“Taking turns” MAC protocols

channel partitioning MAC protocols:

- share channel *efficiently* and *fairly* at high load
- inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

random access MAC protocols

- efficient at low load: single node can fully utilize channel
- high load: collision overhead

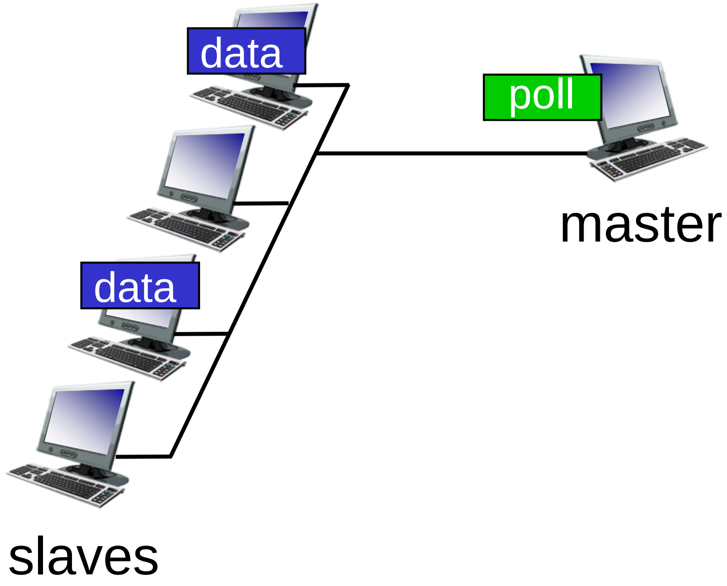
“taking turns” protocols

- look for best of both worlds!

“Taking turns” MAC protocols

polling:

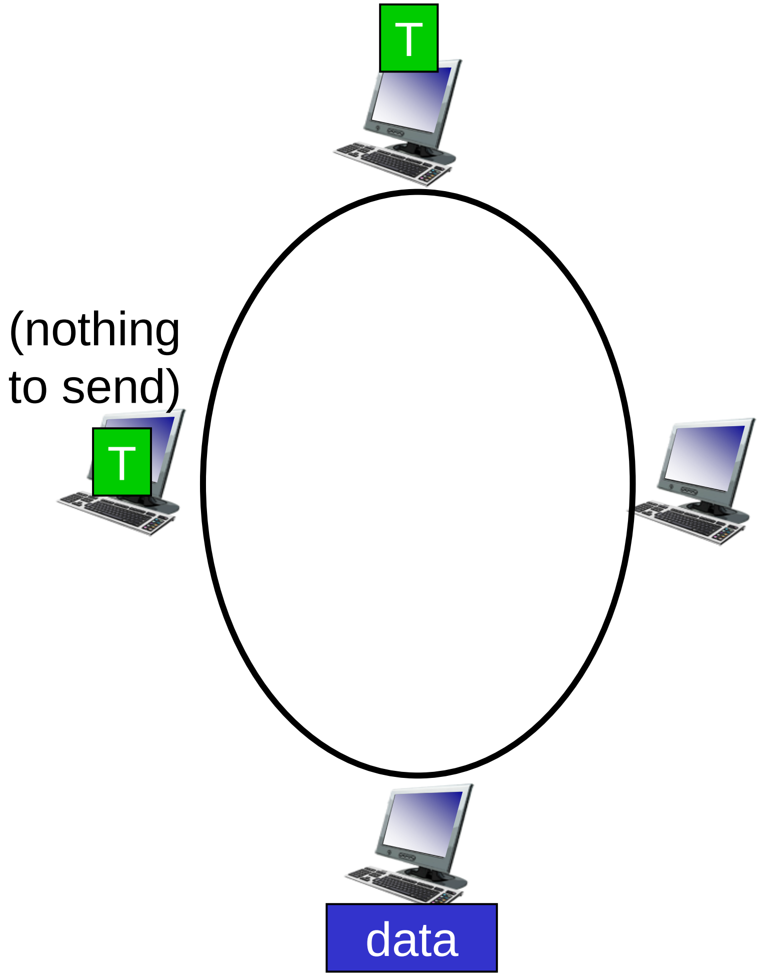
- master node “invites” other nodes to transmit in turn
- typically used with “dumb” devices
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)



“Taking turns” MAC protocols

token passing:

- control *token* passed from one node to next sequentially.
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)



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
  - FDDI, token ring

Link layer, LANs: roadmap

- introduction
- error detection, correction
- multiple access protocols
- LANs
  - addressing, ARP in action
  - Ethernet
  - switches
  - VLANs
- a day in the life of a web request

MAC addresses

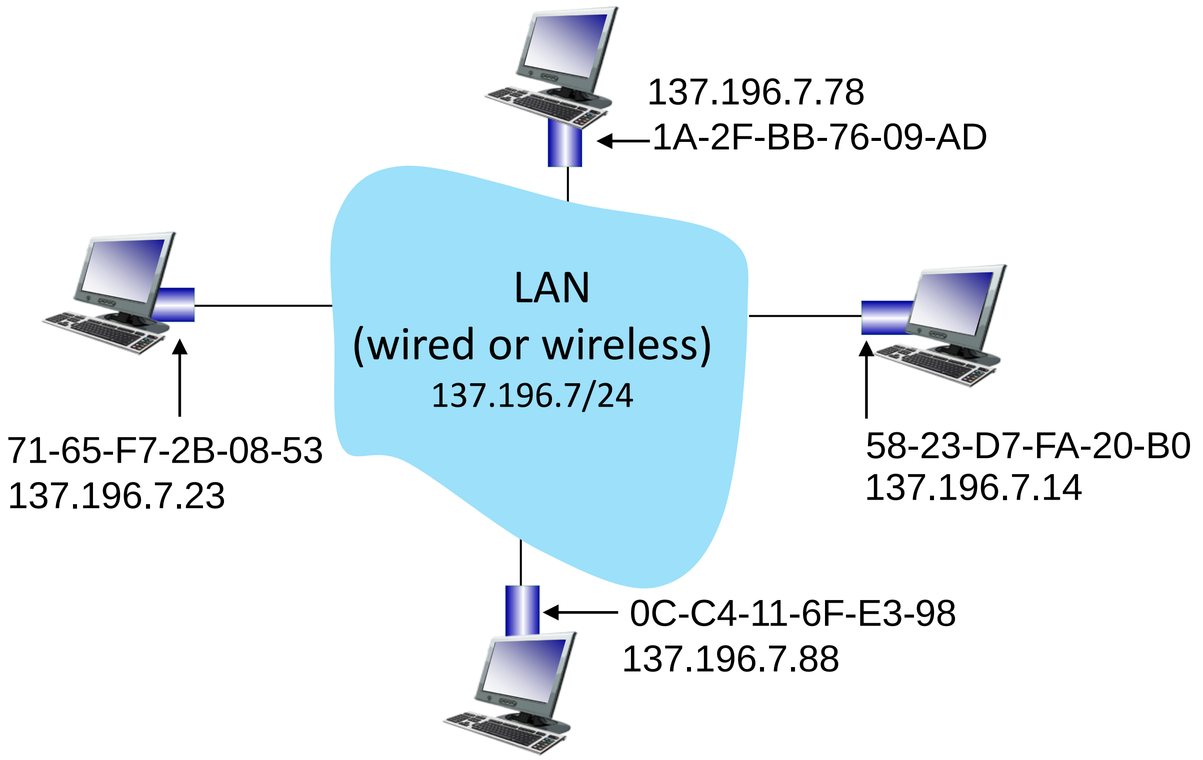
- 32-bit IP address:
  - *network-layer* address for interface
  - used for layer 3 (network layer) forwarding
  - e.g.: 128.119.40.136
- MAC (or LAN or physical or Ethernet) address:
  - function: used "locally" to get frame from one interface to another physically-connected interface (same subnet, in IP-addressing sense)
  - 48-bit MAC address (for most LANs) burned in NIC ROM, also sometimes software settable
  - e.g.: 1A-2F-BB-76-09-AD

