CS 43: Computer Networks

24:Link Layer - Ethernet

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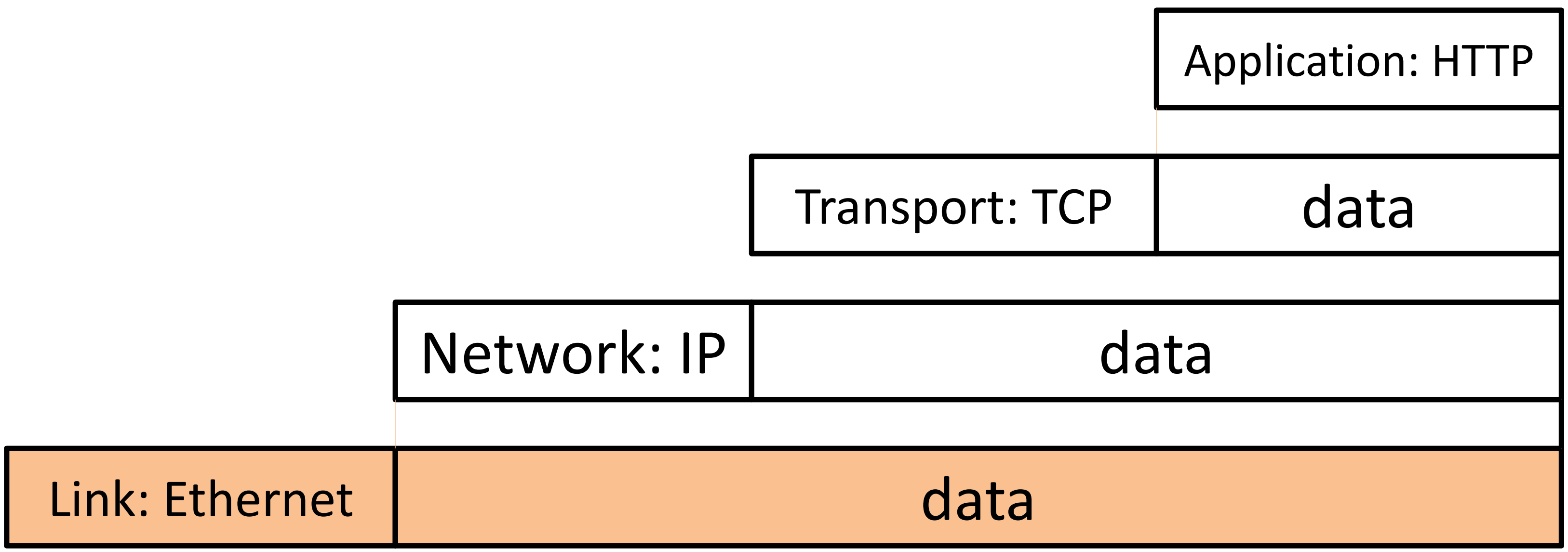
SWARTHMORE COLLEGE

Reading Quiz

Link Layer

- Function: Addressing, Framing, Media Access



Last Class

- The link layer provides lots of functionality:
  - addressing, framing, media access, error checking
  - could be used independently of IP!
  - typically only small scale
- Many different technologies out there.
  - copper wires, optics, wireless, satellite
  - differing challenges for each

An ideal multiple access protocol…

Given: broadcast channel of rate R bps

1. if only one node wants to transmit, it can send at rate R.
2. when M nodes want to transmit, each can send at average rate R/M (fairness)
3. fully decentralized:
   - no synchronization of clocks, slots
   - no special node to coordinate transmissions
4. simple

Media Access Control (MAC) Strategies

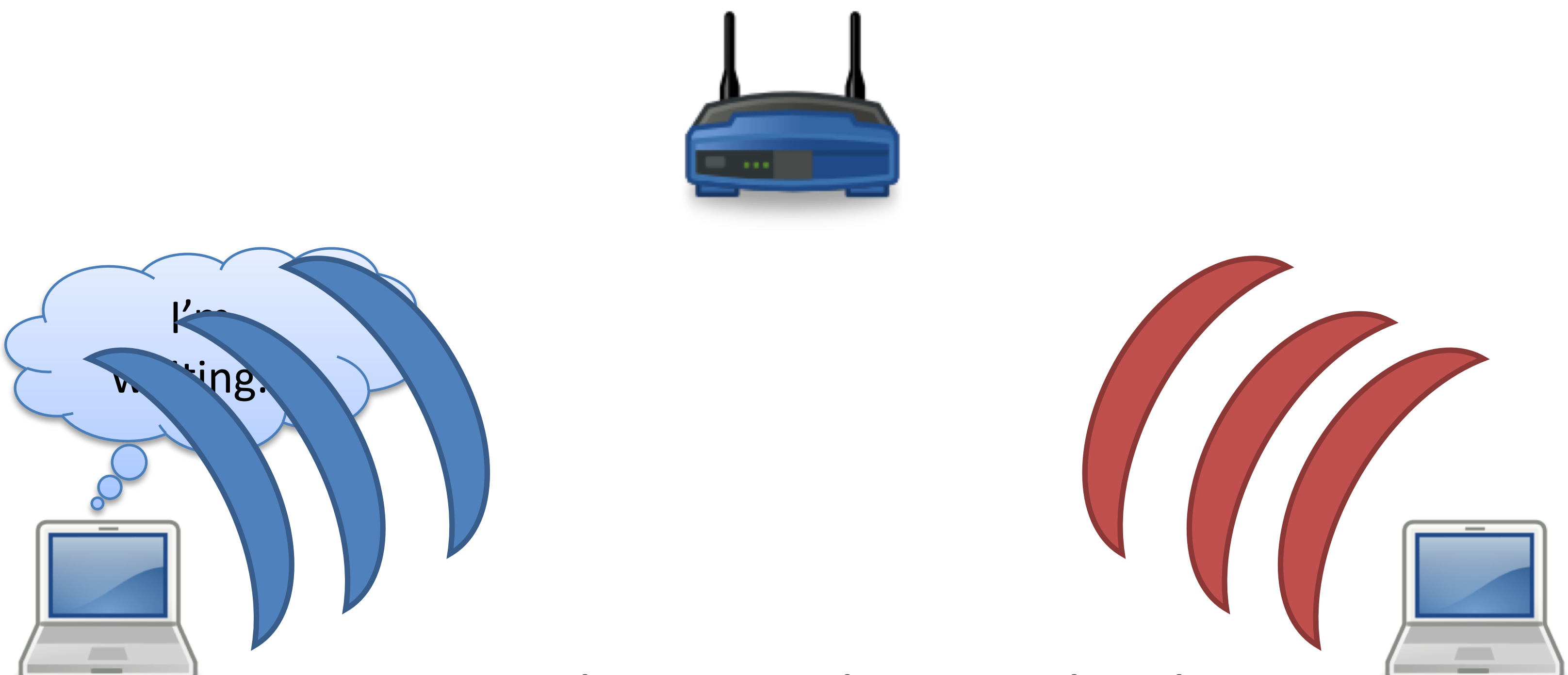
- channel partitioning
  – divide channel into smaller "pieces" (time slots, frequency, code)
  – allocate piece to node for exclusive use
- random access
  – channel not divided, allow collisions
  – "recover" from collisions
- taking turns
  – nodes coordinate with one another to take turns, share channel

In Practice…

- Techniques often combined.
  - Example: DOCSIS: Data Over Cable Service Interface Specifications: Cable Modem – Cable Provider
  - Frequency division of channels
  - TDMA Upstream with bandwidth contention (random access) requests by cable modems
- What about wireless Ethernet?
  - Old joke: "I don't know what the next link layer technology will look like, but I'm sure it will be named Ethernet."

WiFi (802.11)

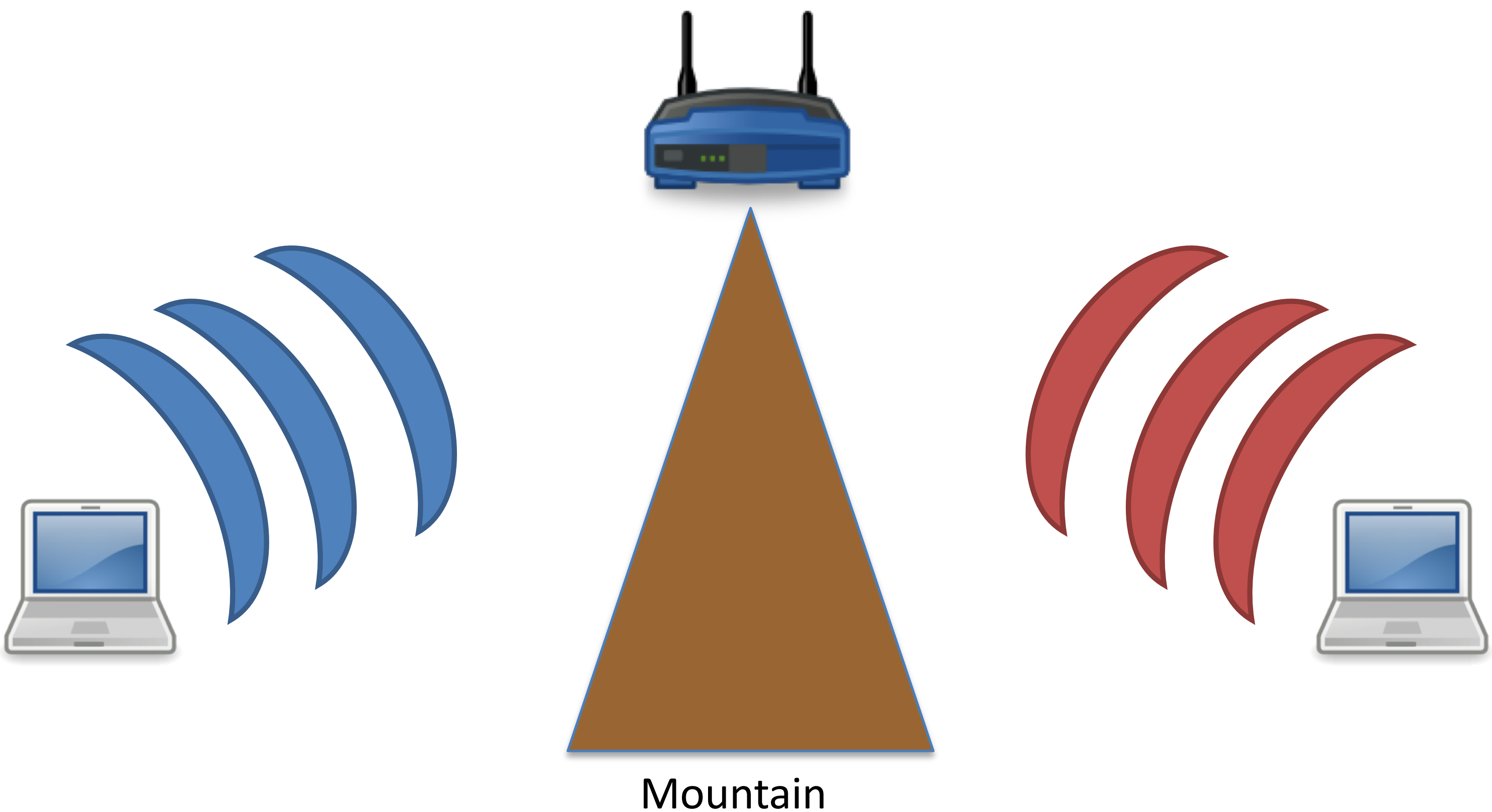
- Senders do carrier sensing like Ethernet.



Assumes hosts can hear each other!

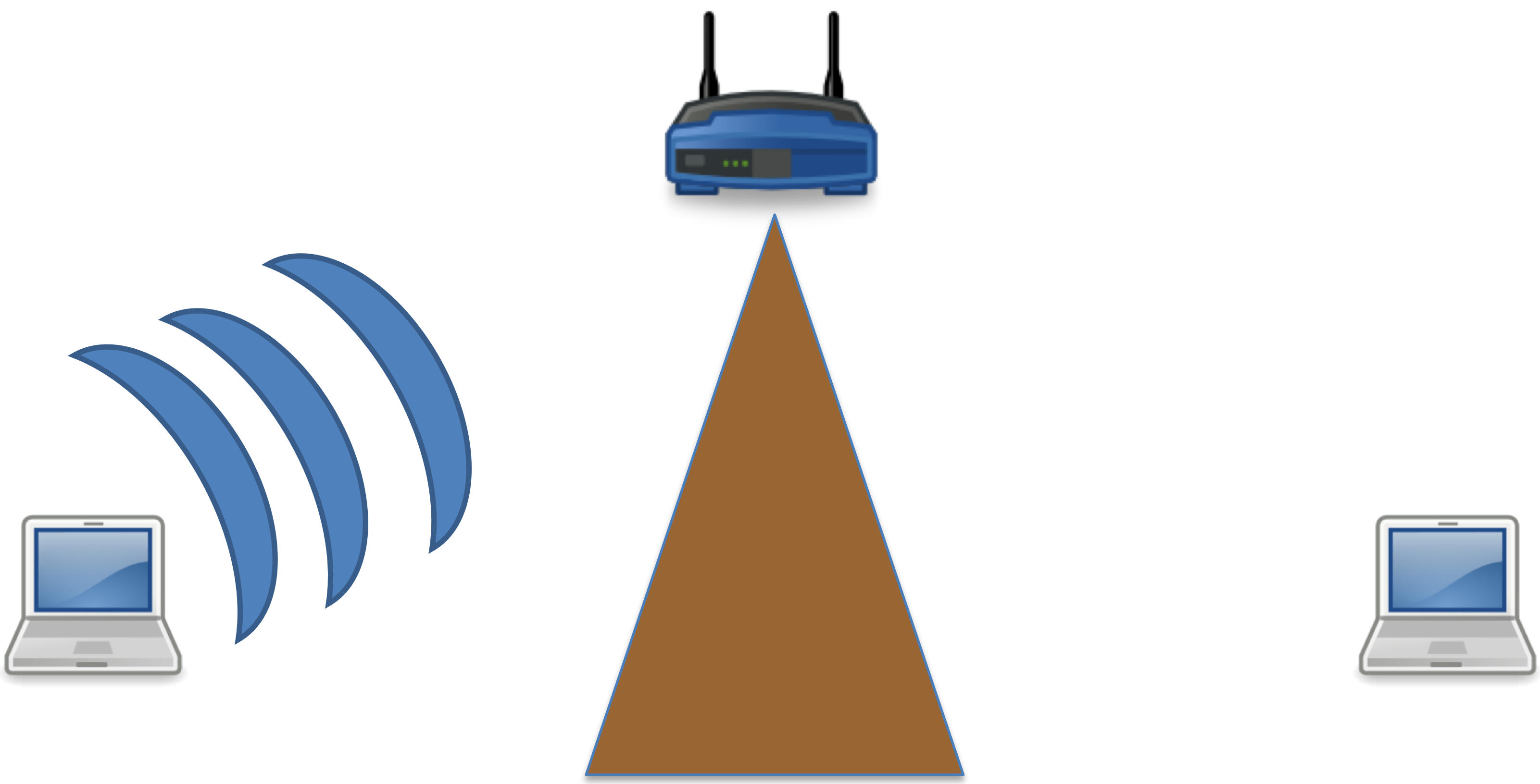
"Hidden Terminal" Problem

- Senders collide at receiver, but they can't hear each other!



