Information Network

Lecture 13: Link Layer (Part 2)

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Reminder

- **Short Test in class on January 22**
- The test will be on PandA and will take approximately 30 minutes.
- Please bring your computer, make sure that it is charged and that you can use PandA.
- No materials are allowed, but you can use your own pen and paper for calculations and to make notes during the test.
- Final Grade: Homeworks 20%, Short Test 20%, Report 60%

Link layer

- The network layer provides a communication service between any two hosts
- Between the hosts, there are a series of communication links, some wired and some wireless, starting at the source, passing through a series of switches and routers and ending at the destination.
- The link layer deals with how packets are sent through the individual links on the communication path

Link layer

6.1 introduction, services

6.2 multiple access protocols

6.3 LANs

- addressing, ARP
- Ethernet
- switches

Link layer addressing

- IP Addresses are only used on the network layer. The Link layer does not know about IP addresses.
- Hosts and routers not only have network layer (IP) addresses but also link-layer addresses, which are very different from IP addresses.
- Link-layer addresses correspond to the adapters (network interfaces) instead of the host or router itself.
- A host or router with multiple interfaces will have multiple link-layer addresses.
- The link layer address is called LAN address, physical address or media access control (MAC) address.

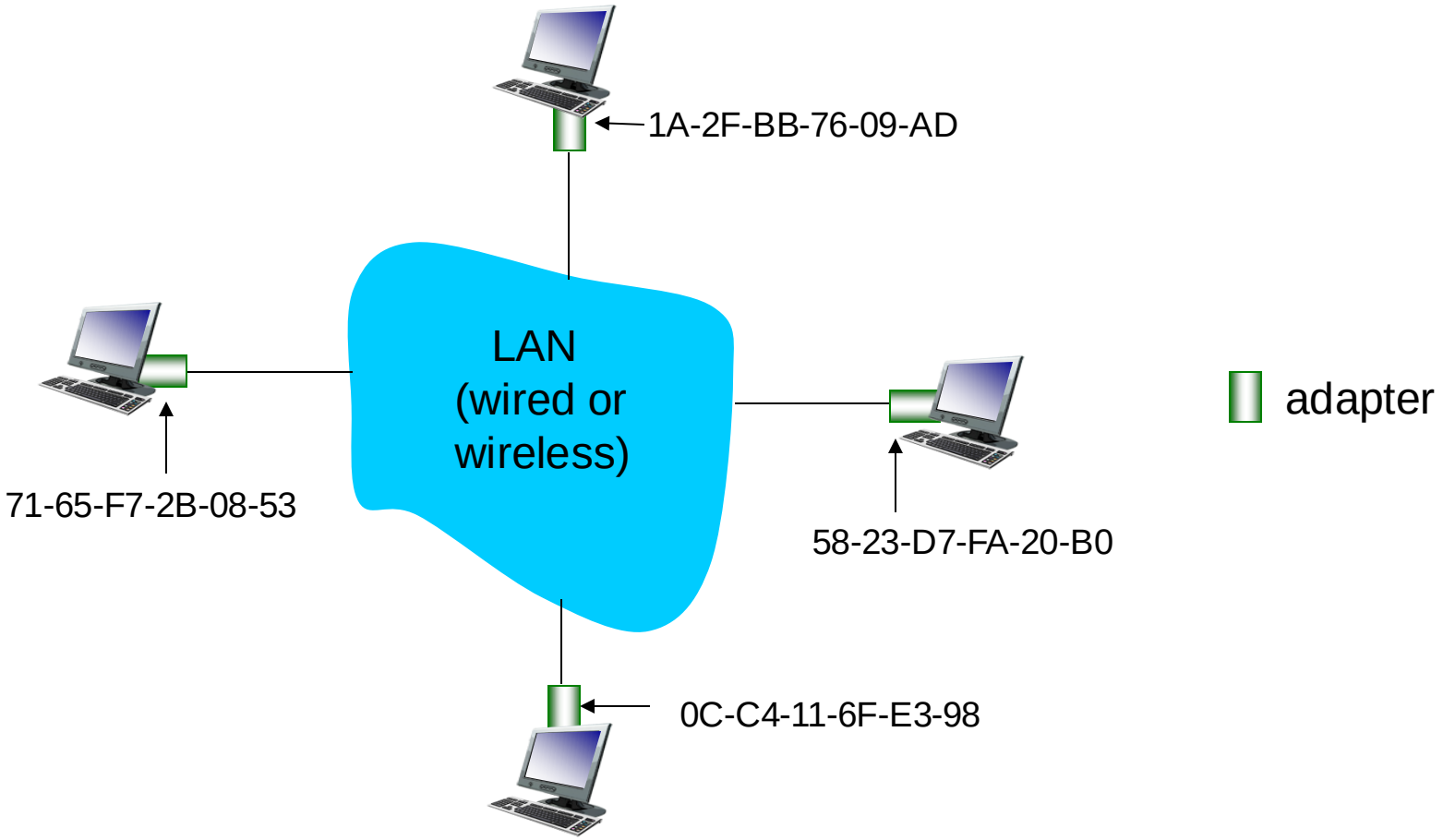
MAC addresses and ARP

- 32-bit IP address:
  - *network-layer* address for interface
  - used for layer 3 (network layer) forwarding
- MAC (or LAN or physical or Ethernet) address:
  - function: *used 'locally" to get frame from one interface to another physically-connected interface (same network, in IP-addressing sense)*
  - 48 bit MAC address (for most LANs) typically burned into network device hardware
  - Designed to be permanent, no two adapters have the same address.
  - e.g.: 1A-2F-BB-76-09-AD

hexadecimal (base 16) notation
(each "numeral" represents 4 bits)

MAC addresses and ARP

each adapter on LAN has unique *MAC* address



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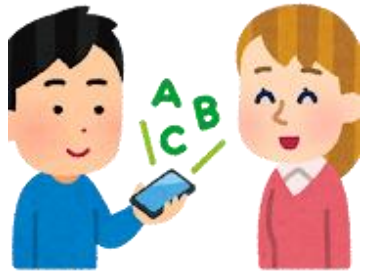
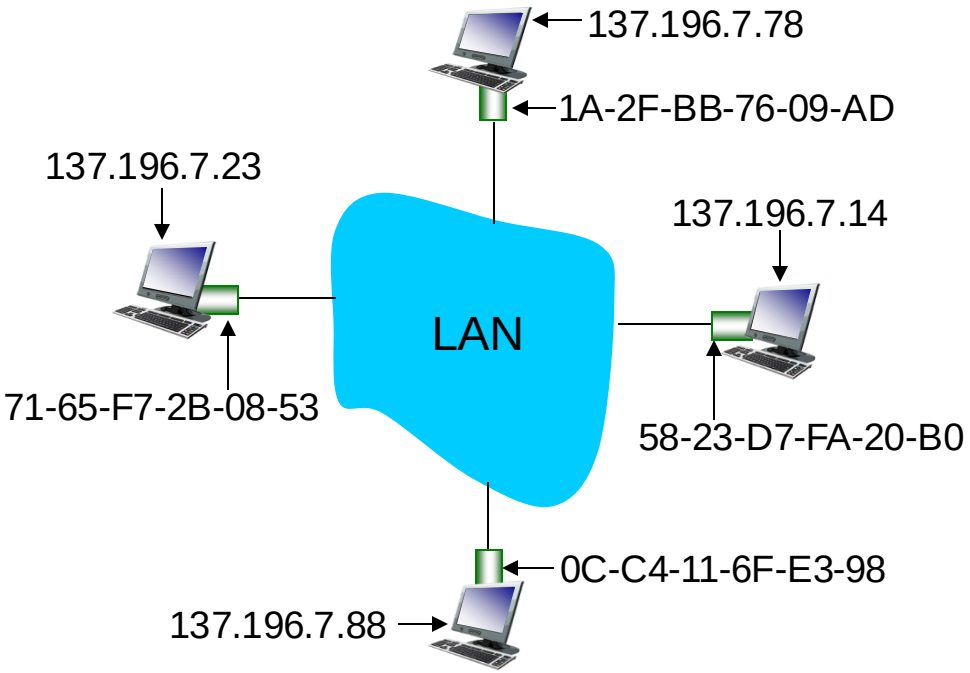
MAC addresses (more)

- MAC address allocation administered by IEEE
- manufacturer buys portion of MAC address space (to assure uniqueness)
- MAC flat address ➜ portability
  - can move LAN card from one LAN to another
  - MAC address: like “My Number”
  - IP address: like postal address
- IP hierarchical address *not* portable
  - address depends on IP subnet to which node is attached

