CS4450

Computer Networks: Architecture and Protocols

Lecture 6
Data Link Layer

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Announcements

• Exam 1 on 09/21
  • Material: everything covered until Wed lecture
    • Slides, Problem set 1, Problem set 2 (up to Question 4)
  • Infinite time, should be doable in ~90 minutes
  • Open-notes, open-book, open-Internet, open-everything, except...
  • Talking to any human or alien

• Exam structure
  • Several conceptual questions
  • Several “problems” (e.g., Q1 and Q2 on pset 2 were in past exams)

• For all those who declared their conflicts
  • We have already sent an email; please respond by tomorrow
  • If we missed you, meet me after the lecture today
Announcements

LOST sessions

• There seems to be some confusion

• LOST sessions should not be your “first” option
  • Not meant to provide you with exclusive TAs all the time

• Office hours and Ed Discussions are your first options
  • If you are still feeling LOST, then ask for one

• When you send a request for the LOST session
  • Tell us what you have tried before requesting a session

• As noted on the website, no LOST sessions 1 week prior to exams
Context for Today’s Lecture

• You now understand
  • Network sharing (in depth)
  • Architectural principles (in depth)
  • Design goals for the Internet (& computer networks, in depth)
  • End-to-end working of the Internet (at a high-level)

• Now, time to dive deeper:
  • Link Layer (~1 week)
  • Network Layer (~4 weeks)
  • Transport Layer (~3 weeks)

• Today: Link layer
Goals for Today’s Lecture

- Link layer:
  - Broadcast medium
  - Sharing broadcast medium
  - Carrier Sense Multiple Access - Collision Detection (CSMA/CD)
Data Link Layer
Two types of communication mediums

- **Point-to-point**
  - The high-level ideas discussed so far were for point-to-point
- **Broadcast**
  - Original design of Link layer protocols
  - More recent versions have moved to point-to-point
    - We will discuss why so!

**Network Adapters (e.g., NIC — network interface card)**

- The hardware that connects a machine to the network
- Has a “name” — MAC (Medium access control) address
Point-to-Point vs. Broadcast Medium

- **Point-to-point**: dedicated pairwise communication
  - E.g., long distance fiber link
  - E.g., Point-to-point link between two routers

- **Broadcast**: shared wire or medium
  - Traditional Link Layer (Ethernet)
  - 802.11 wireless LAN
Data Link Layer: Broadcast (until ~2000s)

- Ever been to a party?
  - Tried to have an interesting discussion?
- Fundamental challenge?
  - Collisions
Broadcast Medium: Desirable properties

- One and only one: data delivery
- How do we design a broadcast medium protocol for data delivery?

source

NIC  NIC

link-layer “protocol”

destination

NIC
Where it all Started: AlohaNet

- **Norm Abramson:**
  - Left Stanford in 1970
  - So he could SURF
  - Set up first data communication system for Hawaiian islands
  - Central hub at University of Hawaii, Oahu
Aloha Signaling

- Two channels: random access, broadcast

- Sites send packets to hub
  - Random access channel
  - Each site transmits packets at “random” times
  - If a packet not received (due to collision), site resends

- Hub sends packets to all sites
  - Broadcast channel
  - Sites can receive even if they are also sending

- **Challenge: Requires a centralized hub**
  - If the hub fails, the entire network fails
  - Not always a good design (remember the design goals?)
Sharing a broadcast channel

- **Context:** a shared broadcast channel
  - Must avoid/handle having multiple sources speaking at once
  - Otherwise collisions lead to garbled data
  - Need **distributed algorithm** for sharing channel
  - Algorithm determines **when** and **which** source can transmit

- **Three classes of techniques**
  - **Frequency-division multiple access:** divide channel into pieces
  - **Time-division multiple access:** divide channel into time slots
  - **Random access:** allow uncoordinated access
    - Detect collisions, and if needed, recover from collisions
    - More in the Internet style!
Frequency-Division Multiple Access (FDMA)