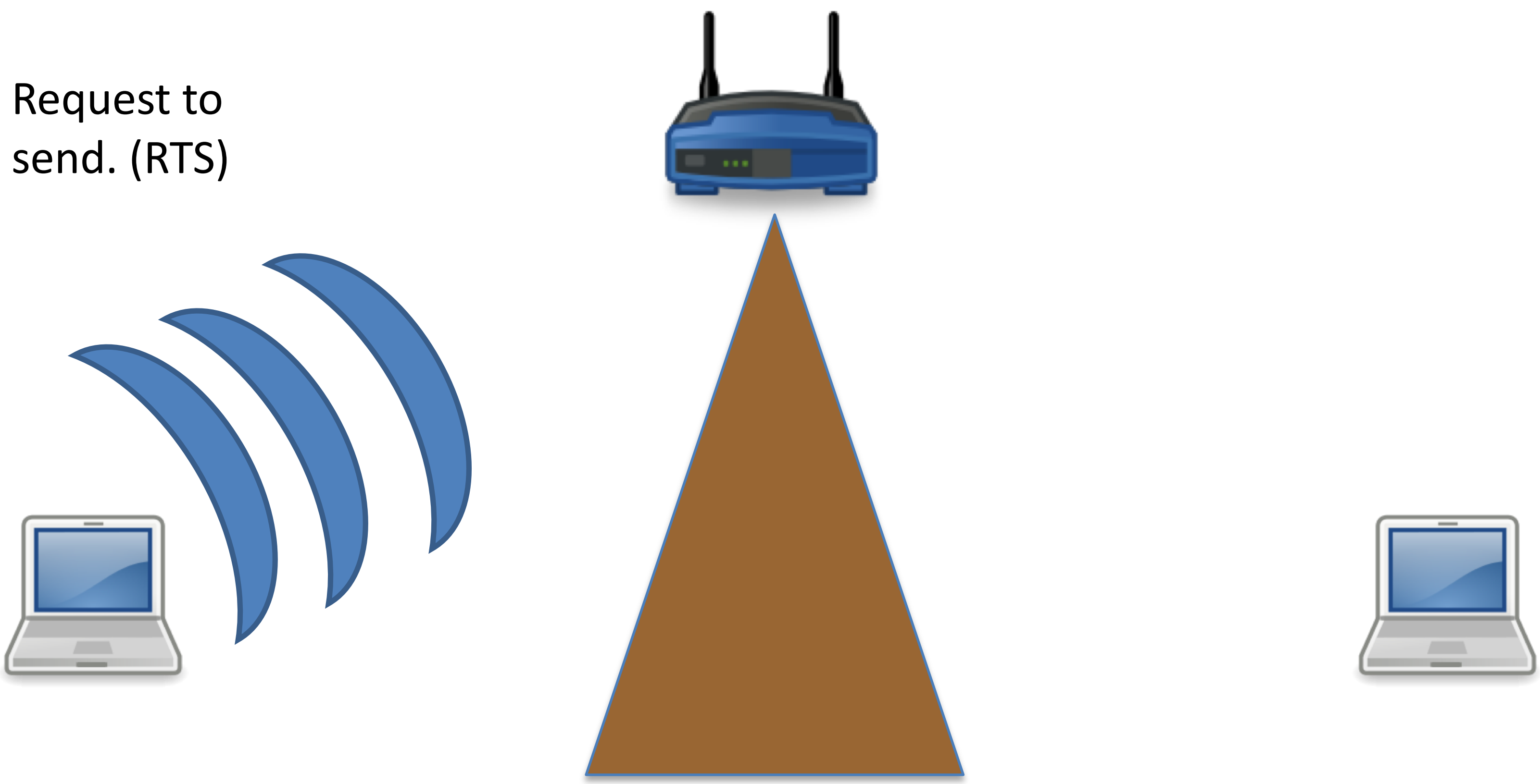
CSMA/CA (Collision Avoidance)

- If sending small (threshold configurable) frame, just send it.



CSMA/CA (Collision Avoidance)

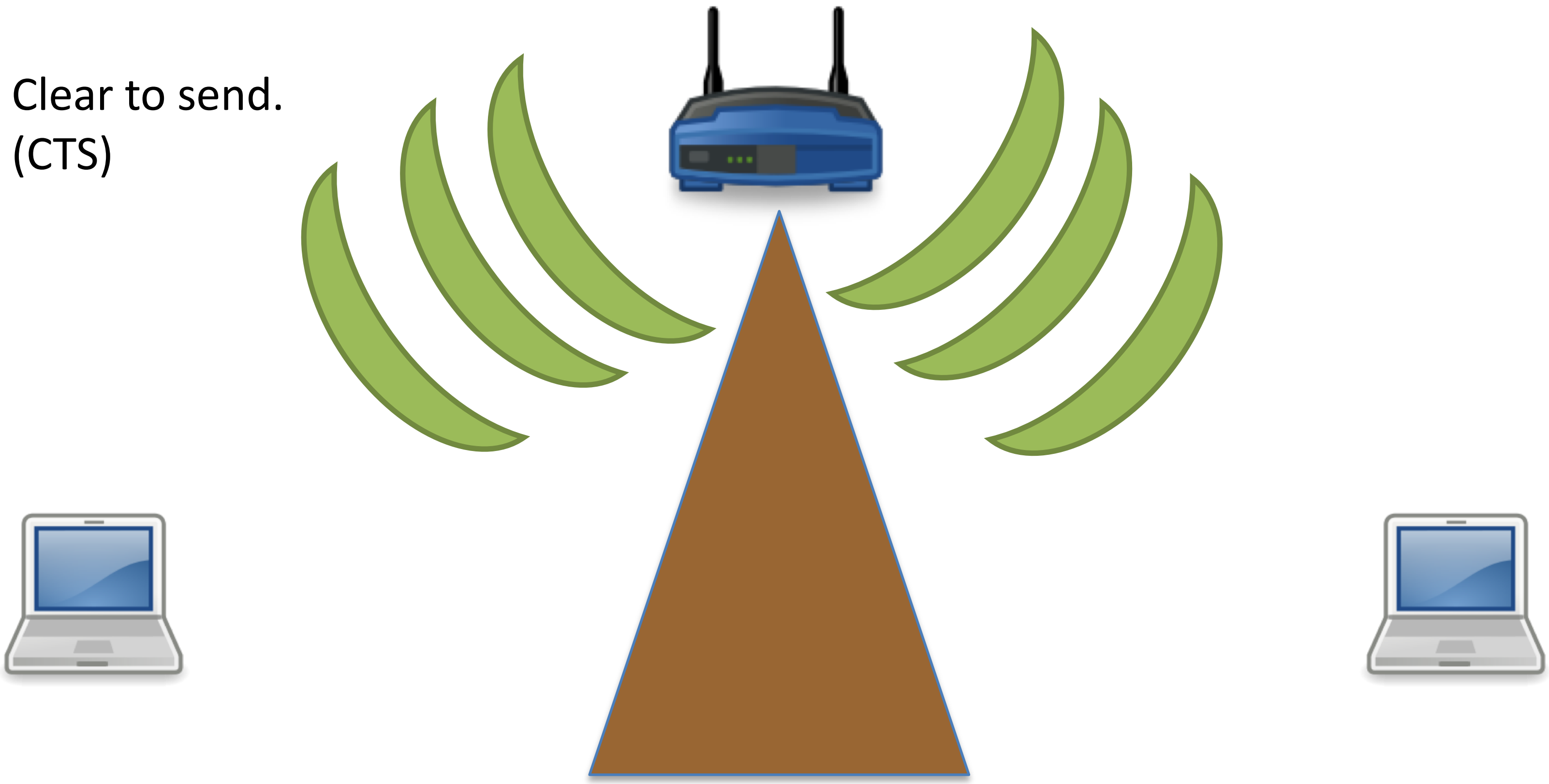
- If sending large frame, ask for permission first.



CSMA/CA (Collision Avoidance)

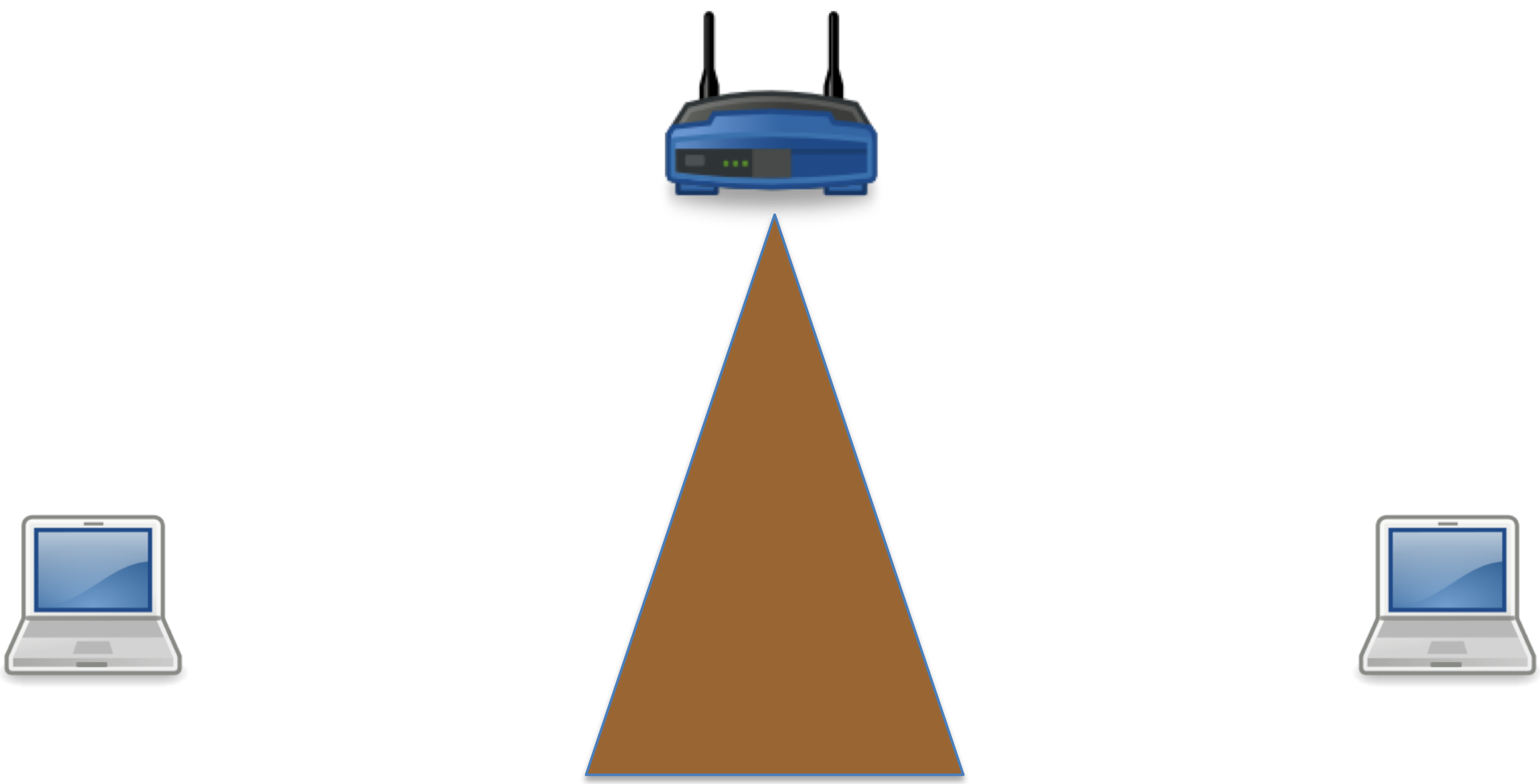
- If granted, it will be heard by everyone.

Clear to send.
(CTS)



CSMA/CA (Collision Avoidance)

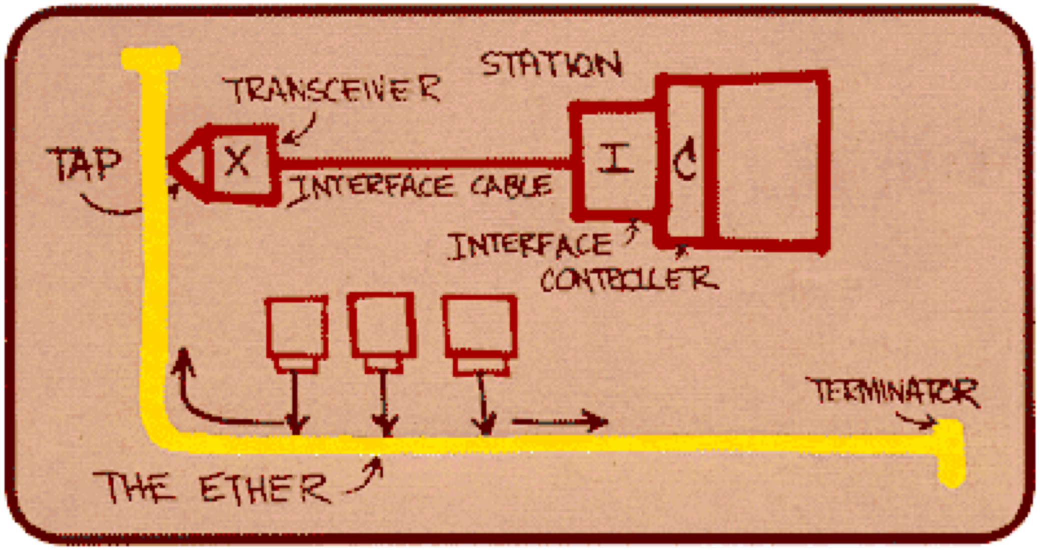
- RTS/CTS is like taking turns.



Summary of MAC protocols

- channel partitioning, by time, frequency or code
  - Time Division, Frequency Division
- random access (dynamic),
  - ALOHA, S-ALOHA, CSMA, CSMA/CD
  - carrier sensing:
    - easy in some technologies (wire), hard in others (wireless)
  - CSMA/CD used in Ethernet
  - CSMA/CA used in 802.11
- taking turns
  - Polling from central site, token passing
  - Bluetooth, FDDI, token ring

Ethernet



Metcalfe's Ethernet sketch

"Dominant" wired LAN technology:

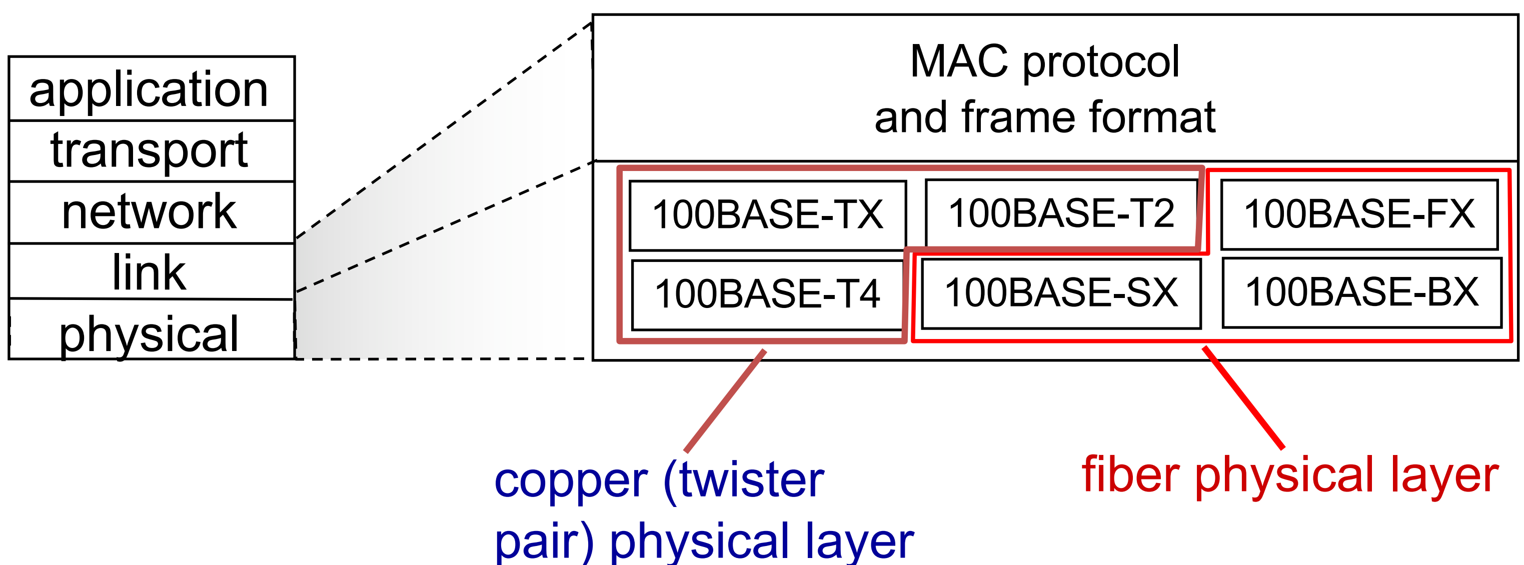
- cheap $20 for NIC
- first widely used LAN technology
- simpler, cheaper than token LANs and ATM
- kept up with speed race: 10 Mbps – 10 Gbps

