



Computer Networks

Lecturer: ZHANG Ying

Fall semester 2022

FINAL EXAM

- Time: November 17th, Exam time will be 16:00 – 18:00 (Next Thursday), **all students should enter platform at 15:30 for identity check with your student card and passport.**
- Platform: Tencent Meeting (Meeting code will be provided 35 min before)
- Closed-book paper-based exam.
- Setting requirements:
 - Camera-based live streaming. The camera should cover NOT ONLY the face, BUT ALSO the desk and the computer screen in a light- sufficient environment.
 - Mic should be OPEN all the time.
 - Ask question ONLY with mic
 - Strictly no other communication
- The detailed policy will be shared for everyone soon and we will have an **environment check before exam next week. (Tentative time: 15th Nov, 16:00)**

CSMA (carrier sense multiple access)



humans at a cocktail party
(shared air, acoustical)

- *Listen before speaking* - **carrier sensing**
- *Stop talking if someone else begins talking* - **collision detection**

CSMA (carrier sense multiple access)

simple **CSMA**: listen before transmit:

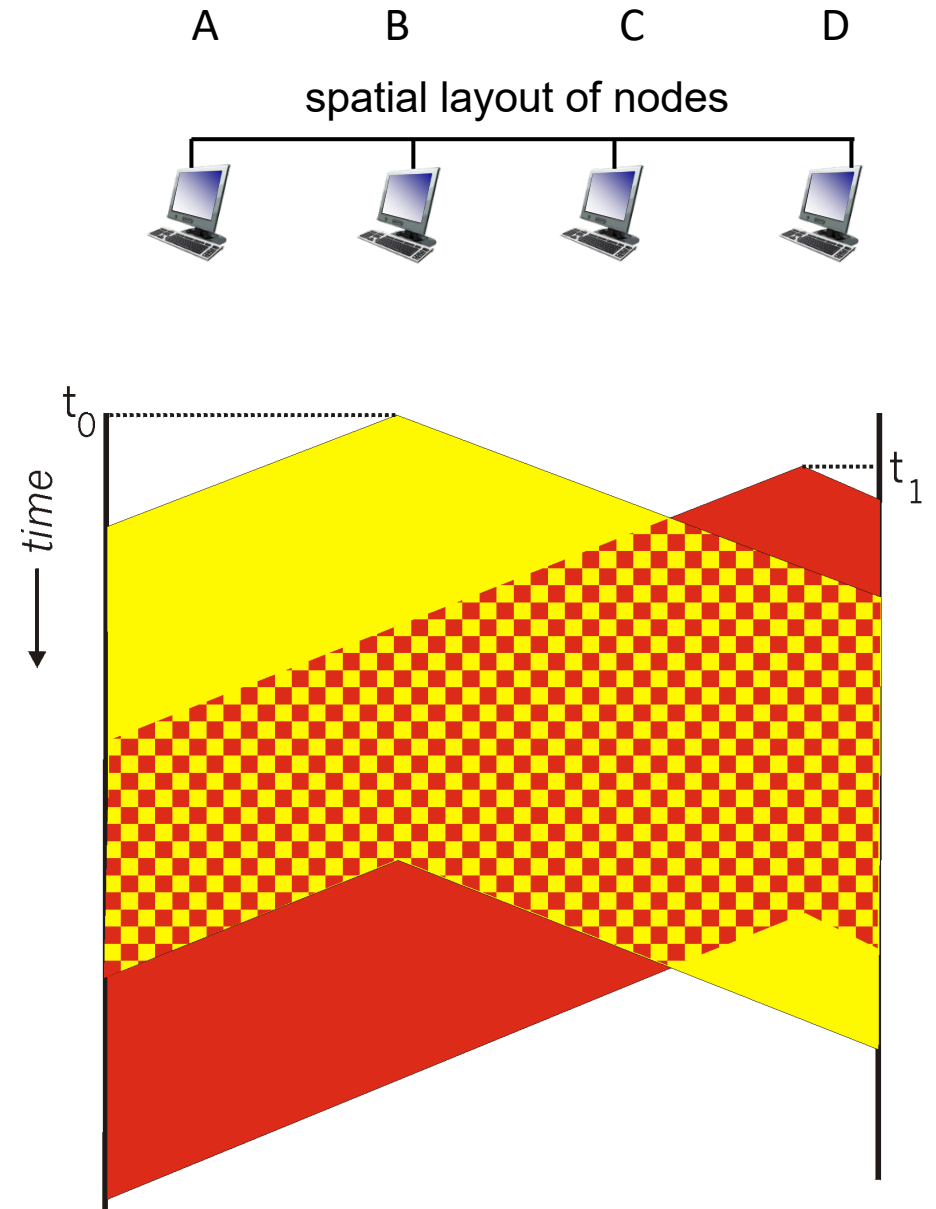
- if channel sensed idle: transmit entire frame
 - if channel sensed busy: defer transmission
- human analogy: don't interrupt others!

CSMA/CD: CSMA with *collision detection*

- collisions *detected* within short time
 - colliding transmissions aborted, reducing channel wastage
 - collision detection easy in wired, difficult with wireless
- human analogy: the polite conversationalist

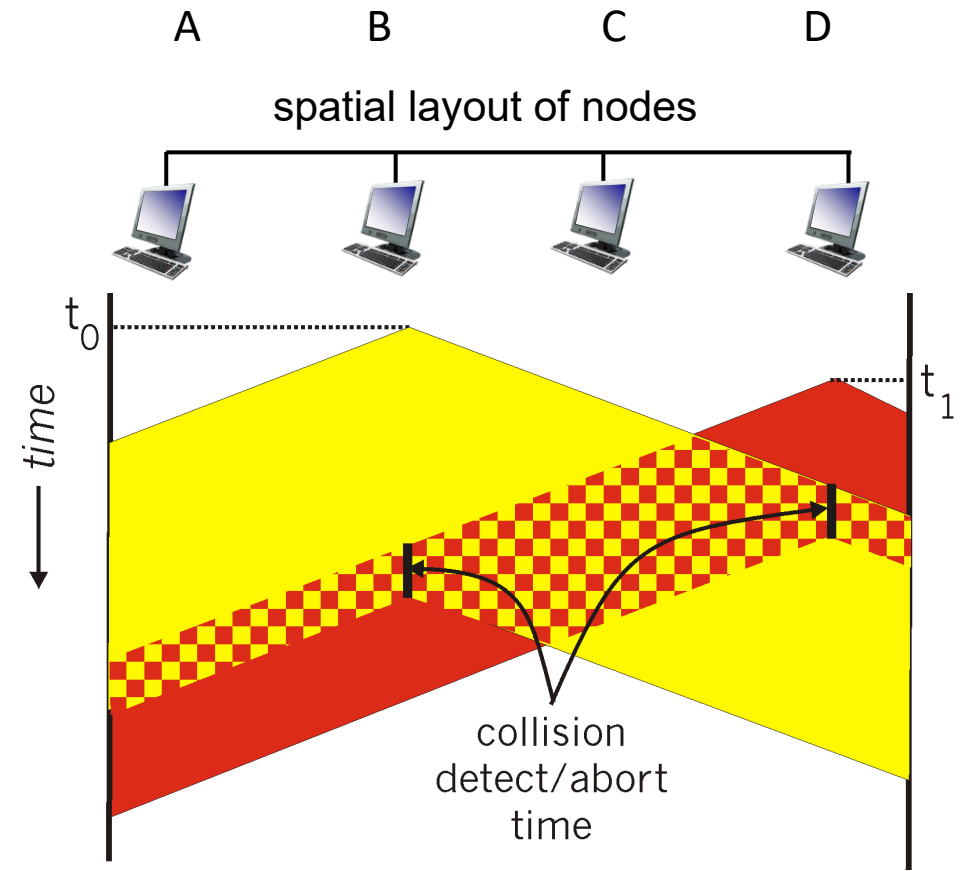
CSMA: collisions

- collisions *can* still occur with carrier sensing:
 - propagation delay means two nodes may not hear each other's just-started transmission
- **collision**: entire packet transmission time wasted
 - distance & propagation delay play role in determining collision probability