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

MAC addresses

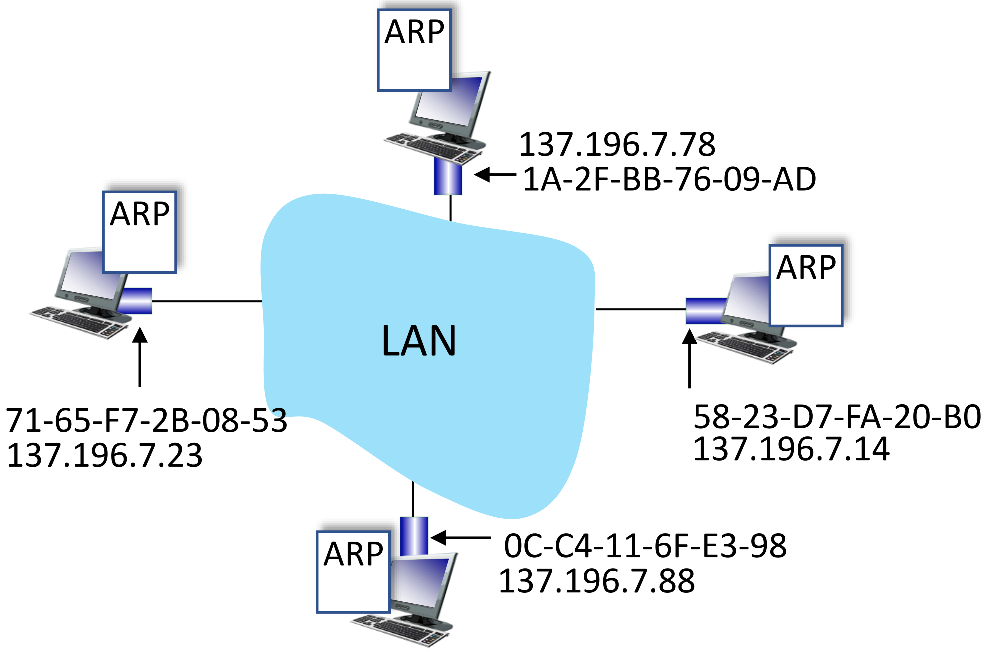
each interface on LAN

- has unique 48-bit MAC address
- has a locally unique 32-bit IP address (as we've seen)



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 in action

example: A wants to send datagram to B

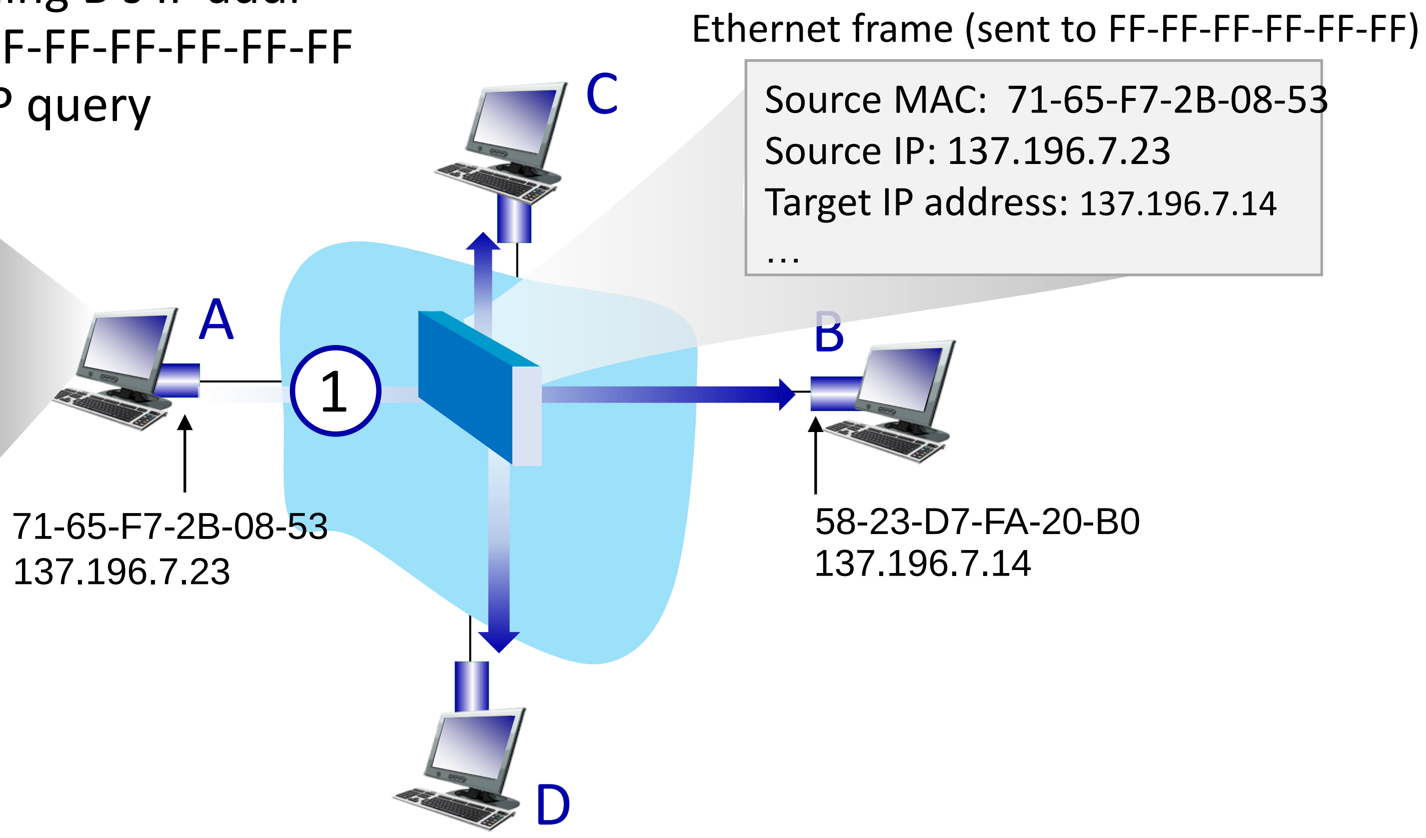
- B's MAC address not in A's ARP table, so A uses ARP to find B's MAC address