Ethernet: unreliable, connectionless

- Connectionless: no handshaking between sending and receiving NICs
- Unreliable: receiving NIC doesn't send acks or nacks to sending NIC
  - data in dropped frames recovered only if initial sender uses higher layer reliable delivery (e.g., TCP), otherwise dropped data lost
- Ethernet's MAC protocol:
  CSMA/CD with binary exponential backoff

802.3 Ethernet standards: link & physical layers

- Many different Ethernet standards
  - Common MAC protocol and frame format
  - Speeds: 2 Mbps, 10 Mbps, 100 Mbps, 1Gbps, 10Gbps
  - Physical layer media: fiber, copper cable



Ethernet frame structure

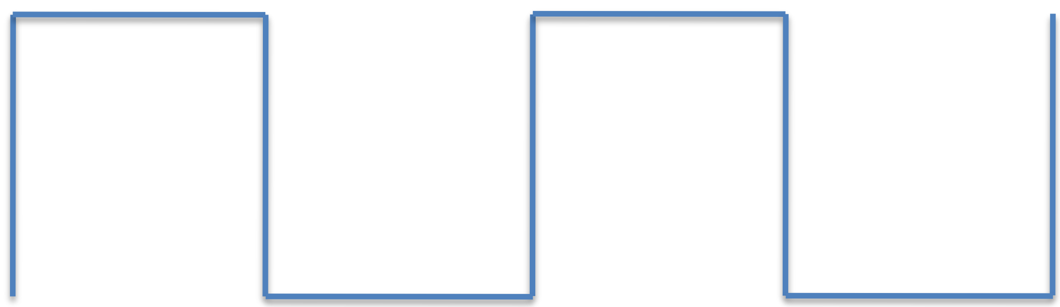
Sender encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame

preamble:

- 7 bytes with pattern 10101010 followed by one byte with pattern 10101011

Clock Synching

- Bits represented as voltages, either low or high
- We will read one bit per clock cycle



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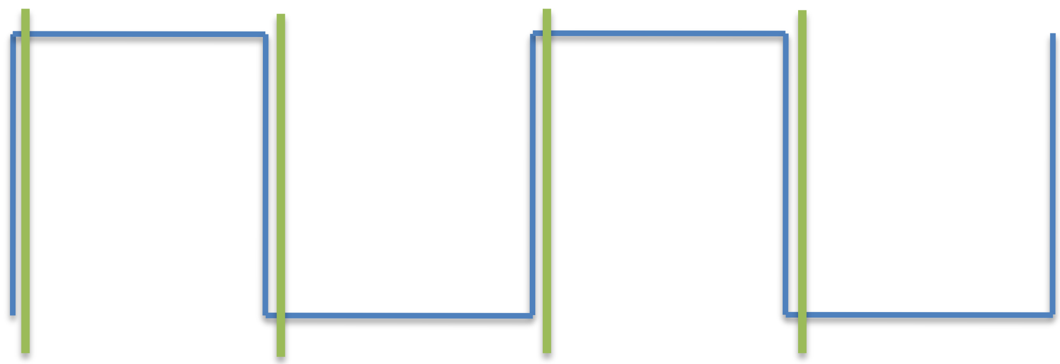
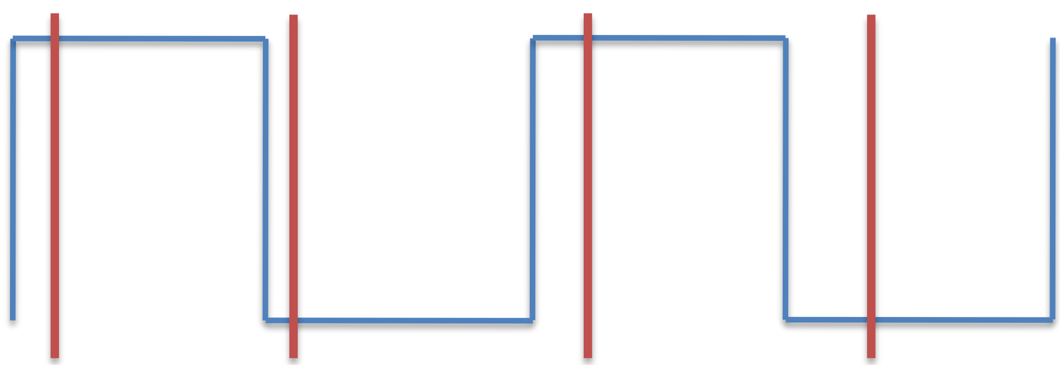


Ideal receiver: Sample signal at regular interval.

For 1 Gbps Ethernet, ~1 nanosecond interval.

Clock Synching

- Bits represented as voltages, either low or high
- We will read one bit per clock cycle



Problem: receiver clock may not agree with sender!

Preamble let's receiver see several 0 -> 1 -> 0 -> … transitions.

Ethernet frame structure (more)

- addresses: 6 byte source, destination MAC addresses
  - if adapter receives frame with matching destination address, or with broadcast address (e.g. ARP packet), it passes data in frame to network layer protocol
  - otherwise, adapter discards frame
- type: indicates higher layer protocol (mostly IP but others possible, e.g., Novell IPX, AppleTalk)
- CRC: cyclic redundancy check at receiver
  - error detected: frame is dropped

MAC Addresses

- MAC (or LAN or physical or Ethernet) address:
  - 48 bit MAC address
  - e.g.: 1A-2F-BB-76-09-AD

hexadecimal (base 16) notation
(each digit represents 4 bits)

MAC vs. IP Addresses

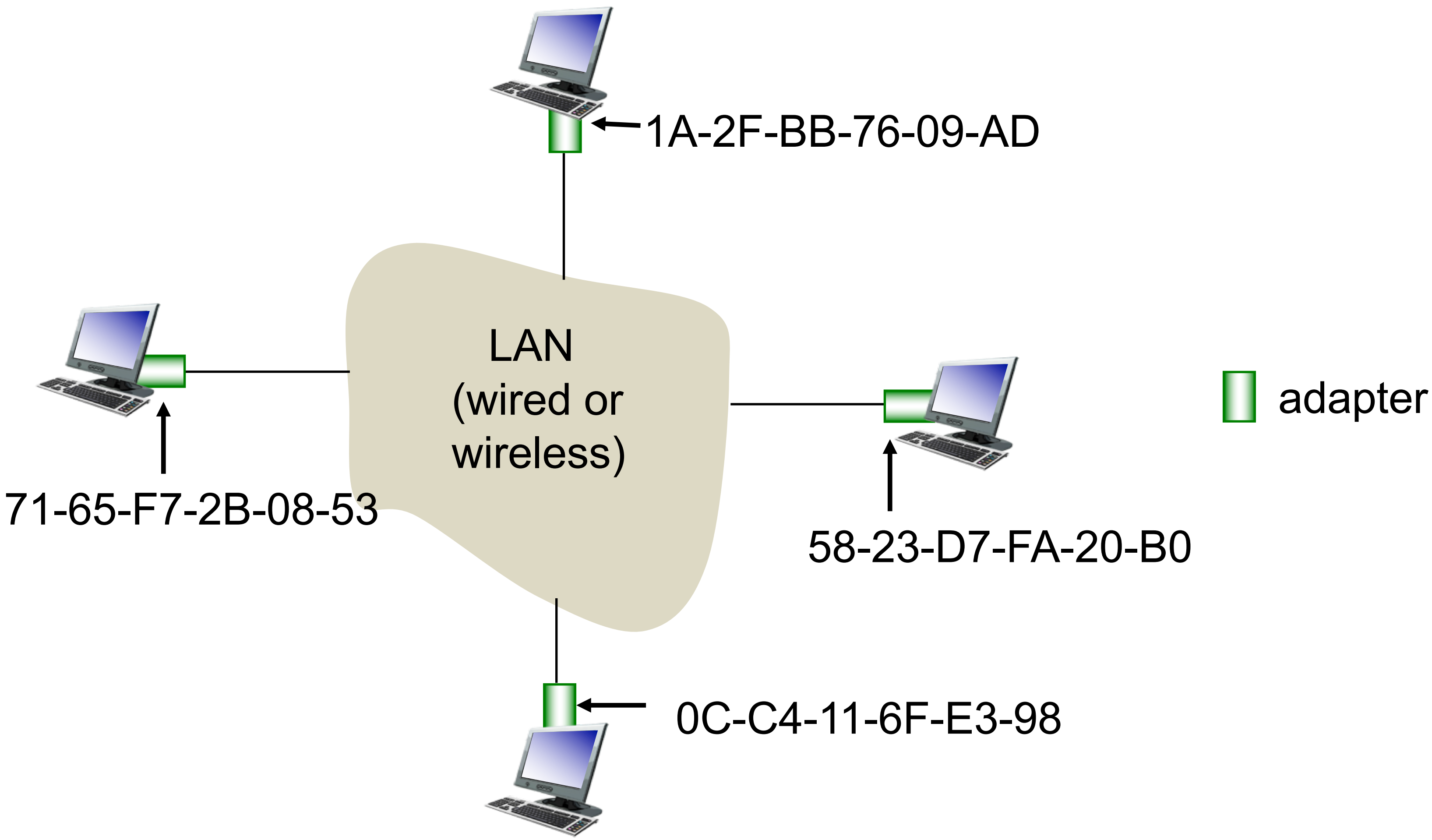
- 32-bit IP address
- IP hierarchical address not portable!
  - address depends on IP subnet to which node is attached
- used by network layer for end-to-end routing

- 48 bit MAC address burned in NIC ROM.
- MAC flat address: portability
  - can move LAN card from one LAN to another
- used locally to get from one interface to another physically-connected interface

Analogy:
MAC address: like Social Security Number
IP address: like postal address

MAC Addresses

Each interface/adapter on LAN has unique MAC address



ARP: Address Resolution Protocol

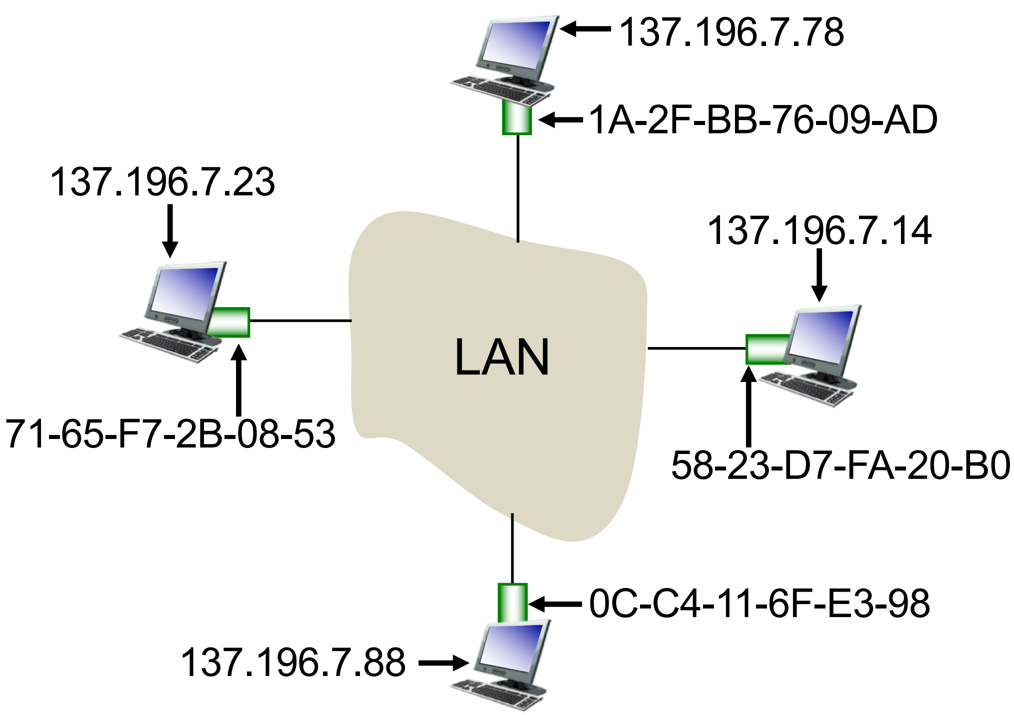
Question: how to determine interface's MAC address, knowing its IP address?

ARP table: each IP node (host, router) on LAN has table

- IP/MAC address mappings for some LAN nodes:

  < IP address; MAC address; TTL>

- TTL (Time To Live): time after which address mapping will be forgotten (typically 20 min)



ARP protocol & LAN communication

- A wants to send datagram to B. A knows B’s IP address.
  - B’s MAC address not in A’s ARP table.

- A broadcasts ARP query packet, containing B's IP address
  - dest Ethernet address = FF-FF-FF-FF-FF-FF
  - all nodes on LAN receive ARP query, most ignore it

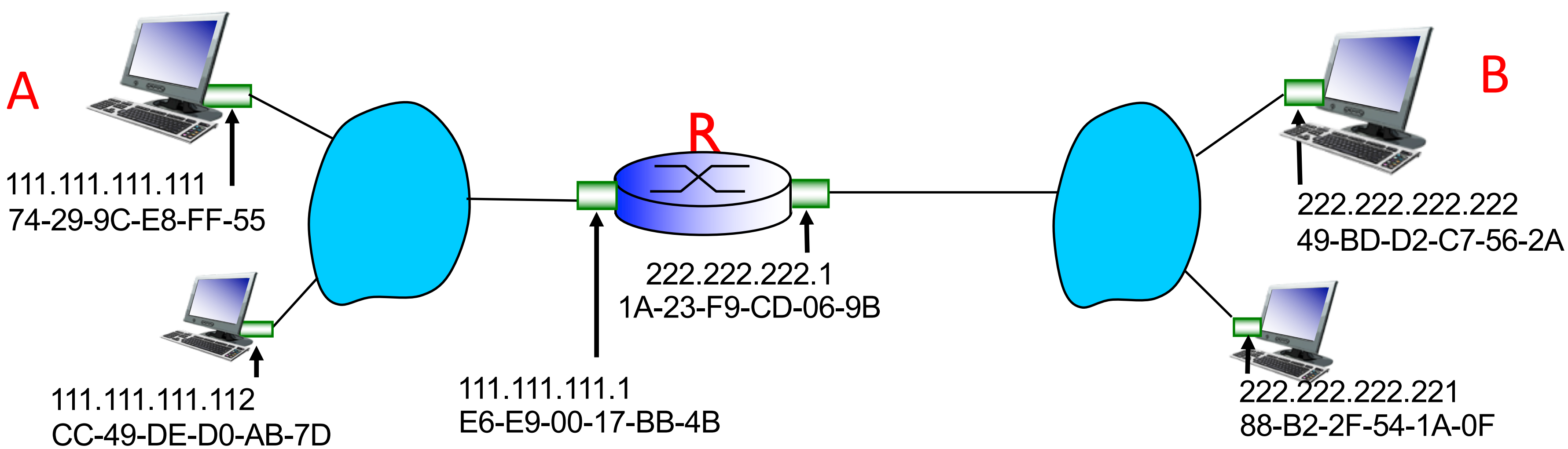
- B receives ARP packet, replies to A with its (B's) MAC address
  - frame sent to A’s MAC address (unicast)

- A caches IP-to-MAC address pair in its ARP table until timeout
  - soft state: times out unless refreshed, can be reacquired

Addressing: routing to another LAN

Walkthrough: send datagram from A to B via R

- focus on addressing – at IP and MAC layer
- assume A knows B's IP address (e.g., DNS lookup)
- how many subnets are present in this figure?