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)

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ARP protocol: same LAN

- A wants to send datagram to B
  - B's MAC address not in A's ARP table.
- A broadcasts ARP query packet, containing B's IP address
  - destination MAC address = FF-FF-FF-FF-FF-FF
  - all nodes on LAN receive ARP query
- B receives ARP packet, replies to A with its (B's) MAC address
  - frame sent to A's MAC address (unicast)

- A caches (saves) IP-to-MAC address pair in its ARP table until information becomes old (times out)
  - information that times out (goes away) unless refreshed
  - nodes create their ARP tables *without intervention from net administrator*

ARP protocol in action

example: A wants to send datagram to B

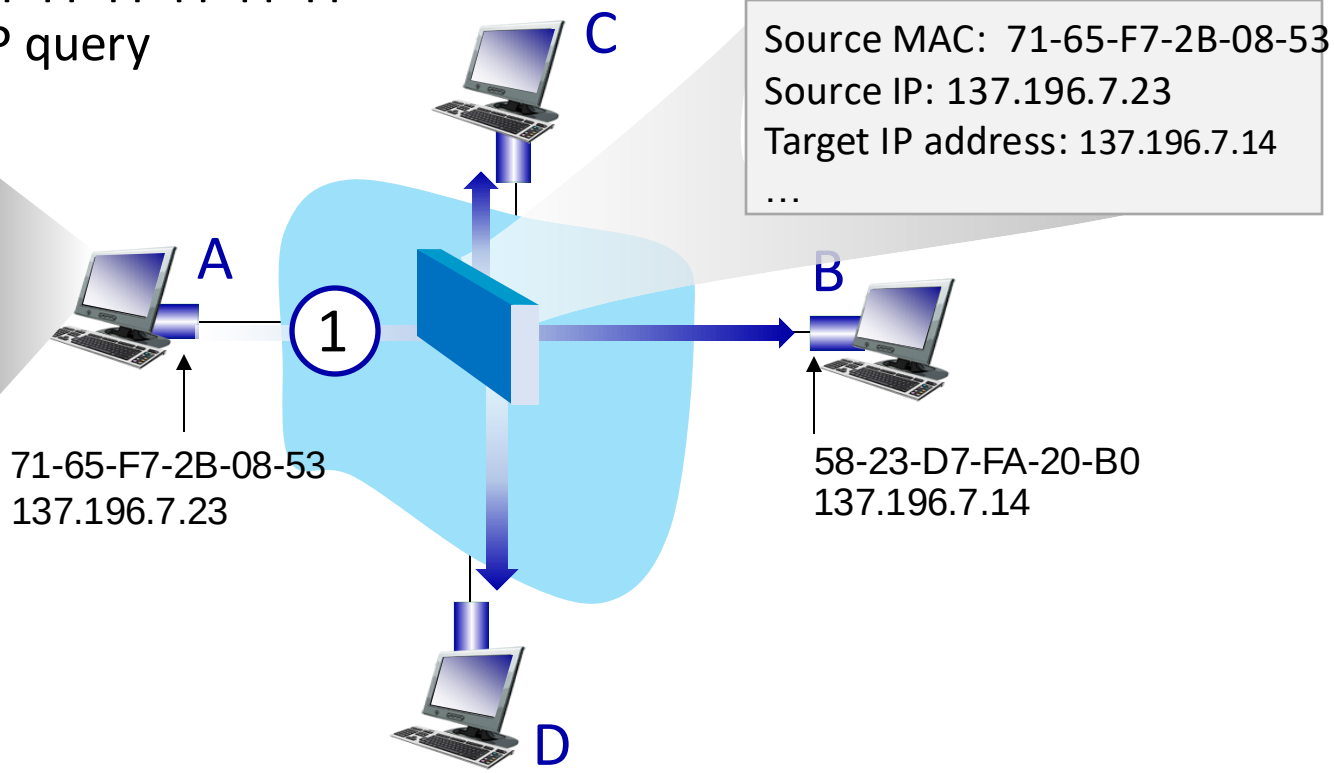
- B's MAC address not in A's ARP table, so A uses ARP to find B's MAC address

A broadcasts ARP query, containing B's IP addr

1
- destination MAC address = FF-FF-FF-FF-FF-FF
- all nodes on LAN receive ARP query

ARP table in A

IP addr	MAC addr	TTL



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ARP protocol in action

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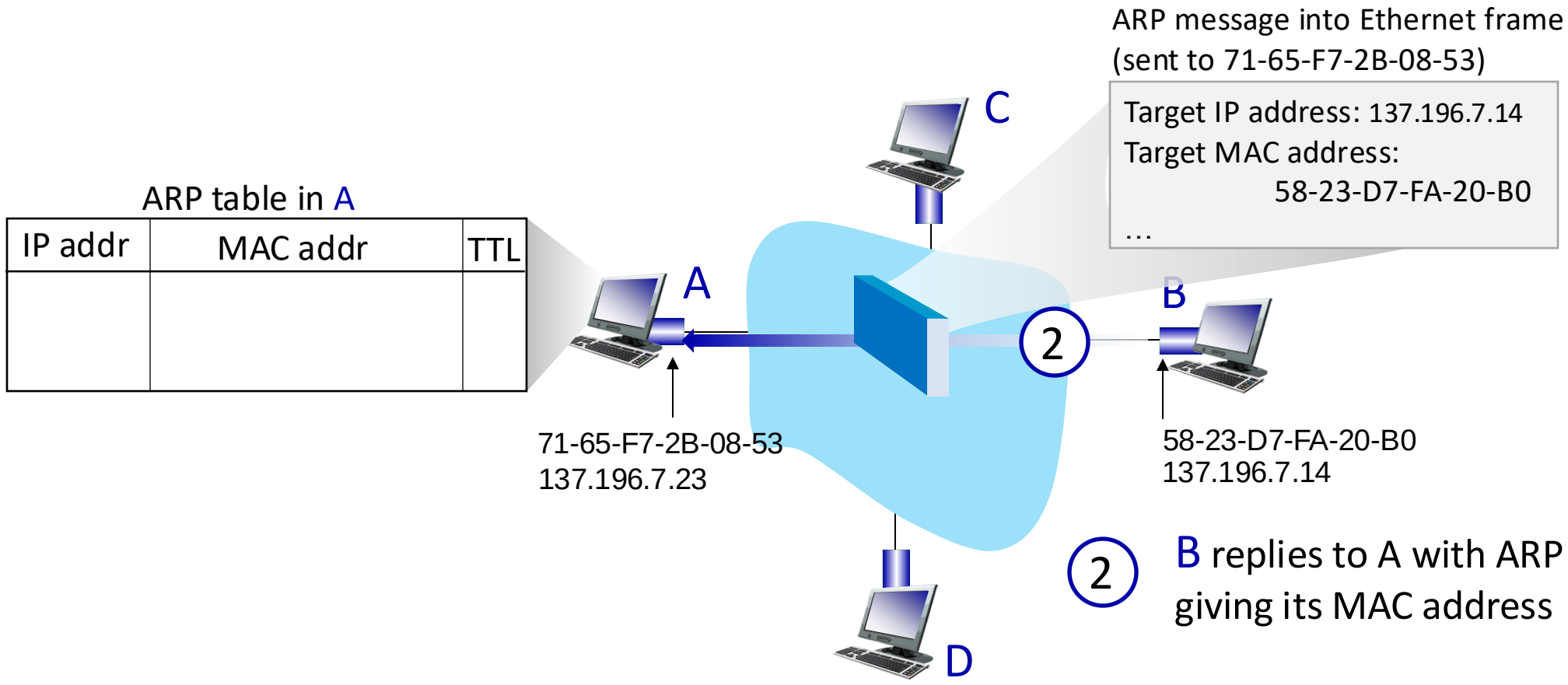