CSMA/CD:

- CSMA/CS reduces the amount of time wasted in collisions
 - transmission aborted on collision detection



CSMA/CD efficiency

- T_{prop} = max prop delay between 2 nodes in LAN
- t_{trans} = time to transmit max-size frame

$$\text{efficiency} = \frac{1}{1 + 5t_{\text{prop}}/t_{\text{trans}}}$$

- efficiency goes to 1
 - as t_{prop} goes to 0
 - as t_{trans} goes to infinity
- better performance than ALOHA: and simple, cheap, decentralized!

“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

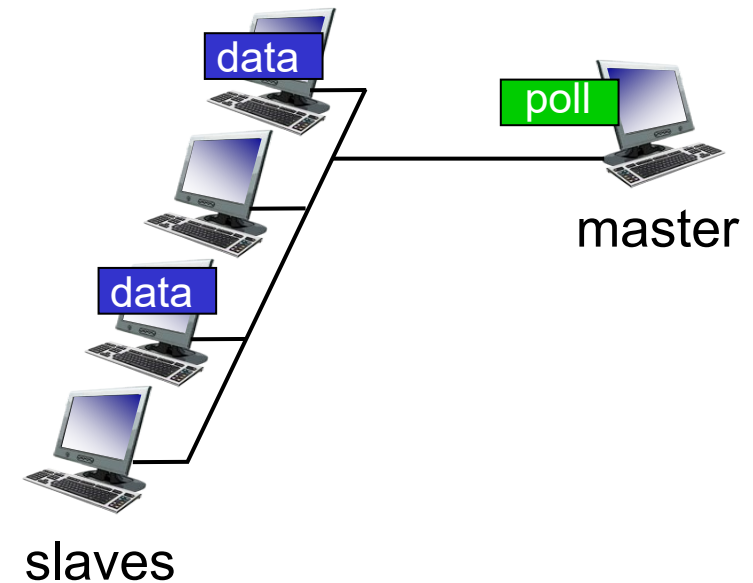
“taking turns” protocols

- look for best of both worlds!

“Taking turns” MAC protocols

polling:

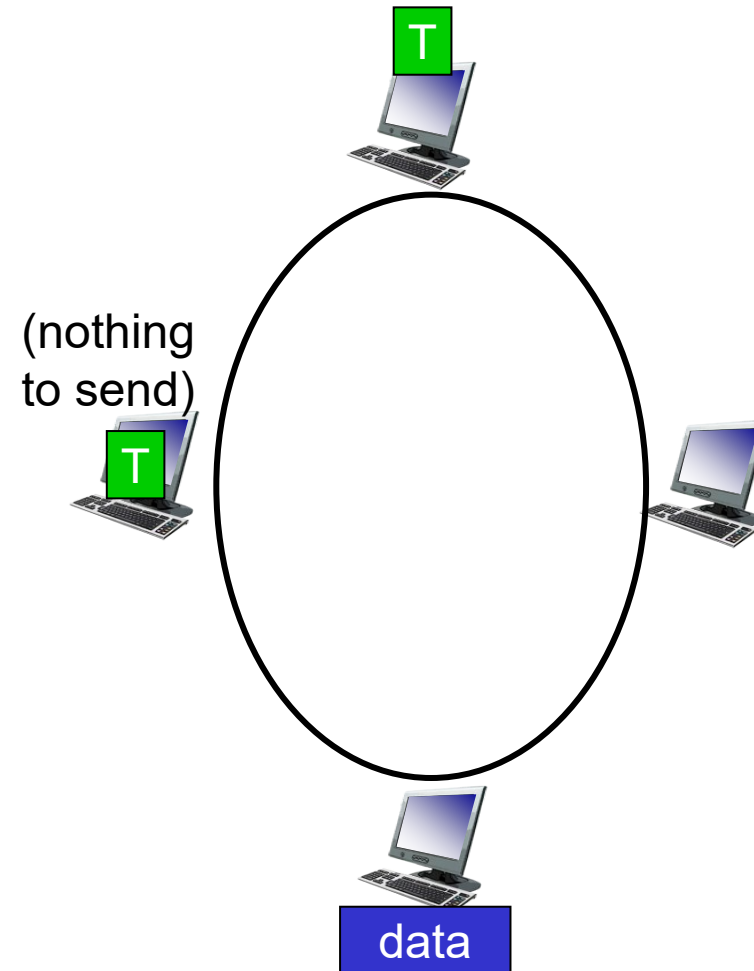
- master node “invites” other nodes to transmit in turn
- typically used with “dumb” devices
- concerns:
 - polling overhead
 - latency
 - single point of failure (master)



“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
 - Bluetooth, FDDI, token ring