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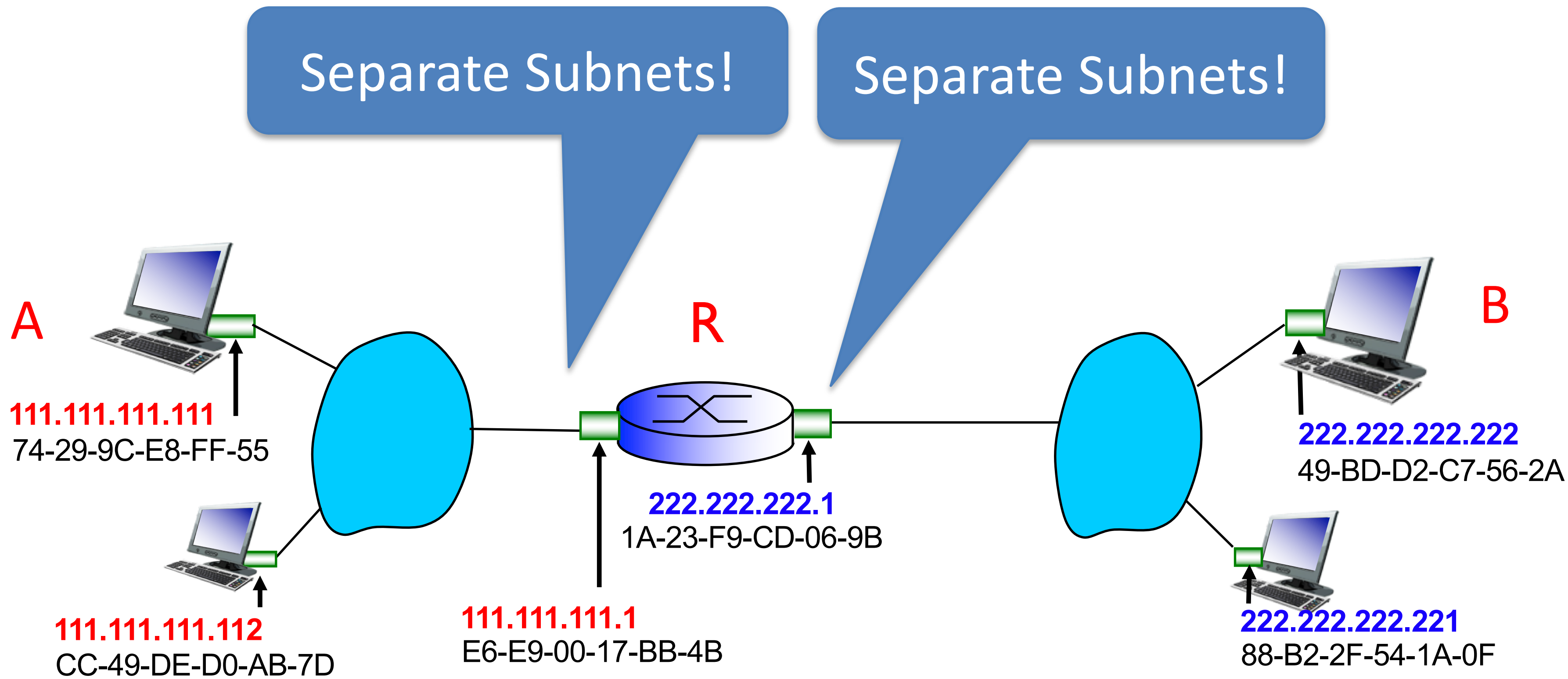
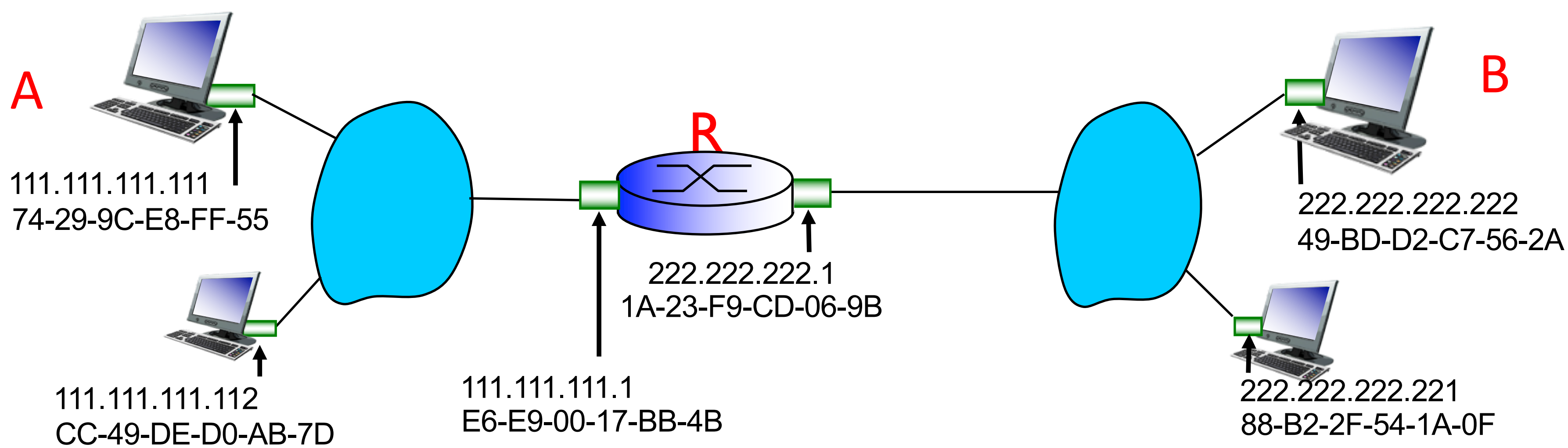


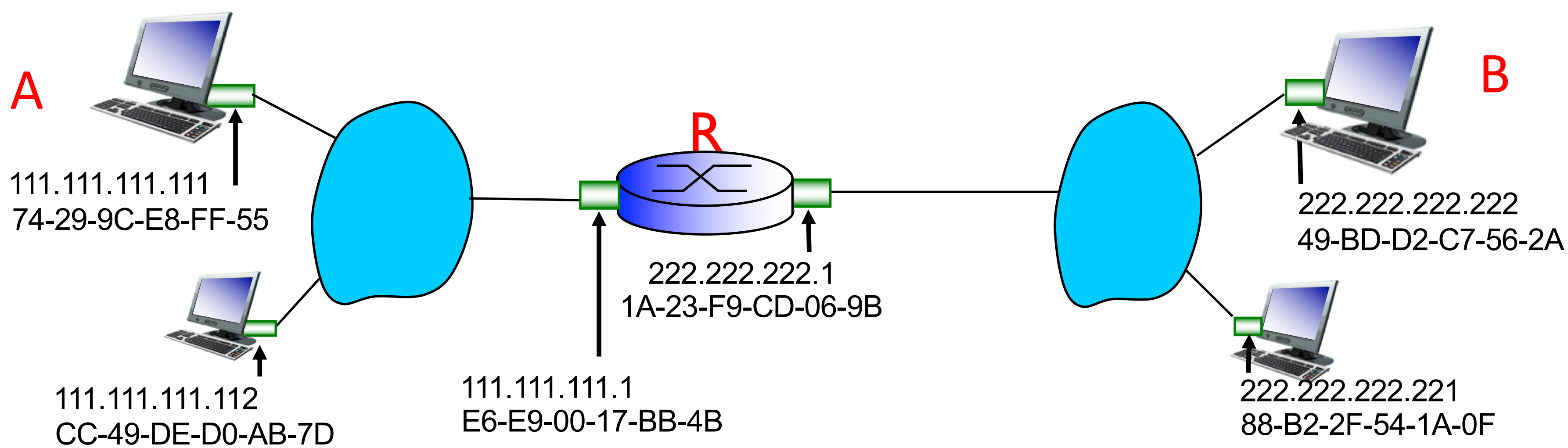
Walkthrough: send datagram from A to B via R

1. Who do we address as the IP packet destination ?
2. Who do we forward it to on the first hop?



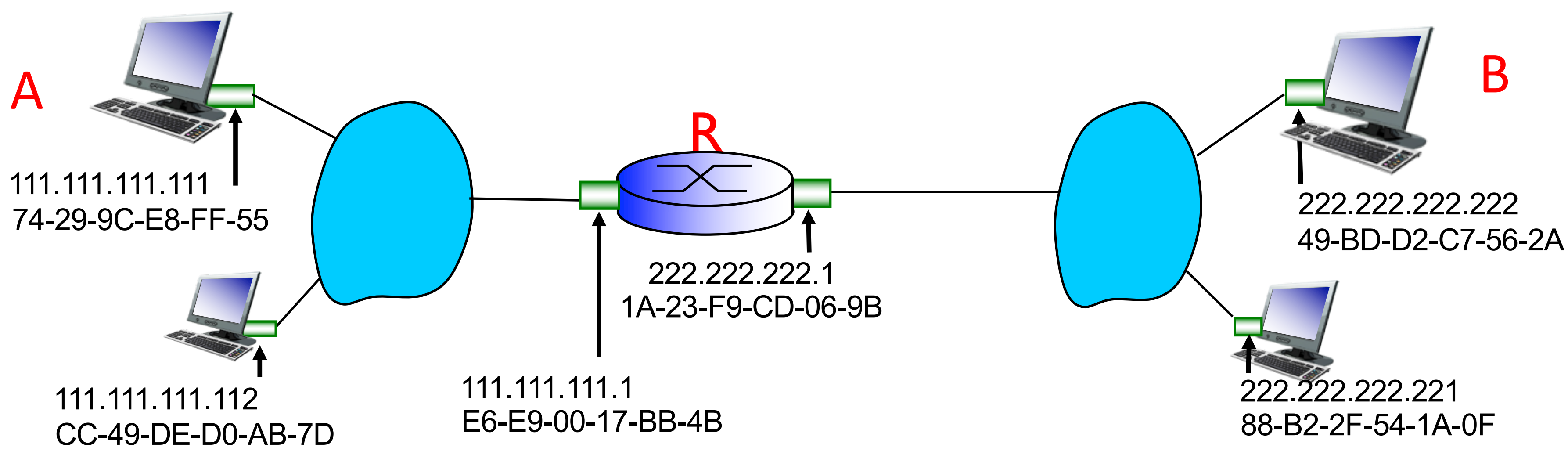
Walkthrough: send datagram from A to B via R

1. Who do we address as the IP packet destination ?
   - IP Address to B (End-to-end address to express where we want to get to)



Walkthrough: send datagram from A to B via R

2. Who do we forward it to on the first hop?
    - MAC Address to R (Intermediate address to send to router)



How does A learn the IP address of the router?

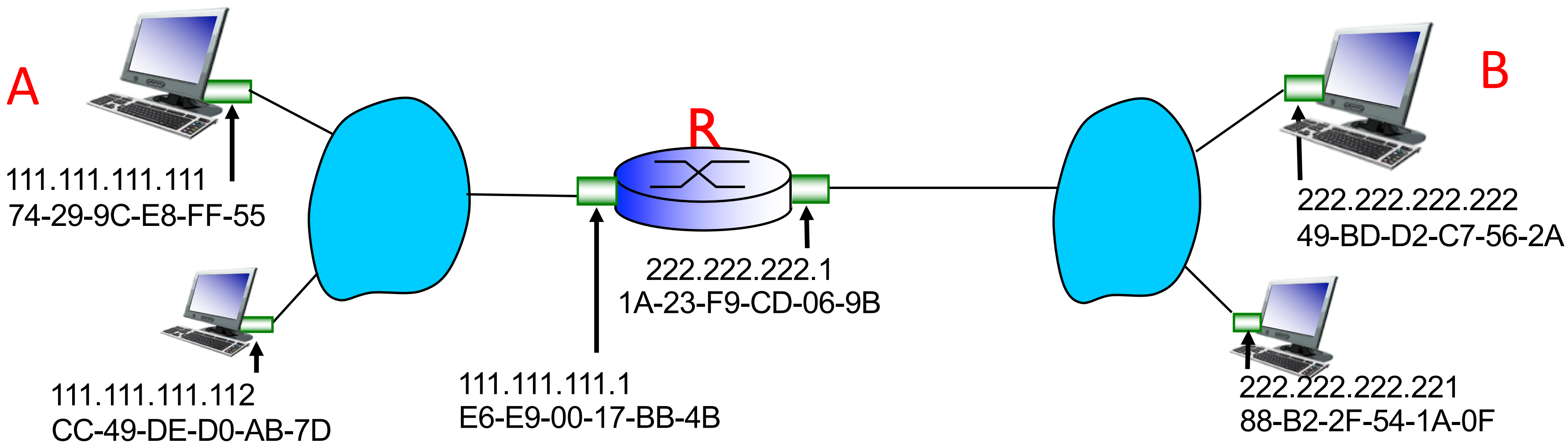
A. ARP: Address Resolution Protocol

B. DHCP: Dynamic Host Configuration Protocol

C. IP: Internet Protocol

D. Routing Protocol

why do we even need the IP address of Router ?



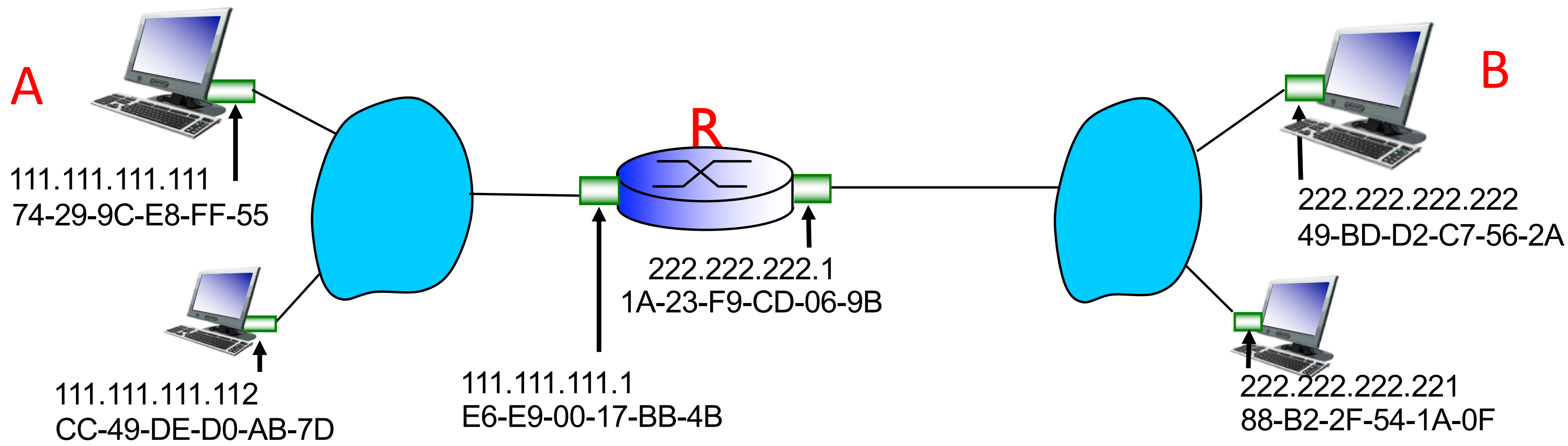
How does A learn the IP address of the Router ?