1 A broadcasts ARP query, containing B's IP addr

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

ARP table in A

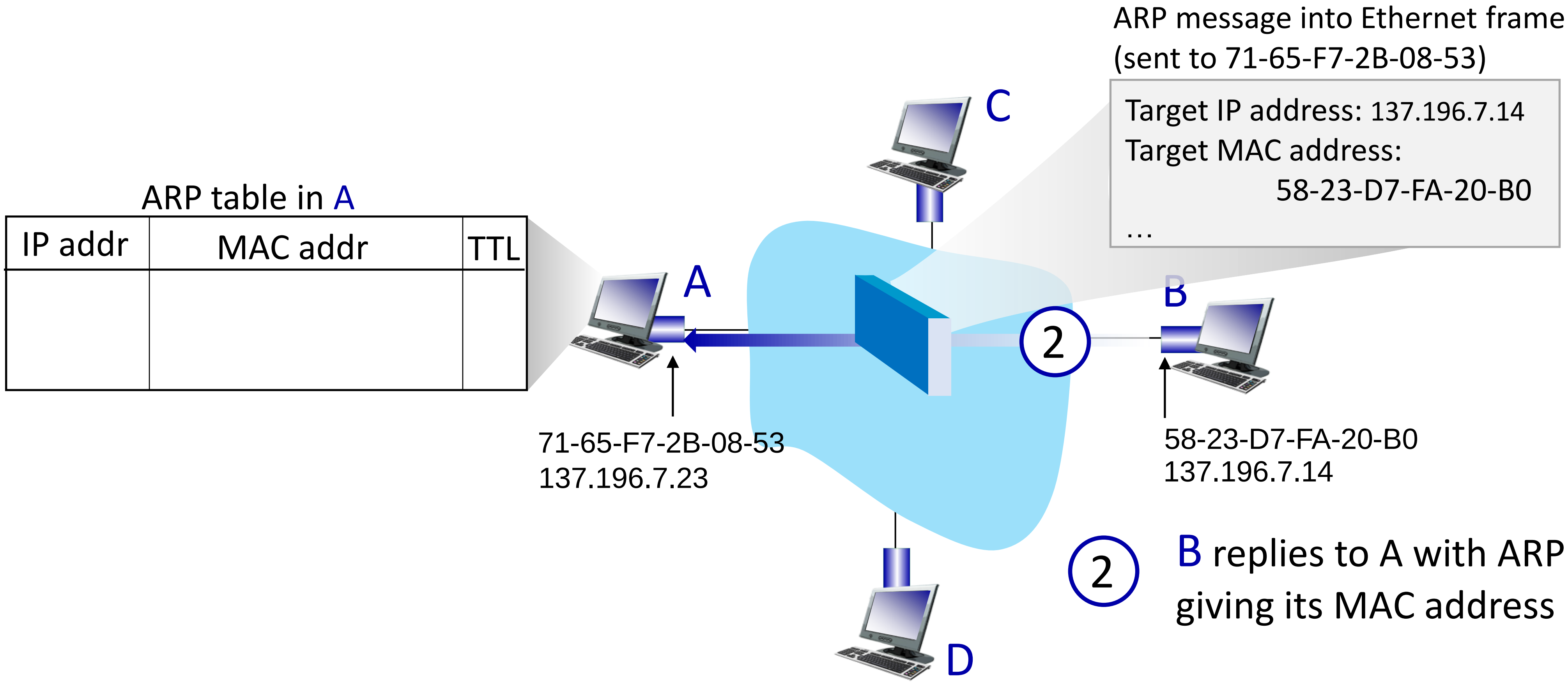
IP addr	MAC addr	TTL



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



2 B replies to A with ARP response, giving its MAC address

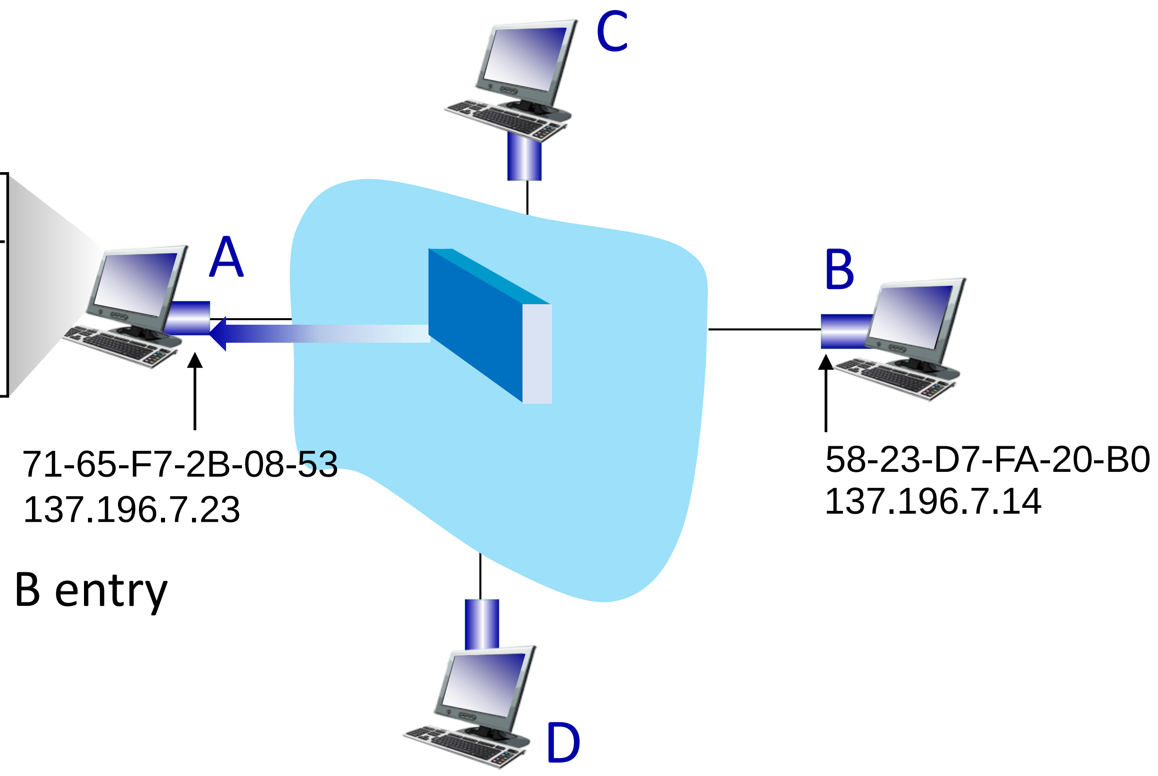
ARP protocol in action

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

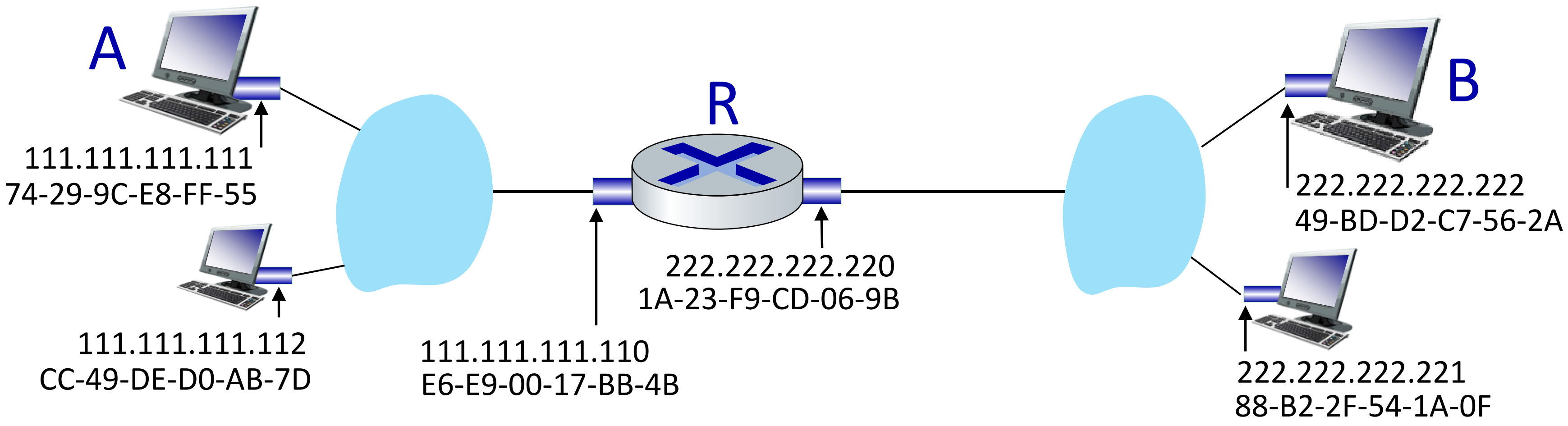


3 A receives B's reply, adds B entry into its local ARP table

Routing to another subnet: addressing

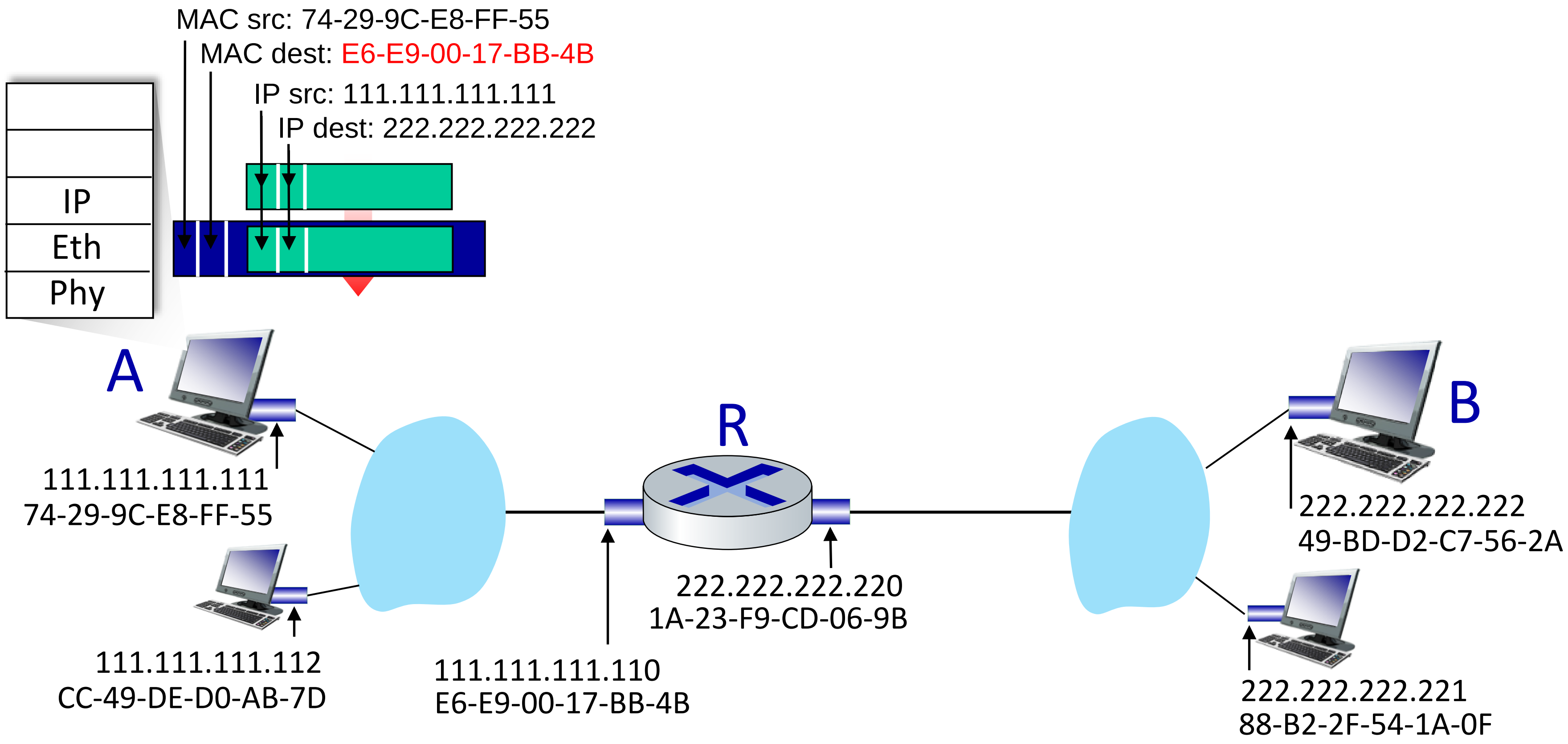
walkthrough: sending a datagram from *A* to *B* via *R*

