CMPE 150:
Introduction to Computer Networks

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Class Information

- Class web site:  
  www.soe.ucsc.edu/classes/cmpe150/Spring03/

- Class Newsgroup
  - ucsc.class.cmpe150

- TA Section
  - Mondays @ 5:00PM – Thursdays @10:00AM
    - Baskin *White Boards* area
(Optional) Class Project

- Network programming project
  - In lieu of taking final examination
- Goal:
  - Build an FTP client/server from scratch
  - Using ‘C’ language
- Details on web page... now...
  - Due by June 4th...
Homework Assignments

Homework assignment #2

Due by May 1......
Homework Assignments

Late Homework Rules:

-10% reduction first day
-5% each additional day

Not accepted after one week

Solutions handed out at one week
CMPE 150: Introduction to Computer Networks

LECTURE 5:

Medium Access Control, Part III
Conflict-Free MAC Protocols

- **Conflict-free:**
  - Fixed assignment (TDMA, FDMA, CDMA)
  - Reservations
  - Polling
  - Token passing
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
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.
Channel Partitioning (CDMA)

CDMA (Code Division Multiple Access)

- unique “code” assigned to each user; i.e., code set partitioning
- used mostly in wireless broadcast channels (cellular, satellite, etc)
- all users share same frequency, but each user has own “chipping” sequence (i.e., code) to encode data
- **encoded signal** = (original data) X (chipping sequence)
- **decoding:** inner-product of encoded signal and chipping sequence
- allows multiple users to “coexist” and transmit simultaneously with minimal interference (if codes are “orthogonal”)
**CDMA Encode/Decode**

**Sender**
- Data bits: \(d_1 = -1\), \(d_0 = 1\)
- Code: 1 1 1 1 1 1 1 1 1 1
- Channel output: \(Z_{i,m} = d_i \cdot c_m\)

**Receiver**
- Code: 1 1 1 1 1 1 1 1 1 1
- Slot 1 received input: 1 1 1 1 1 1 1 1 1 1
- Slot 0 received input: 1 1 1 1 1 1 1 1 1 1
- Symbol value: \(d_i = \sum_{m=1}^{M} Z_{i,m} \cdot c_m\)
- Channel output: 1 1 1 1 1 1 1 1 1 1
- Symbol value: \(d_0 = 1\), \(d_1 = -1\)
Token Passing

- **Basic Scheme:**
  - A token granting the right to transmit is circulated among stations.
  - Station with something to send receiving token changes the token into a start of packet and sends its packet.
  - The token is sent back to the system when the sender is done.

- **Two transmission strategies:**
  - *Release after transmission (RAT):* Sender releases the token immediately after transmitting its packet.
  - *Release after reception (RAR):* Sender waits until it hears the last bit of its own transmission before releasing the token.

- Token Passing protocols can be used in any network topology; however, token management is simpler in rings.
RAT Strategy

Token circulates until it reaches S
Source changes token to start-of-frame delimiter
D copies the data
S takes frame out
(packet length is actually longer than token circulation time)
Delays in Token Ring

- Delays are bounded in token ring nets!
- Each station can hold the token for a maximum amount of time, and there is a finite number of stations in the net.
- The maximum medium access time (MMAT) is defined to be the time elapsed from the start of a current packet transmission by a node to the time when it can have the “floor” of the network again.
LAN Technologies

- Ethernet
- Wireless LANs
- Token-passing LANs (if time allows)
Ethernet

Dominant LAN technology:
- cheap $20 for 100Mbs!
- First widely used LAN technology
- Simpler, cheaper than token LANs and ATM
- Kept up with speed race: 10, 100, 1000 Mbps

Metcalfe’s Ethernet sketch
Ethernet Frame Structure

Sending adapter encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame

- **Preamble:**
  - 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
  - Used to synchronize receiver, sender clock rates
Ethernet Frame Structure

- **Addresses**: 6 bytes
  - if adapter receives frame with matching destination address, or with broadcast address (e.g., ARP packet), it passes data in frame to net-layer protocol
  - Otherwise, adapter discards frame.

- **Type**: indicates the higher layer protocol, mostly IP but others may be supported such as Novell IPX and AppleTalk.

