Outline

- Lecture review:
  - Link layer

Link layer: introduction

- understand principles behind link layer services:
  - data framing
  - error detection, correction — CRC (cyclic redundancy check)
  - sharing a broadcast channel: multiple access
  - link layer addressing
- local area networks: Ethernet, VLANs

Delivering packet at link layer

- Basic communication models
  - Unicast
  - Broadcast
  - Multicast
- What, how, why?

Broadcast

- Replicate at source, or in-network
- Flooding (FYI)
  - Reverse path forwarding (RPF)
  - Spanning tree

Multicast (FYI)

- Address range
  - class-D IP: 224.0.0.0 — 239.255.255.255
- Protocols:
  - IGMP
  - DVMRP, PIM

Medium Access Links and Protocols

- Two types: point-to-point, broadcast
- **Broadcast** channel shared by multiple hosts
  - What if we only have unicast channel?
  - What's the pros and cons for a broadcast channel?
- Three classes of Multiple Access Control (MAC) protocols
  - Channel partitioning: FDMA, TDMA, CDMA
  - Random access: Aloha, CSMA/CD, Ethernet
  - Taking turns: Token ring/passing
  - **Pros and cons for each class of protocol?**

Random access: slotted ALOHA

- Assumptions:
  - all frames same size
  - time divided into equal size slots (time to transmit 1 frame)
  - nodes start to transmit only slot beginning
  - nodes are synchronized
  - if 2 or more nodes transmit in slot, all nodes detect collision

Random access: slotted ALOHA

- suppose: N nodes with many frames to send, each transmits in slot with probability p
- Pr(given node has success in a slot) = p(1-p)^(N-1)
- Pr(any node has a success) = Np(1-p)^(N-1)
- max efficiency: find p* that maximizes Np(1-p)^(N-1)
- Take the limit of Np*(1-p*)^(N-1) as N goes to infinity, yields:
    - max efficiency = 1/e = .37

Random access: ALOHA efficiency

- Slotted ALOHA max efficiency = 1/e = .37
- Unslotted ALOHA max efficiency = 1/2e = .18

Quick question

- Consider a network with four nodes using slotted ALOHA. The probability that any node transmits is p at a given time.
- What is the probability that four nodes are transmitting?
- What is the probability that a specific node succeed to transmit a frame?
  - P[4 nodes transmit] = p^4 (1-p)^5
  - P[a specific node succeed] = p(1-p)^8

CSMA (carrier sense multiple access)

- Listen before transmit:
  - if channel sensed idle: transmit entire frame
  - if channel sensed busy, defer transmission
  - “don’t interrupt others!”
- Channel busy?
  - 1-persistent CSMA: retry immediately
  - p-persistent CSMA: retry immediately with probability p
  - Non-persistent CSMA: retry after a random interval
- Collision?
  - hidden terminal problem

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: received signal strength overwhelmed by local transmission strength

CSMA/CD (collision detection)

- A: sense channel, wait if necessary, when channel is idle, transmit and monitor the channel
- If detect collision then {
  - abort and send jam signal;
  - update collision-count (n++);
  - delay for K slots (1 slot = 512bits transmission time) goto A
    - **chooses *K* at random from {*0,1,2, …, 2^m-1*}.**
- } else {finish sending the frame; reset collision-count (n = 0)}
- collision detection: compare transmitted, received signal strengths

Quick question

- Consider two nodes trying to transmit frames at the same time t=0 with CSMA/CD. Suppose link rate is 512kb/s. Propagation delay is negligible. Assume delay in collision detection / aborting transmission is t0.
- What is the probability that two nodes both fail to transmit at time t=t0?
- How long would node 1 to wait at maximum after second collision?

Quick question

- What is the probability that two nodes both fail to transmit at time t=t0?
  - Both detect collision at t=0. Then at t=t0, each node transmit with probability ½.
  - P[two node both fail] = 1/4
- How long would node 1 to wait at maximum after second collision?
  - Transmission delay for 512 bits = 1ms
  - Waiting time at maximum (2^2-1) * 1ms = 3ms