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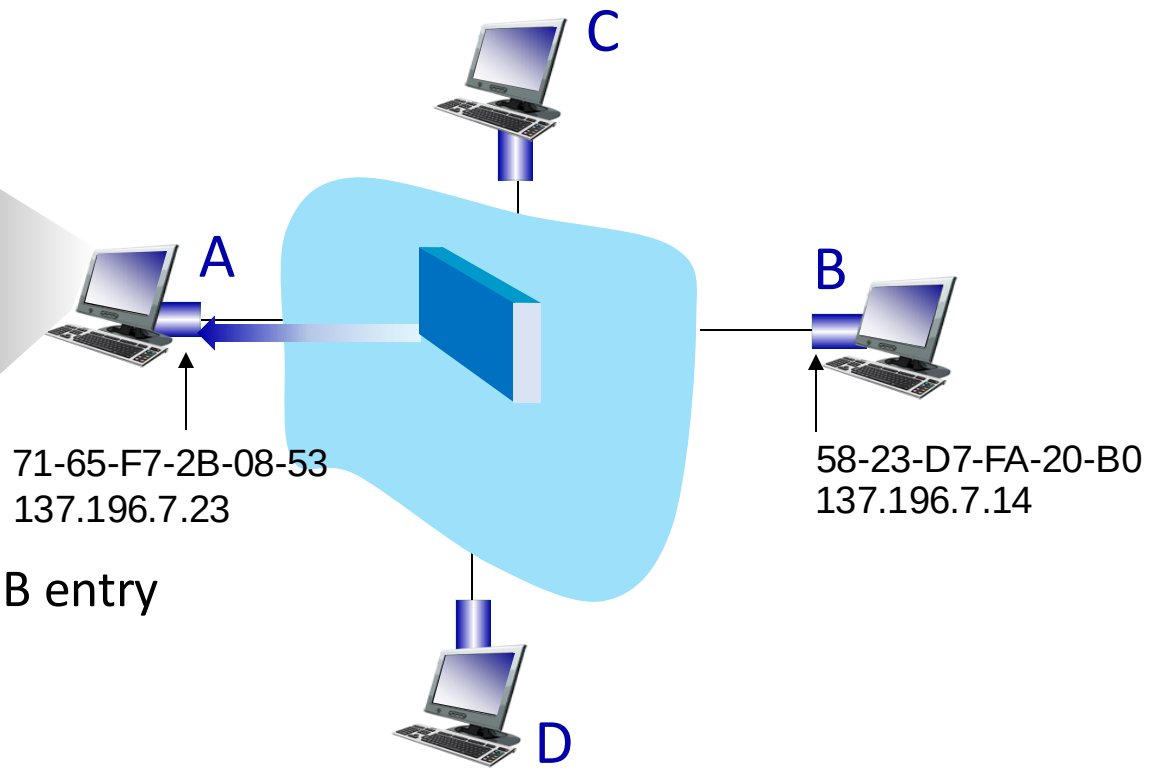
ARP protocol in action

example: A wants to send datagram to B

- B's MAC address not in A's ARP table, so A uses ARP to find B's MAC address

ARP table in A

IP addr	MAC addr	TTL
137.196.7.14	58-23-D7-FA-20-B0	500



③ A receives B's reply, adds B entry into its local ARP table

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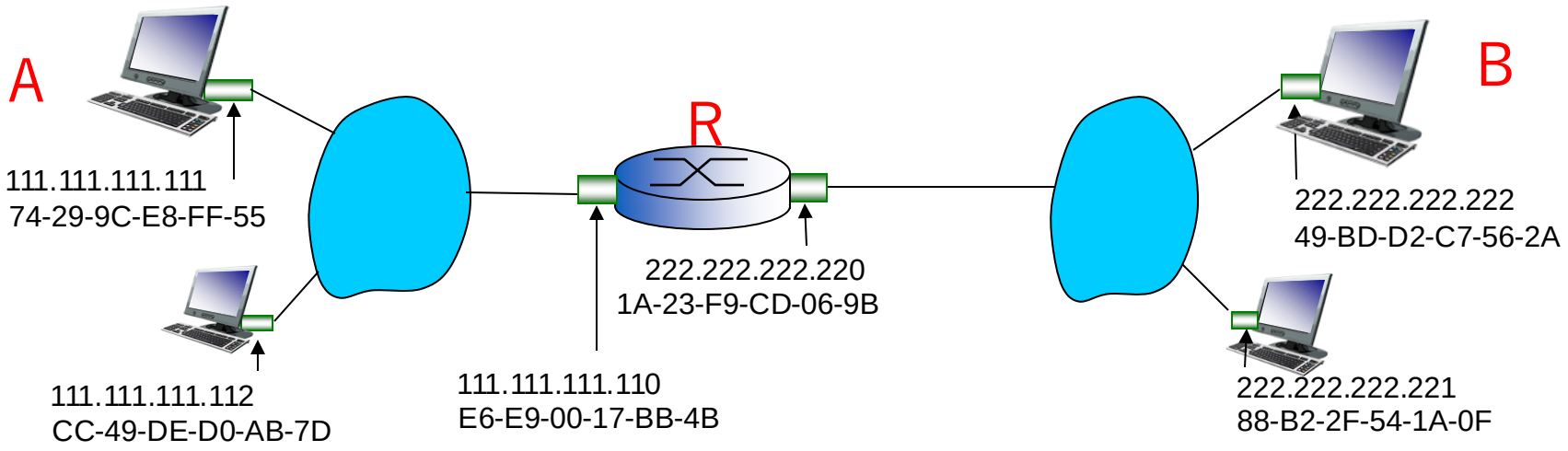
ARP protocol

- ARP operates when a host wants to send a datagram to another host on the same subnet.
- What if a host wants to send a network-layer datagram to a host across a router to another subnet?

Addressing: routing to another LAN

walkthrough: send datagram from A to B via R

- focus on addressing – at IP (datagram) and MAC layer (frame)
- assume A knows B's IP address
- assume A knows IP address of first hop router, R
- assume A knows R's MAC address (ARP)



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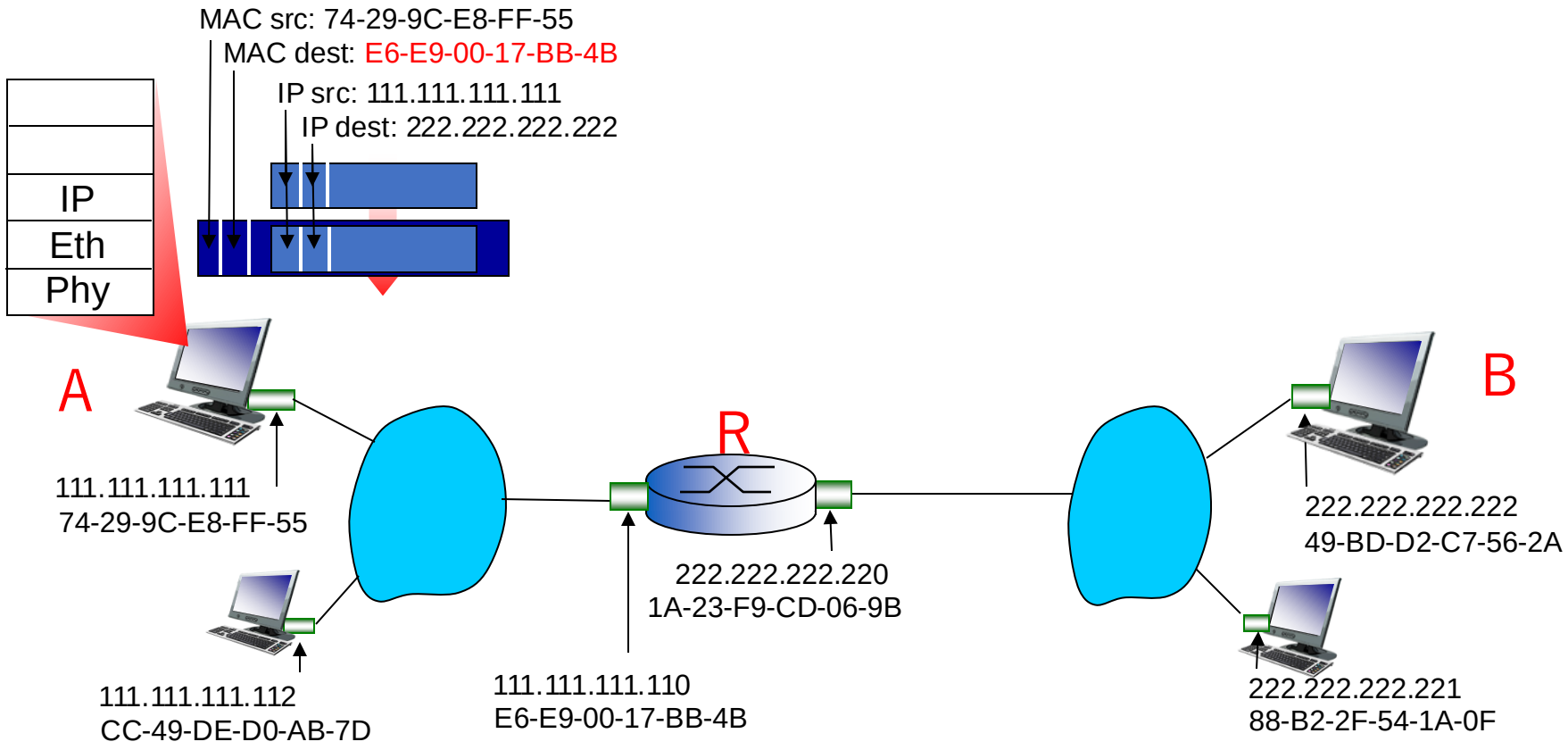
Addressing: routing to another LAN

