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

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!

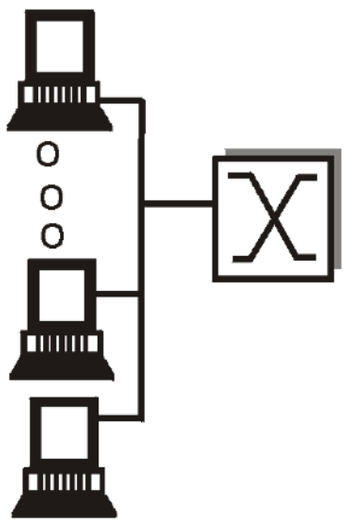
- **Network Adapters (e.g., NIC — network interface card)**
    - The hardware that connects a machine to the network
    - Has a “name” — MAC (Medium access control) address



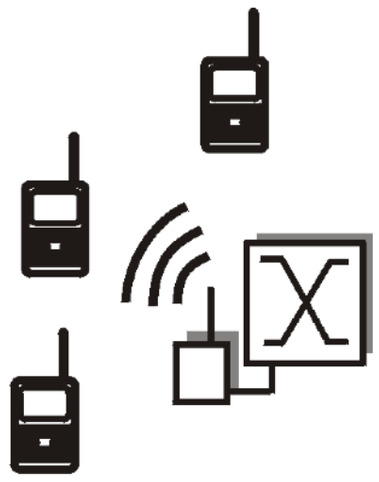
Point-to-Point vs. Broadcast Medium

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

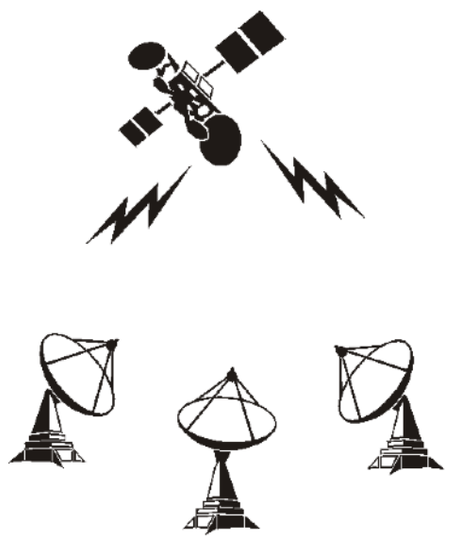
- Broadcast: **shared** wire or medium
    - Traditional Link Layer (Ethernet)
    - 802.11 wireless LAN



shared wire
(e.g. Ethernet)



shared wireless
(e.g. Wavelan)



satellite

cocktail party

Data Link Layer: Broadcast (until ~2000s)

- **Ever been to a party?**
    - Tried to have an interesting discussion?
- **Fundamental challenge?**
    - **Collisions**

