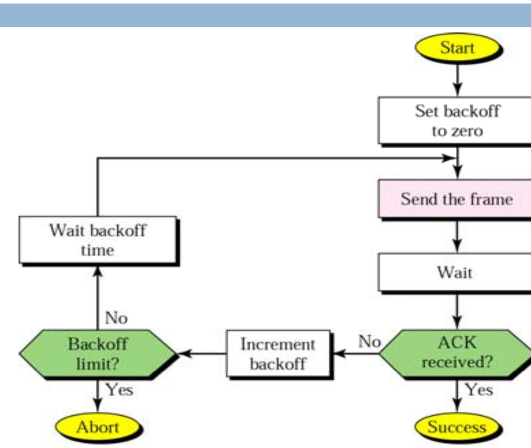

Carrier Sense Multiple Access (CSMA)

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- Carrier sense
  - Listen (sense) before sending
  - Do not send unless the medium is idle
- Reduces the possibility of collisions
  - Does not eliminate collisions
  - Propagation delay
    - Takes time before all other stations can sense a transmission

Persistence Strategy

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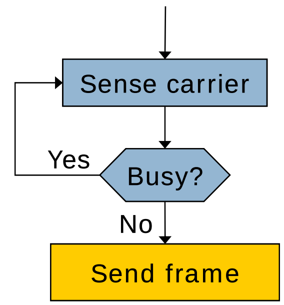
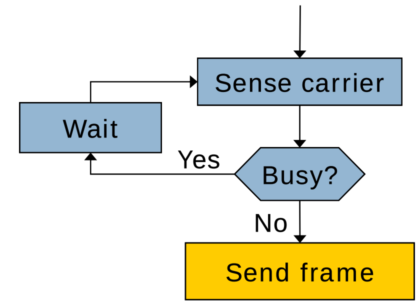
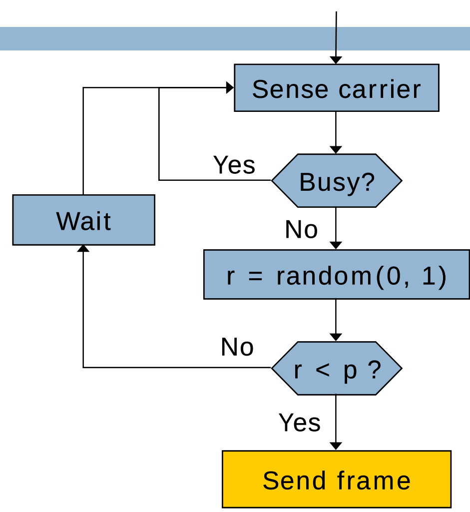




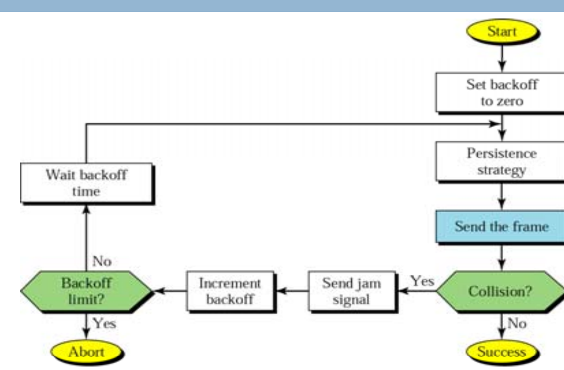
- **1-persistent**
  - **Send as soon as channel is idle**
- **Non-persistent**
  - **Wait a random period of time before sensing again**

p-Persistent

- When channel is idle
  - Send with probability *p*
  - Wait and then sense again with probability (1-*p*)



CSMA with Collision Detection (CSMA/CD)



- Exponential back-off
  - Wait $2^N \times$ max_propagation_time after collision, where N is number of transmission attempts
- Send jam so other stations detect collision as well

Ethernet: Unreliable, connectionless

- connectionless: No handshaking between sending and receiving NICs
- unreliable: receiving NIC doesn't send acks or nacks to sending NIC
  - stream of datagrams passed to network layer can have gaps (missing datagrams)
  - gaps will be filled if app is using TCP
  - otherwise, app will see gaps
- Ethernet's MAC protocol: unslotted CSMA/CD

Ethernet CSMA/CD algorithm

1. NIC receives datagram from network layer, creates frame
2. If NIC senses channel idle, starts frame transmission If NIC senses channel busy, waits until channel idle, then transmits
3. If NIC transmits entire frame without detecting another transmission, NIC is done with frame !
4. If NIC detects another transmission while transmitting, aborts and sends jam signal
5. After aborting, NIC enters **exponential backoff**: after *m*th collision, NIC chooses *K* at random from $\{0,1,2,\ldots,2^m-1\}$. NIC waits K·512 bit times, returns to Step 2

