Outline

• Forward Error Correction (FEC)
• MAC Protocols
  – Channel Partitioning vs. Random Access Protocols
    • Aloha and Slotted Aloha
    • CSMA
    • CSMA/CD (Ethernet)
Forward Error Correction

• FEC is an error detection and error correction mechanism
  - Adds redundant information in the frame so the receiver can reconstruct the frame

• Which is better?
  - Go-Back-N
  - FEC
Space Communications Example
MAC Protocols

- Problem: How to share medium among multiple senders
- Different Solutions
  - Channel Partitioning (FDMA, TDMA, CDMA)
  - Taking Turns (Token Ring)
  - Random Access (Aloha, CSMA, CSMA/CD)
Goals of MAC Protocols

- MAC Protocols arbitrate access to a common shared channel among a population of users

- Goals
  - Fair among users
  - High efficiency
  - Low delay
  - Fault tolerant
**ALOHA**

- Packet radio network created by the University of Hawaii in the 70’s
  - Star topology
  - Two channels: Broadcast channel, Random Access channel

- Basic Idea:
  - Let a node transmit when it has data to send
  - If frame was destroyed then retransmit after a random period of time
    - Feedback about packet reception status is sent over the broadcast channel
ALOHA Efficiency

- **Assumptions**
  - Infinite number of users
  - Frame arrivals are modeled by a Poisson process with rate $\lambda$
  - Retransmissions can also be modeled by a Poisson process with rate $G > \lambda$
  - Throughput $S = GP_0$
    - $P_0 = $ probability frame does not suffer a collision
ALOHA: Collision Probability

- Frame $t_x$ time: $t$
- Vulnerable interval: $2t$
- Prob[$k$ frames generated]:
  $$\Pr[k] = \frac{G^k e^{-2G}}{k!}$$
- $P_0 = e^{-2G}$
- $S = Ge^{-2G}$
- Max throughput is 0.184 when $G=0.5$
Slotted ALOHA

- Time is divided into slots equal to the frame transmission time
  - Central station sends *clock tick* signal
  - Satellite stations are allowed to send only immediately after hearing clock tick
- Vulnerable time is equal to $t$
- Throughput $S = Ge^{-G}$ (max = 0.37, $G=1$)
- Expected number of retransmissions:

  \[ E = \sum_{k=1}^{\infty} kP_k = \sum_{k=1}^{\infty} ke^{-G} (1 - e^{-G})^{k-1} = e^G \]
Comparison
CSMA (Carrier Sense Multiple Access)

**CSMA:** listen before transmit:
- If channel sensed idle: transmit entire frame
- If channel sensed busy, defer transmission

- Human analogy: don’t interrupt others!
CSMA collisions

collisions *can still occur*: propagation delay means two nodes may not hear each other’s transmission

collision: entire packet transmission time wasted

note: role of distance & propagation delay in determining collision probability
CSMA Variants

• Persistent CSMA: Backlogged nodes will immediately transmit after channel becomes idle
  - Higher probability of collisions at high loads

• P-Persistent CSMA: If channel is idle transmit with probability $p$
  - Higher delay at low loads
Performance
CSMA/CD (Collision Detection)

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: receiver shut off while transmitting

• Human analogy: the polite conversationalist
CSMA/CD collision detection

collision detect/abort time

t₀

t₁

A B C D

space

CS 349/Fall05
Ethernet uses CSMA/CD

- 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
1. Adapter gets datagram from upper layer 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,\ldots,2^m-1\}. Adapter waits K*512 bit times and 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

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

• Assume: k stations, prob transmit = p
  Pr[node acquires channel] = A = kp(1 − p)^{k-1}
  \( p = \frac{1}{k}, A \to \frac{1}{e}, k \to \infty \)
  Pr[contention interval has j slots] = A(1 − A)^{j-1}
  \( \bar{w} = \frac{1}{A} \)
  mean contention interval = \( \frac{2\tau}{A} \)

\[
S = \frac{P}{P + 2\frac{\tau}{A}} \approx \frac{P}{P + 5.4\tau}
\]

Notation:
• L link length
• B link speed
• c speed of light
• F frame size
Efficiency as a function of $\tau$
Ethernet Frame Structure

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

**802.3**
- **Bytes:** 7 1 6 6 2 46-1500 0-46 4
- **Preamble**: 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
- **SFD**: used to synchronize receiver, sender clock rates

**Ethernet**
- **Bytes:** 7 1 6 6 2 2 1 3 2 38-1492 4

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

- **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
Ethernet Technologies: 10Base2

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

Repeater:
- 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
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!
Interconnecting LANs

- Bridges (aka Ethernet switches) were introduced to allow the interconnection of several local area networks (LANs) without a router.
- By partitioning a large LAN into multiple smaller networks, there are fewer collisions, and more parallel communications.
- It is now common for the port of an Ethernet switch to connect to just one (or a small number of) hosts.
An Ethernet Network

Problem:
- Shared network limits throughput.
- Lots of collisions reduces efficiency.
Ethernet Switching

Benefits:
- Number of collisions is reduced. If only one computer per port, no collisions can take place (each cable is now a self-contained point-to-point Ethernet link).
- Capacity is increased: the switch can forward multiple frames to different computers at the same time.
One Ethernet Switch
Not an atypical LAN (IP network)
1. Examines the header of each arriving frame.
2. If the Ethernet DA is in its table, it forwards the frame to the correct output port(s).
3. If the Ethernet DA is not in its table, it broadcasts the frame to all ports (except the one through which it arrived).
4. The table is learned by examining the Ethernet SA of arriving packets.
Switch learns that 'F' is reachable through port 5
Q: How do we prevent loops?
Perspective

- Ethernet is extremely successful
  - Low cost compared to FDDI, Token Ring
  - Key: Use same cabling infrastructure, framing

- Some issues
  - Nondeterministic Service
  - No priorities
  - Min frame size may be large