- Frequency sharing
  - Divide the channel into frequencies
  - Every source is assigned a subset of frequencies
    - And transmits data only on its assigned frequency

- Goods: no collisions

- Not-so-good:
  - A source may have nothing to send (frequency wasted)
  - Interference may cause disruption
  - Hard to implement for wired networks

- Used in many wireless networks
  - E.g., radio
Time-Division Multiple Access (TDMA)

- **Time sharing**
  - Divide time into *slots*
  - Divide data into *frames*
    - Such that a frame can be transmitted in one slot
  - **Every source is assigned a subset of slots**
    - And transmits a frame only in its assigned slot

- **Goods: no collisions**

- **Not-so-good: Underutilization of resources**
  - During a slot, a source may have nothing to send
  - When the source has something to send, wait for its slot
Random Access

- **Bob Metcalfe:**
  - Xerox PARC
  - Visits Hawaii, and gets the idea
  - Shared wired medium
Life lesson:
If you want to invent great things,
go to Hawaii :-}
Link Layer (Media Access Control, or MAC) Protocol

- When source has a frame to send
  - Transmit at full bandwidth
  - No a priori coordination among nodes

- Two or more transmitting sources => collision
  - Frame lost

- Link-layer protocol specifies:
  - How to detect collision
  - How to recover from collisions
LETS TRY!

Multiple source-destination pairs
Design a protocol that allows sharing the broadcast medium

source1
Adapter

source2
Adapter

destination
Adapter

link-layer “protocol”
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!

- Does this eliminate all collisions?
  - **No,** because of nonzero propagation delay

- Solution:
  - Include a **Collision Detection (CD)** mechanism
  - If a collision detected
    - Retransmit
CSMA/CD (Carrier Sense Multiple Access, Collision Detection)

- CSMA/CD: carrier sensing
  - Collisions detected within short time
  - Colliding transmissions aborted, reducing wastage

- Collision detection easy in wired (broadcast) LANs
  - Compare transmitted and received signals

- Collision detection difficult in wireless LANs
Once a collision is detected ... 

- **When should the frame be resent?**

- Immediately?
  - Every NIC would start sending immediately
  - Collision again!

- Take turns?
  - Back to time division multiplexing
CSMA/CD in one slide!

- **Carrier Sense**: continuously listen to the channel
  - If idle: start transmitting
  - If busy: wait until idle

- **Collision Detection**: listen while transmitting
  - No collision: transmission complete
  - Collision: abort transmission; send jam signal

- **Random access**: exponential back off
  - After collision, transmit after “waiting time”
  - After k collisions, choose “waiting time” from \( \{0, \ldots, 2^{k-1}\} \)
  - Exponentially increasing waiting times
  - But also, exponentially larger success probability
CSMA/CD (Collision Detection): An example

Attempt 1: Suppose a collision happens

Attempt 2: Four possibilities
Success with Probability = 0.5
What is the success probability in attempt 3?

Answer: 0.75
Performance of CSMA/CD

• Time spent transmitting a frame (collision)
  • Proportional to distance $d$; why?

• Time spent transmitting a frame (no collision)
  • Frame length $p$ divided by bandwidth $b$

• Rough estimate for efficiency ($K$ some constant)

\[
E \sim \frac{p}{b + Kd}
\]

• Observations:
  • For large frames AND small distances, $E \sim 1$
  • Right frame length depends on $b$, $K$, $d$
  • As bandwidth increases, $E$ decreases
    • That is why high-speed LANs are switched
Evolution

- **Ethernet was invented as a broadcast technology**
  - Hosts share channel
  - Each packet received by all attached hosts
  - CSMA/CD

- **Current Ethernets are “switched” (next lecture)**
  - Point-to-point medium between switches;
  - Point-to-point medium between each host and switch
  - No sharing, no CSMA/CD