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



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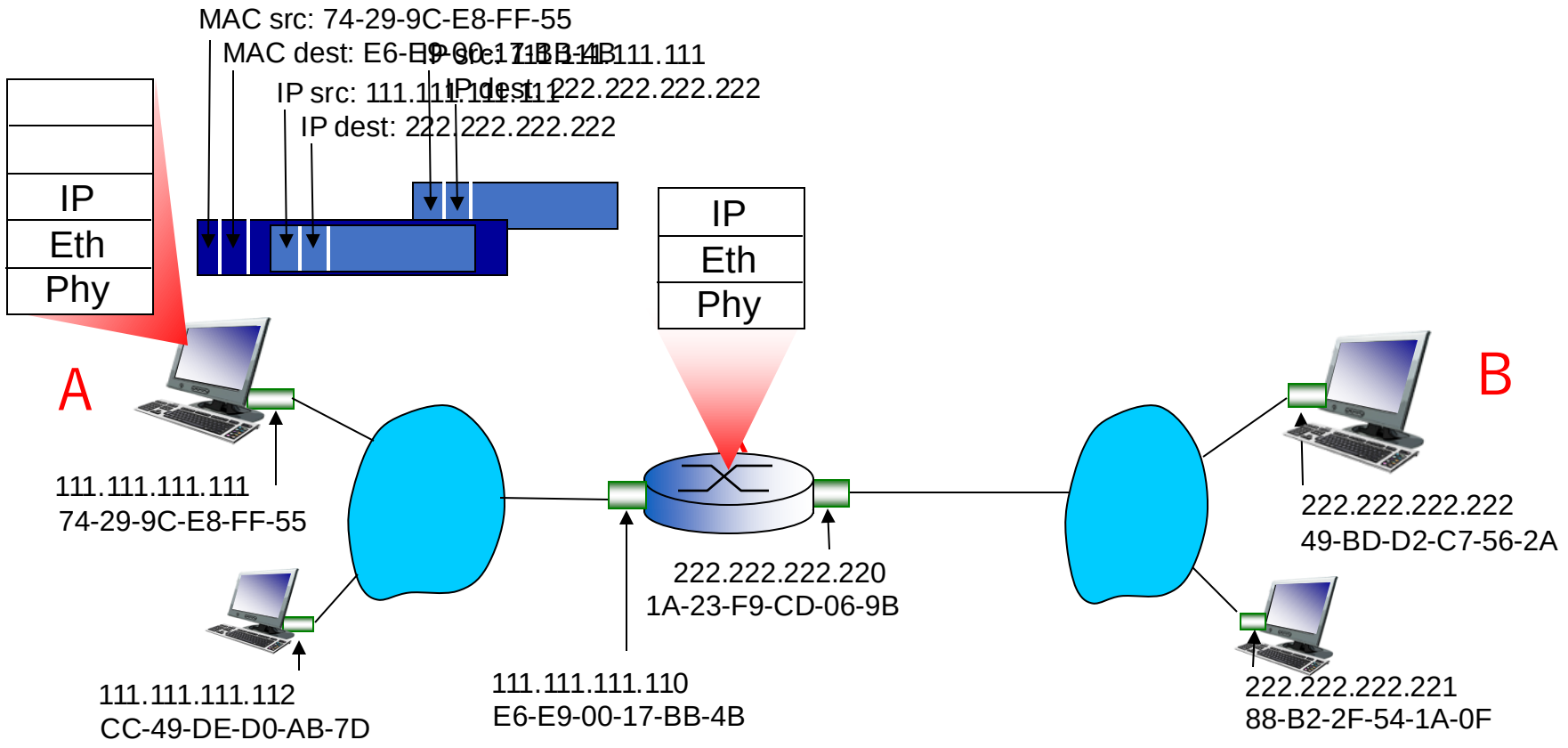
Addressing: routing to another LAN

- frame sent from A to R
- frame received at R, datagram removed, passed up to IP



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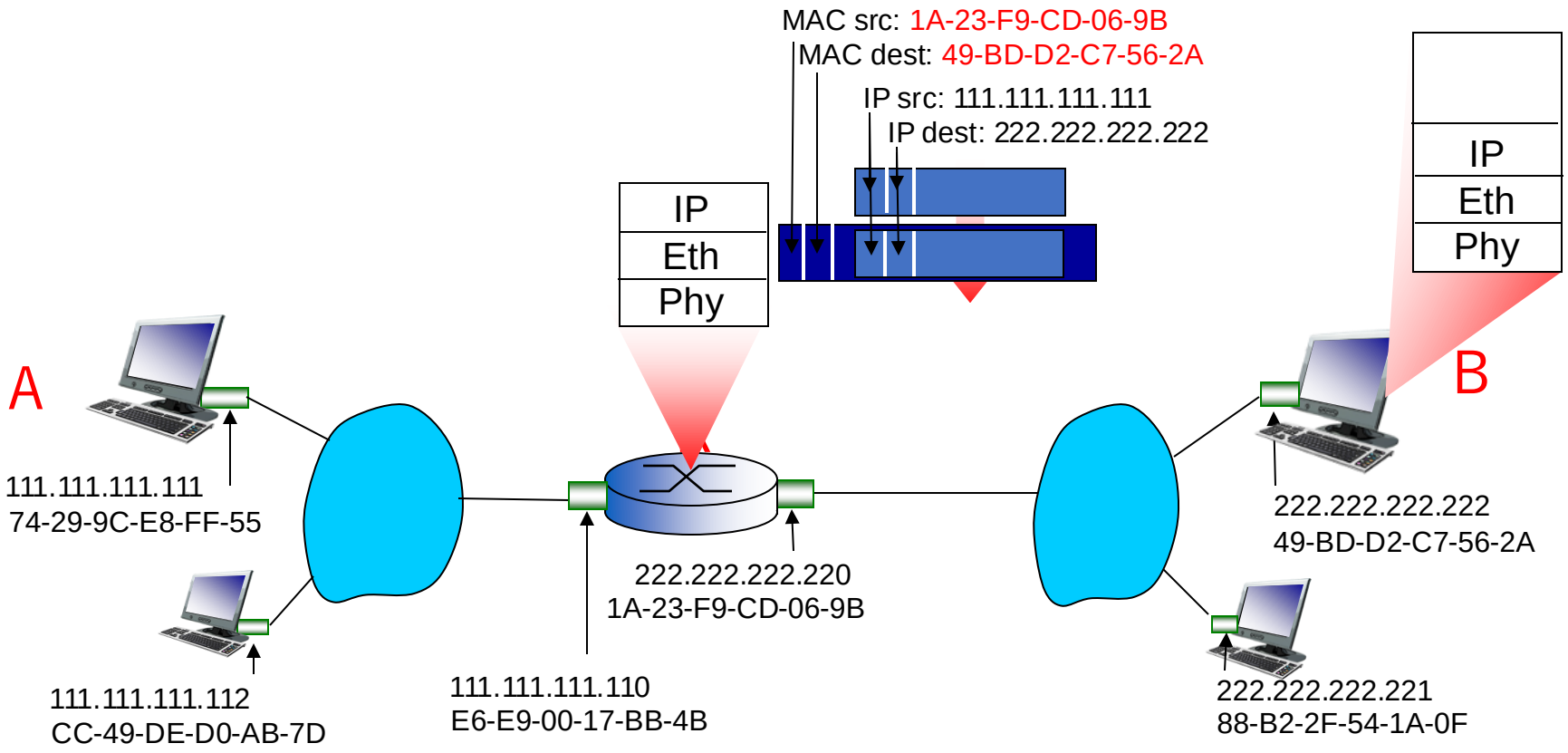
Addressing: routing to another LAN

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



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Addressing: routing to another LAN