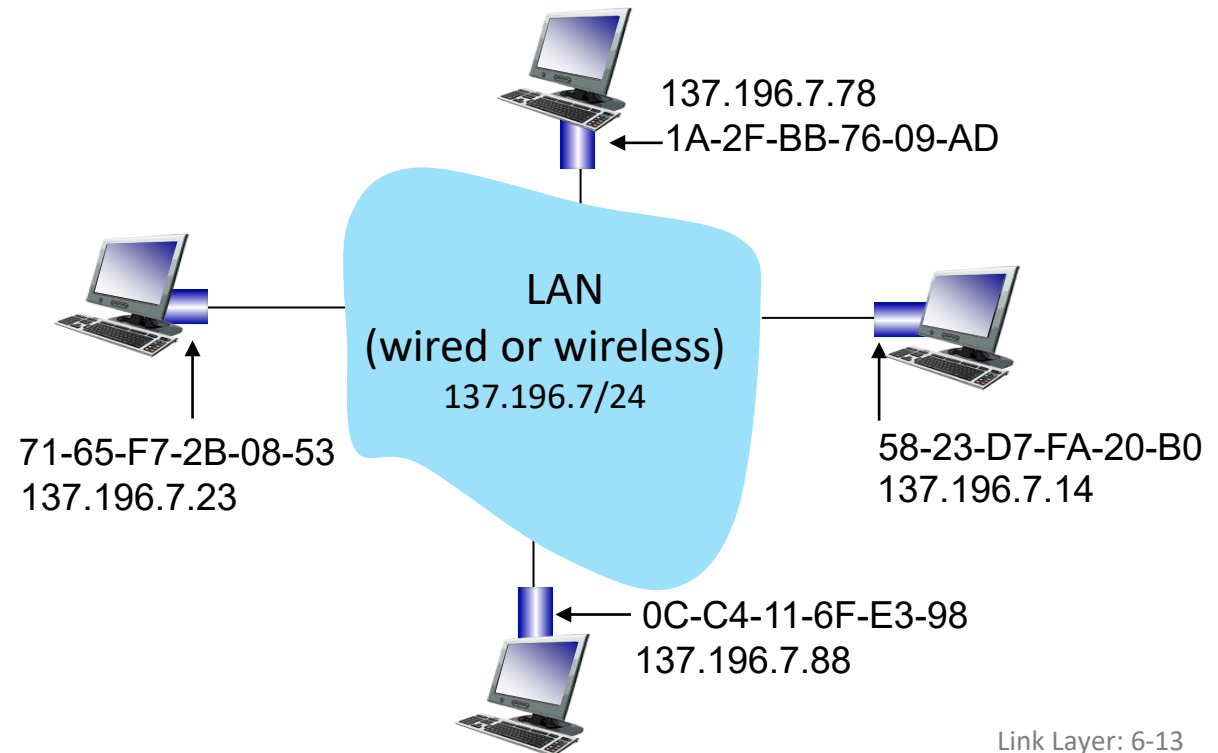
Link layer, LANs: roadmap

- introduction
- error detection, correction
- multiple access protocols
- **LANs**
 - addressing, ARP



MAC addresses

- 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
- each interface on LAN
 - has unique 48-bit MAC address
 - has a locally unique 32-bit IP address (as we’ve seen)

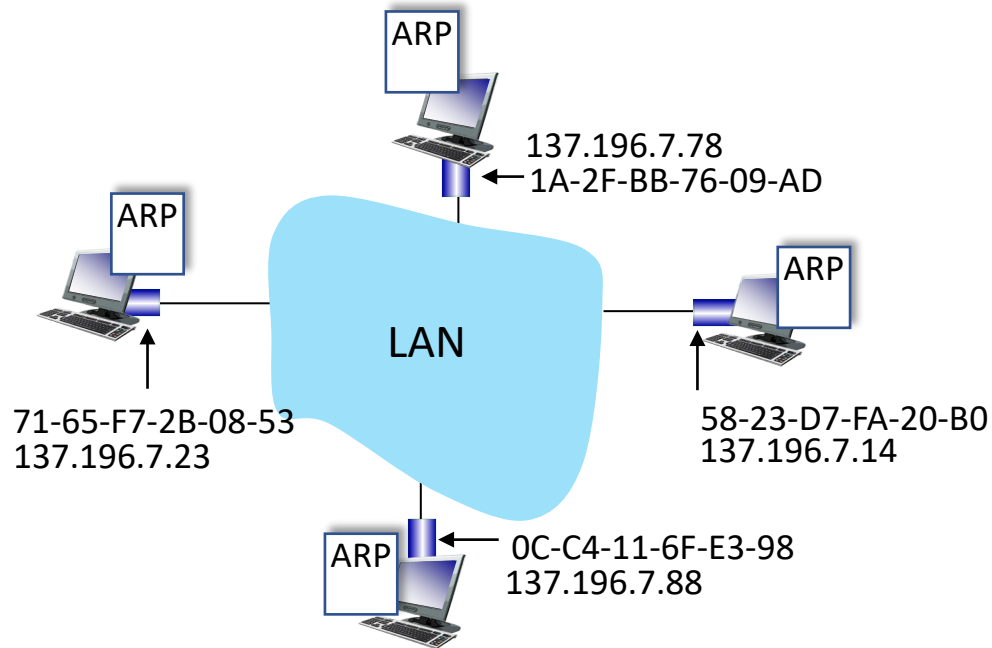


MAC addresses

- MAC address allocation administered by IEEE
- manufacturer buys portion of MAC address space (to assure uniqueness)
- analogy:
 - MAC address: like Social Security Number
 - IP address: like postal address
- MAC flat address: portability
 - can move interface from one LAN to another
 - recall IP address *not* portable: 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)

ARP protocol in action

example: A wants to send datagram to B

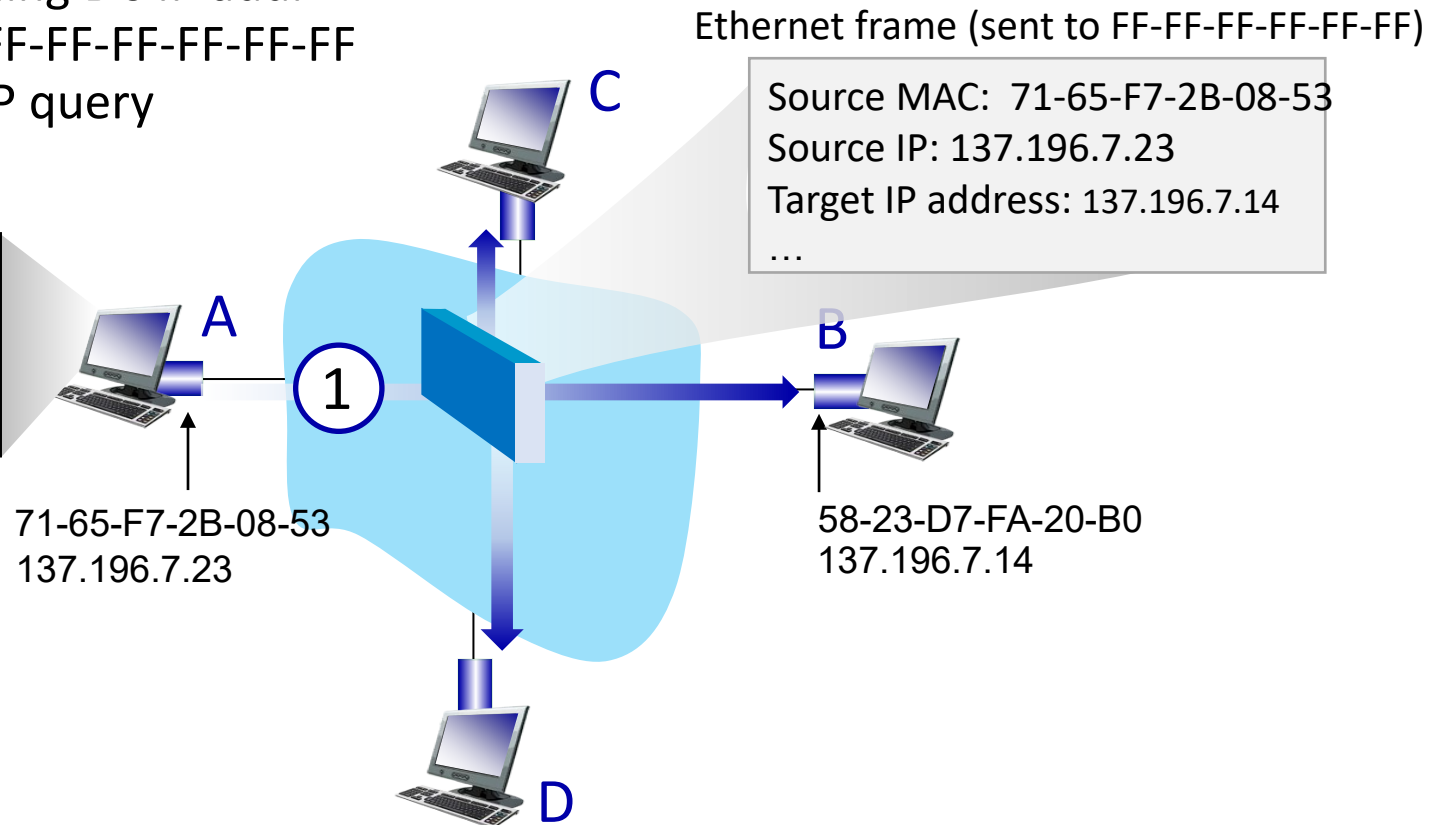
- B's MAC address not in A's ARP table, so A uses ARP to find B's MAC address