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



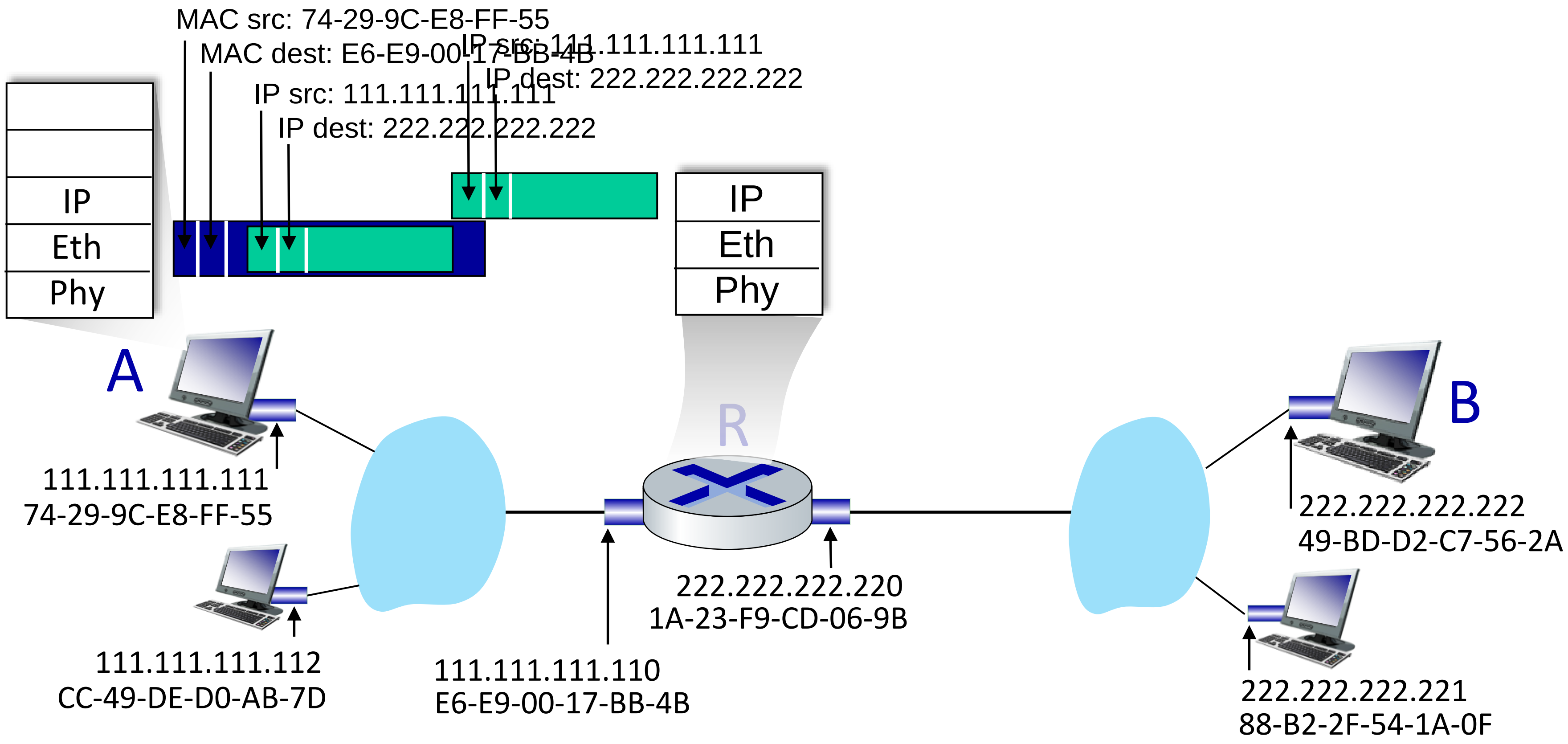
Routing to another subnet: addressing

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



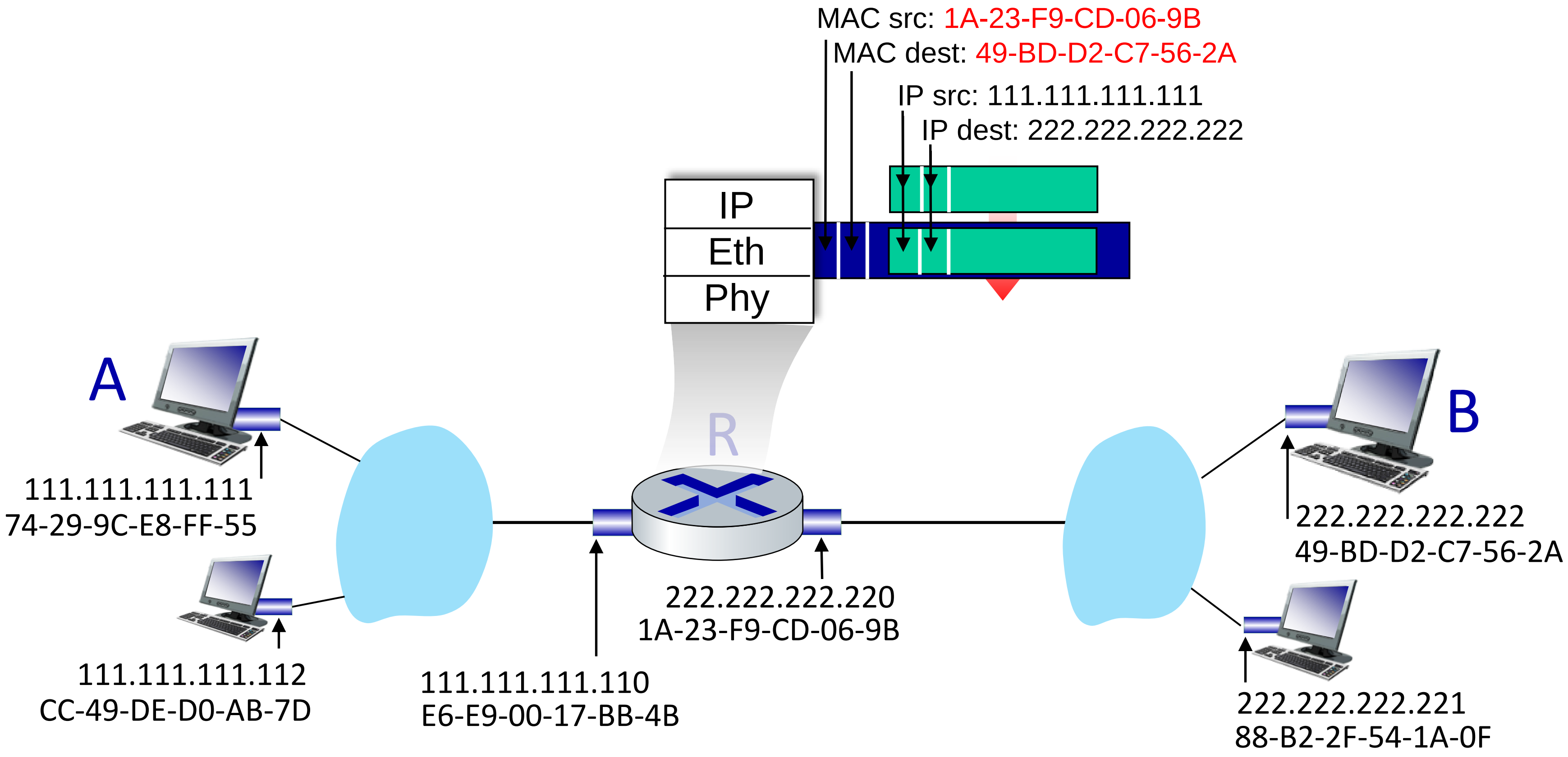
Routing to another subnet: addressing

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



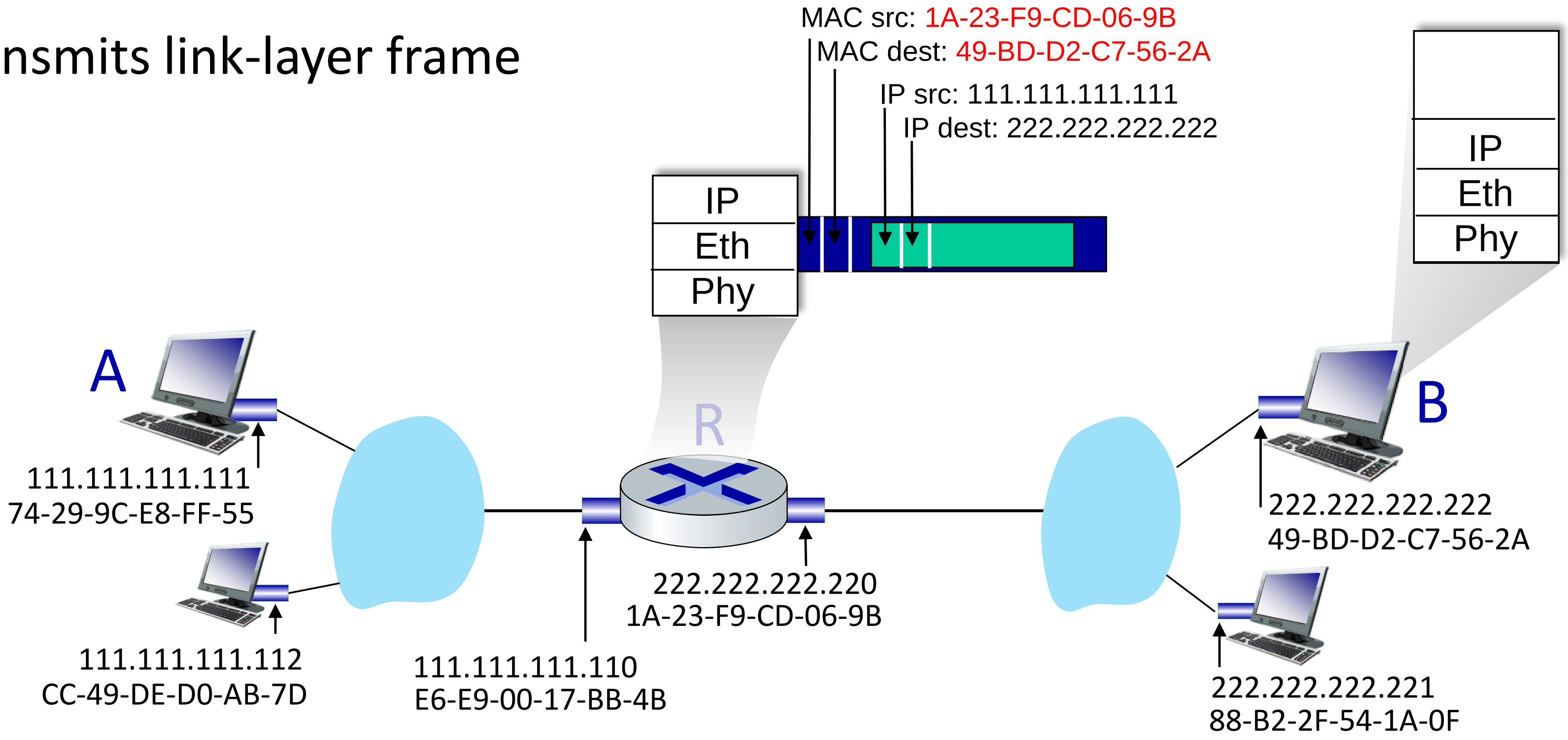
Routing to another subnet: addressing

- R determines outgoing interface, passes datagram with IP source A, destination B to link layer
- R creates link-layer frame containing A-to-B IP datagram. Frame destination address: B's MAC address



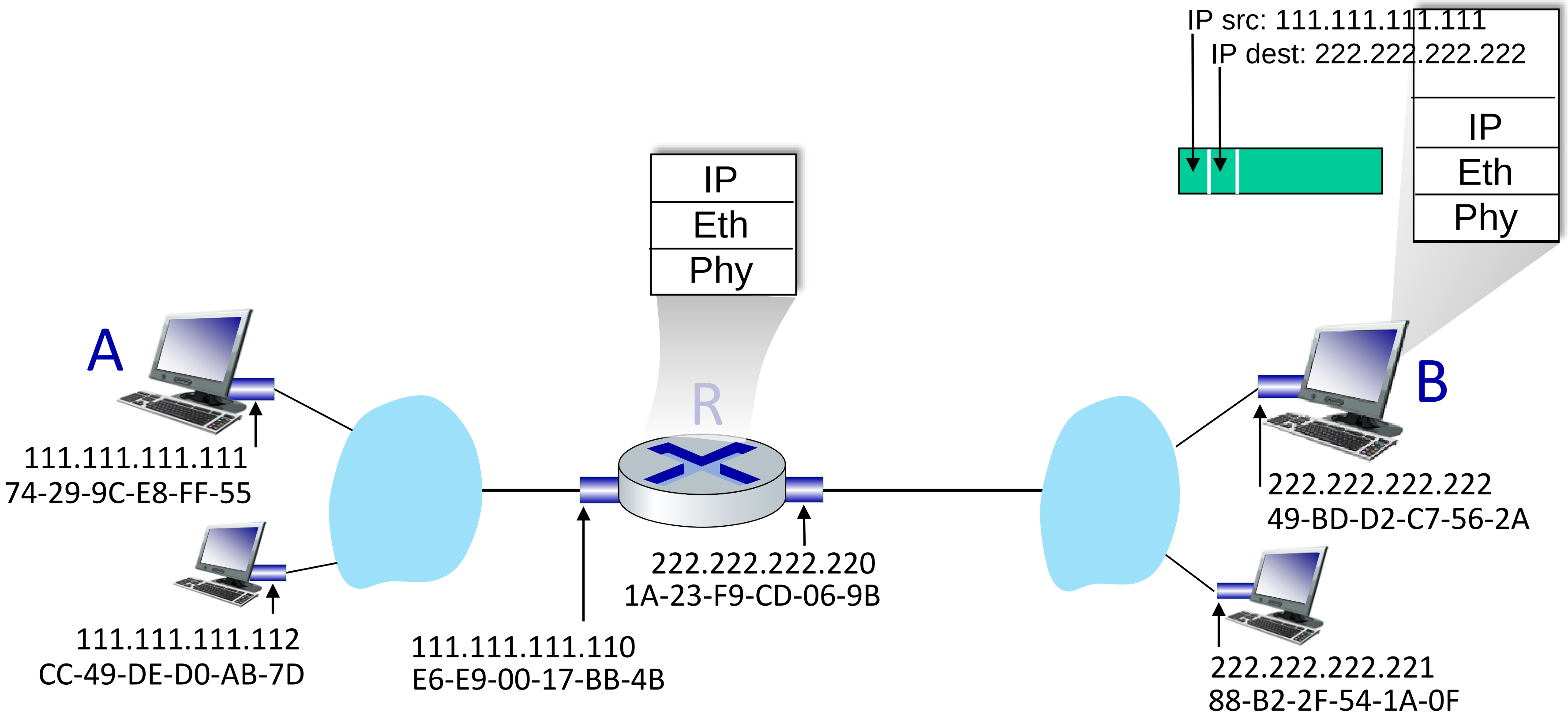
Routing to another subnet: addressing

- R determines outgoing interface, passes datagram with IP source A, destination B to link layer
- R creates link-layer frame containing A-to-B IP datagram. Frame destination address: B's MAC address
- transmits link-layer frame



Routing to another subnet: addressing

- B receives frame, extracts IP datagram destination B
- B passes datagram up protocol stack to IP



Link layer, LANs: roadmap

- introduction
- error detection, correction
- multiple access protocols
- LANs
  - addressing, ARP
  - Ethernet
  - switches
  - VLANs
- link virtualization: MPLS
- data center networking