Ethernet's CSMA/CD (more)

Jam Signal: make sure all other transmitters are aware of collision; 48 bits

Bit time: .1 microsec for 10 Mbps Ethernet ;
for K=1023, wait time is about 50 msec

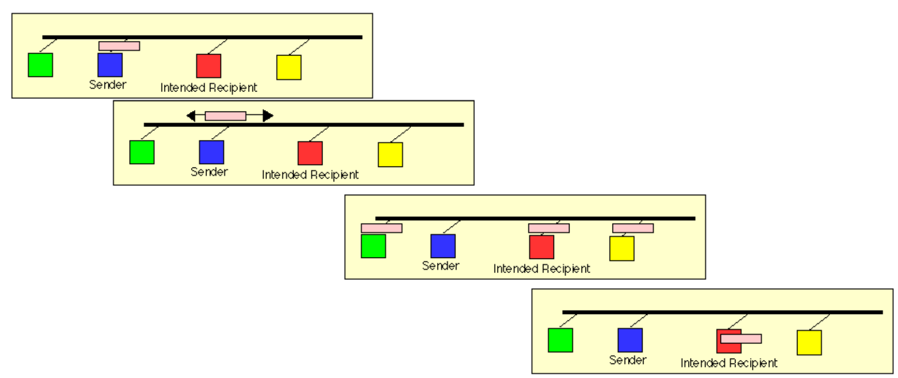
See/interact with Java applet on AWL Web site: highly recommended !

Exponential Backoff:

- *Goal*: adapt retransmission attempts to estimated current load
  - heavy load: random wait will be longer
- first collision: choose K from {0,1}; delay is K· 512 bit transmission times
- after second collision: choose K from {0,1,2,3}…
- after ten collisions, choose K from {0,1,2,3,4,…,1023}

CSMA/CD

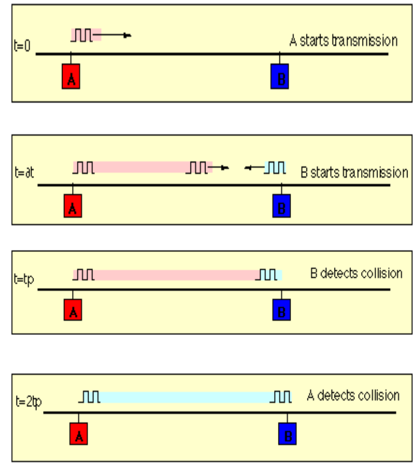
MAC header contains a MAC destination address which ensure only the specified destination actually forwards the received frame (Others discard the frames).



CSMA/CD

- When a collision occurs, i.e., excess current above what it is generating (> 24 mA for coaxial Ethernet), it stops transmission immediately.
- Transmits a 32-bit jam sequence such that receivers discard the frame due to a CRC error.
- To ensure collision detection, Ethernet defines a minimum frame size.
- The minimum frame size is related to distance, media, and number of nodes (Ethernet Slot Time).

Collision Detection



At time t=0, a frame is sent on the idle medium by A.

A short time later, B also transmits. (In this case, the medium, as observed by the NIC at B happens to be idle too).

After T_{pr}, the NIC at B detects the other transmission from A, and is aware of a collision, but NIC A has not yet observed that NIC B was also transmitting. B continues to transmit, sending the Ethernet Jam sequence (32 bits).

After one complete round trip propagation time (twice T_{pr}), both NICs are aware of the collision. A transmits a complete Jam Sequence. Finally the cable becomes idle.

Collision Detection

- Requires that stations still transmit when the colliding packet arrives
  - Collisions detected by all stations
  - Minimum packet size and maximum bus length
    - 72 bytes (64 bytes at data link layer) and 500 meters for 10Base5 ("Thick Ethernet")

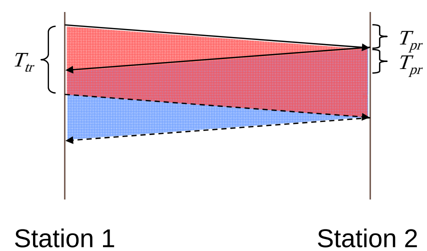
$$T_{tr} \geq 2T_{pr}$$

$$\frac{P}{B} \geq 2\frac{L}{v}$$

P: packet size [bit]
B: bandwidth (transmission speed) [bit/s]
L: bus length [m]
v: signal propagation speed [m/s]