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

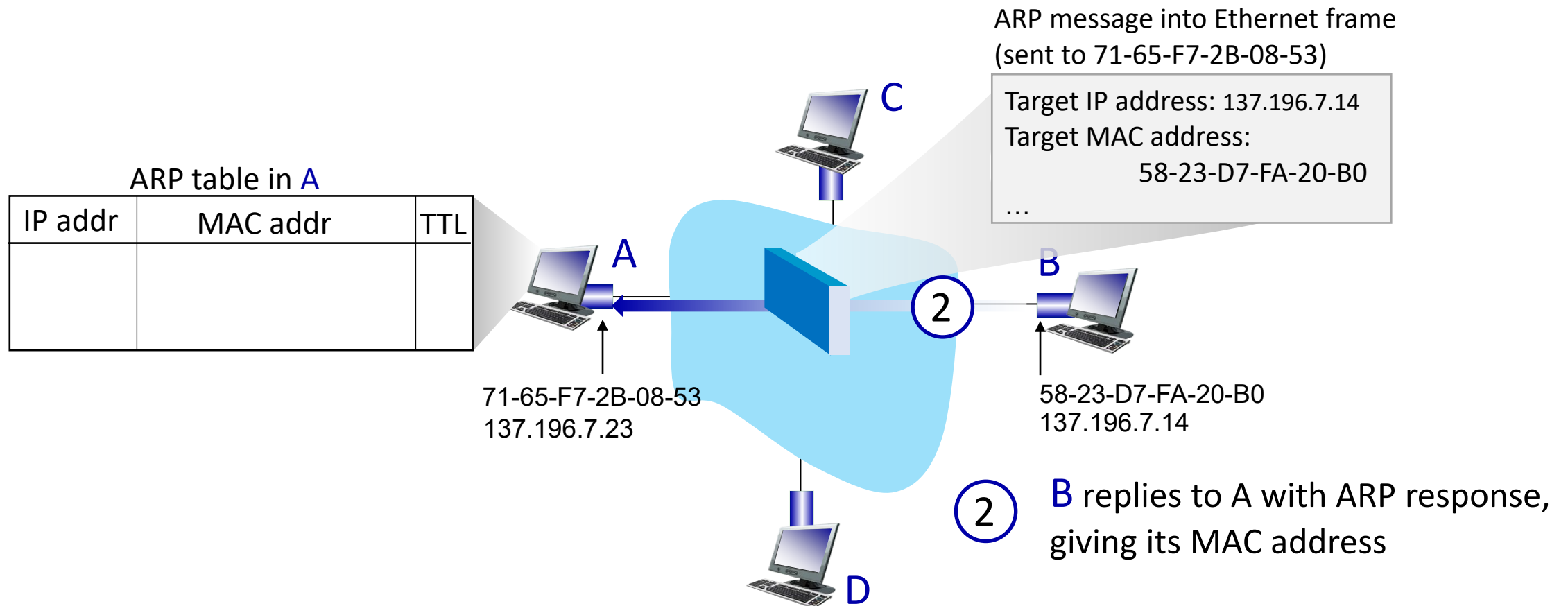
IP addr	MAC addr	TTL



ARP protocol in action

example: A wants to send datagram to B

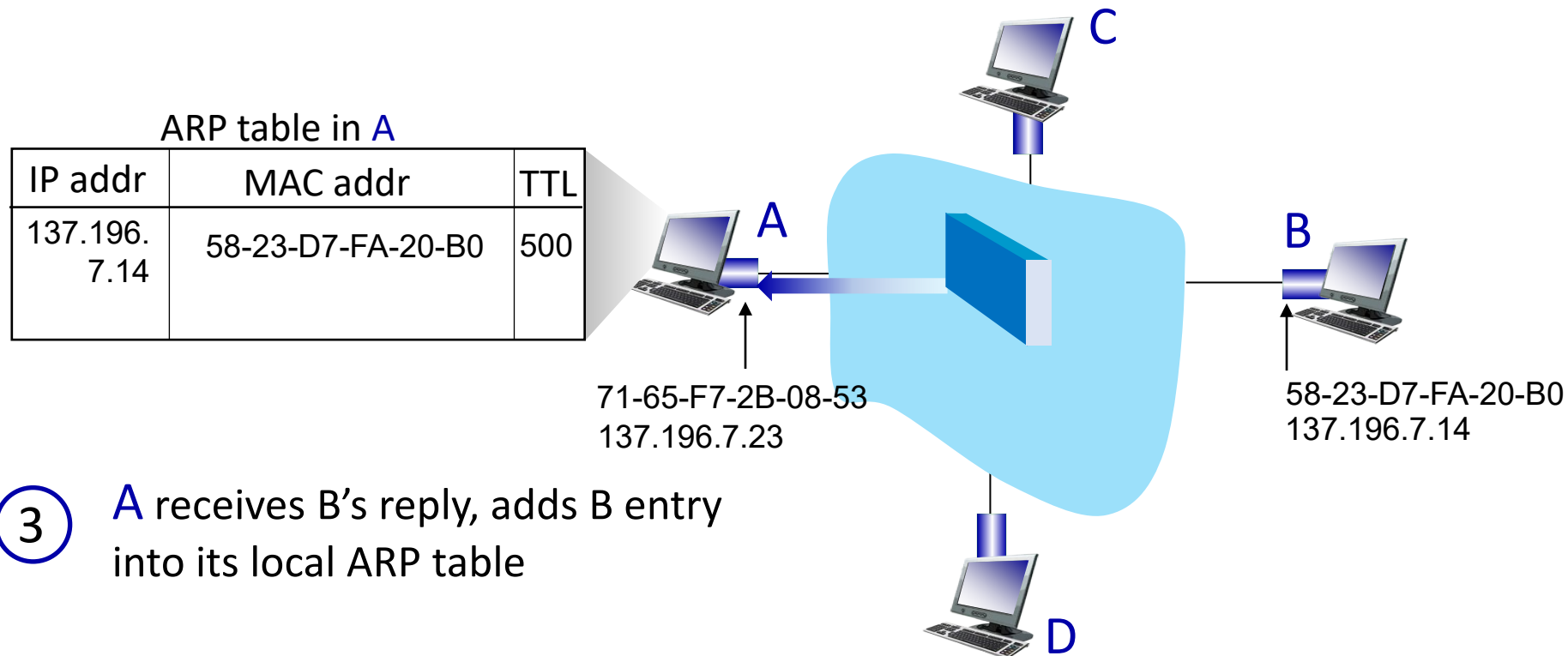
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ARP protocol in action