A. ARP: Address Resolution Protocol

B. DHCP: Dynamic Host Configuration Protocol (it gives you your IP address, and the IP address of the router to get to the Internet and it is up to you figure out the MAC address)

C. IP: Internet Protocol

D. Routing Protocol



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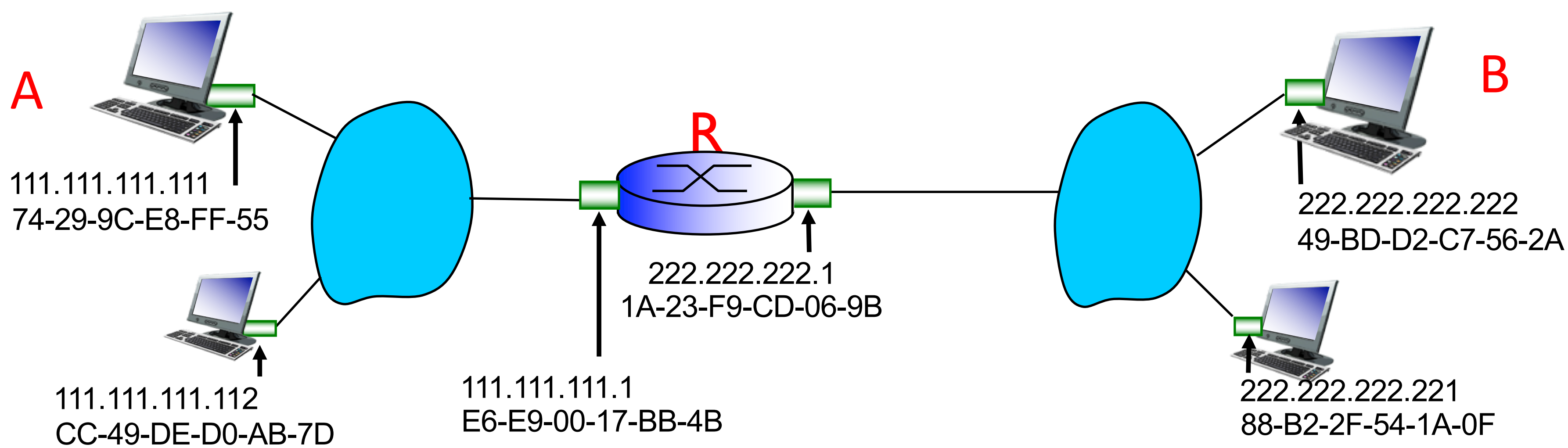

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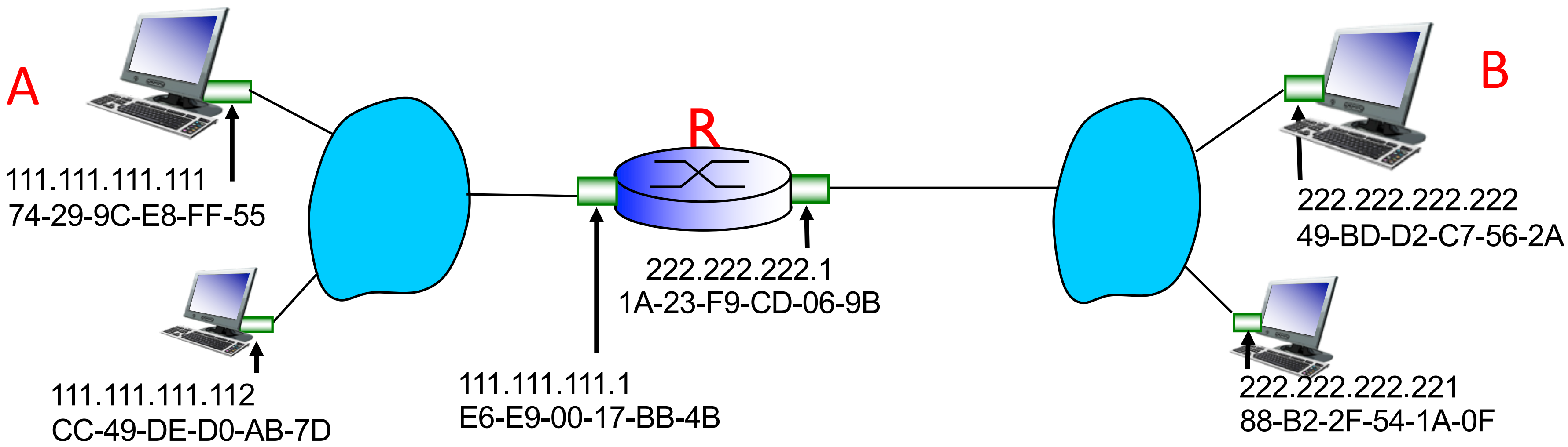
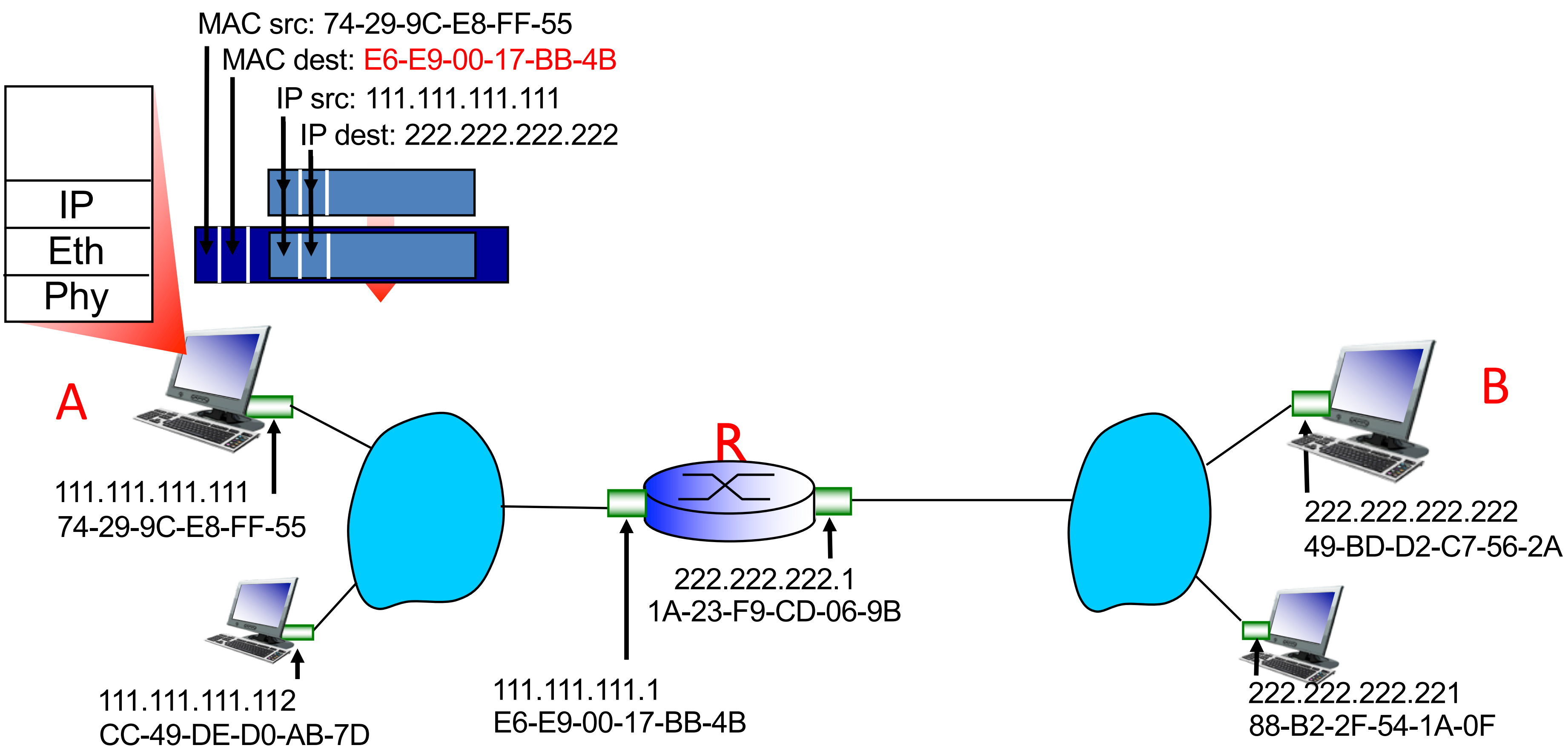


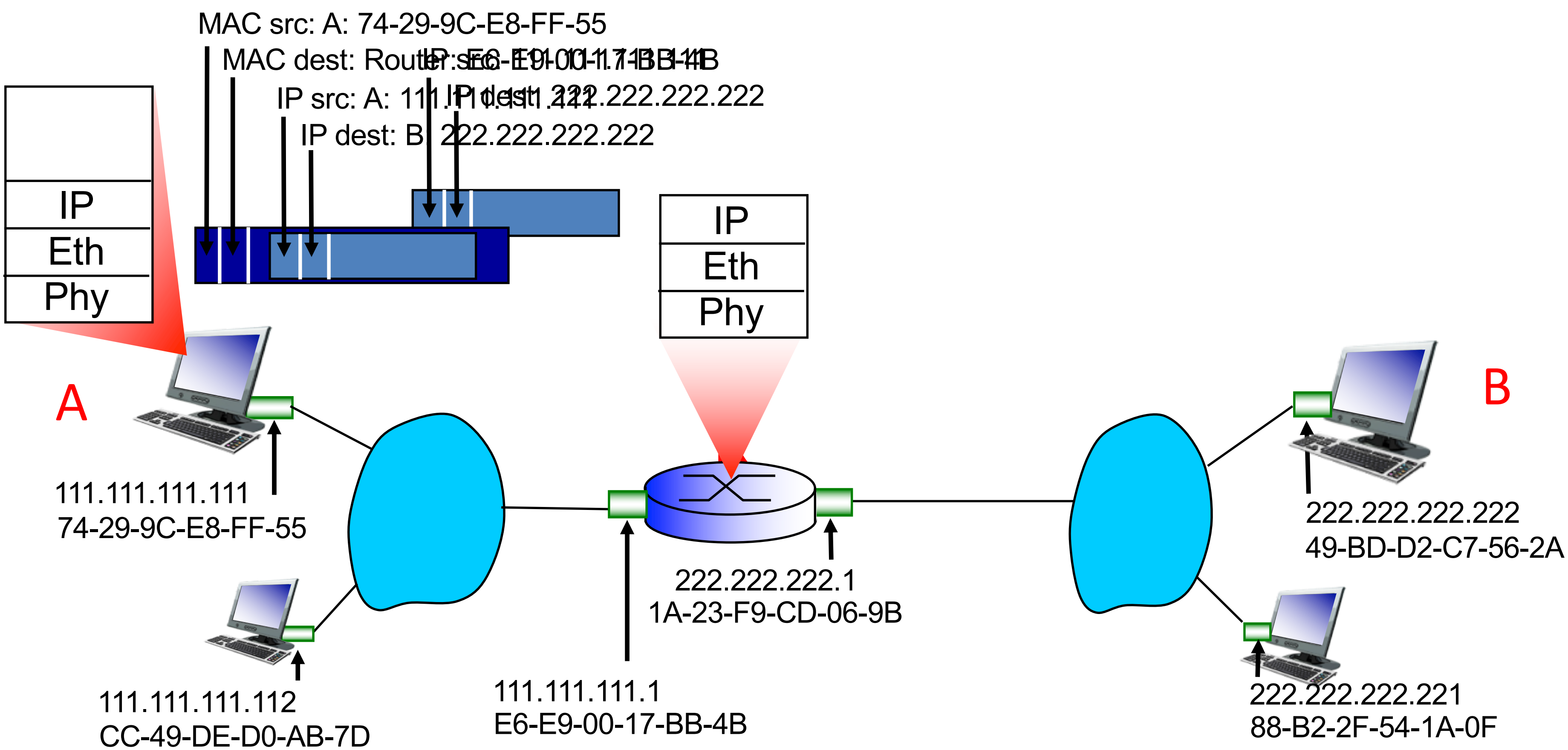
Addressing: routing to another LAN

- A creates IP datagram with IP source A, destination B
- A creates link-layer frame with R's MAC address as dest, frame contains A-to-B IP datagram



Addressing: routing to another LAN

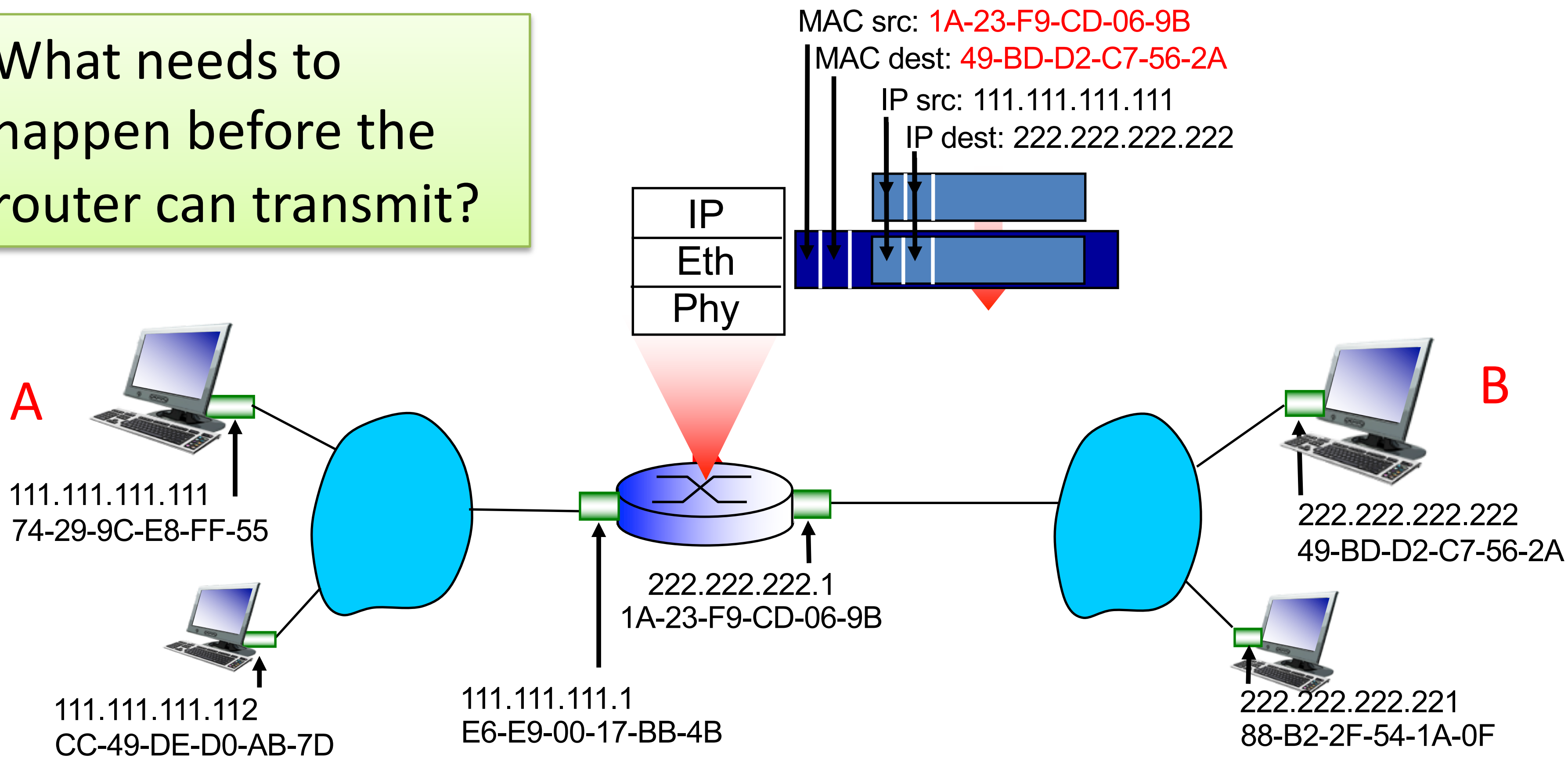
- frame sent from end host A to Router
- frame received at Router, datagram removed, passed up to IP



Addressing: routing to another LAN

- Router forwards datagram with IP source A, destination B
- Router creates link-layer frame with B's MAC address as dest, frame contains A-to-B IP datagram

What needs to happen before the router can transmit?