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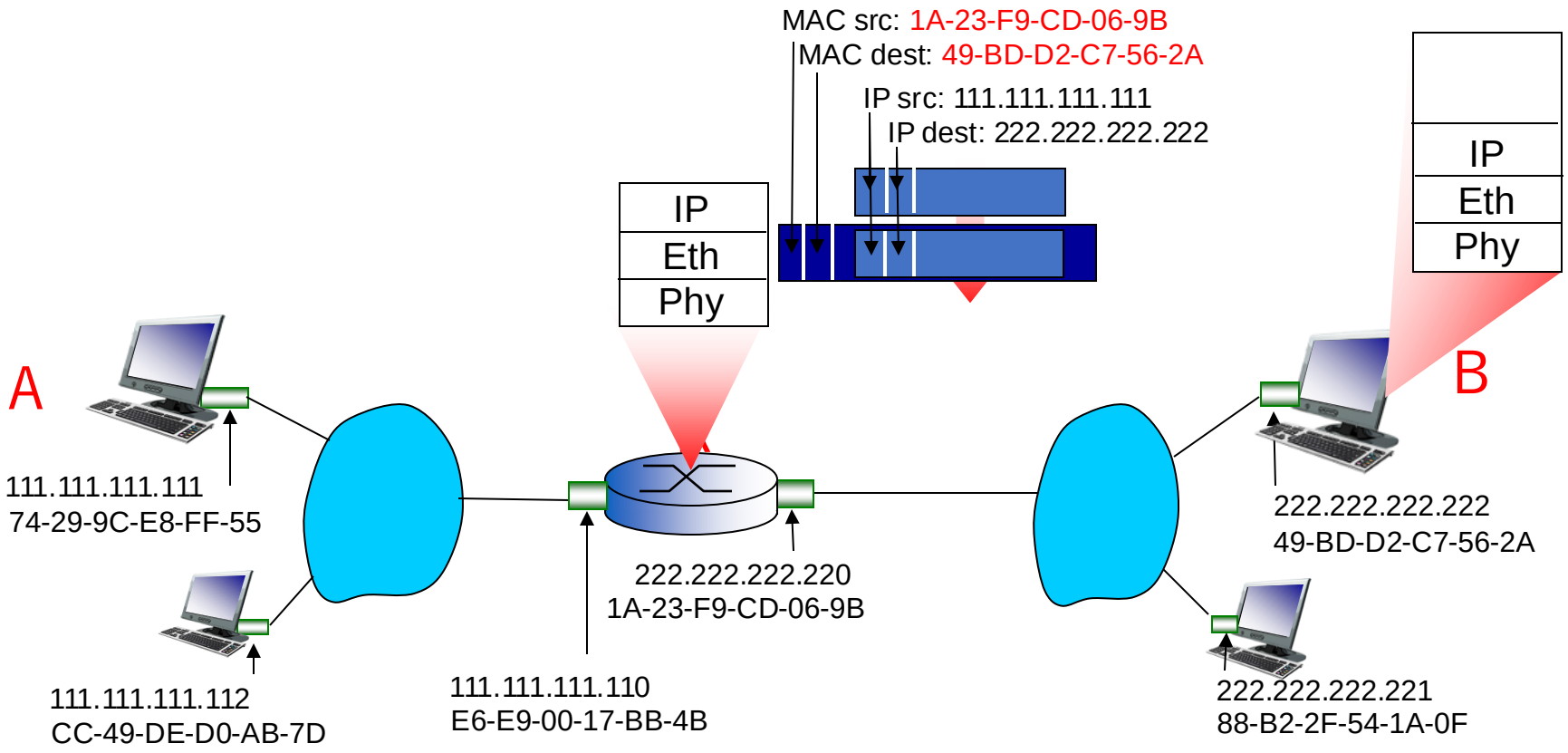

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Addressing: routing to another LAN

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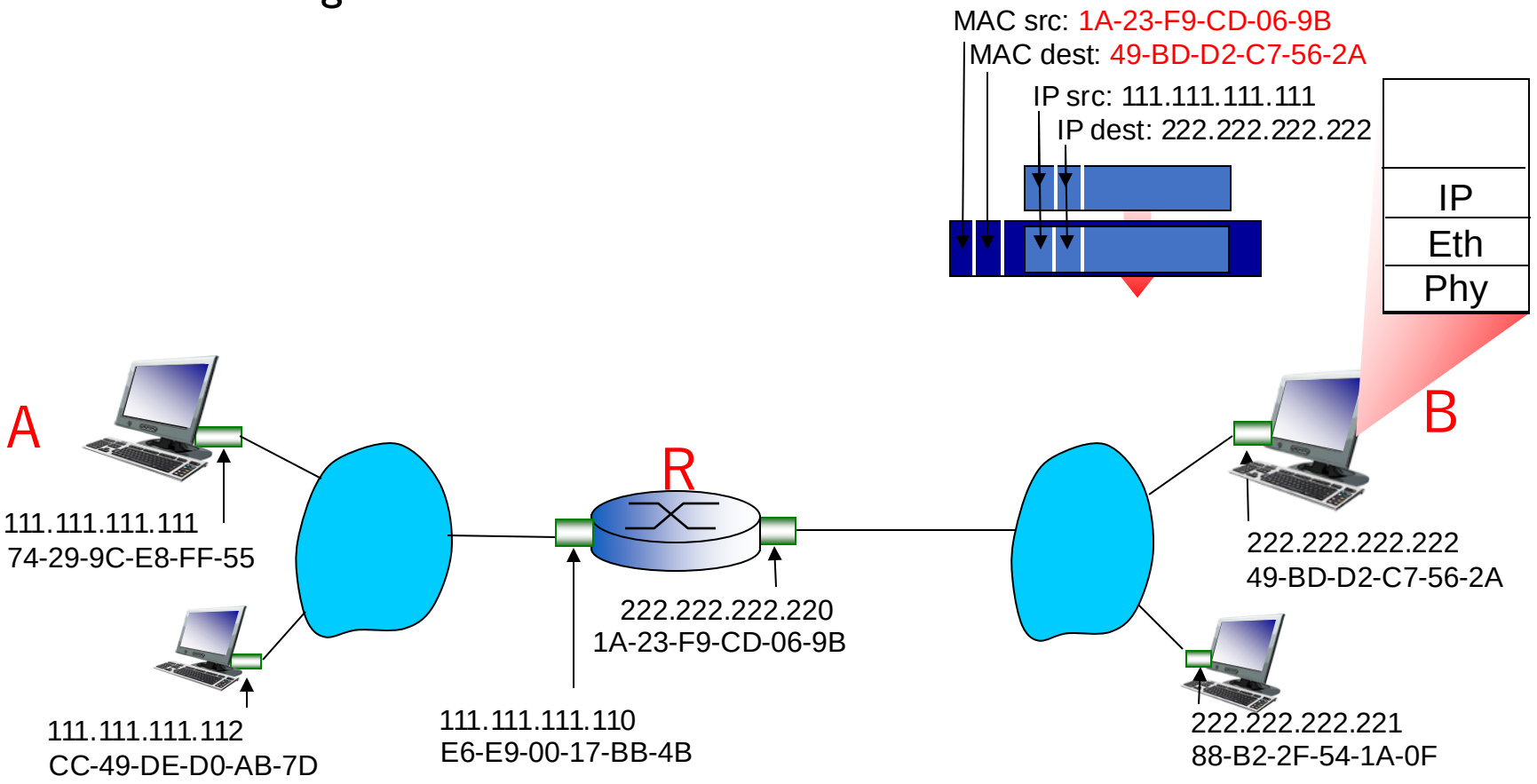