example: A wants to send datagram to B

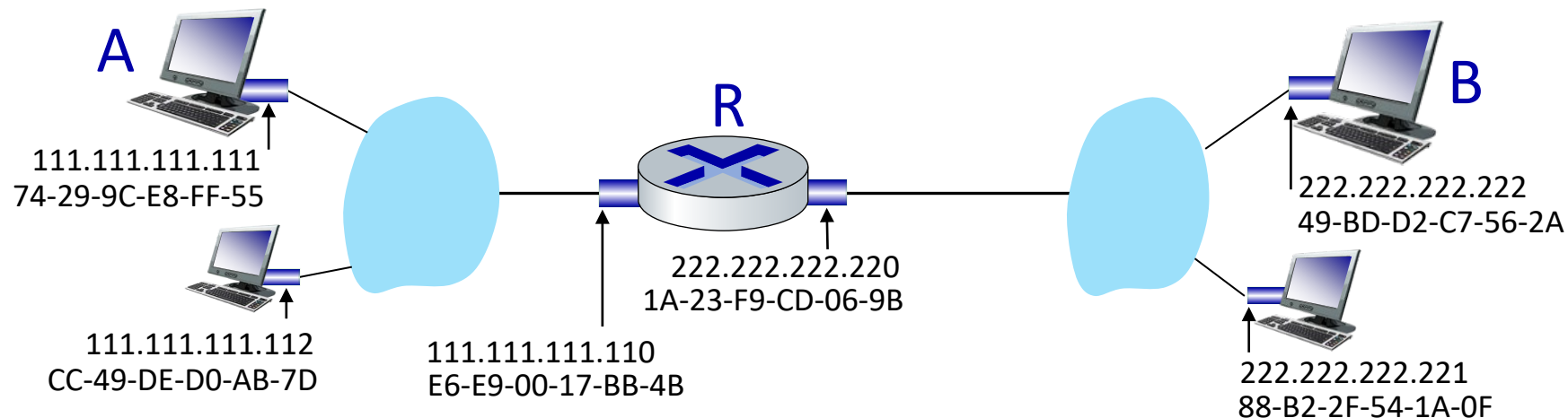
- B's MAC address not in A's ARP table, so A uses ARP to find B's MAC address



Routing to another subnet: addressing

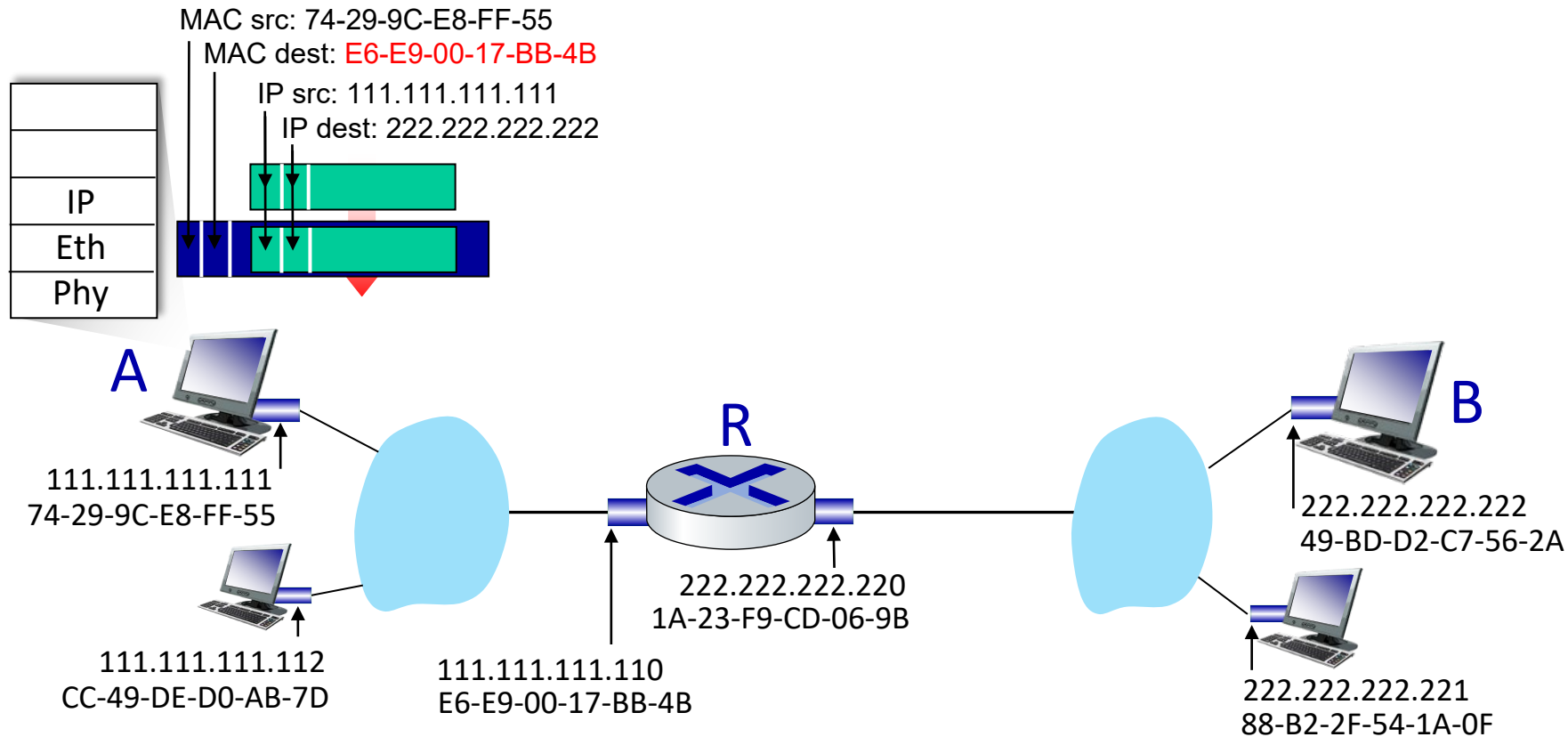
walkthrough: sending a datagram from *A* to *B* via *R*

- 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
 - A knows R's MAC address