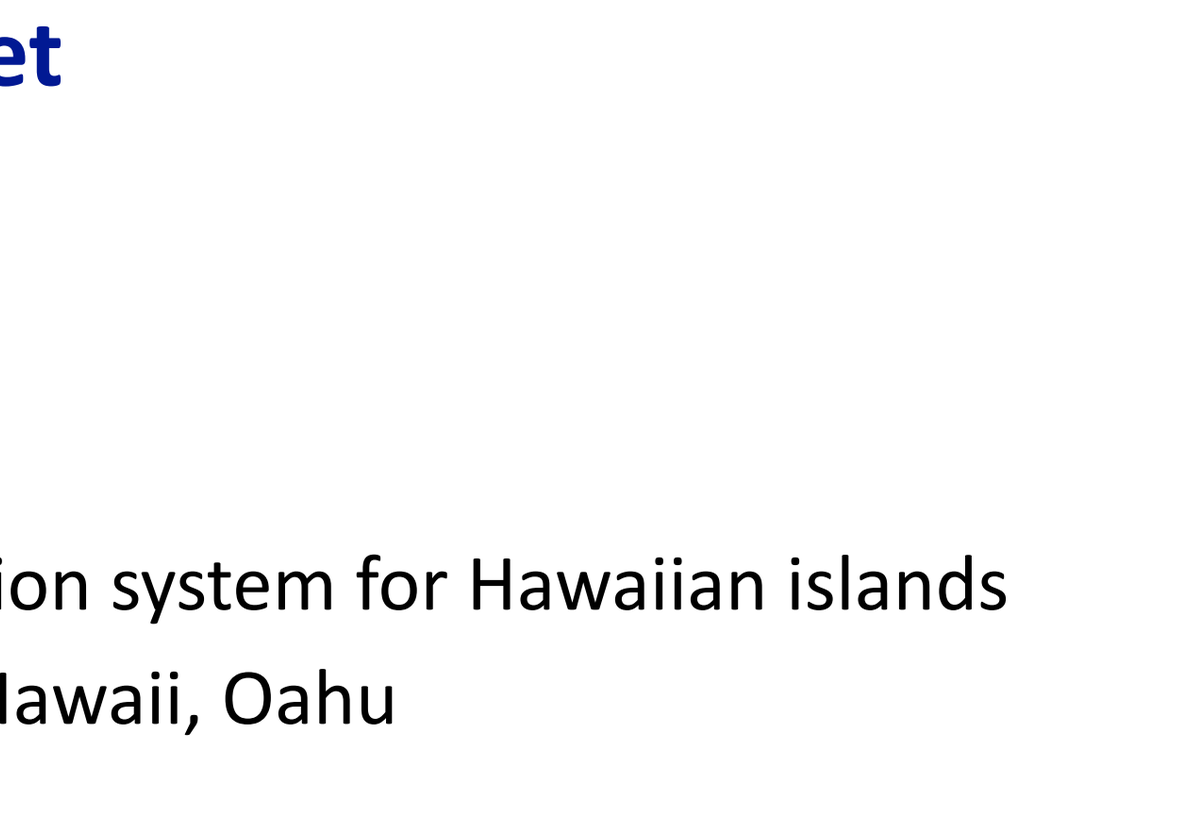
Broadcast Medium: Desirable properties

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

link-layer “protocol”

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)

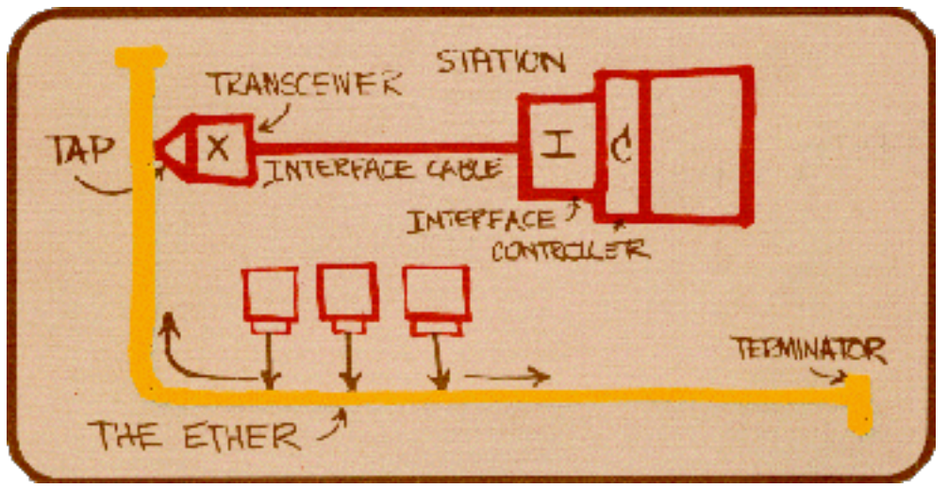
- **Time sharing**
    - Divide time into **slots**
    - Divide data into **frames**
        - Such that a frame can be transmitted in one slot
    - **Every source is assigned a subset of slots**
        - And transmits a frame only in its assigned slot