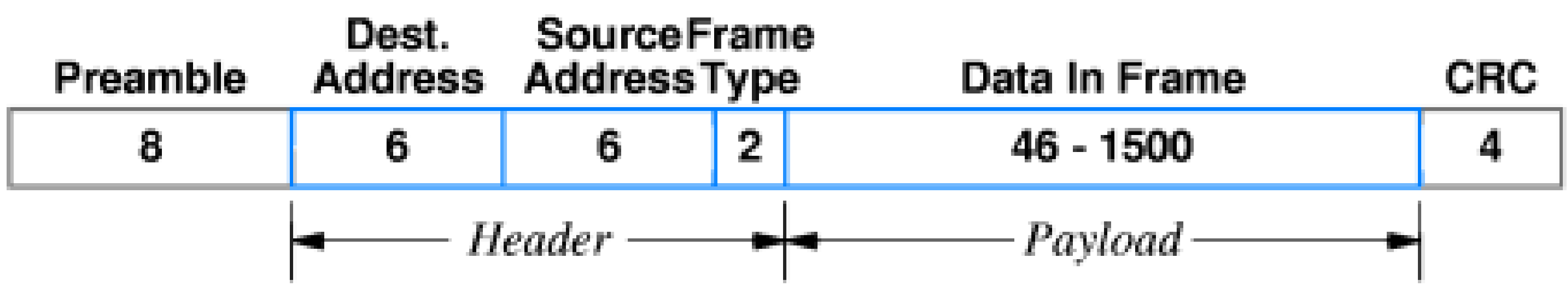
Ethernet

- Connectionless and unreliable protocol
  - Why doesn't Ethernet provide reliable data transfer?
- MAC protocol: CSMA/CD + exponential backoff
  - Can we use CSMA/CD in wireless network?
- Switch-based Ethernet
  - No real broadcast channel anymore
  - Self-learning algorithm: support plug-and-play
    - **Differences between routing table, switch table and ARP table?**

MAC address

- MAC address allocation by IEEE (who assigns IP?)
- MAC address is flat -> portability (IP address is ___?)
- Format: 48 bit address
  - AA-BB-CC-DD-EE-FF
  - Broadcast address: FF-FF-FF-FF-FF-FF

Ethernet Frame



- Min frame size: 64 Bytes
  - why? (to reliably detect collisions)
- Max frame size: 1514 Bytes
  - why? (to fair share the media)

Ethernet CSMA/CD

- 1. NIC receives datagram from network layer, creates frame
- 2. If NIC senses channel idle, starts frame transmission. If NIC senses channel busy, waits until channel idle, then transmits.
- 3. If NIC transmits entire frame without detecting another transmission, NIC is done with frame !
- 4. If NIC detects another transmission while transmitting, aborts and sends jam signal
- 5. After aborting, NIC enters binary exponential backoff:

Switch

- Examine each incoming frame’s MAC address, forward to the destination LAN if dest. host is on a different LAN
- store-and-forward
- switch table: self-learning algorithm
    - (MAC address of host, interface to reach host, timestamp)