Packet Size Versus Bus Length

$$T_{tr} > 2T_{pr} \Leftrightarrow \frac{S}{C} > \frac{2L}{v}$$



S: frame size [bit]
C: link capacity [bit/s]
L: bus length [m]
v: signal propagation speed [m/s]

- Collisions must be detected by all stations
- Minimum packet size and maximum bus length
  - 72 bytes (64 bytes at data link layer) and 500 meters for 10Base5 ("Thick Ethernet")

Wireless LAN (CSMA/CA)

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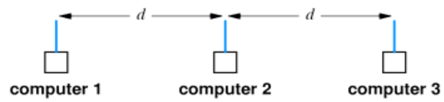
- Problem with CSMA/CD in combination with radio (wireless) signals
  - Collision detection is not reliable



- E.g., asymmetry: computer 3 might not receive the signals from computer 1 to computer 2
  - Hidden station problem, signal fading
- Requires ability to send data and detect collisions at the same time
  - More costly hardware, higher bandwidth

CSMA/CD (Collision Detection)

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CSMA/CD: carrier sensing, deferral as in CSMA

- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage

- collision detection:
  - easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - difficult in wireless LANs: received signal strength overwhelmed by local transmission strength
- human analogy: the polite conversationalist

Wireless Networks—Hidden Terminal

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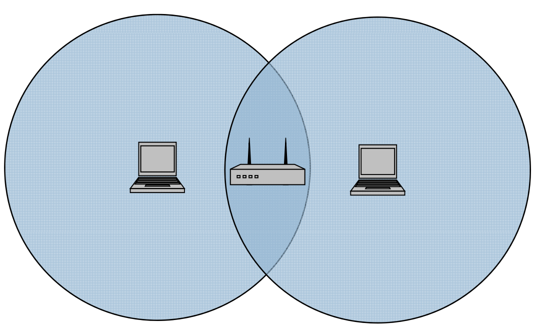

- Stations may not detect each others signals

CSMA/CA (cont'd)

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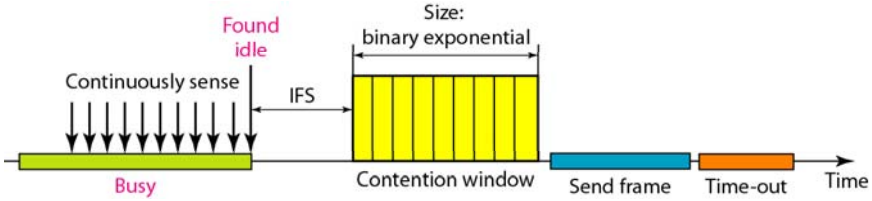
- CSMA/CA
  - Carrier Sense Multiple Access with Collision Avoidance
  - Control signals before transmission
  - Carrier sense:
    - do not transmit immediately when medium gets idle (p-persistence)
    - Wait random time
      - lower collision probability

Figure 12.16 Timing in CSMA/CA



Note

In CSMA/CA, the IFS can also be used to define the priority of a station or a frame.

Note

In CSMA/CA, if the station finds the channel busy, it does not restart the timer of the contention window;
it stops the timer and restarts it when the channel becomes idle.

CSMA/CA Wait Procedure

- When medium is busy
- Wait a random amount of time
  - But only decrement timer when medium is idle
- IEEE 802.11 Wireless LAN

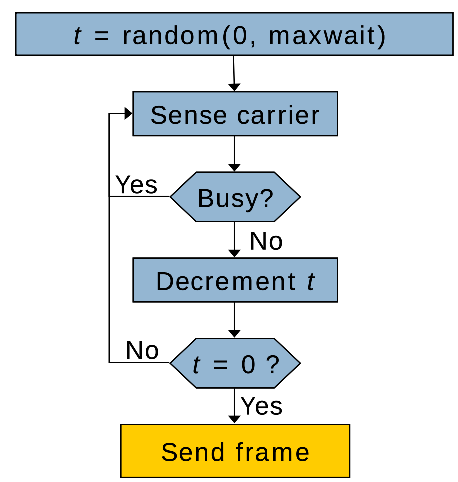
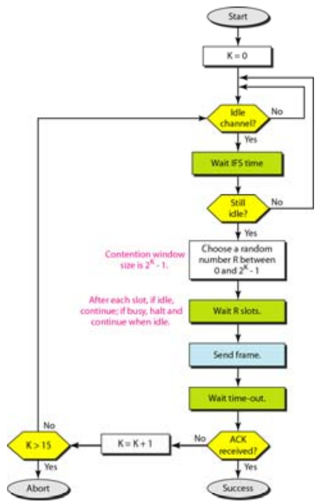
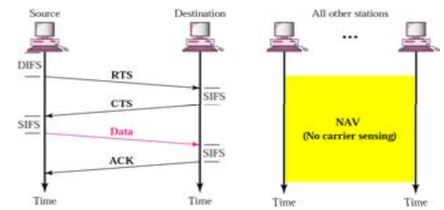