- **CRC**: checked at receiver, if error is detected, the frame is simply dropped.
Unreliable, Connectionless Service

- **Connectionless**: No handshaking between sending and receiving adapter.
- **Unreliable**: Receiving adapter doesn’t send acks or nacks to sending adapter.
  - Stream of datagrams passed to network layer can have gaps.
  - Gaps will be filled if app is using TCP.
  - Otherwise, app will see the gaps.
Ethernet uses CSMA/CD

- No slots
- Adapter doesn’t transmit if it senses that some other adapter is transmitting, that is, *carrier sense*
- Transmitting adapter aborts when it senses that another adapter is transmitting, that is, *collision detection*

- Before attempting a retransmission, adapter waits a random time, that is, *random access*
**Ethernet CSMA/CD algorithm**

1. Adaptor gets datagram from and creates frame
2. If adapter senses channel idle, it starts to transmit frame. If it senses channel busy, waits until channel idle and then transmits
3. If adapter transmits entire frame without detecting another transmission, the adapter is done with frame!
4. If adapter detects another transmission while transmitting, aborts and sends jam signal
5. After aborting, adapter enters exponential backoff: after the $m^{th}$ collision, adapter chooses a $K$ at random from $\{0,1,2,...,2^{m-1}\}$. Adapter waits $K*512$ bit times and returns to Step 2
Ethernet’s CSMA/CD

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 x 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 Efficiency

- $T_{prop} = \text{max prop between 2 nodes in LAN}$
- $t_{trans} = \text{time to transmit max-size frame}$

$$\text{efficiency} = \frac{1}{1 + 5 \frac{t_{prop}}{t_{trans}}}$$

- Efficiency goes to 1 as $t_{prop}$ goes to 0
- Goes to 1 as $t_{trans}$ goes to infinity
- Much better than ALOHA, but still decentralized, simple, and cheap
Ethernet Technologies: 10Base2

- **10**: 10Mbps; **2**: under 200 meters max cable length.
- Thin coaxial cable in a bus topology.

- Repeaters used to connect up to multiple segments.
- Repeater repeats bits it hears on one interface to its other interfaces: physical layer device only!
- Has become a legacy technology.
10BaseT and 100BaseT

- 10/100 Mbps rate; latter called “fast ethernet”
- \( T \) stands for Twisted Pair
- Nodes connect to a hub: “star topology”; 100 m max distance between nodes and hub

- Hubs are essentially physical-layer repeaters:
  - bits coming in one link go out all other links
  - no frame buffering
  - no CSMA/CD at hub: adapters detect collisions
  - provides net management functionality
Manchester Encoding

- Used in 10BaseT, 10Base2
- Each bit has a transition
- Allows clocks in sending and receiving nodes to synchronize to each other
  - no need for a centralized, global clock among nodes!
- Handled at the physical layer!
Gbit Ethernet

- Use standard Ethernet frame format
- Allows for point-to-point links and shared broadcast channels
- In shared mode, CSMA/CD is used; short distances between nodes to be efficient
- Uses hubs, called here “Buffered Distributors”
- Full-Duplex at 1 Gbps for point-to-point links
- 10 Gbps now!
CSMA/CD Technology Issues

- IEEE802.3 and Ethernet are based on CSMA/CD.
- CSMA/CD is used over buses and star topologies.
- The most popular topology now (more than 80% of installed base) is the star topology with hubs or switches.
- A hub acts just like a station executing CSMA/CD, and only one transmission can succeed.
- A switch is different!...and is the future.

