ISO OSI Reference Model for Layers

- Application
- Presentation
- Session
- Transport
- Network
- **Datalink**
- Physical

**Service:**
- Framing (attach frame separators)
- Send data frames between peers
- Others:
  - Arbitrate the access to common physical media
  - Per-hop reliable transmission
  - Per-hop flow control

**Media Access**
Up Until Now...

- Short-term contention is lossless:
  - Main resource (link bandwidth) is controlled by router
  - Router deals with short-term contention by queueing packets
  - Usually, centralized algorithms to resolve contention

- Have focused on managing long-term contention
  - Queueing schemes (FQ, FIFO, RED, etc.)
  - End-to-end congestion control (TCP)

This Lecture

- Short-term contention for media yields losses!

- Focus on networking over shared media
  - Ethernet
  - Short-range radio (e.g., wireless LANs)
  - Long-range radio (e.g., packet radio, satellite)

- AKA “multiple-access” problem
  - Don’t go through central router to get access to link
  - Instead, multiple users can access shared medium
  - Usually, decentralized algorithms to resolve contention
Approaches to Medium Access

- **Channel partitioning**
  - Divide channel into smaller “pieces” (e.g., time slots, frequency, code selection)
  - Allocate a piece to given node for exclusive use

- **Random access**
  - Allow collisions
  - “Recover” from collisions

- **“Taking-turns”**
  - Tightly coordinate shared access to avoid collisions

Problem Statement

- **Managing shared media**
  - If two users send at the same time, collision results in no packet being received (e.g., interference)
  - If no users send, channel goes idle
  - Thus, want to have only one user send at a time

- **Achieve high network utilization**
  - TDMA doesn't give high utilization

- **But also use a simple distributed algorithm**
  - No fancy token-passing schemes to avoid collisions
Focus of Lecture

- Understanding basic algorithmic choices
- Simple performance analysis
- Will not stress some practical details
  - Framing, packet formats, etc.

Where it all Started: AlohaNet

- Norm Abramson left Stanford in search of surfing
- Set up first radio-based data communication system connecting the Hawaiian islands
  - Hub at Alohanet HQ (Univ. Hawaii, Oahu)
  - Other sites spread among the islands
- Had two radio channels:
  - Random access: sites sent data on this channel
  - Broadcast: only used by hub to rebroadcast incoming data
Aloha Transmission Strategy

- When new data arrived at site, send to hub for transmission

- Site listened to broadcast channel
  - If it heard data repeated, knew transmission was rec’d
  - If it didn’t hear data correctly, it assumed a collision

- If collision, site waited \textit{random} delay before retransmitting

Simple, but Radical in Concept!

- Aloha is to multiple access what Internet is to telephony, i.e., revolutionary!

- Previous attempts all partitioned channel
  - TDMA, FDMA, CDMA, etc.

- Aloha optimized the common case (few senders) and dealt with collisions through retries
  - Sound familiar?
**Why Better than Time Slot Schemes?**

- In TDMA, you have to wait your turn
  - Delay proportional to number of participating sites

- In Aloha, can send immediately

- Aloha gives much lower delays, at the price of lower utilization (as we will see)

**Variation: Slotted Aloha**

- Divide time into slots
  - Requires some way to synchronize geographically distributed sites (non-trivial problem!)

- Contend for transmission only at the beginning of slots, never in the middle of slots

- Effect is to decreases chance of “partial collisions”
  - Twice as efficient as un-slotted Aloha. Why?
Performance of Slotted Aloha

- Time is divided into equal size slots (packet transmission time)
- Node with new arriving packet: transmit at beginning of next slot
- If collision: retransmit packet in future slots with probability $p$, until successful.

Success (S), Collision (C), Empty (E) slots

Efficiency of Slotted Aloha

- What is the maximum fraction of successful transmissions?
- Suppose $N$ stations have packets to send
  - Each transmits in slot with probability $p$
  - Probability of successful transmission $S$ is (very approximate analysis!):

  by a particular node $i$: $S_i = p (1-p)^{N-1}$

  by exactly one of $N$ nodes
  
  $S = \text{Prob (only one transmits)} = Np (1-p)^{N-1} \leq 1/e = 0.37$

  but must have $p$ proportional to $1/N$
**Ethernet**

- Bob Metcalfe, Xerox PARC, visits Hawaii and gets an idea!
- Shared medium (coax cable)
- Can “sense” carrier to see if other nodes are broadcasting at the same time
  - Sensing is subject to time-lag
  - Only detect those sending a short while before
- Monitor channel to detect collisions
  - Once sending, can tell if anyone else is sending too

---

**CSMA and CSMA/CD**

- Carrier sense multiple access: CSMA
  - Listen before you start sending

- CSMA with collision detect: CSMA/CD
  - Stop sending when you detect another station is sending
CSMA: Carrier Sense Multiple Access

- CS (Carrier Sense) implies that each node can distinguish between an idle and a busy link

- Sender operations:
  - If channel sensed idle: transmit entire packet
  - If channel sensed busy, defer transmission
    - Various retry algorithms

CSMA collisions

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

Collision:
etire packet transmission time wasted

Note:
role of distance and propagation delay in determining collision probability
CSMA/CD (Collision Detection)