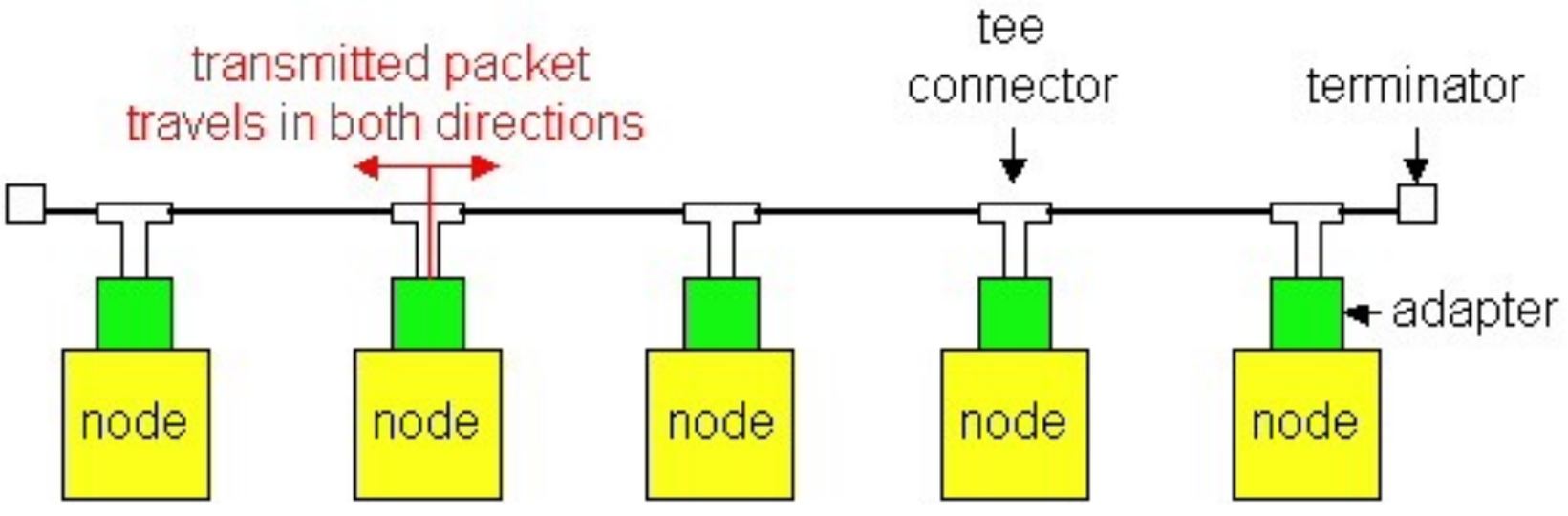
- **Goods: no collisions**

- **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 :-)

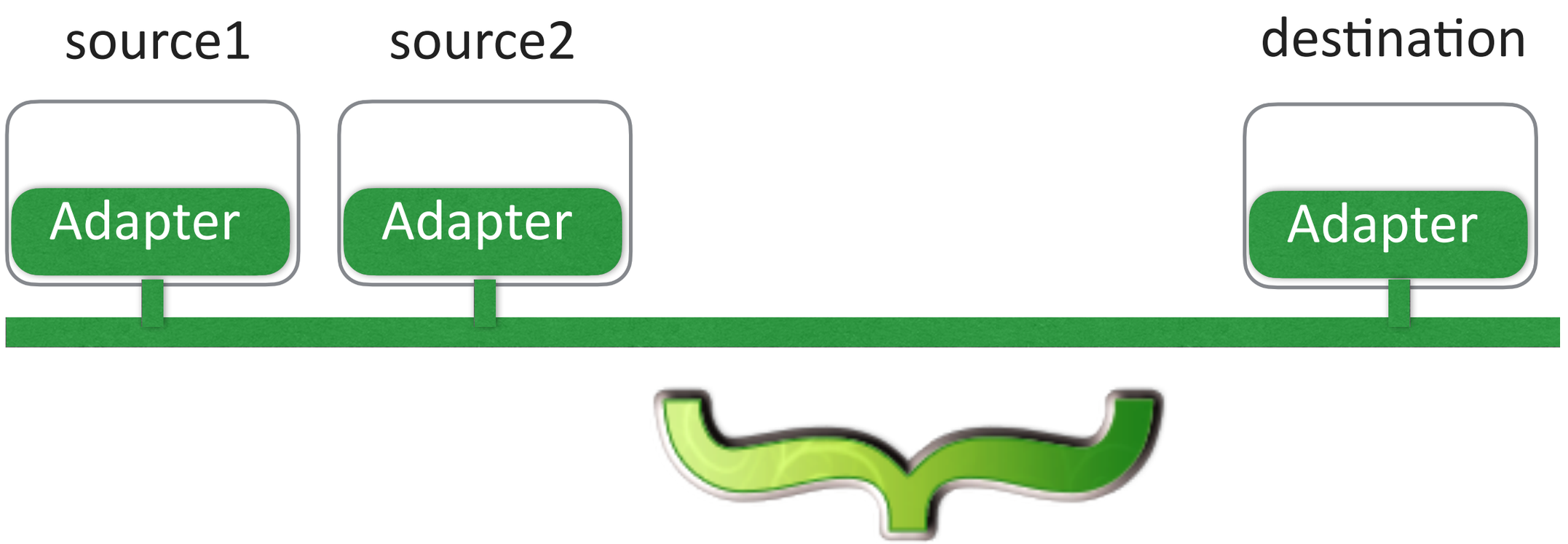
Link Layer (Media Access Control, or MAC) Protocol