Figure 12.17 Flow diagram for CSMA/CA



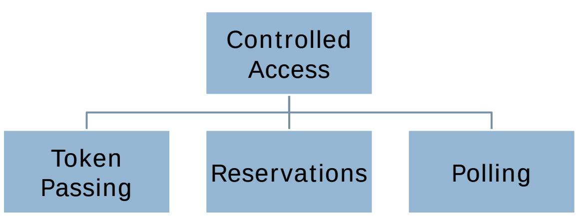
CSMA/CA With RTS/CTS



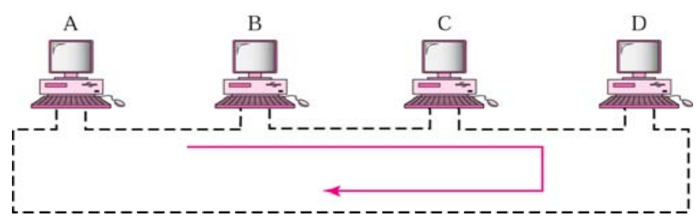
- Request-to-send/clear-to-send (RTS/CTS) handshake
  - RTS/CTS frames contain Duration field
    - Period of time the medium is reserved for transfer
  - Other stations remain quite during this period
- Need not be used for all frames
  - Overhead too high for small frames

CONTROLLED ACCESS

In controlled access, the stations consult one another to find which station has the right to send. A station cannot send unless it has been authorized by other stations. We discuss three popular controlled-access methods.

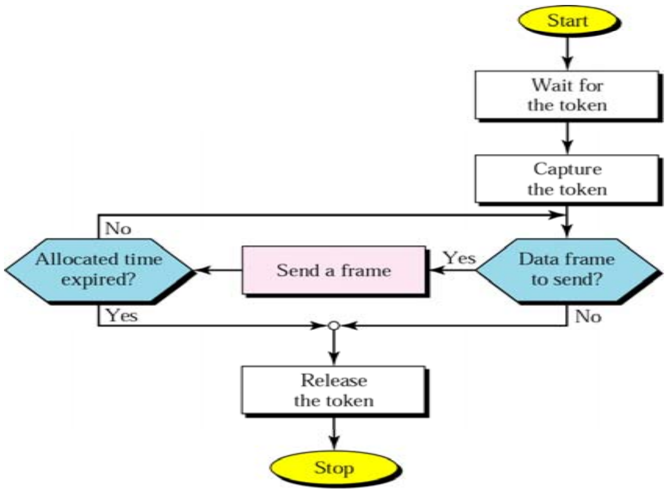


Token Passing



- Token (a control frame) circulates among the nodes
- The node that holds the token has the right to transmit
- Current station, predecessor, and successor
- Used in Token Ring LAN