- a day in the life of a web request

Ethernet

"dominant" wired LAN technology:

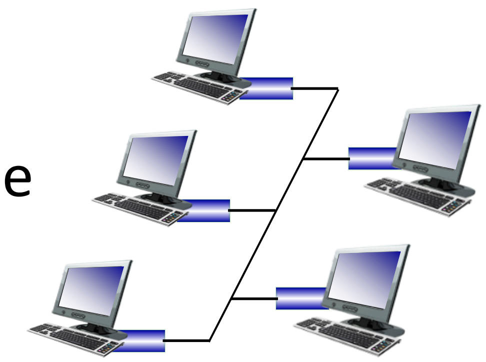
- first widely used LAN technology
- simpler, cheap
- Speed: 10 Mbps – 400 Gbps

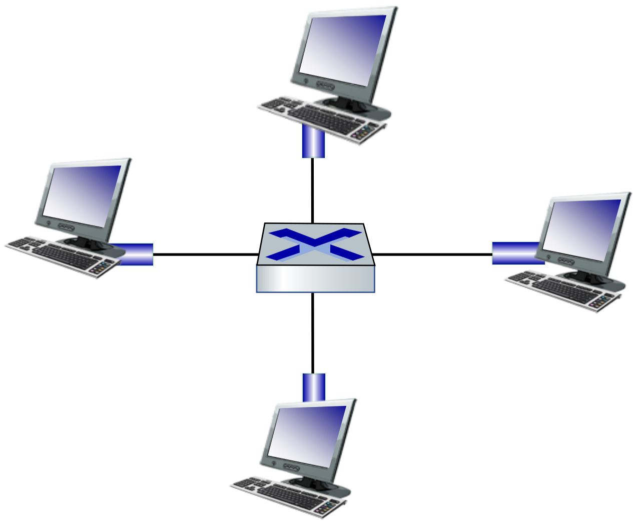
  - Ethernet (10Mbps)
  - Fast Ethernet (100Mbps)
  - Gigabit Ethernet (1000Mbps/1Gbps)
  - 10 Gig Ethernet (10Gbps)
  - Terabit Ethernet (TbE) : speed > 100Gbits/s

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
  - each “spoke” runs a (separate) Ethernet protocol (nodes do not collide with each other)

bus: coaxial cable

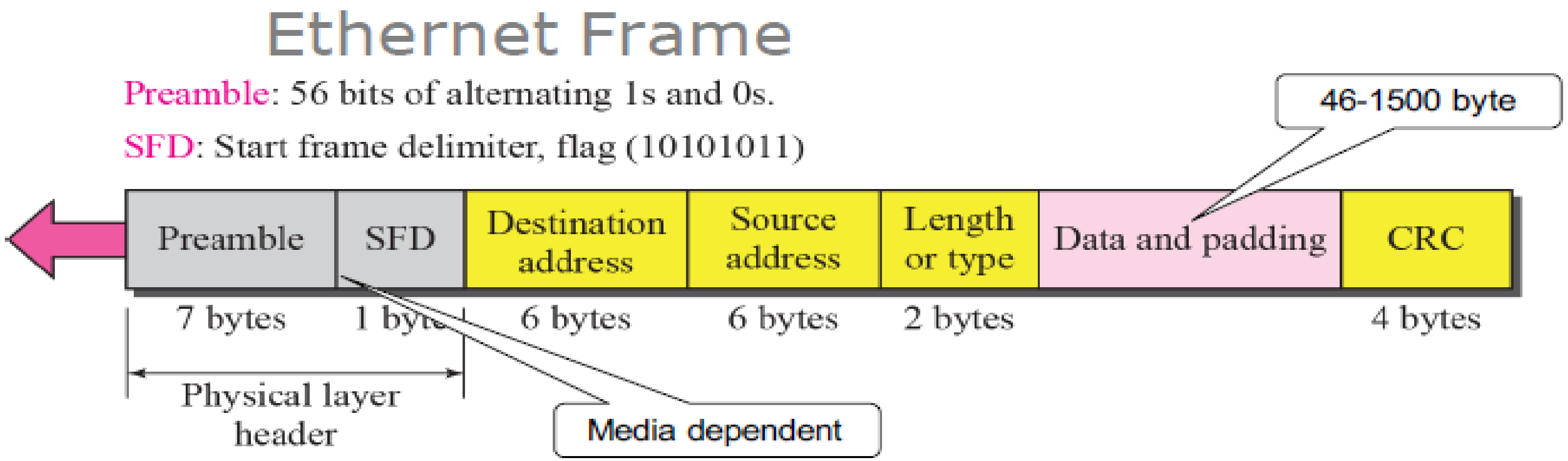




switched

Ethernet frame structure

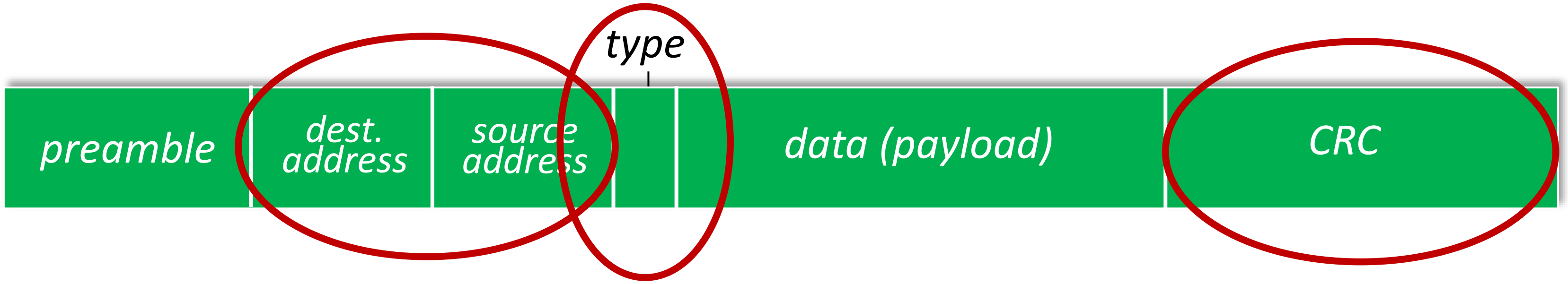
sending interface encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame



preamble:

- used to synchronize receiver, sender clock rates
- 7 bytes of 10101010 followed by one byte of 10101011

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 (0x8137), AppleTalk (0x809B) , ARP (0X0806) , IPV4 (0X0800), IPv6 (0x86DD)
- CRC: cyclic redundancy check at receiver
  - error detected: frame is dropped

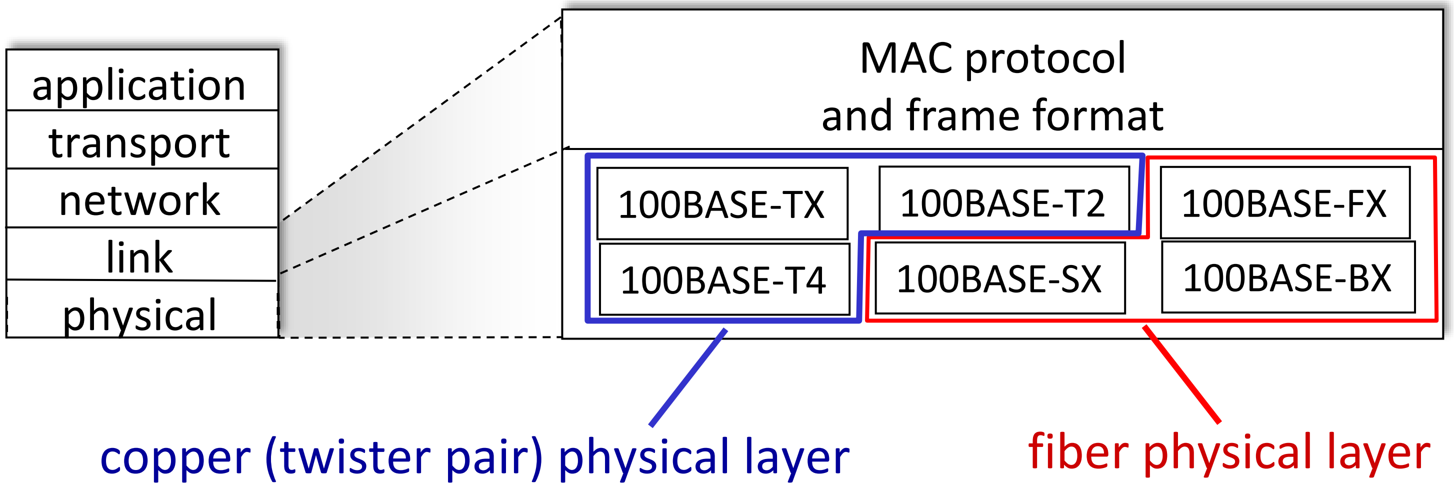
Ethernet: unreliable, connectionless

- connectionless: no handshaking between sending and receiving NICs
- unreliable: receiving NIC doesn't send ACKs or NAKs to sending NIC
  - data in dropped frames recovered only if initial sender uses higher layer reliability (e.g., TCP), otherwise dropped data lost
- Ethernet's MAC protocol: CSMA/CD with binary backoff