Switch stores concurrently transmitted packets.
No collisions.
Higher throughput
Limited by the switch architecture.
IEEE 802.11 Wireless LAN

- **802.11b**
  - 2.4-5 GHz unlicensed radio spectrum
  - up to 11 Mbps
  - direct sequence spread spectrum (DSSS) in physical layer
    - all hosts use same chipping code
    - widely deployed, using base stations

- **802.11a**
  - 5-6 GHz range
  - up to 54 Mbps

- **802.11g**
  - 2.4-5 GHz range
  - up to 54 Mbps

All use CSMA/CA for multiple access

All have base-station and ad-hoc network versions
Base-Station Approach

- Wireless host communicates with a base station
  - base station = access point (AP)
- Basic Service Set (BSS) (a.k.a. “cell”) contains:
  - Wireless hosts
  - Access point (AP): base station
- BSS’s combined to form distribution system (DS)
Ad Hoc Network approach

- No AP (i.e., base station)
- Wireless hosts communicate with each other
  - To get packet from wireless host A to B may need to route through wireless hosts X, Y, Z
- Applications:
  - “laptop” meeting in conference room, car
  - Interconnection of “personal” devices
  - Battlefield
- IETF MANET (Mobile Ad hoc Networks) working group
IEEE 802.11: Multiple Access

- Collision if 2 or more nodes transmit at same time
- CSMA makes sense:
  - get all the bandwidth if you’re the only one transmitting
  - shouldn’t cause a collision if you sense another transmission
- Collision detection doesn’t work: hidden terminal problem
IEEE 802.11 MAC Protocol: CSMA/CA

802.11 CSMA: sender
- if sense channel idle for **DIFS** sec.
  then transmit entire frame (no collision detection)
- if sense channel busy
  then binary backoff
802.11 CSMA receiver
- if received OK
  return ACK after **SIFS**
  (ACK is needed due to hidden terminal problem).
Collision Avoidance Mechanisms

- Problem:
  - two nodes, hidden from each other, transmit complete frames to base station
  - wasted bandwidth for long duration!

- Solution:
  - small reservation packets
  - nodes track reservation interval with internal “network allocation vector” (NAV)
Collision Avoidance: RTS-CTS exchange

- Sender transmits short RTS (request to send) packet: indicates duration of transmission
- Receiver replies with short CTS (clear to send) packet
  - notifying (possibly hidden) nodes
- Hidden nodes will not transmit for specified duration: NAV
Collision Avoidance: RTS-CTS exchange

- RTS and CTS short:
  - collisions less likely, of shorter duration
  - end result similar to collision detection
- IEEE 802.11 allows:
  - CSMA
  - CSMA/CA: reservations
  - polling from AP
Summary of Bluetooth

- Low-power, small radius, wireless networking technology
  - 10-100 meters
- Omnidirectional
  - Not line-of-sight infrared
- Interconnects gadgets
- 2.4-2.5 GHz unlicensed radio band
- Up to 721 kbps

- Interference from wireless LANs, digital cordless phones, microwave ovens:
  - Frequency hopping helps
- MAC protocol supports:
  - Error correction
  - ARQ
- Each node has a 12-bit address
“Taking Turns” MAC protocols

Channel partitioning MAC protocols:
- share channel efficiently and fairly at high load
- inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

Random access MAC protocols
- efficient at low load: single node can fully utilize channel
- high load: collision overhead

“taking turns” protocols
look for best of both worlds!
“Taking Turns” MAC protocols

Polling:
- master node “invites” slave nodes to transmit in turn
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)

Token passing:
- control **token** passed from one node to next sequentially.
- token message
- concerns:
  - token overhead, latency, single point of failure (token), complexity.
Ethernet versus Token Ring

- Token ring:
  - Efficient at heavy traffic.
  - Guaranteed delay.
  - Fair.
  - Supports priorities.
  - But, ring/token maintenance overhead.
    - Centralized monitoring.
- Ethernet is simple and cheap!
- Switched Ethernet is easiest approach.
IF TIME ALLOWS....
Details on token-passing technologies
Token Bus 1

- Token: special-purpose frame that *circulates* when all stations are idle.
- Physically, token bus is linear or tree-shaped topology; logically, it operates as ring.
Token Bus 2

- In CSMA/CD (802.3) starvation may occur, i.e., stations can wait forever to transmit.
- In token bus, every station has a chance to transmit (token).
- No collisions! i.e., contention-free.
Token Bus 3

- Token passes around in pre-defined order.
- Once station acquires token, it can start transmitting.
- When done, passes the token onto next station.
Token Bus 4

- Limited efficient due to passing of the token.