- **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

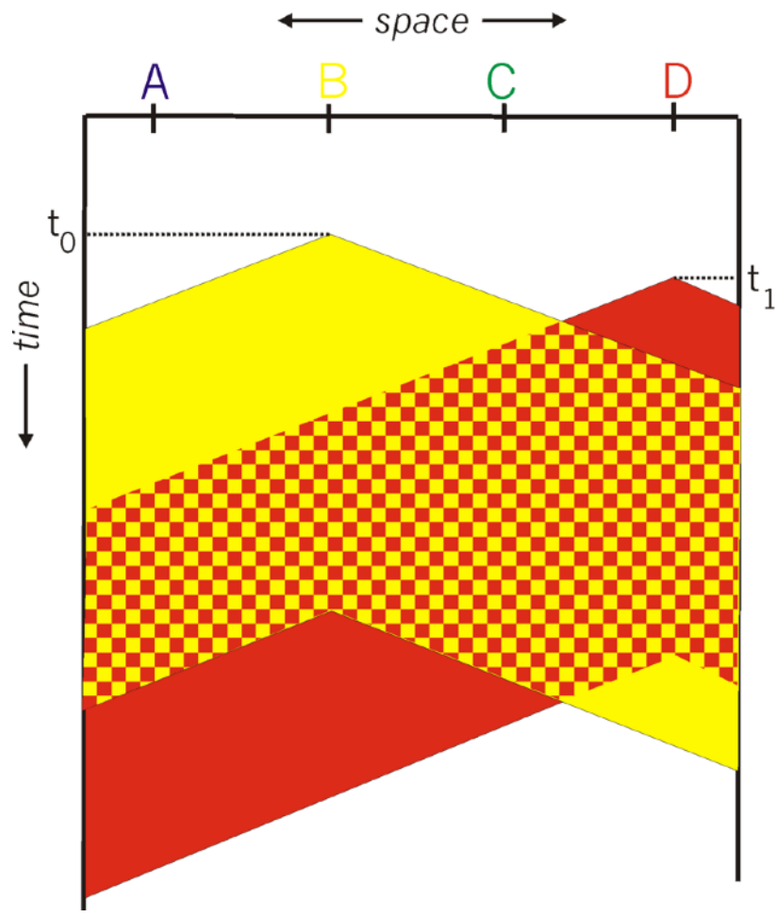
Design a protocol that allows sharing the broadcast medium