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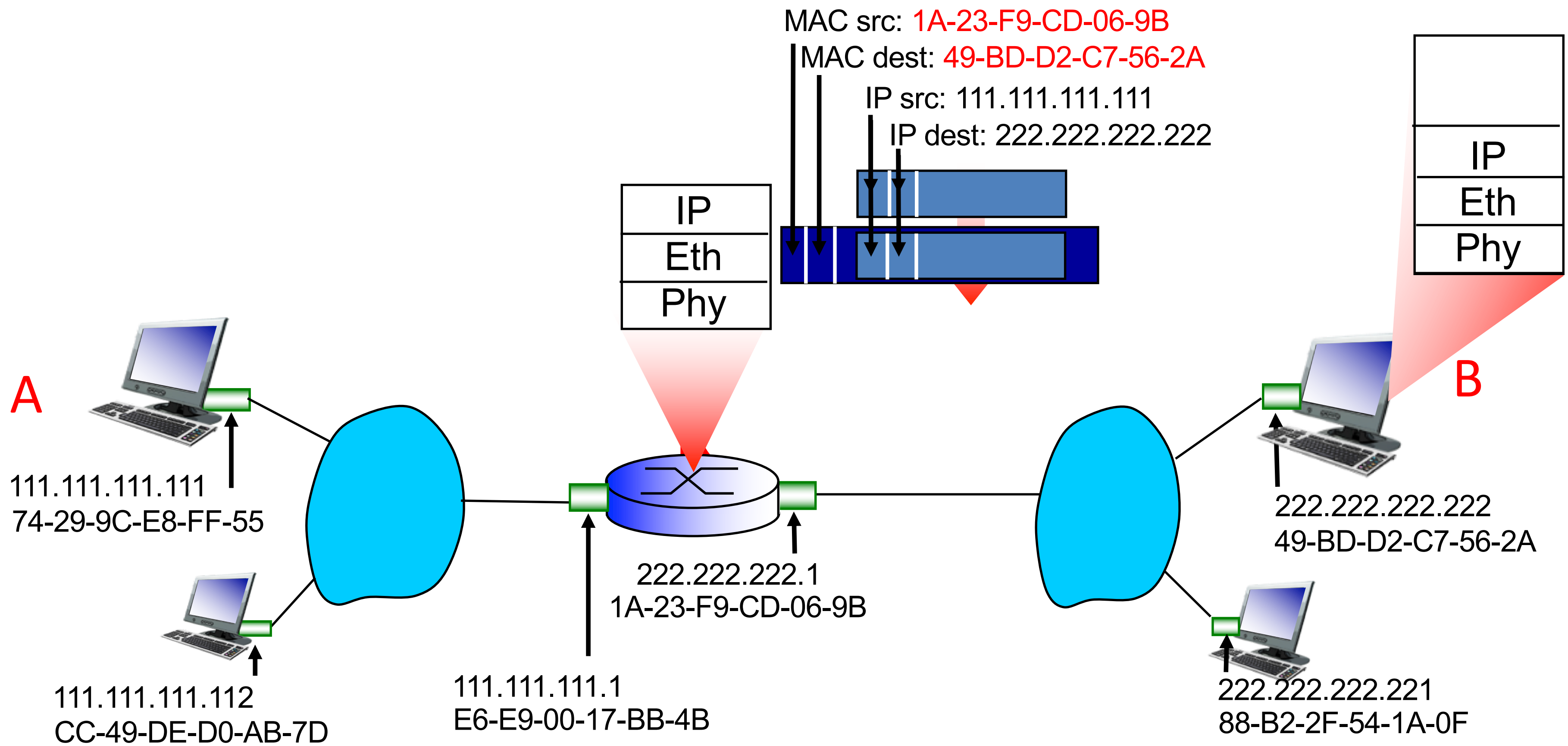

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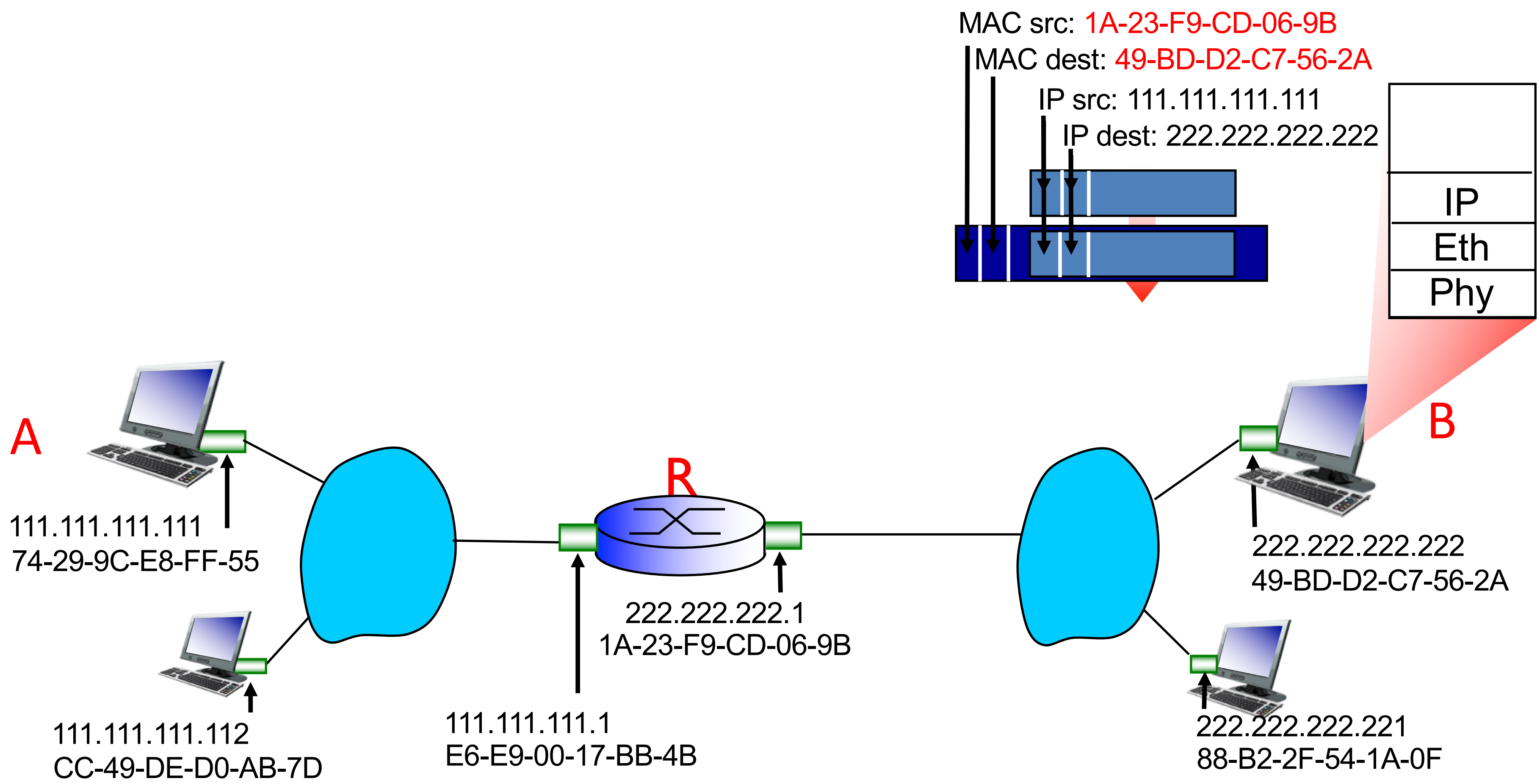
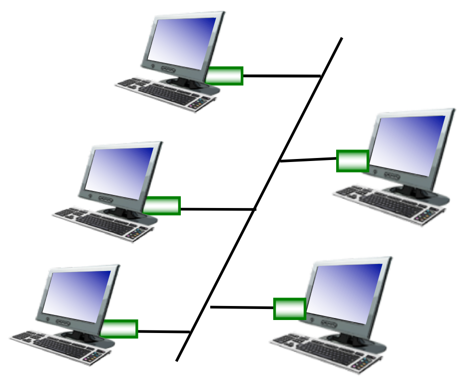
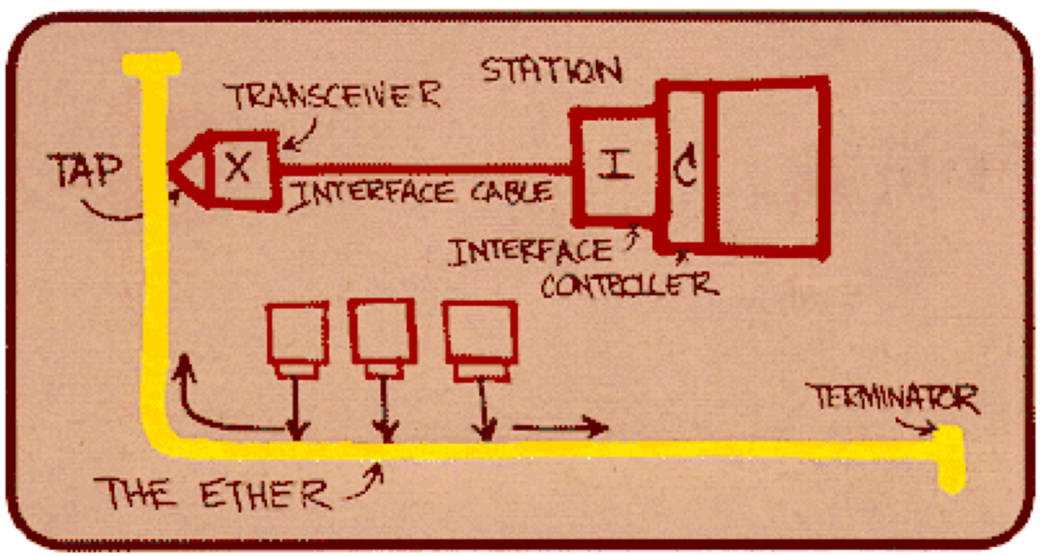


Physical Topology: Bus

- *Bus:* popular through mid 90s
  - all nodes in same collision domain (transmissions collide with each other)

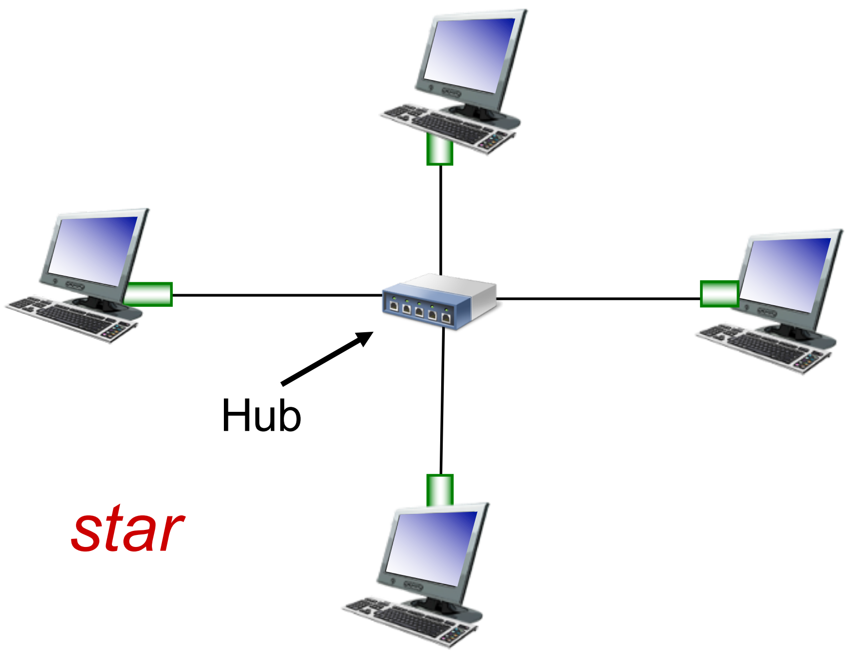


bus: coaxial cable



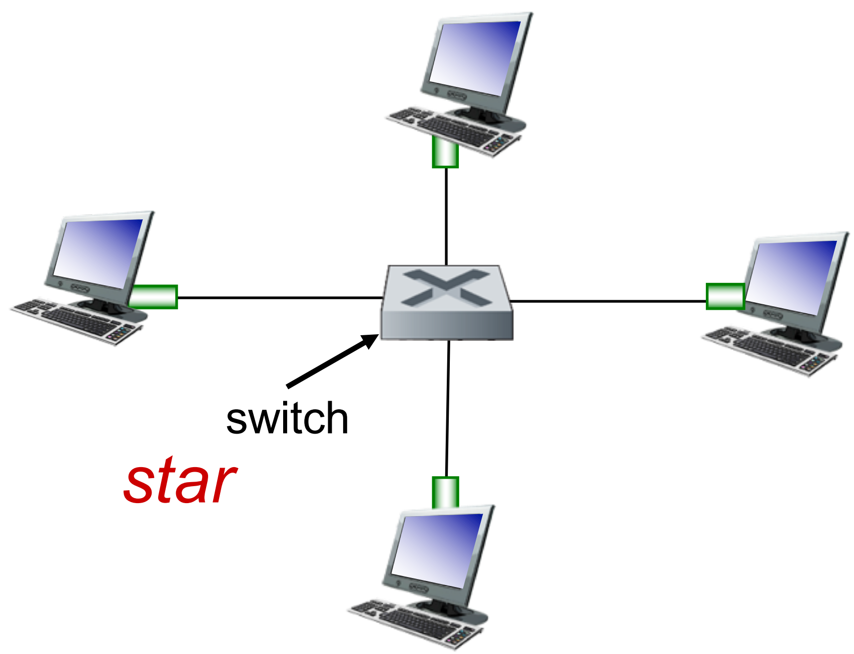
Physical Topology: Star

- *Hub* in the center:
  - broadcasts all messages to all hosts
  - retransmits on collisions
  - often considered a physical layer device (like a bus wire)

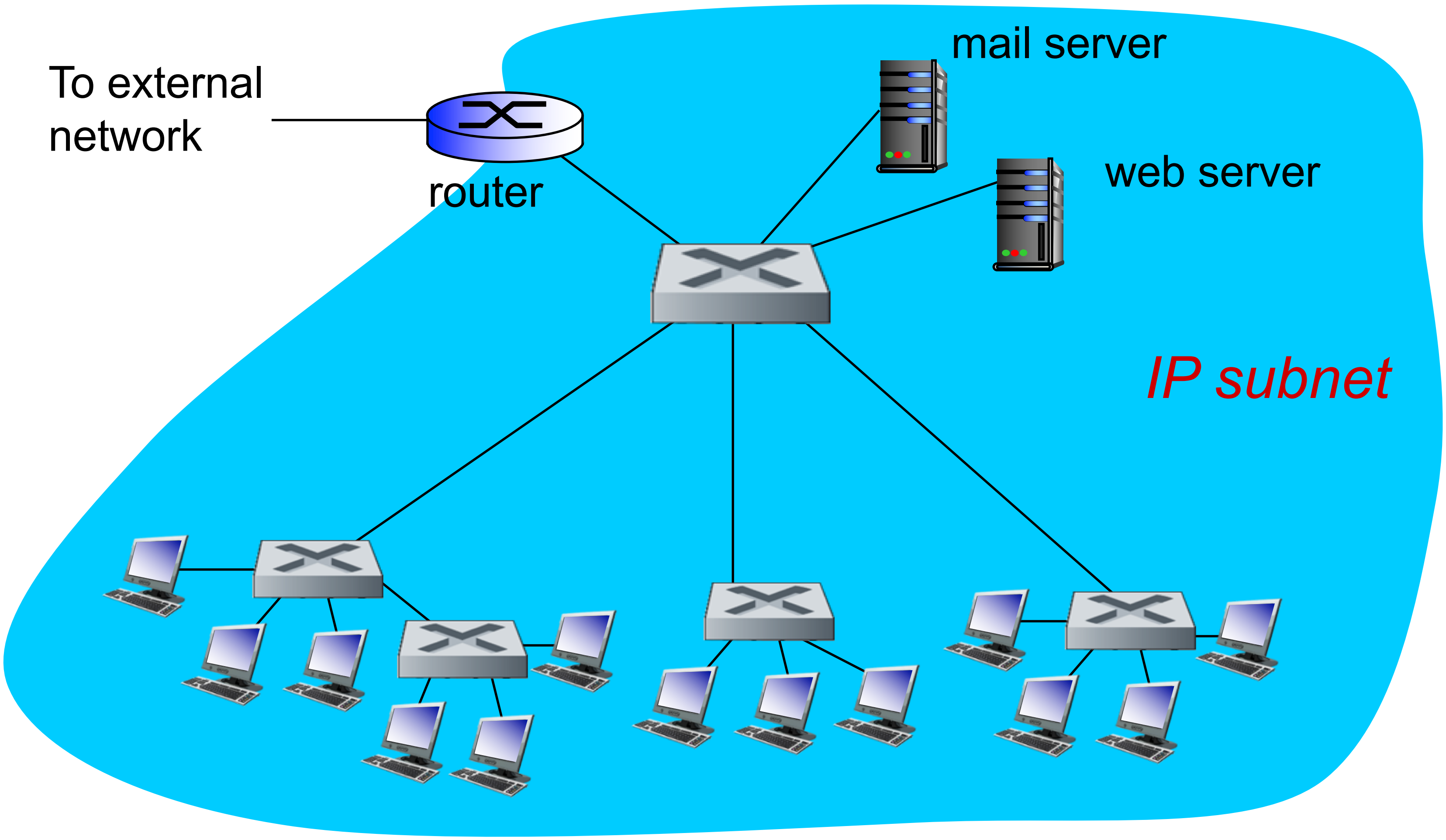


Physical Topology: Star (Switched)