- Collisions detected within short time
- Colliding transmissions aborted, reducing channel wastage
- This is relatively easy in wired LANs:
  - Measure signal strengths
  - Compare transmitted, received signals
- Difficult in wireless LANs
Ethernet Frame Structure

- Sending adapter encapsulates IP datagram

- 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, frame is received by all adapters on a LAN and dropped if address does not match
- Type: 2 bytes, indicates the higher layer protocol
  - E.g., IP, Novell IPX, AppleTalk
- CRC: 4 bytes, checked at receiver, if error is detected, the frame is simply dropped
- Data payload: maximum 1500 bytes, minimum 46 bytes
Ethernet’s CSMA/CD

- Sense channel, if idle
  - If detect another transmission
    - Abort, send jam signal
    - Delay, and try again
  - Else
    - Send frame

- Receiver accepts:
  - Frames addressed to its own address
  - Frames addressed to the broadcast address (broadcast)
  - Frames addressed to a multicast address, if it was instructed to listen to that address
  - All frames (promiscuous mode)

Ethernet’s CSMA/CD (more)

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

- Exponential back-off
  - 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 or more collisions, choose K from \{0,1,2,3,4,\ldots,1023\}
Minimum Packet Size

- Why put a minimum packet size?
- Give a host enough time to detect collisions
- In Ethernet, minimum packet size = 64 bytes (two 6-byte addresses, 2-byte type, 4-byte CRC, and 46 bytes of data)
- If host has less than 46 bytes to send, the adaptor pads (adds) bytes to make it 46 bytes
- What is the relationship between minimum packet size and the length of the LAN?

Minimum Packet Size (more)

a) Time = t; Host 1 starts to send frame

b) Time = t + d; Host 2 starts to send a frame just before it hears from host 1's frame

c) Time = t + 2*d; Host 1 hears Host 2's frame detects collision

LAN length = (min_frame_size)*(light_speed)/(2*bandwidth) =
= (8*64b)*(2.5*10^8mps)/(2*10^7 bps) = 6400m approx

What about 100 mbps? 1 gbps? 10 gbps?
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!

10BaseT and 100BaseT

- 10/100 Mbps rate; later called “fast ethernet”
- T stands for Twisted Pair
- Hub to which nodes are connected by twisted pair, thus “star topology”
10BaseT and 100BaseT (more)

- Max distance from node to Hub is 100 meters
- Hub can disconnect “jabbering” adapter
- Hub can gather monitoring information, statistics for display to LAN administrators

- Hubs still preserve one collision domain
  - Every packet is forwarded to all hosts
- Use bridges to address this problem
  - Bridges forward a packet only to the destination leading to the destination

GigaBit Ethernet

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

- Why not just one big LAN?
  - Limited amount of supportable traffic: on single LAN, all stations must share bandwidth
  - Limited length
  - Large “collision domain” (can collide with many stations)

Family of Backoff Algorithms

- Use slotted transmission scheme
  - Carrier sense is irrelevant in slotted model

- When experience $k^{th}$ collision for a particular packet, send packet with probability $1/f(k)$ in each successive slot (until transmitted)

- Ethernet uses $f(k)=2^k$ (with a bound on $k$)
WiFi (802.11)

- Designed for use in limited geographical area (i.e., couple of hundreds of meters)

- Designed for three physical media (run at either 1Mbps or 2 Mbps)
  - Two based on spread spectrum radio
  - One based on diffused infrared

Ethernet vs 802.11

- Ethernet: one shared “collision” domain

- 802.11: radios have small range compared to overall system: collisions are local
  - Collisions are at receiver, not sender
  - Carrier-sense plays different role

- CSMA/CA not CSMA/CD
  - Collision avoidance, not collision detection
Collision Avoidance: The Problems

- Reachability is not transitive: if A can reach B, and B can reach C, it doesn’t necessarily mean that A can reach C.

- Hidden nodes: A and C send a packet to B; neither A nor C will detect the collision!

- Exposed node: B sends a packet to A; C hears this and decides not to send a packet to D (despite the fact that this will not cause interference).

Multiple Access with Collision Avoidance (MACA)

- Before every data transmission
  - Sender sends a Request to Send (RTS) frame containing the length of the transmission
  - Receiver responds with a Clear to Send (CTS) frame
  - Sender sends data
  - Receiver sends an ACK; now another sender can send data

- When sender doesn’t get a CTS back, it assumes collision
Other Nodes

- When you hear a CTS, you keep quiet until scheduled transmission is over (hear ACK)

- If you hear RTS, but not CTS, you can send
  - Interfering at source but not at receiver is ok
  - Can cause problems when a CTS is interfered with

Summary

- Problem: arbitrate between multiple hosts sharing a common communication media

- Wired solution: Ethernet (use CSMA/CD)
  - Detect collisions
  - Backoff exponentially on collision

- Wireless solution: 802.11 (CSMA/CA)
  - Use MACA protocol
  - Cannot detect collisions; try to avoid them
  - Distribution system & frame format in discussion sections
What You Need to Know

- Basics of Aloha and Ethernet contention algorithms
- Basics of 802.11 contention algorithm