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?**

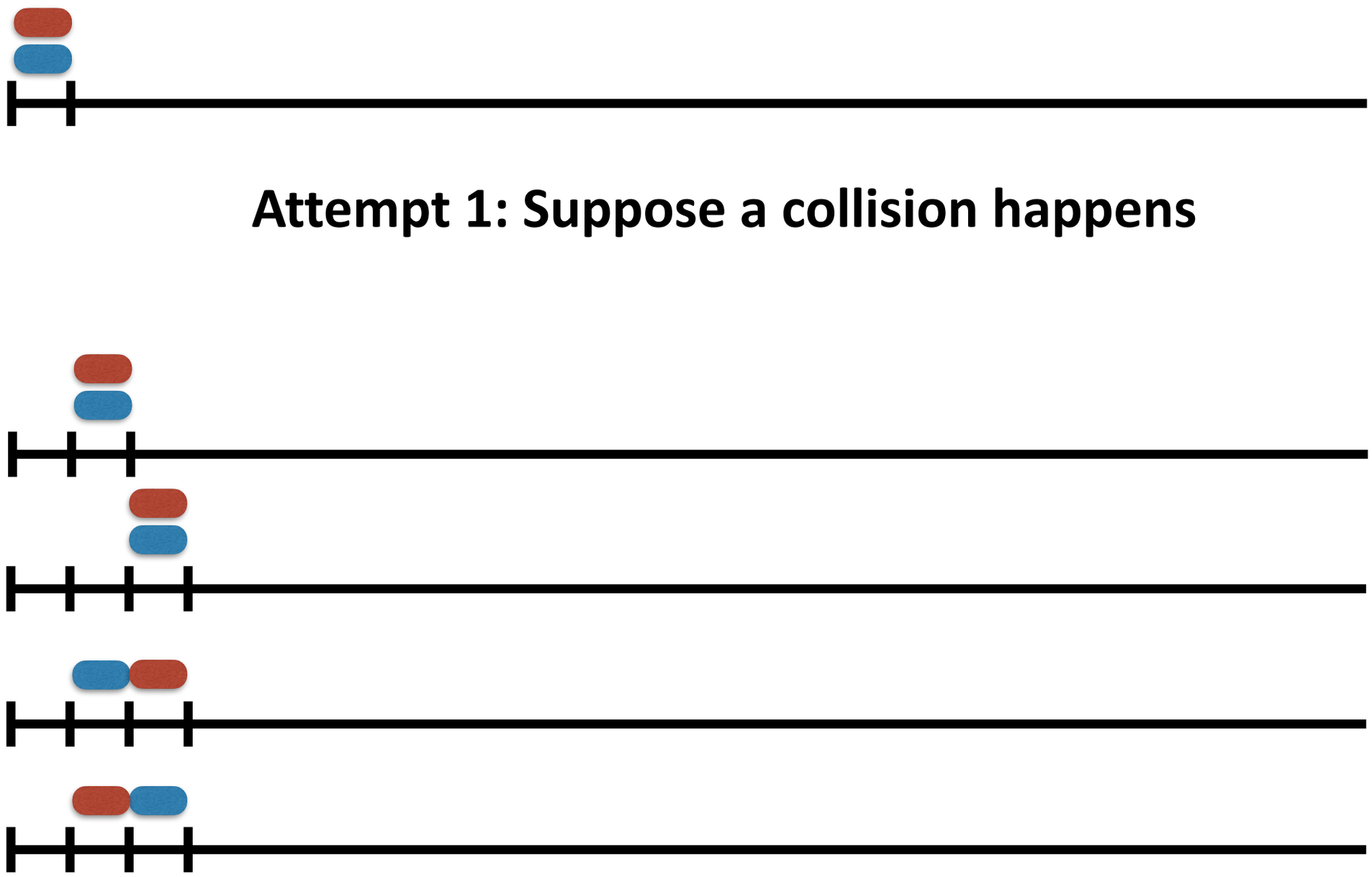
- Immediately?
    - Every NIC would start sending immediately
    - Collision again!

- 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)**

$$E \sim \frac{\frac{p}{b}}{\frac{p}{b} + Kd}$$

- Observations:
  - For large frames AND small distances, E ~ 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