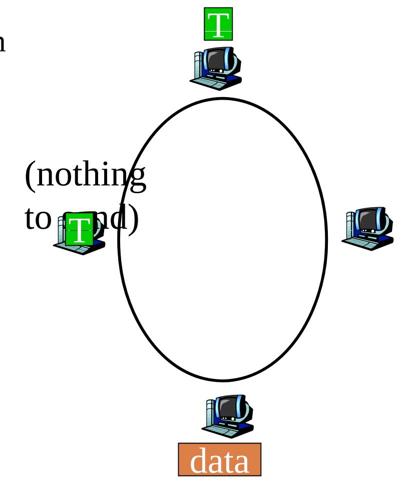
Token Passing Procedure



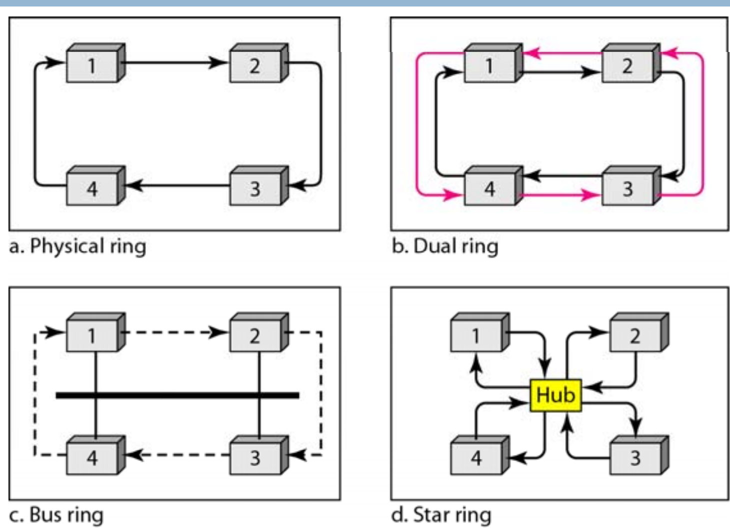
"Taking Turns" MAC protocols

Token passing:

- control **token** passed from one node to next sequentially.
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)



Logical ring and physical topology in token-passing access method

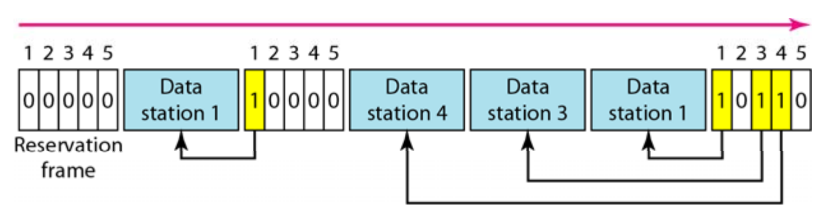


Reservation

Reservation

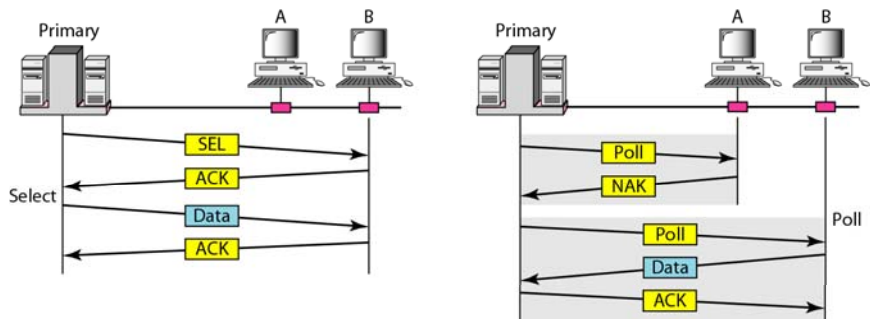
In the reservation access method, a station needs to make a reservation before sending data. Time is divided into intervals. In each interval, a reservation frame precedes the data frames sent in that interval.

If there are *N* stations in the system, there are exactly *N* reservation minislots in the reservation frame. Each minislot belongs to a station. When a station needs to send a data frame, it makes a reservation in its own minislot. The stations that have made reservations can send their data frames after the reservation frame.



Polling

Polling works with topologies in which one device is designated as a **primary station** and the other devices are **secondary stations.** All data exchanges must be made through the primary device even when the ultimate destination is a secondary device.

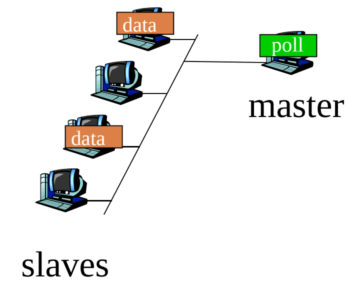


Select **Poll**

"Taking Turns" MAC protocols

Polling:

- master node "invites" slave nodes to transmit in turn
- typically used with "dumb" slave devices
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)



Channelization

- FDMA
  - A station is allocated a frequency band on an FDM link
- TDMA
  - Entire bandwidth is one channel
  - A station is allocated time slots on a TDM link
- CDMA (Code Division Multiple Access)
  - Entire bandwidth is one channel
    - Data from all inputs are transmitted at the same time
  - Based on coding theory, and uses sequences of numbers called chips generated using Walsh Tables.

Summary of DLL

Standards for the Data Link Layer

ISO:	HDLC (High Level Data Link Control)
IEEE:	802.2 (LLC), 802.3 (Ethernet) 802.5 (Token Ring) 802.11(Wireless LAN)
ITU:	Q.922 (Frame Relay Standard) Q.921 (ISDN Data Link Standard) HDLC (High Level Data Link Control)
ANSI:	3T9.5 ADCCP (Advanced Data Communications Control Protocol)