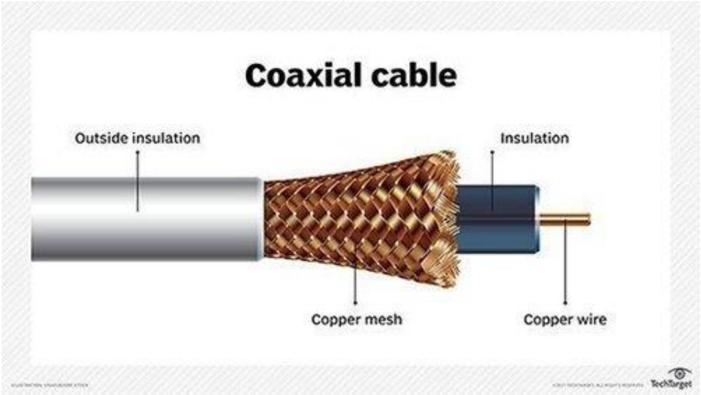
802.3 Ethernet standards: link & physical layers

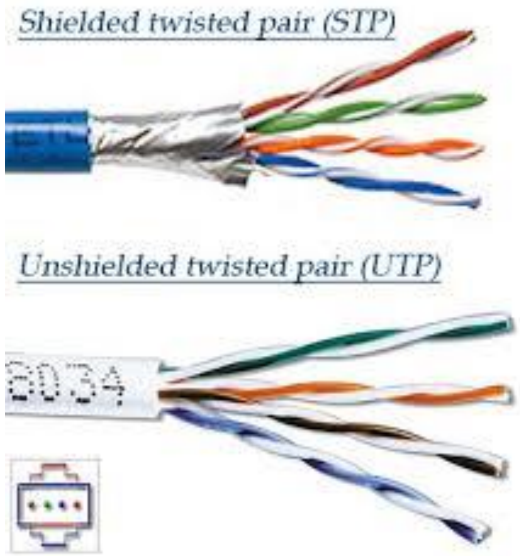
- *many* different Ethernet standards
  - common MAC protocol and frame format
  - different Transmission Rates

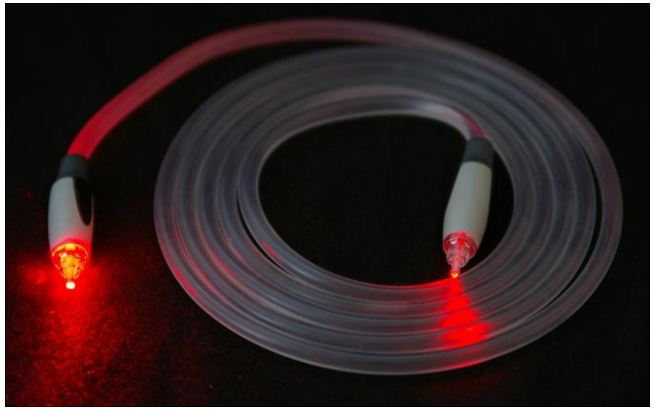
    2 Mbps, 10 Mbps, 100 Mbps, 1Gbps, 10 Gbps, 400 Gbps
  - different cabling: Copper and Optical fiber
  - Most common: Twisted pair cable (Cat 4, 5, 6, 7, 8, ...) with RJ45 connector

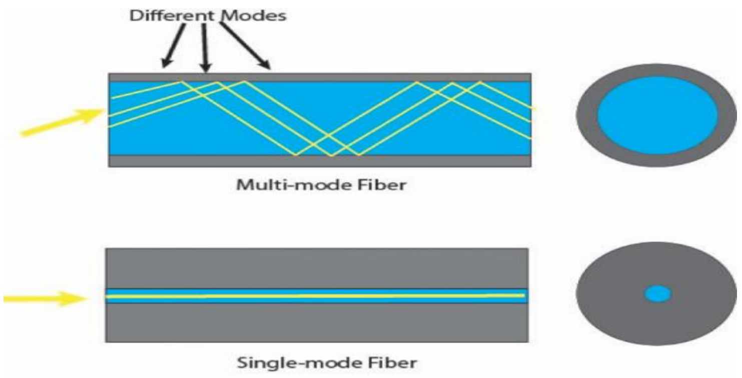


Cables


Coaxial cable
Outside insulation
Insulation
Copper mesh
Copper wire


Shielded twisted pair (STP)
Unshielded twisted pair (UTP)




Different Modes
Multi-mode Fiber
Single-mode Fiber

Ethernet

Physical Media :-

10 Base5 - Thick Co-axial Cable with Bus Topology

10 Base2 - Thin Co-axial Cable with Bus Topology

10 BaseT - UTP Cat 3/5 with Tree Topology

10 BaseFL - Multimode/Singlemode Fiber with Tree Topology

Maximum Segment Length

10 Base5 - 500 m

10 Base2 - 185m (~200m)

10 BaseT - 100 m

Fast Ethernet

- 100 Mbps bandwidth
- Uses same CSMA/CD media access protocol and packet format as in Ethernet.
- 100BaseTX (UTP) and 100BaseFX (Fiber) standards
- Physical media :-
    - 100 BaseTX - UTP Cat 5e
    - 100 BaseFX - Multimode / Singlemode Fiber
- Maximum Segment Length
    - 100 Base TX - 100 m
    - 100 Base FX - 2 Km (Multimode Fiber)
    - 100 Base FX - 20 km (Singlemode Fiber)

Gigabit Ethernet

- 1 Gbps bandwidth.
- Uses same CSMA/CD media access protocol as in Ethernet.
- 1000BaseT (UTP), 1000BaseSX (Multimode Fiber) and 1000BaseLX (Multimode/Singlemode Fiber) standards.
- Maximum Segment Length
    - 1000 Base T - 100m (Cat 5, Cat5e, Cat 6)
    - 1000 Base SX - 275 m (Multimode Fiber)
    - 1000 Base LX - 512 m (Multimode Fiber)
    - 1000 Base LX - 20 Km (Singlemode Fiber)
    - 1000 Base LH - 80 Km (Singlemode Fiber)

10 Gig Ethernet (10GE, 10GbE, or 10GigE)

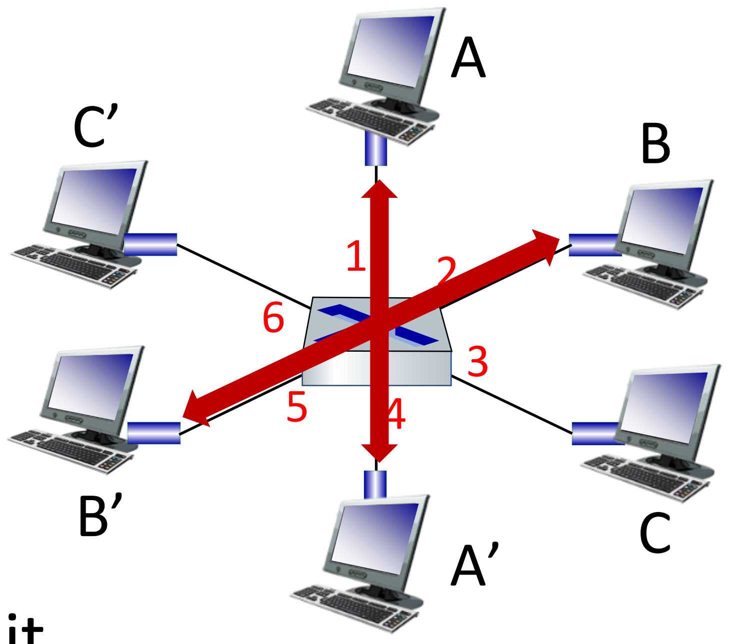
- 10 Gbps bandwidth.
- Uses same CSMA/CD media access protocol as in Ethernet.
- Maximum Segment Length
    - 10GBase-T - 100 m (Cat6A, Cat7)
    - 10GBase-LR - 10 Km (Singlemode Fiber)
    - 10GBase-ER - 40 Km (Singlemode Fiber)