- *Switch:* prevails today
  - each "spoke" runs a (separate) Ethernet protocol (nodes do not collide with each other)
  - Full duplex: No collisions on spoke



Institutional Network (Tree)

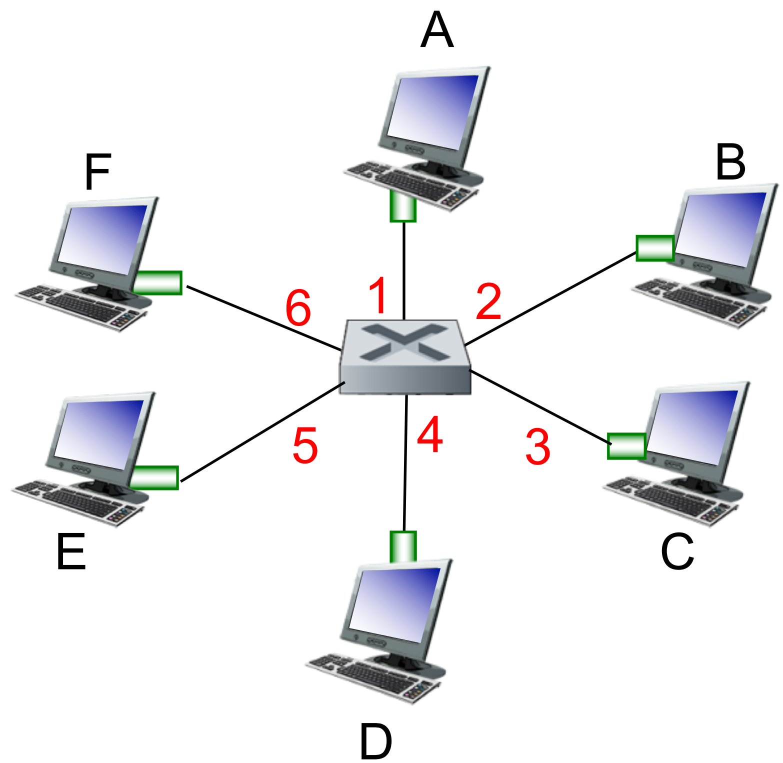


Ethernet switch

- link-layer device: takes an *active* role
  - store, forward Ethernet frames
  - examines incoming frame's MAC address, selectively forwards frame to one-or-more outgoing links when frame is to be forwarded on segment, uses CSMA/CD to access segment
- transparent
  - hosts are unaware of presence of switches
- plug-and-play, self-learning
  - switches do not need to be configured

Switch: multiple simultaneous transmissions

- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol used on *each* incoming link, but no collisions; full duplex
  - each link is its own collision domain
- *switching:* A-to-D and B-to-E can transmit simultaneously, without collisions

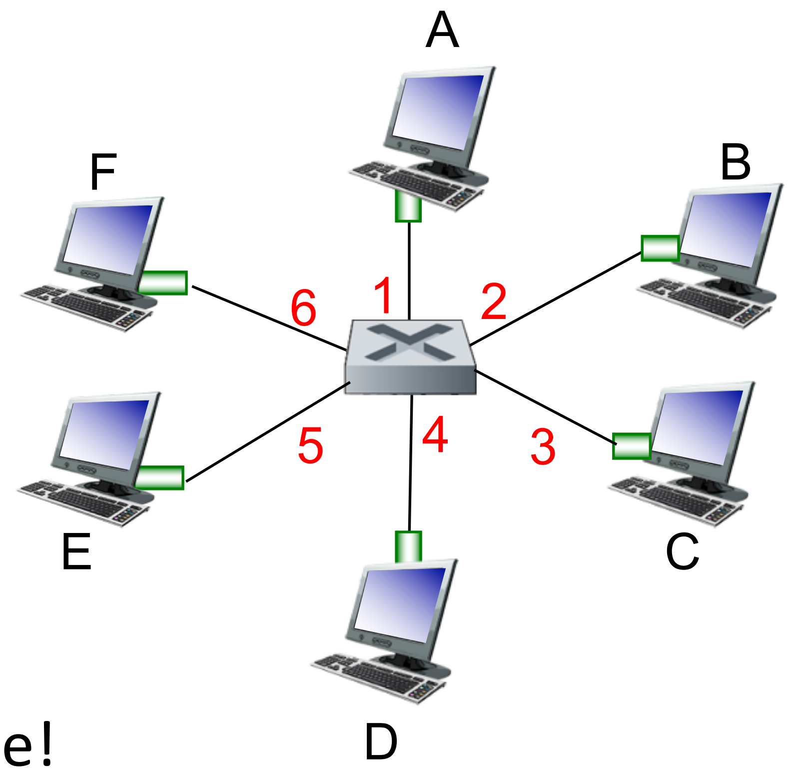


switch with six interfaces (1,2,3,4,5,6)

Switch forwarding table

Q: how does switch know D reachable via interface 4, E reachable via interface 5?

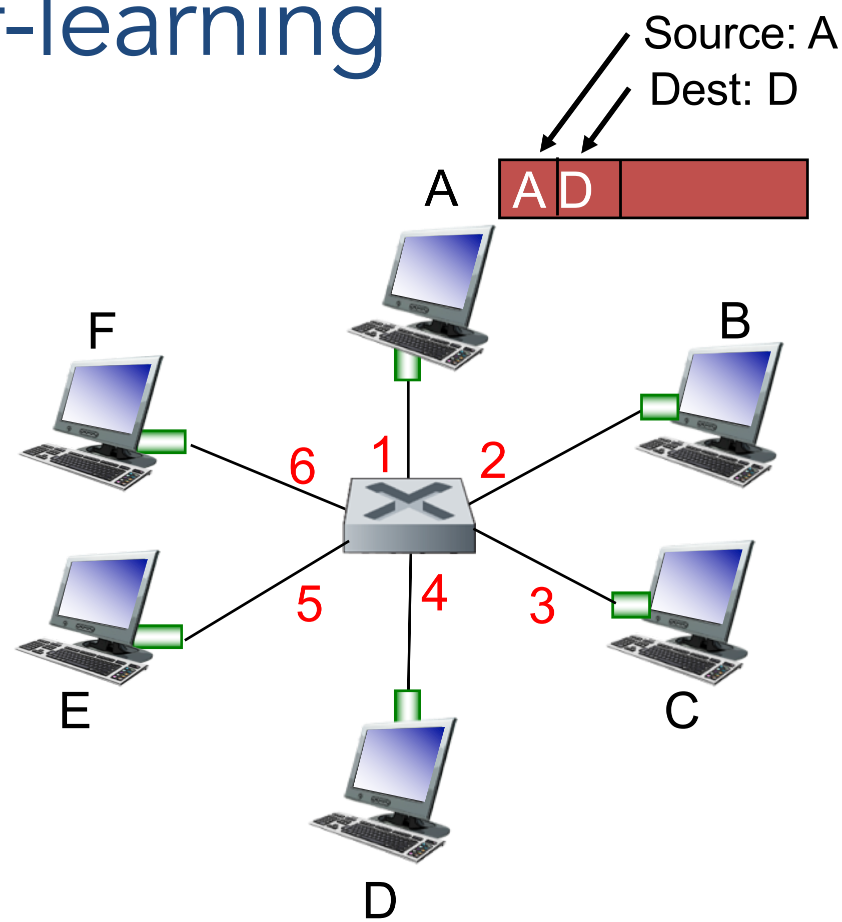
- A: each switch has a forwarding table, each entry:
  - (MAC address of host, interface to reach host, time stamp)
  - looks like a router's forwarding table!



switch with six interfaces (1,2,3,4,5,6)

Switch: self-learning

- switch *learns* which hosts can be reached through which interfaces
  - when frame received, switch "learns" location of sender: incoming LAN segment
  - records sender/location pair in switch table

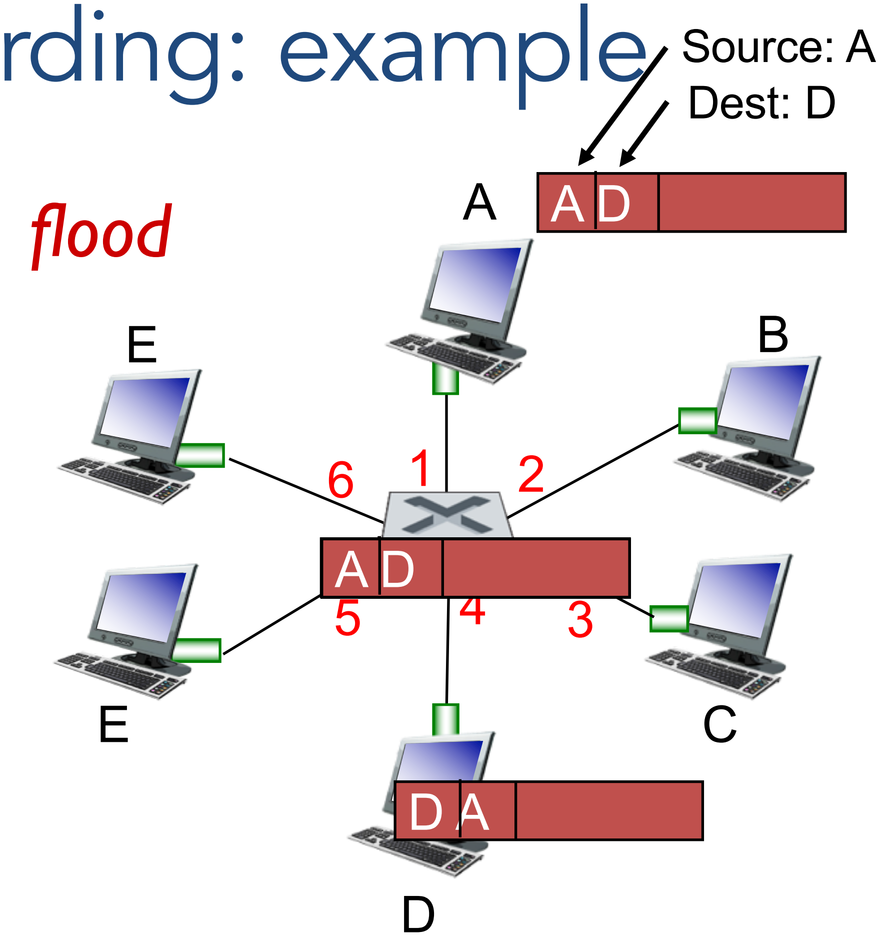


MAC addr	interface	TTL
A	*1*	*60*

Switch table (initially empty)

Self-learning, forwarding: example

- frame destination, D, location unknown:
- destination A location known: selectively send on just one link



MAC addr	interface	TTL
A	*1*	*60*
D	*4*	*60*

switch table (initially empty)

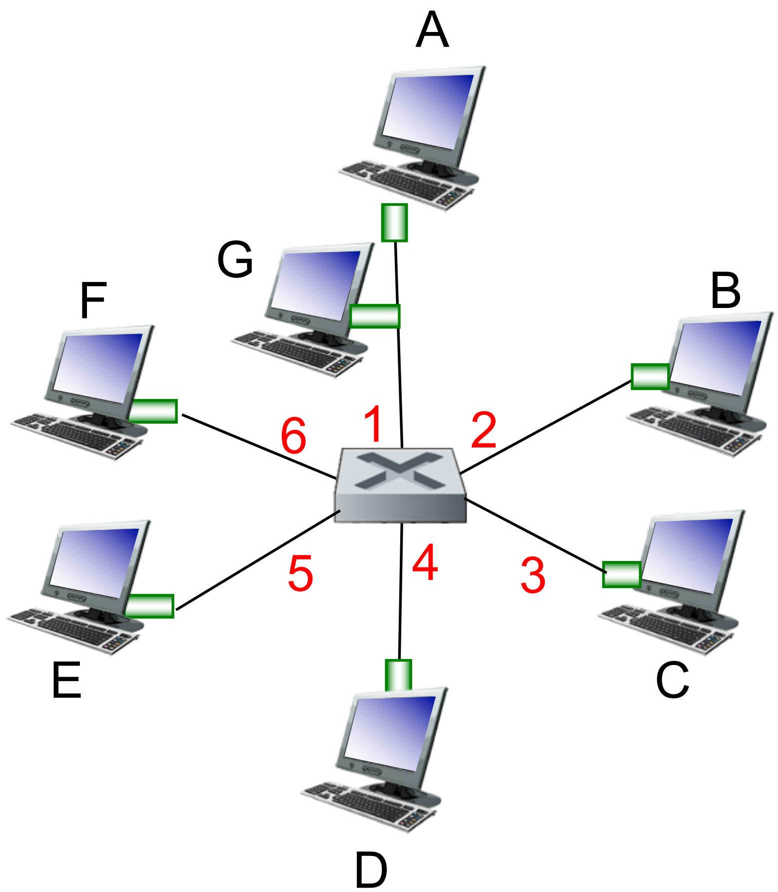
Suppose the switch receives a packet from A to G. (Assume it knows what interface both A and G are on.) It should…

A. Flood the packet

B. Throw the packet away

C. Send the packet out on interface 1

D. Do something else



Switch: frame filtering/forwarding

when frame received at switch:

1. record incoming link, MAC address of sending host
2. index switch table using MAC destination address
3. if entry found for destination {

    if destination on segment from which frame arrived
        drop frame

    else

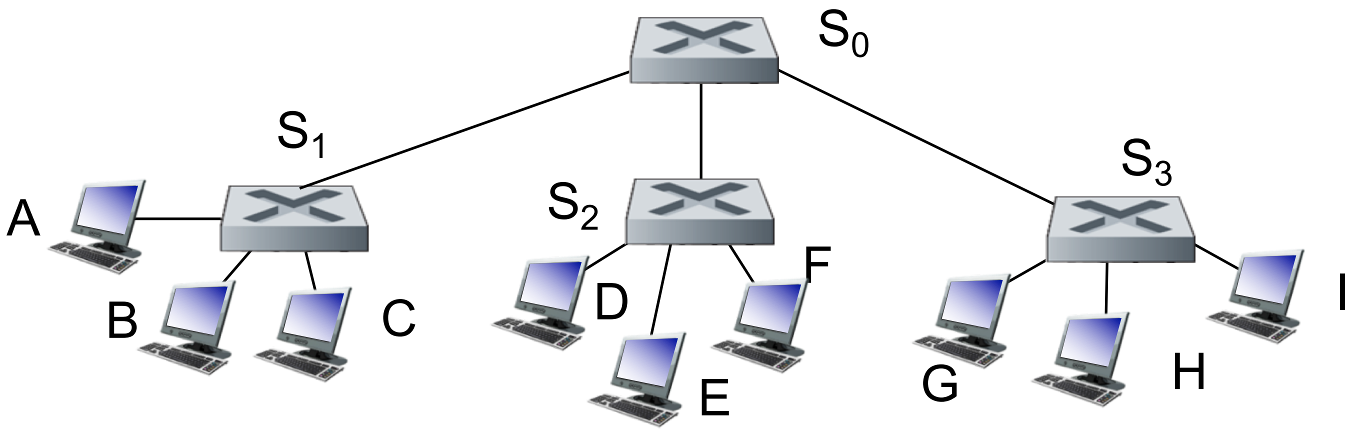
        forward frame on interface indicated by entry

    }

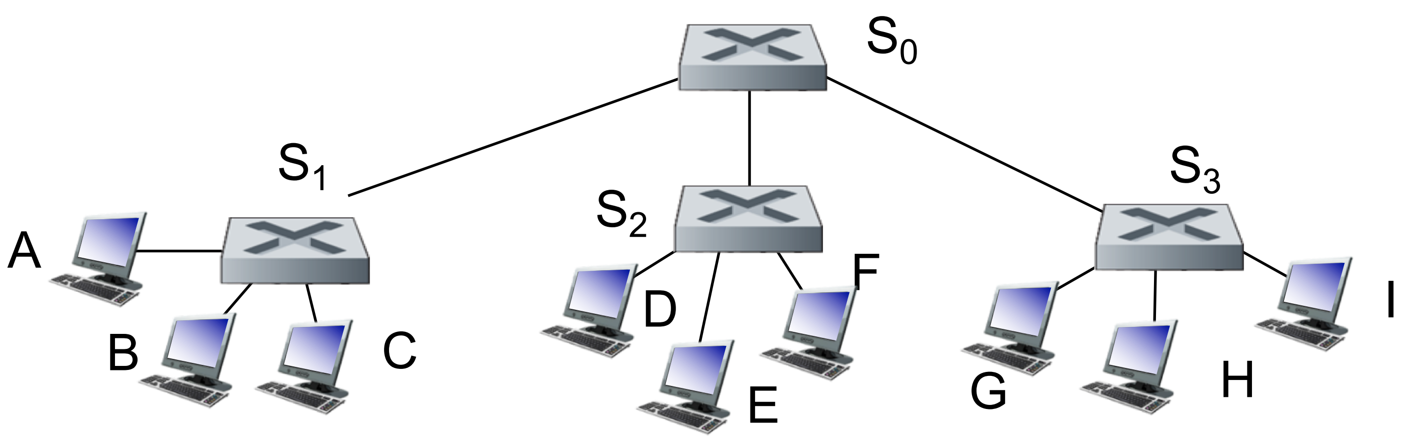
  else flood /* forward on all interfaces except arriving
                interface */

Interconnecting switches

- Switches often connected to form trees.



Sending from A to G - how does S1 know to forward frame destined to G via S4 and S3?



A. A network administrator will need to configure this.

B. S_1 will automatically learn the entire path.

C. S_1 will learn to send packets to G on the interface that leads to S_4.

Eve wants to snoop and read all of the frames being sent to anyone on the LAN. She will NOT be able to do this on a..

A. Bus

B. Hub

C. Switch

D. She can do this on all of these

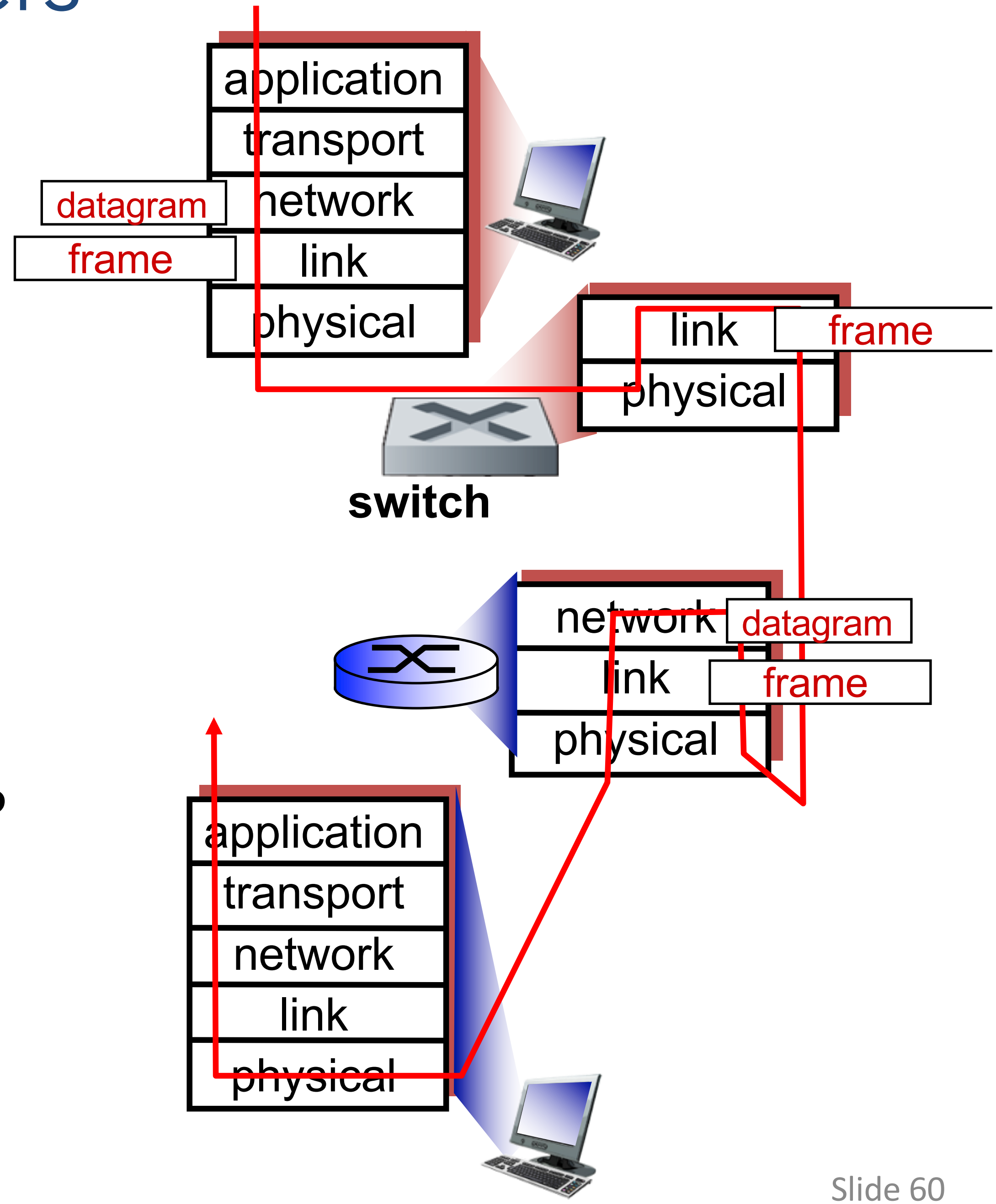
Switches vs. routers

both are store-and-forward:

- *routers:* network-layer devices (examine network-layer headers)
- *switches:* link-layer devices (examine link-layer headers)

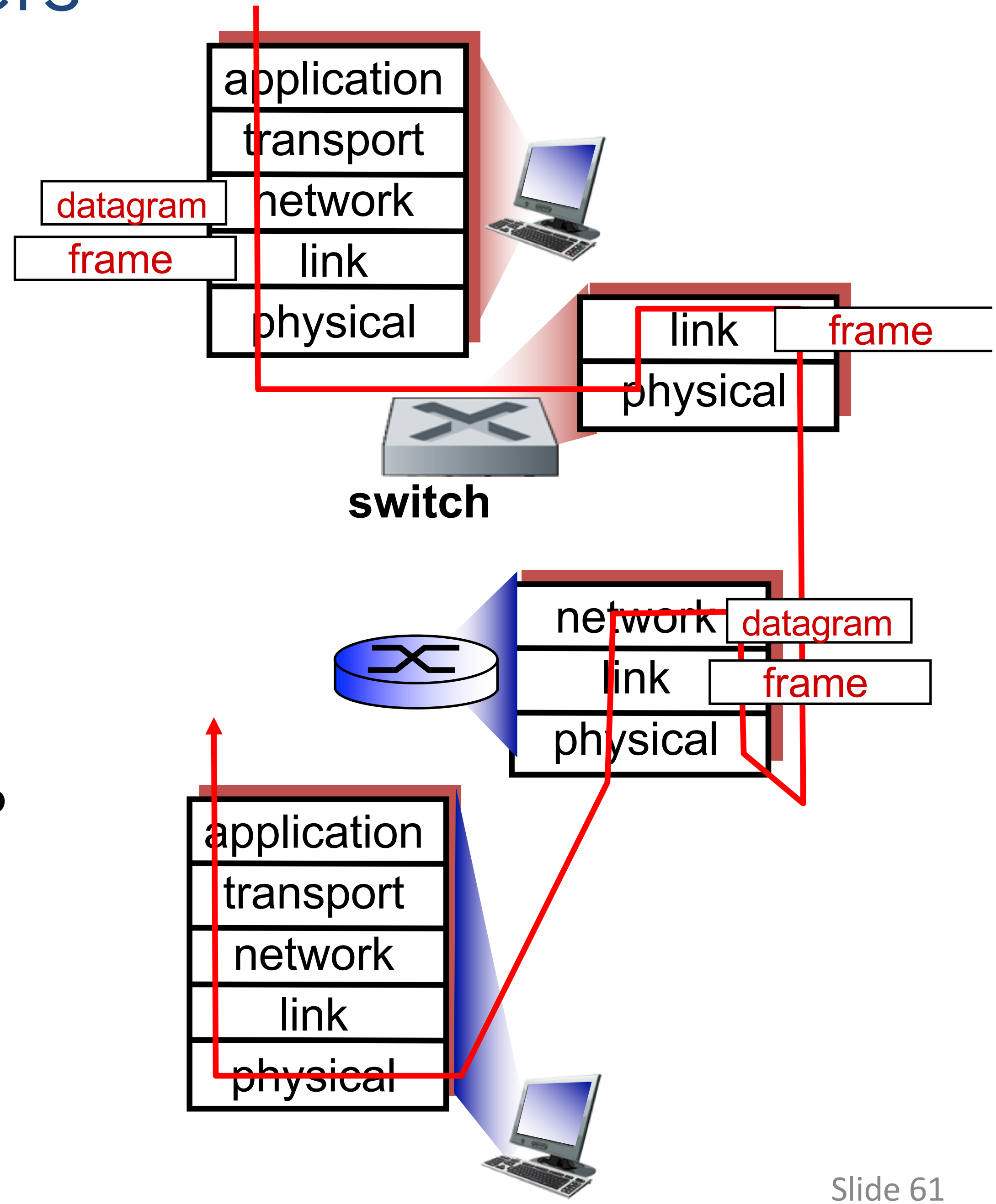
both have forwarding tables:

- *routers:* compute tables using routing algorithms, IP addresses
- *switches:* learn forwarding table using flooding, learning, MAC addresses



Switches vs. routers

Switches do NOT run a complex coordination protocol like routing.



both have forwarding tables:

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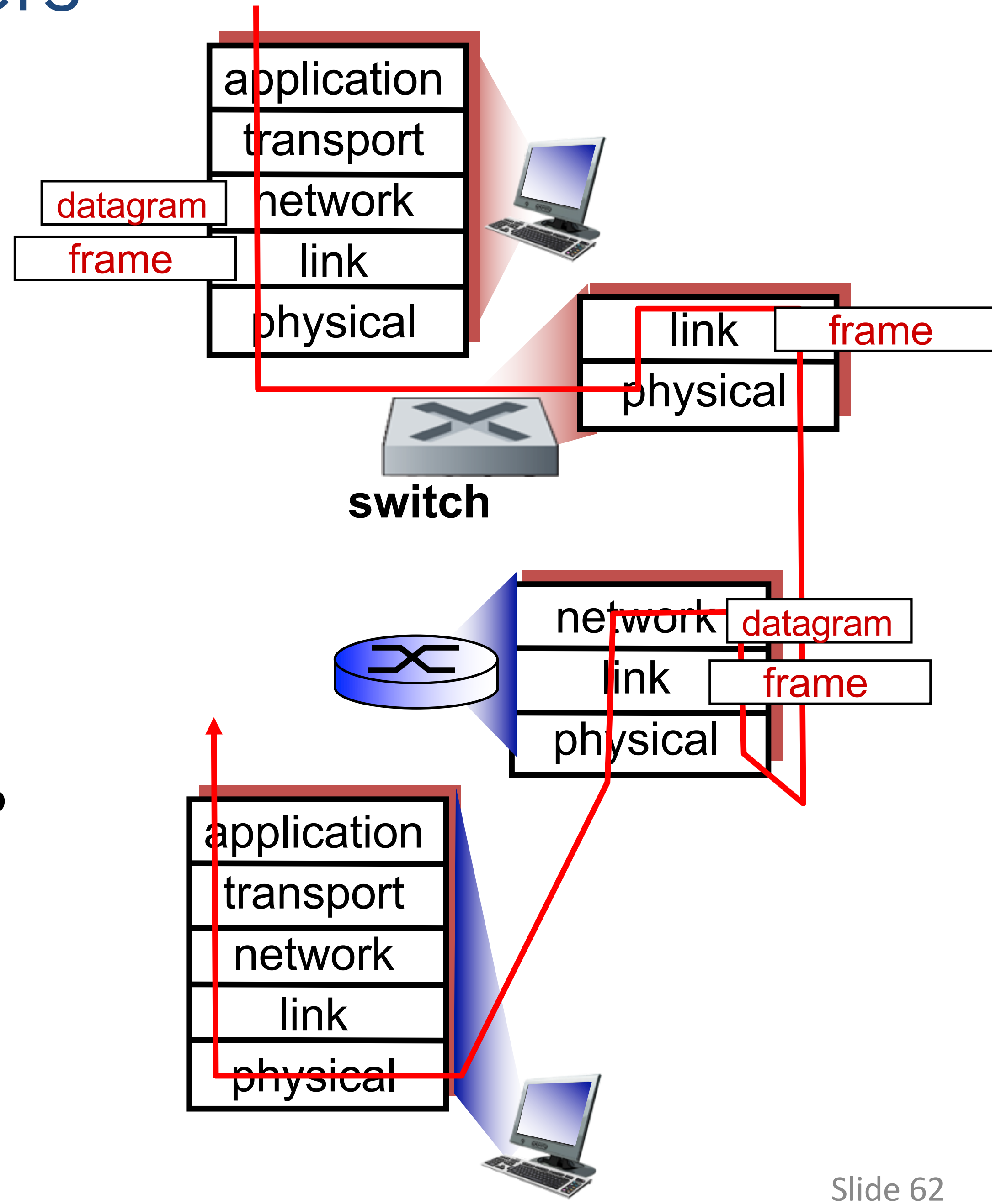
Switches vs. routers

You do NOT address frames directly to a switch (unless you're configuring it).



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- *routers:* compute tables using routing algorithms, IP addresses
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Summary

- LAN address: flat (vs. hierarchical IP)

- Many potential topologies:
  - Bus: shared wire, star (hub)
  - Switched: star, tree

- Switches learn who is connected, selectively forward toward destination