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Link layer

6.1 introduction, services

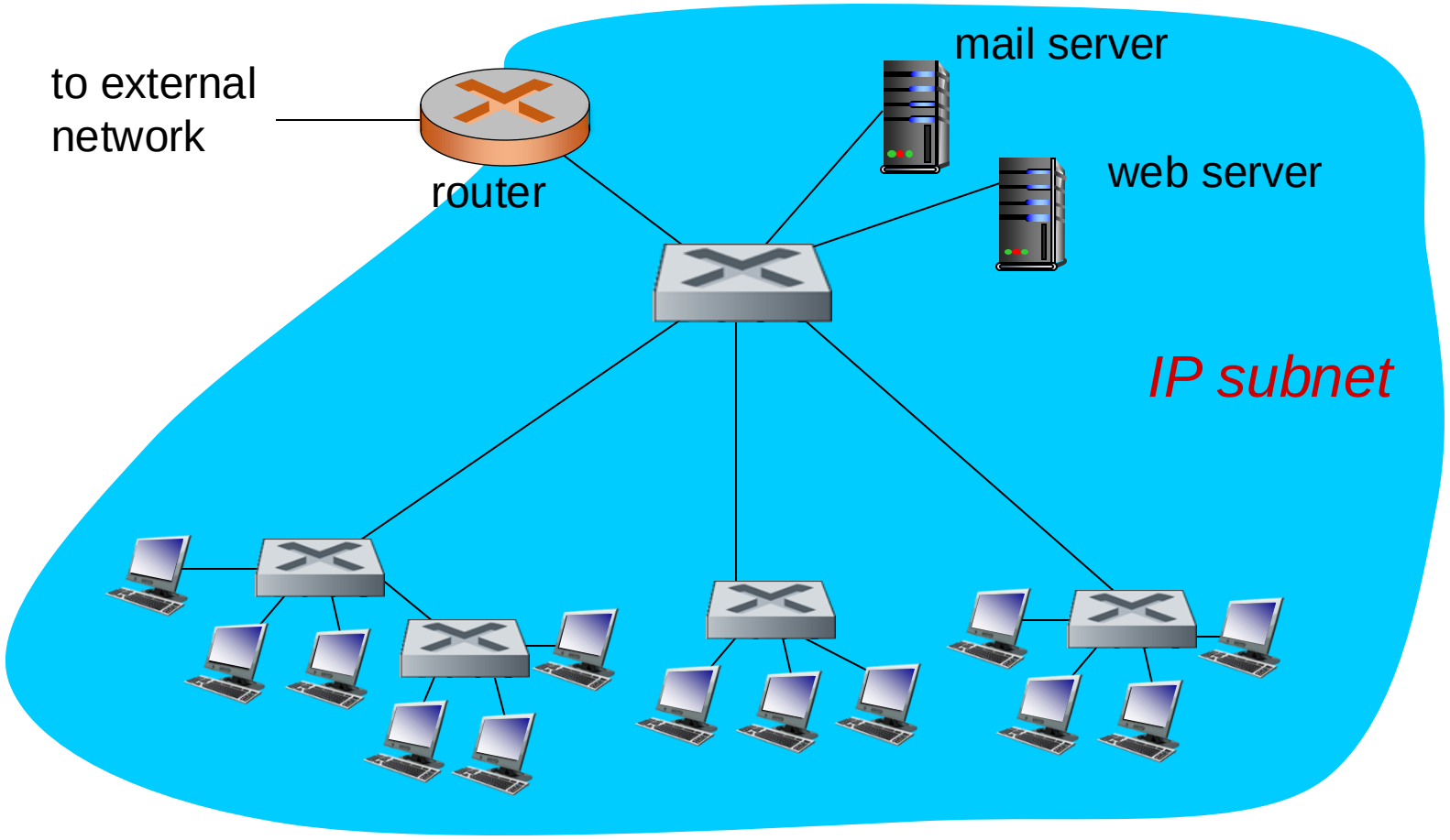
6.2 error detection, correction

6.3 multiple access protocols

6.4 LANs

- addressing, ARP
- Ethernet
- switches

Institutional network



Ethernet

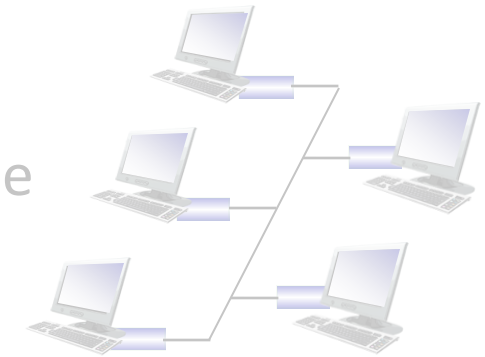
"dominant" wired LAN technology:

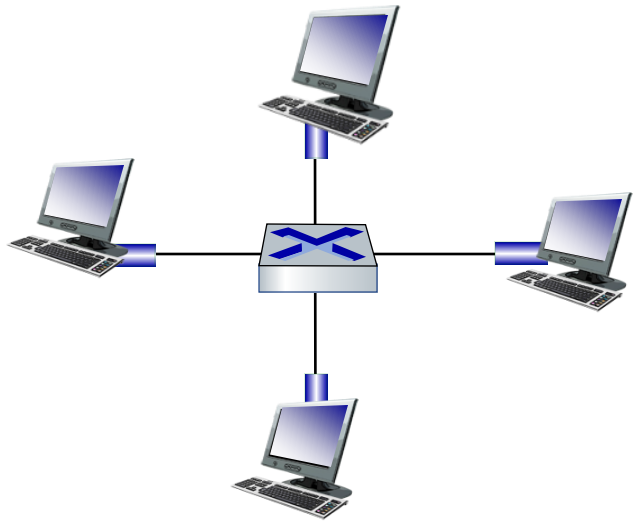
- first widely used LAN technology
- simple, cheap
- kept up with speed race: 10 Mbps – 400 Gbps

Ethernet: physical topology

- bus: popular through mid 90s
  - all nodes in same collision domain (can collide with each other)
- switched: prevails today
  - active link-layer 2 *switch* in center
  - nodes do not collide with each other

bus: coaxial cable

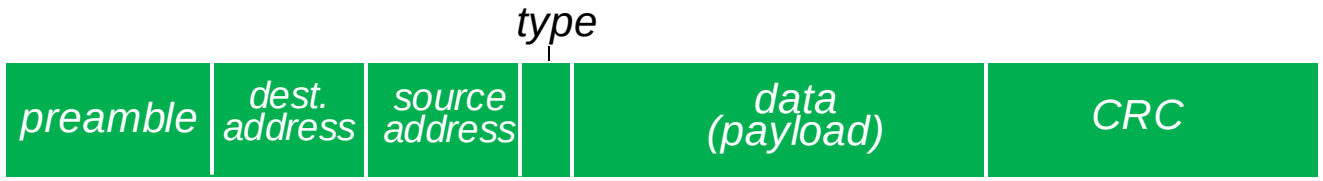




switched

Ethernet frame structure

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

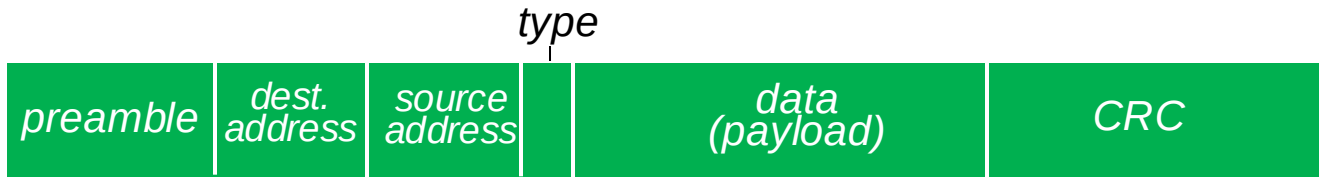


preamble:

- 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
- The first 7 bytes used to wake up the receiving adapters and synchronize the clock to sender's clock (the size of an interval used to transmit one bit as electronic voltage)

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., ARP, Novell IPX, AppleTalk)
- *CRC:* cyclic redundancy check – checksum used at receiver for error detection
  - error detected: frame is dropped



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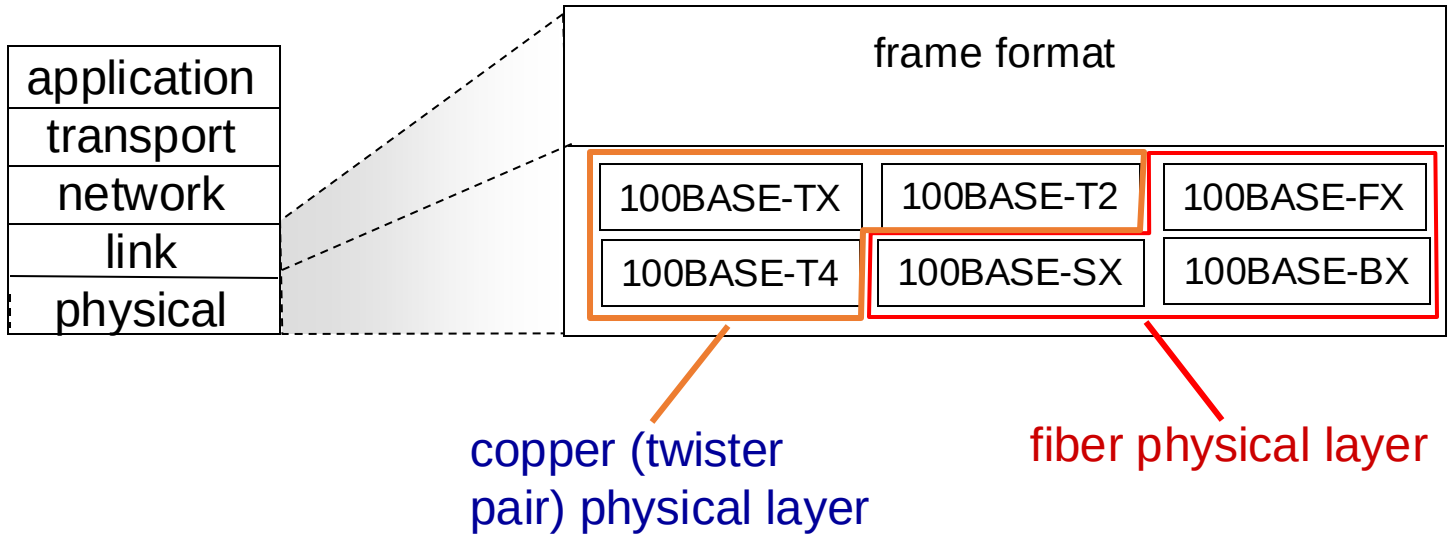
Ethernet: unreliable, connectionless