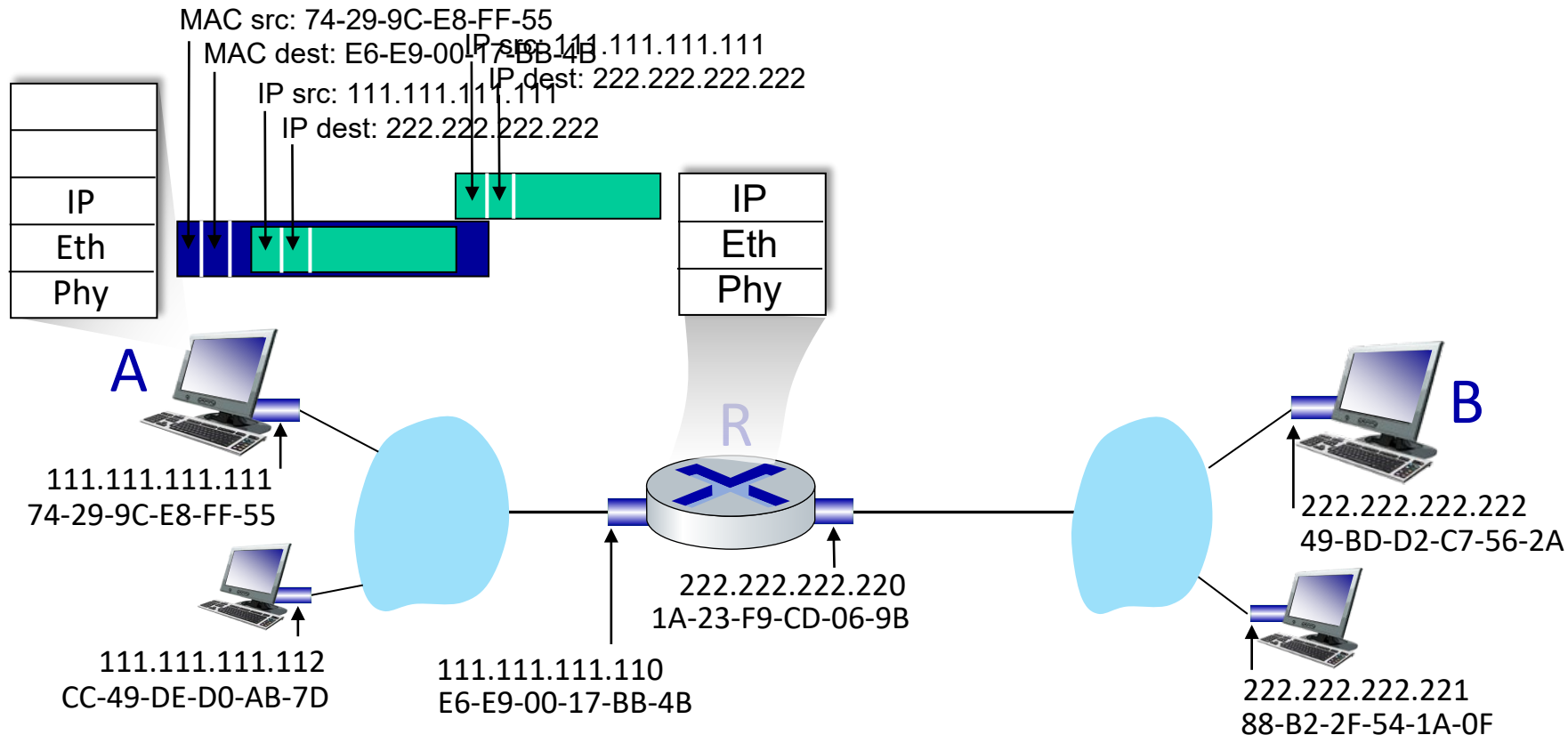
Routing to another subnet: addressing

- 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



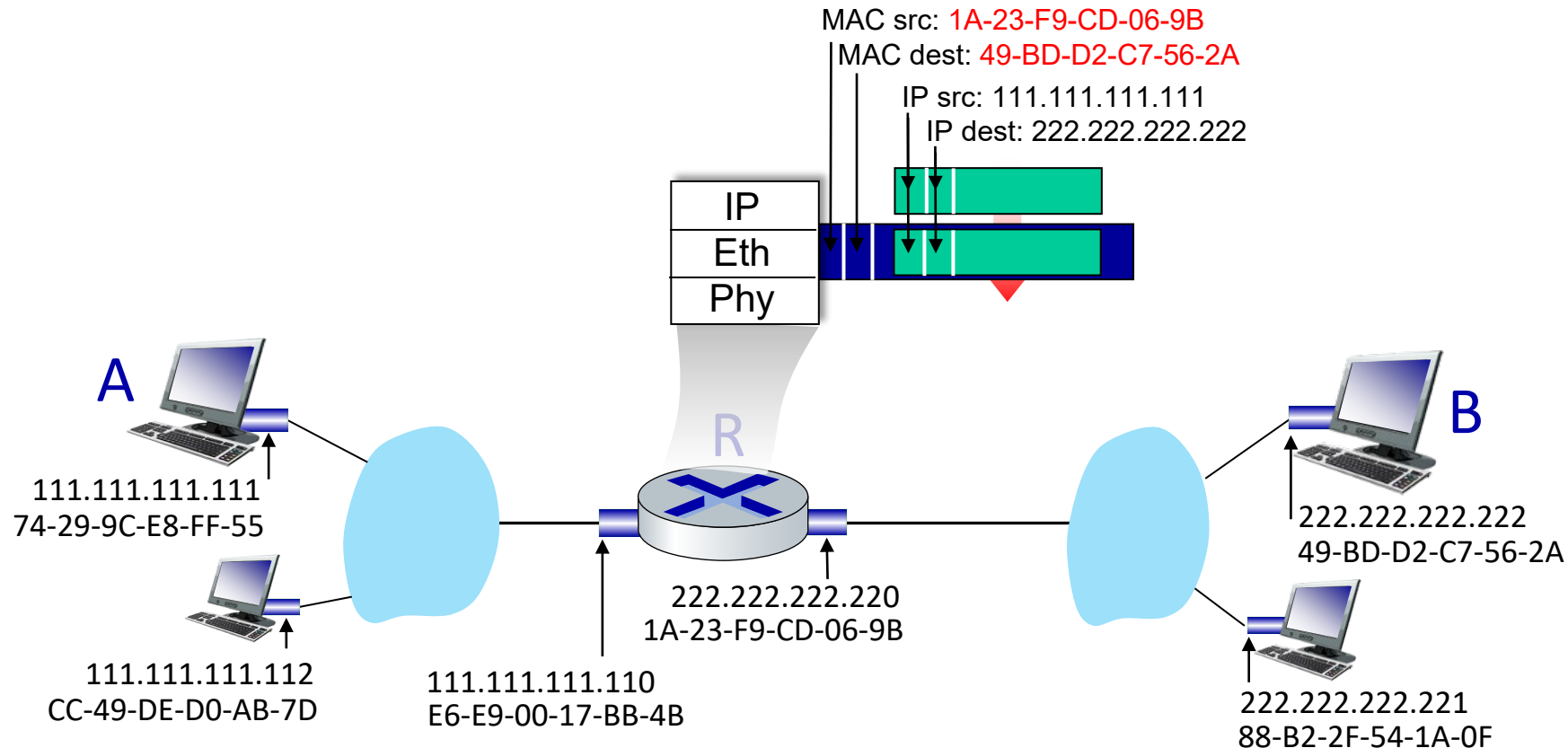
Routing to another subnet: addressing

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



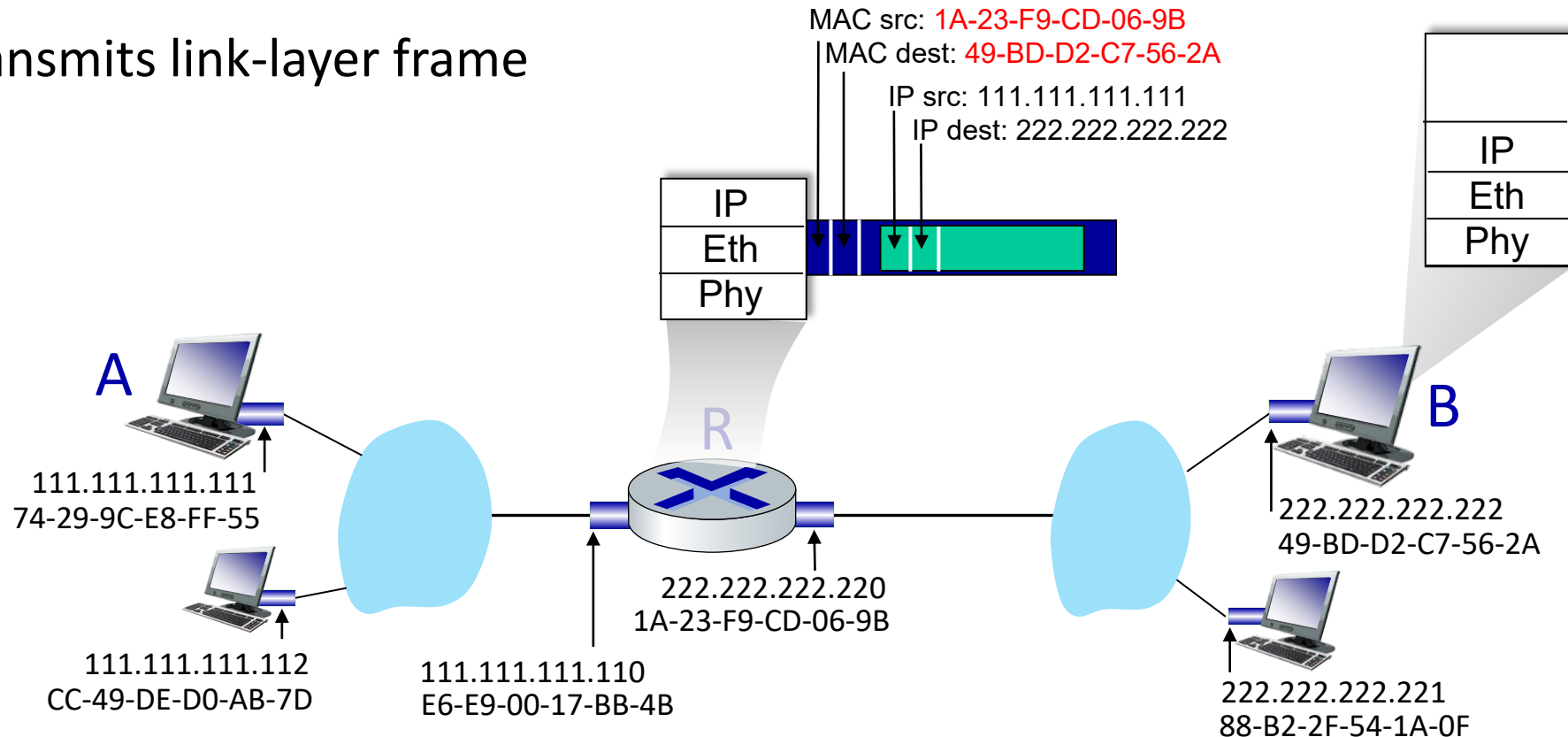
Routing to another subnet: addressing

- 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



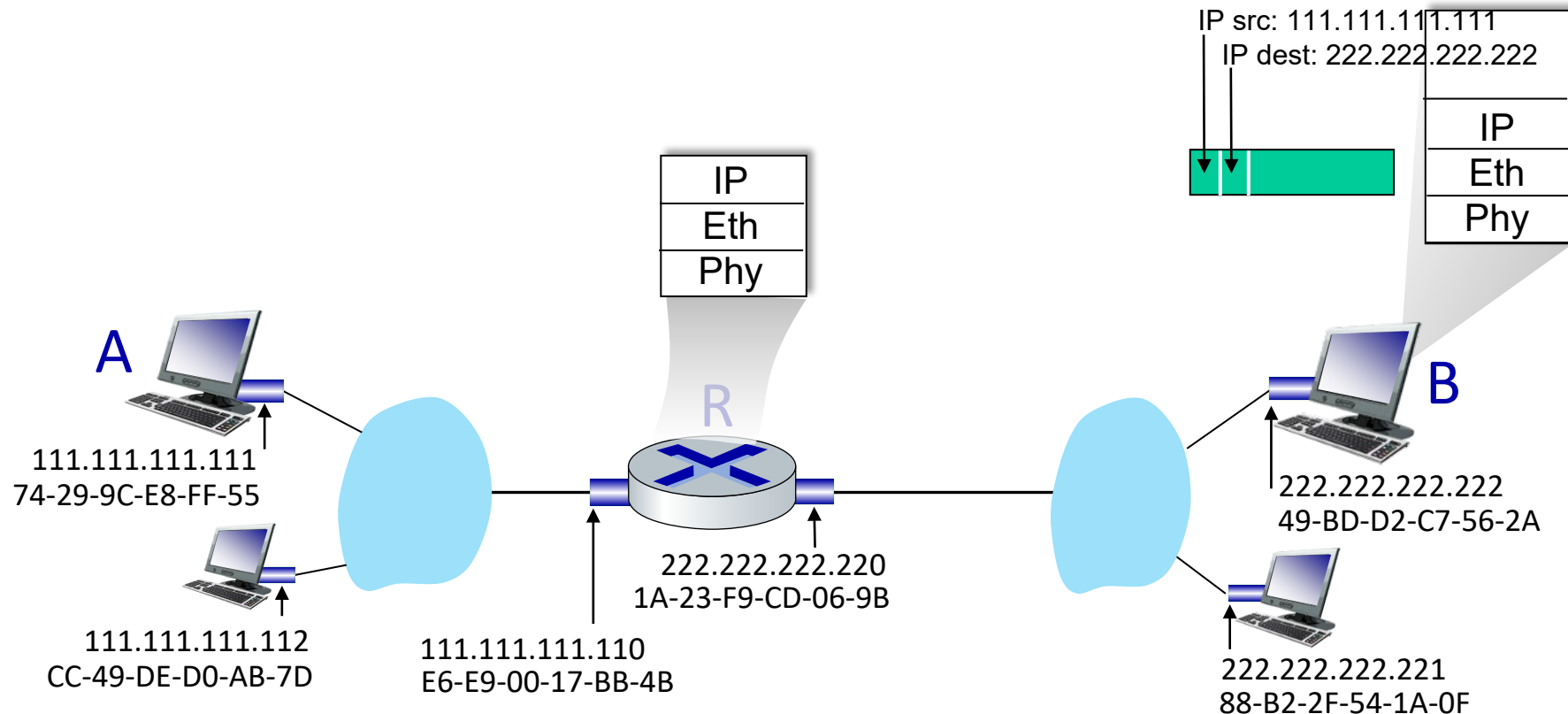
Routing to another subnet: addressing

- 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**

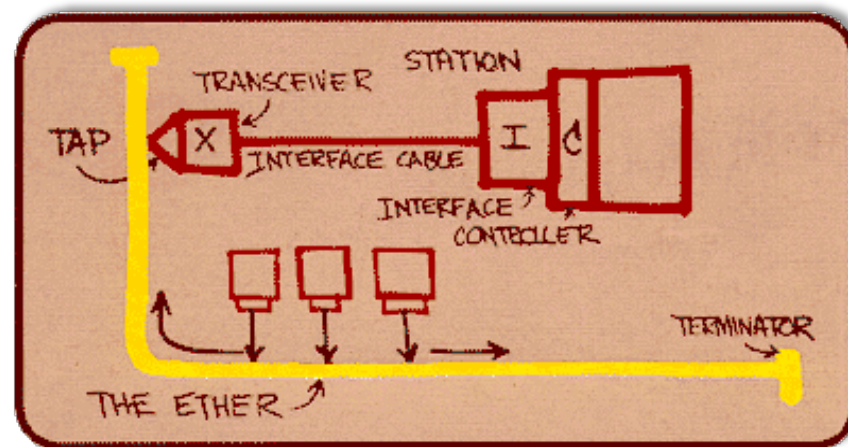


- a day in the life of a web request

Ethernet

“dominant” wired LAN technology:

- first widely used LAN technology
- simpler, cheap
- kept up with speed race: 10 Mbps – 400 Gbps
- single chip, multiple speeds (e.g., Broadcom BCM5761)

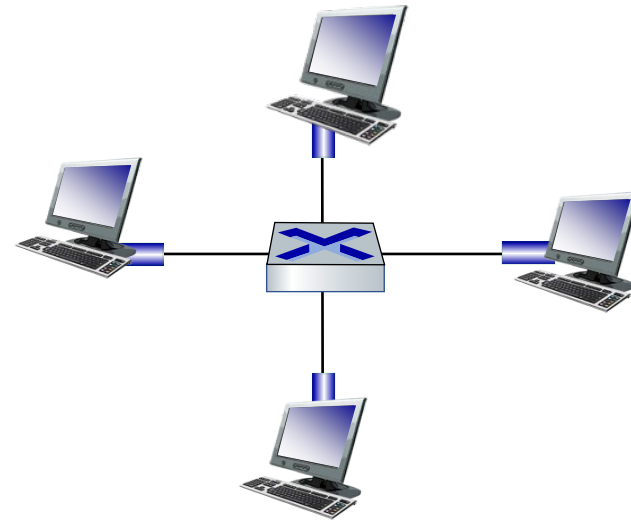