- Issues:
  - Adding/removing stations.
  - Lost token problem.
Token Ring 1

- IEEE 802.5 and FDDI.
- Most commonly used MAC protocol for ring topologies.
- Also uses special-purpose, circulating frame, or token (3 bytes).
- Station that wants to transmit waits till token passes by.
Token Ring 2

- When station wants to transmit:
  - Waits for token.
  - Seizes it by changing 1 bit and token becomes start-of-frame sequence.
  - Station appends remainder of frame.
- When station seizes token and begins transmission, there’s no token on the ring; so nobody else can transmit.
Token Ring 3

- Transmitting station inserts new token when:
  - Station completes frame transmission and
  - Leading edge of frame returns to it after a round-trip.

- If ring length < frame length, 1st. condition implies 2nd.

- 2nd. condition ensures only 1 data frame at a time on the ring.
Token Ring 4

- Under light load, inefficiency due to waiting for the token to transmit.
- Under heavy load, round-robin: fair and efficient.

Issues:
- Token maintenance.
  - Token loss or duplication.
  - Monitoring station can be responsible for ring maintenance (removing duplicates, inserting token)
Token Ring Frame Format

<table>
<thead>
<tr>
<th>SD</th>
<th>AC</th>
<th>FC</th>
<th>DA</th>
<th>SA</th>
<th>Data</th>
<th>FCS</th>
<th>ED</th>
<th>FS</th>
</tr>
</thead>
</table>

SD: starting delimiter; indicates starting of frame.
AC: access control; PPPTMRRRR; PPP and RRR priority and reservation; M monitor bit; T token or data frame.
FC: frame control; if LLC data or control.
DA and SA: destination and source addresses.
FCS: frame check sequence.
ED: ending delimiter; contains the error detection bit E; contains frame continuation bit I (multiple frame transmissions).
FS: frame status.

Token frame
Token Ring Revisited

- Single priority: priority and reservation bits = 0.
- Transmitter seizes token.
  - Sets token bit to 1.
  - Token’s SD and AC are first 2 fields.
  - Station transmits 1 or more frames.
  - Until done or token-holding timer expires.
  - When AC of last frame returns, sets token bit to 0, appends ED: new token.
Detecting Errors

- Frame status bits (end delimiter).
  - A bit: address recognized.
  - C bit: frame copied.
    - A=0, C=0: destination non-existent or not active.
    - A=1, C=0: destination exists but frame not copied.
    - A=1, C=1: frame received.
Token Ring Priority

- Optional priority mechanism in 802.5.
- 3 priority bits: 8 priority levels.
- Service priority: priority of current token.
  - Station can only transmit frame with priority $\geq$ service priority.
  - Reservation bits allow station to influence priority levels trying to reserve next token.
Early Token Release

- Typically, station waits for frame to come back before issuing a new token.
- Problem: low ring utilization.
- ETR option:
  - Station may release token as soon as it completes transmission.
Ethernet versus Token Ring

- Token ring:
  - Efficient at heavy traffic.
  - Guaranteed delay.
  - Fair.
  - Supports priorities.
  - But, ring/token maintenance overhead.
    - Centralized monitoring.

- Ethernet is simple!
High-Speed LANs

- FDDI
- 100VG-AnyLAN
- Fast Ethernet
- Gigabit Ethernet
FDDI 1

- Fiber Distributed Data Interface.
- Similar to 802.5 with some changes due to higher data rates.
- 100Mbps, token ring LAN.
- Also suitable for MANs.
- Fiber or TP as transmission medium.
- Up to 100 repeaters and up to 2 Km (fiber) or 100m (TP) between repeaters.
FDDI 2

- Two counter-rotating fiber rings; only one used for transmission; the other for reliability, i.e., self-healing ring.
FDDI 3

DAS: dual attachment
SAS: single attachment
CON: concentrator
FDDI 4

- Basic differences to 802.5:
  - Station waiting for token, seizes token by failing to repeat it (completely removes it). Original 802.5 technique impractical (high data rate).
  - Station inserts new frame.
  - Early token release by default.
FDDI 5

- FDDI can also be implemented using twisted pair (copper): CDDI.
  - Cheaper.
  - 100m.
- THT: token holding time.
- TRT: token rotation time.