- *connectionless:* no handshaking between sending and receiving network interface controllers
- *unreliable:* receiver doesn't send acks to sender
  - data in dropped frames recovered only if initial sender uses higher layer reliable protocol (e.g., TCP), otherwise dropped data lost

802.3 Ethernet standards: link & physical layers

- *many* different Ethernet standards
  - common frame format
  - different speeds: 2 Mbps, 10 Mbps, 100 Mbps, 1Gbps, 10 Gbps, 40 Gbps
  - different physical layer media: fiber, cable



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Link layer, LANs: outline

6.1 introduction, services

6.2 error detection, correction

6.3 multiple access protocols

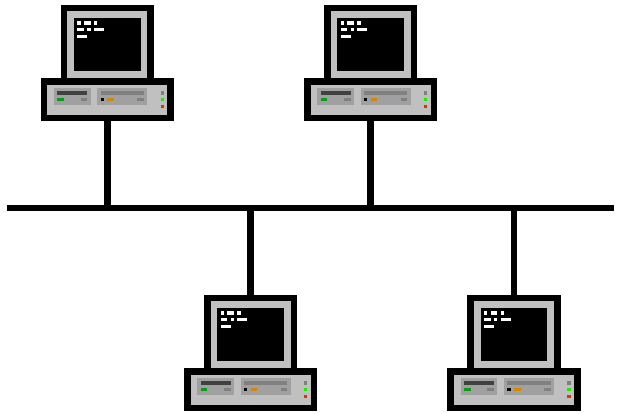
6.4 LANs

- addressing, ARP
- Ethernet
- switches

Hubs and Switches

How are multiple devices connected in the same subnet?

- **Hubs** operate on the physical layer. Each bit is simply recreated, and a copy is sent to all other interfaces



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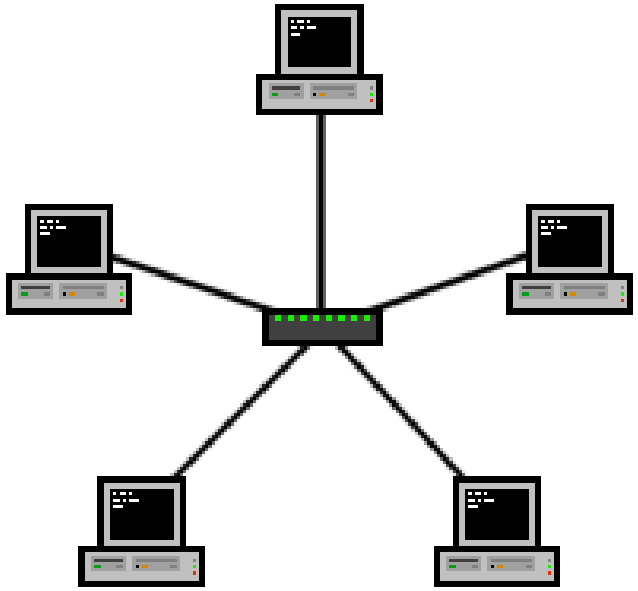
Hubs and Switches

How are multiple devices connected in the same subnet?

- **Switches** operate on the link layer. A switch can establish connections to send messages only to selected destinations.



Ethernet switch

- Switch is a link-layer device: takes an *active* role
  - store, forward Ethernet (or other type of) frames
  - examine incoming frame's MAC address, *selectively* forward frame to one-or-more outgoing links when frame is to be forwarded on segment
- transparent: hosts *unaware* of presence of switches
- plug-and-play, self-learning
  - switches do not need to be configured

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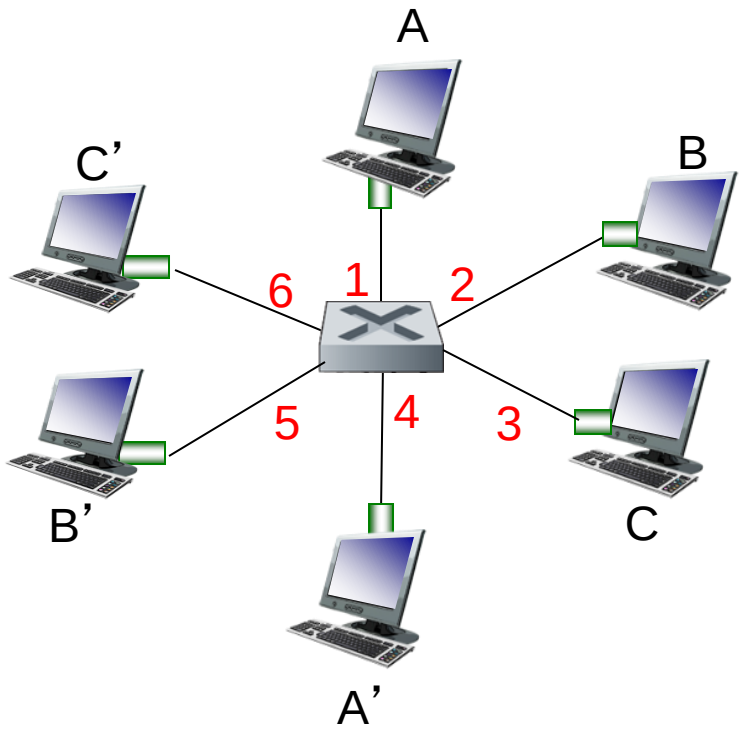
Switch: *multiple* simultaneous transmissions

- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol used on *each* incoming link, but no collisions
- *switching:* A-to-A' and B-to-B' can transmit simultaneously, without collisions



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

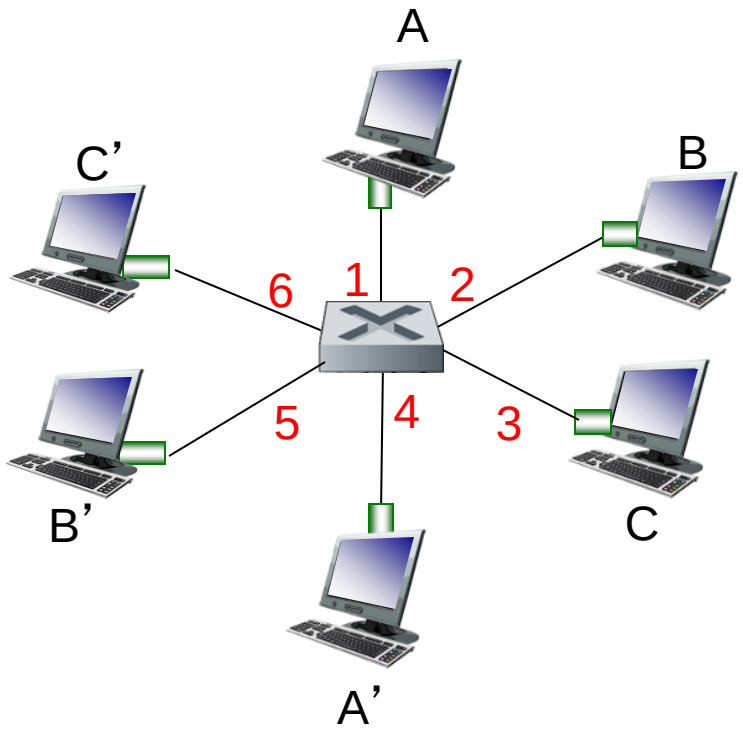
Switch forwarding table

Q: how does switch know A' reachable via interface 4, B' reachable via interface 5?

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

Q: how are entries created, maintained in switch table?

- something like a routing protocol?