Ethernet switch

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

Switch: multiple simultaneous transmissions

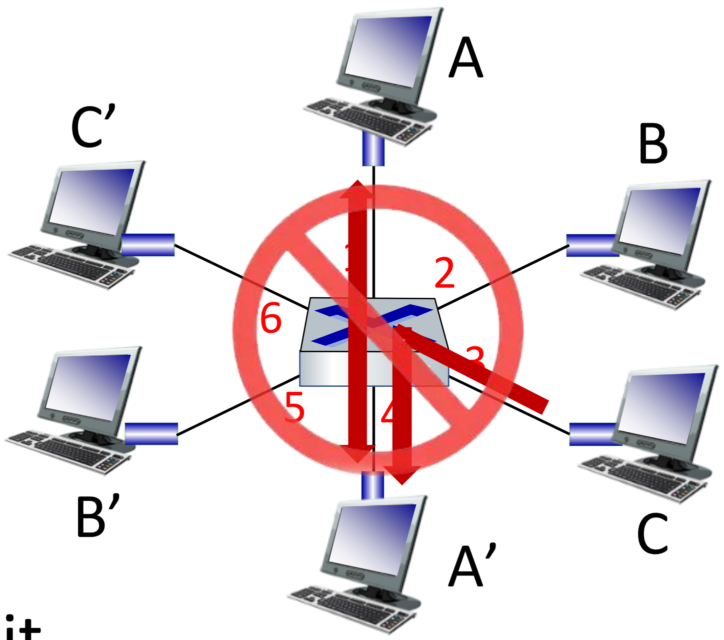
- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol used on *each* incoming link, so:
  - no collisions; full duplex
  - each link is its own collision domain
- switching: A-to-A' and B-to-B' can transmit simultaneously, without collisions



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

Switch: multiple simultaneous transmissions

- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol used on *each* incoming link, so:
  - no collisions; full duplex
  - each link is its own collision domain;
- switching: A-to-A' and B-to-B' can transmit simultaneously, without collisions
  - but A-to-A' and C to A' can *not* happen simultaneously



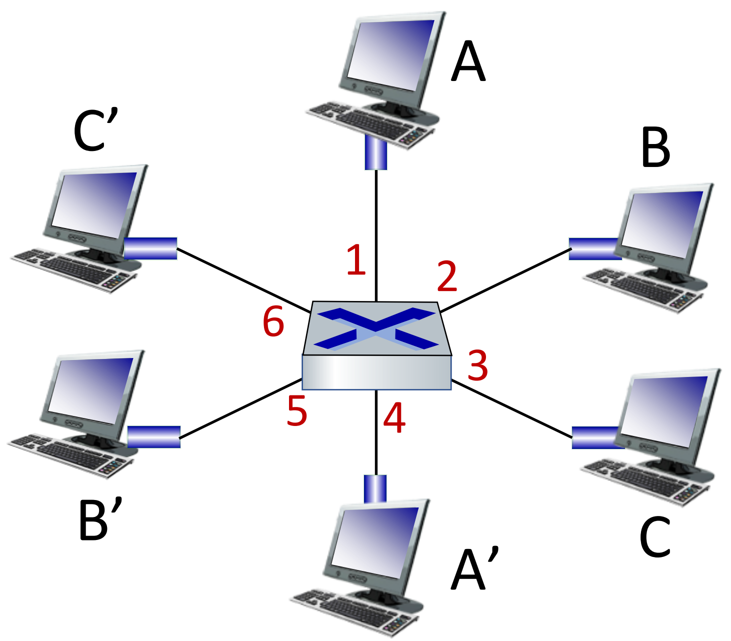
switch with six interfaces (1,2,3,4,5,6)

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!

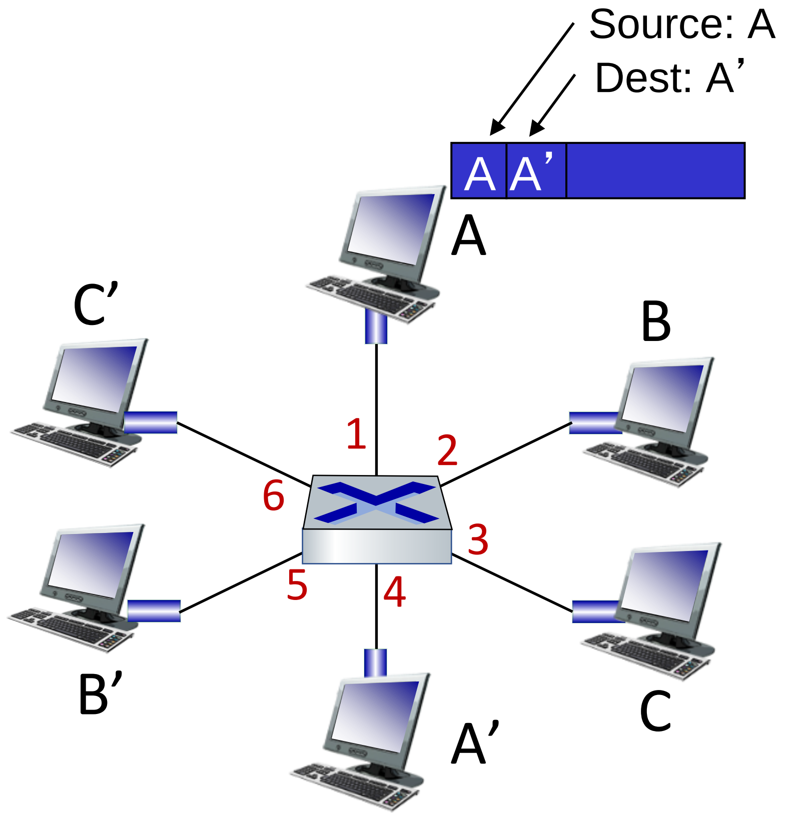


Q: how are entries created, maintained in switch table?

- something like a routing protocol?

Switch: 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)

Switch: frame filtering/forwarding

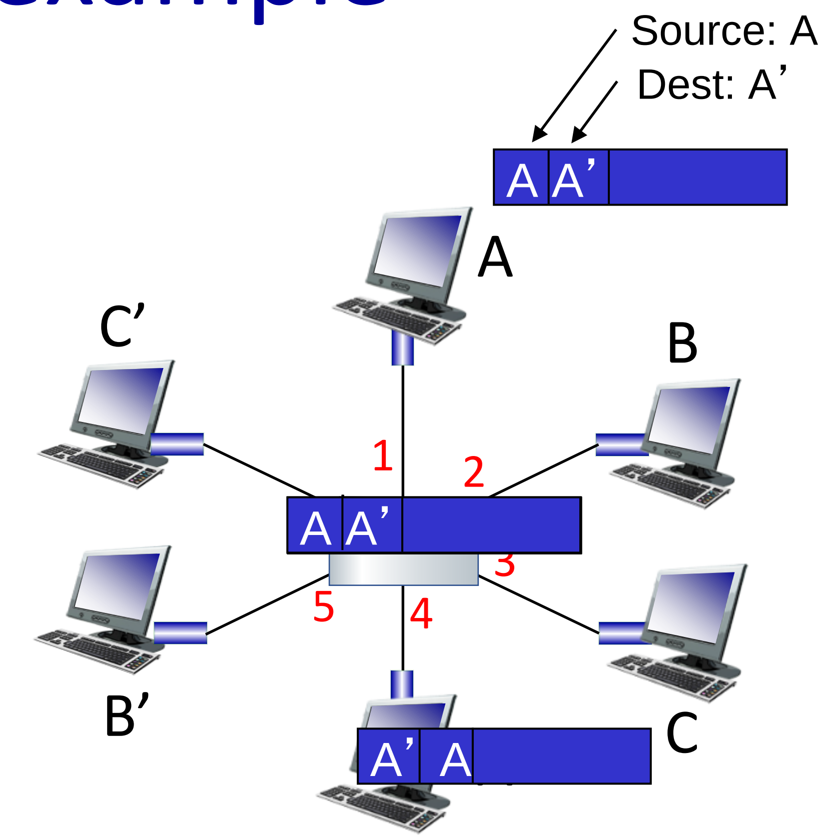
when frame received at switch:

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

```
then {
if destination on segment from which frame arrived
    then drop frame
     else forward frame on interface indicated by entry
 }
else flood  /* forward on all interfaces except arriving interface */
```

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)