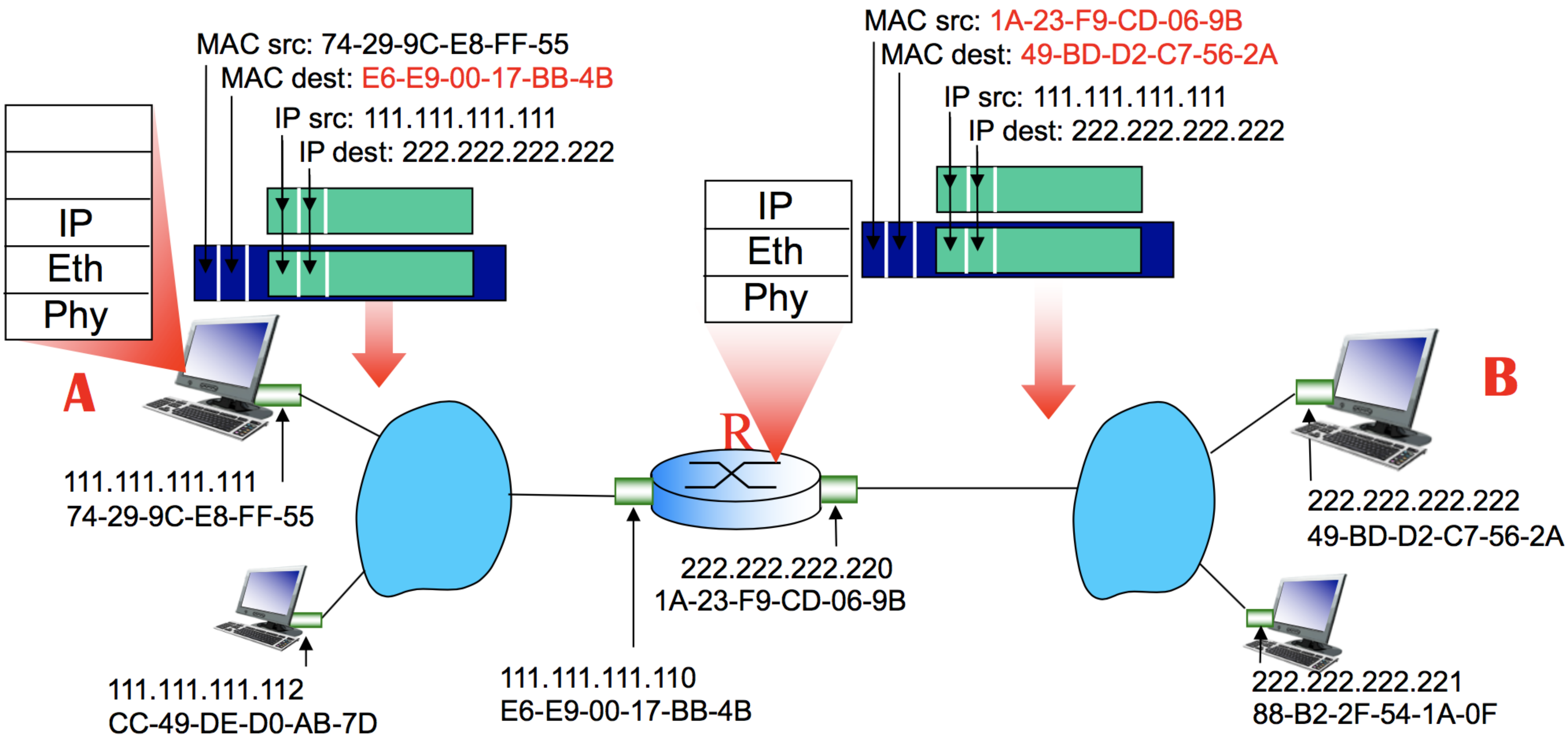
ARP: address resolution protocol

- How to determine interface’s MAC address, knowing its IP address?
- ARP table: each IP node (host, router) on LAN has table
    - IP/MAC address mappings for some LAN nodes:
    - <IP address; MAC address; TTL>
    - called PnP (plug-and-play)
    - soft-state design: information deletes itself after certain time unless being refreshed

ARP: send an IP packet in the same subnet

- A wants to send IP packet to B, but B’s MAC address not in A’s ARP table.
- A broadcasts ARP query packet, containing B's IP address (all nodes on LAN receive ARP query)
  - dest MAC address = FF-FF-FF-FF-FF-FF
- B receives ARP packet, replies to A with its (B's) MAC address
  - frame sent to A’s MAC address (unicast)
- A caches IP-to-MAC address pair in its ARP table until information becomes old (times out)

ARP: send an IP packet across subnets



ARP: send an IP packet across subnets

- Find an entry in the **routing table**
- If entry is saying that packet can be sent directly
  - Lookup MAC for destination IP in **ARP table**
- If entry is saying that packet should be set to the gateway
  - Lookup MAC for the gateway's IP in **ARP table**
- Create frame with the found MAC and original IP packet as a payload
- Send the frame

ARP: send an IP packet across subnets (cont’d)

- Router or node receives the frame, as it is destined to it
- Router removes Ethernet header, finds IP destination address
  - If IP is itself, deliver to transport layer and higher layers
  - If IP is not self and node is router, repeat the previous steps (lookup routing table, lookup ARP, ...)

Router vs. Switch

- Both are store-and-forward devices
  - routers: network layer devices (examine IP headers)
  - switches: link layer devices (examine Ethernet headers)
- Circuit-switch network: connection should be established before forwarding the data
  - At each hop, the circuit path is marked as a label
  - Data forwarding is based on label: **O(1) complexity**
  - **Vulnerable to link/node failures**
- Packet-switched network: connectionless, packets are forwarded based on IP header
  - Longest prefix matching: **O(N) complexity**
  - **Robust to link/node failures**
- **Can we take advantage of both, while preventing any vulnerabilities?**

Tables we learnt

- Routing table
- Forward table
- ARP table

Network devices

- Repeater: PHY layer
  - bits coming in one link go out all other links at same rate
- Hub: link layer
  - packets coming in one port/link, go out all other ports/links
- Switch: link layer