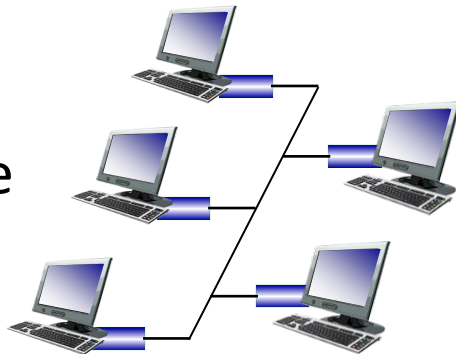


Metcalfe's Ethernet sketch

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

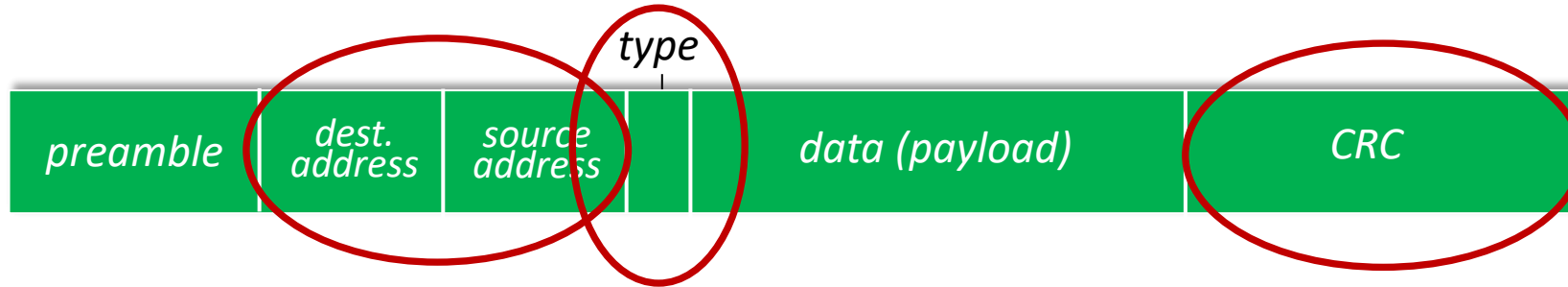
sending interface encapsulates IP datagram (or other network layer protocol packet) in **Ethernet frame**



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, AppleTalk
 - used to demultiplex up at receiver
- **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 rdt (e.g., TCP), otherwise dropped data lost
- Ethernet's MAC protocol: unslotted **CSMA/CD with binary backoff**

Ethernet CSMA/CD algorithm

1. NIC receives datagram from network layer, creates frame
2. If NIC senses channel:
 - if **idle**: start frame transmission.
 - if **busy**: wait until channel idle, then transmit
3. If NIC transmits entire frame without collision, NIC is done with frame !
4. If NIC detects another transmission while sending: abort, send jam signal
5. After aborting, NIC enters *binary (exponential) backoff*:
 - after m th collision, NIC chooses K at random from $\{0, 1, 2, \dots, 2^m - 1\}$. NIC waits $K \cdot 512$ bit times, returns to Step 2
 - more collisions: longer backoff interval

Ethernet CSMA/CD algorithm

binary (exponential) backoff:

- after m th collision, NIC chooses K at random from $\{0, 1, 2, \dots, 2^m - 1\}$. NIC waits $K \cdot 512$ bit times, returns to Step 2
- more collisions: longer backoff interval

Example:

- 1st collision, $m = 1$, range = $\{0, 1\}$
- 2nd collision, $m = 2$, range = $\{0, 1, 2, 3\}$
- 3rd collision, $m = 3$, range = $\{0, 1, 2, 3, 4, 5, 6, 7\}$
- Usually with a upper boundary
- E.g., range = $\{0, 1, 2, 3, \dots, 1023\}$, **exponential backoff**

802.3 Ethernet standards: link & physical layers

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