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

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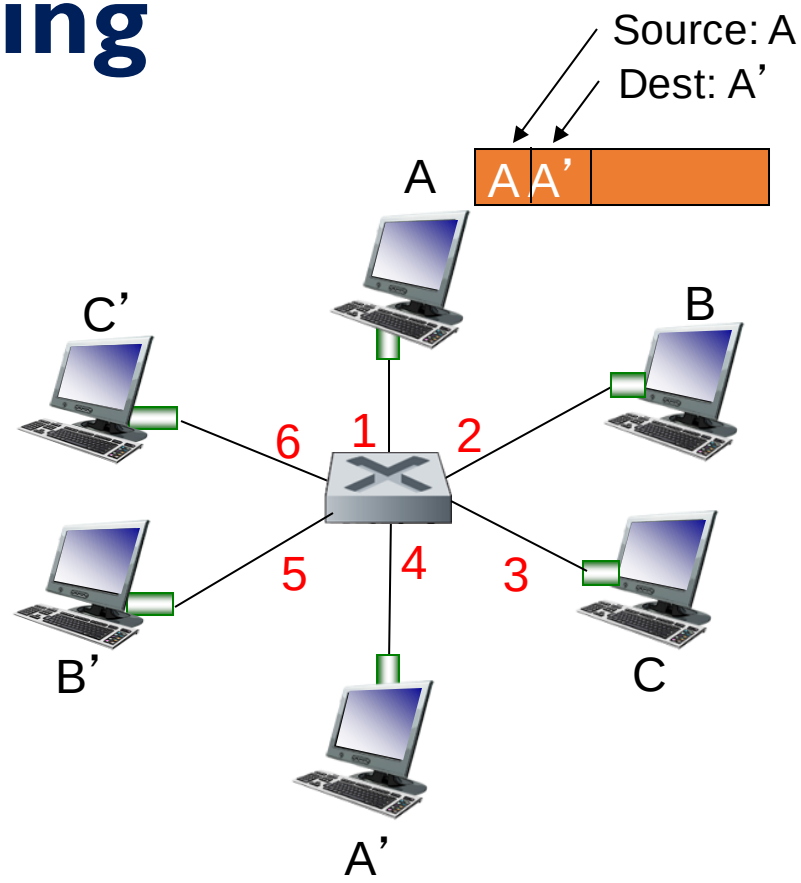
Switch: self-learning

- 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)

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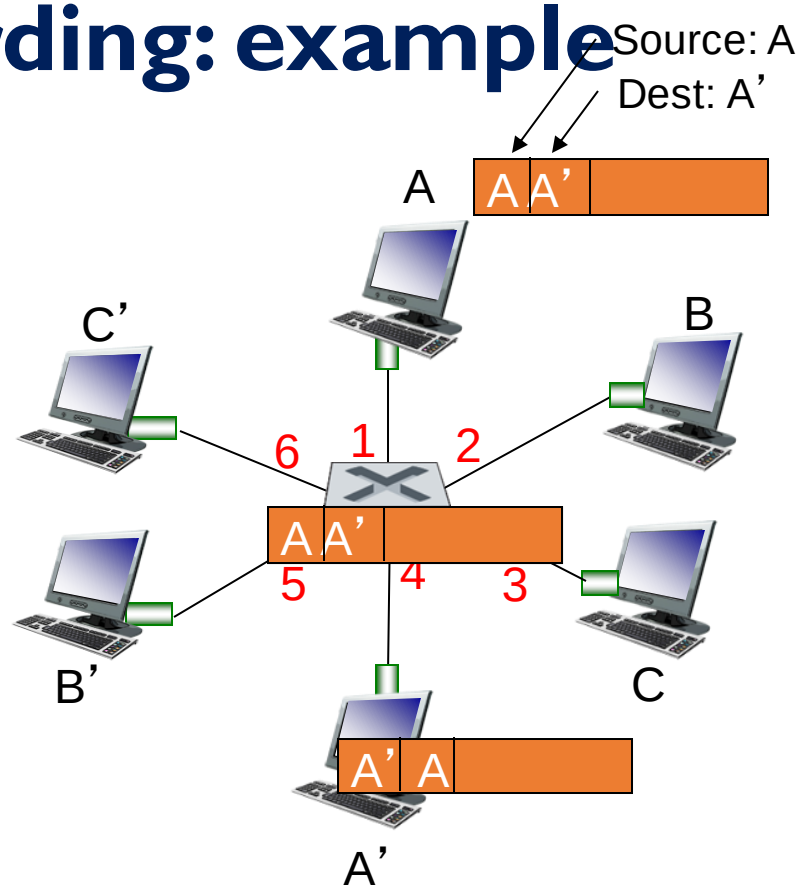
Self-learning, forwarding: example

- frame destination, A', location unknown: *flood*
- destination A location known: selectively send on just one link



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

switch table (initially empty)

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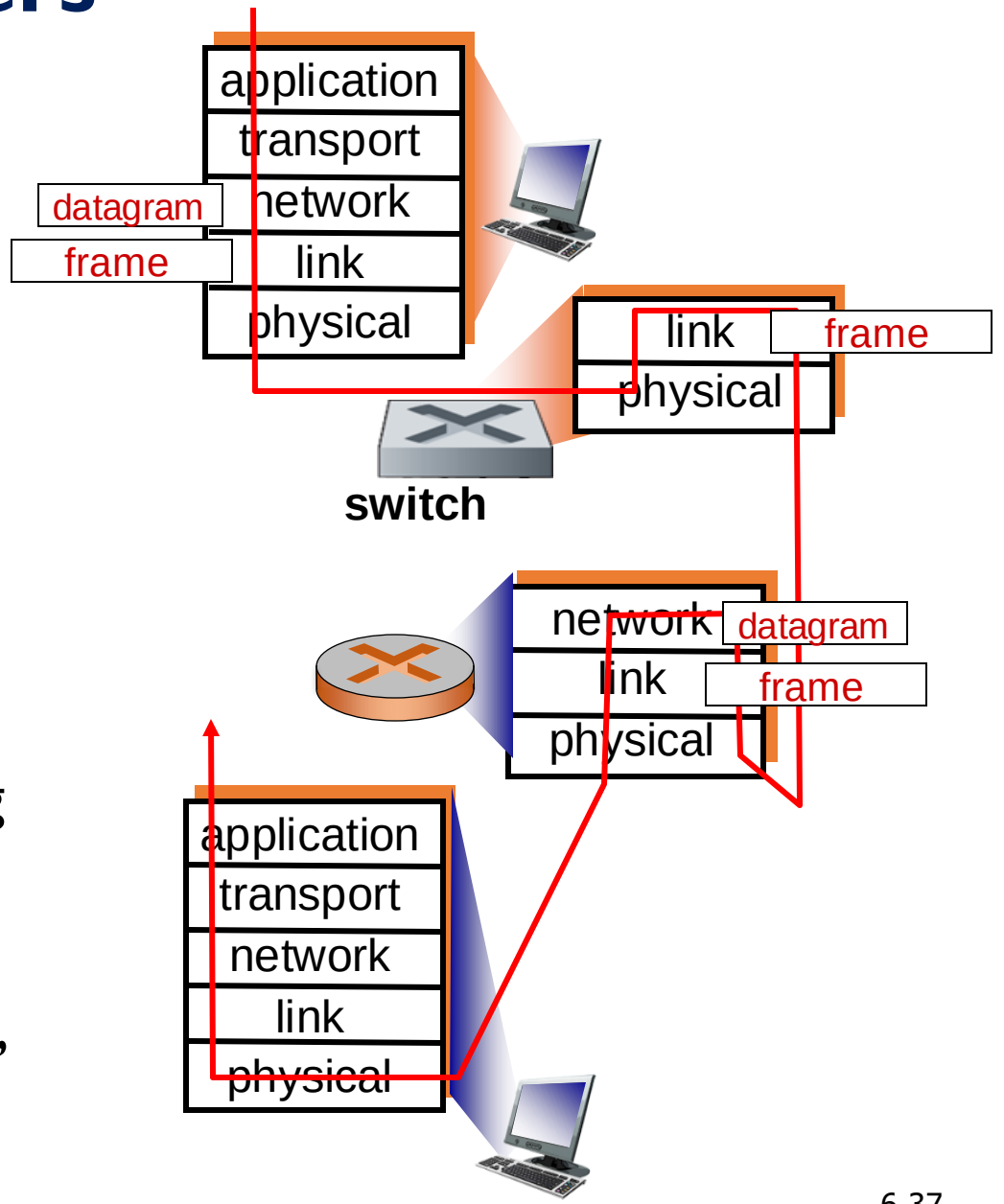
Switches vs. routers

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



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Link Layer Summary

- principles behind data link layer services:
  - sharing a broadcast channel: multiple access
  - link layer addressing
- instantiation, implementation of layer technologies
  - Ethernet
  - Switches

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