50.012 Networks

Lecture 17: Link layer overview

2021 Term 6

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Outline

Introduction to Link Layer

LANs
- addressing, ARP
- Ethernet

Read textbook Section 6.1, 6.2, 6.4

Link layer: introduction

terminology:

- hosts and routers: nodes
- communication channels that connect adjacent nodes along communication path: links
  - wired links
  - wireless links
- layer-2 packet: frame, encapsulates datagram

data-link layer has responsibility of transferring datagram from one node to *physically adjacent* node over a link
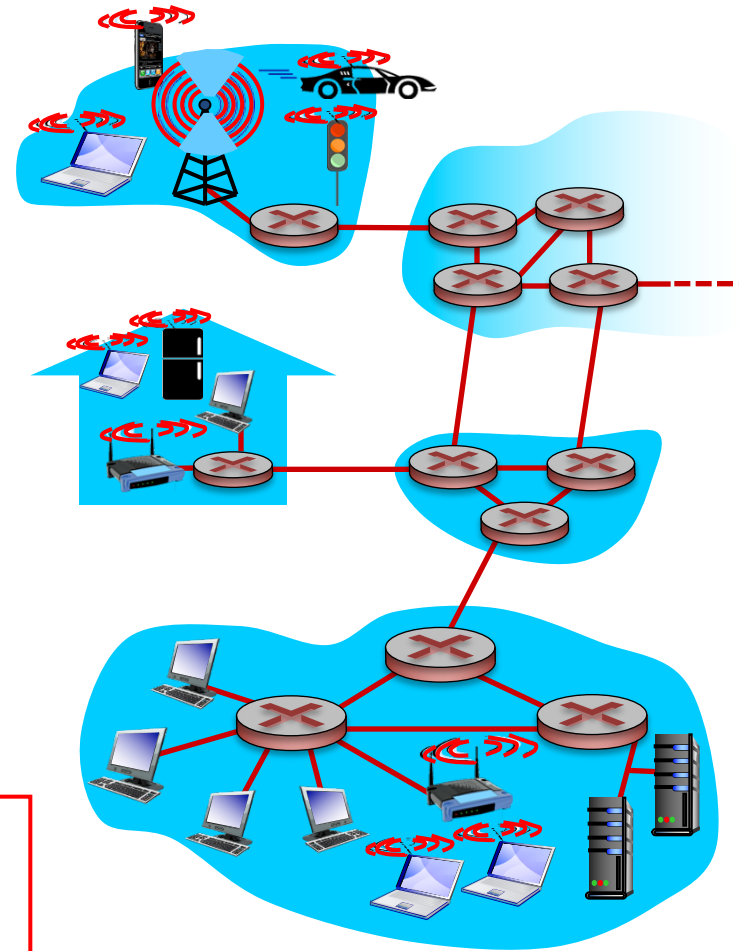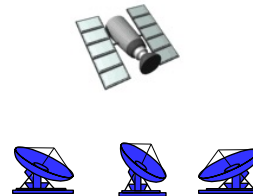
two types of "links"

- point-to-point
  - PPP (point-to-point protocol) for dial-up access
  - point-to-point link between Ethernet switch, host

- *broadcast (shared wire or medium)*
  - old-fashioned Ethernet
  - upstream HFC (hybrid fiber-coaxial cable)
  - 802.11 wireless LAN

| shared wire (e.g., cabled Ethernet) | shared RF (e.g., 802.11 WiFi) | shared RF (satellite) | humans at a cocktail party (shared air, acoustical) |

Link layer: context

- datagram transferred by different link protocols over different links:
  - e.g., 802.11 on first link, PPP on second link, … Ethernet on last link
- each link protocol provides different services
  - e.g., may or may not provide rdt over link

transportation analogy:
- trip from Princeton to Lausanne
  - limo: Princeton to JFK
  - plane: JFK to Geneva
  - train: Geneva to Lausanne
- tourist = datagram
- transport segment = communication link
- transportation mode = link layer protocol
- travel agent = routing algorithm

Link layer services

- *framing, link access:*
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
  - "MAC" addresses used in frame headers to identify source, destination
    - different from IP address!
- *reliable delivery between adjacent nodes*
  - we learned how to do this already!
  - seldom used on low bit-error link (fiber, some twisted pair)
  - wireless links: high error rates
- *half-duplex and full-duplex*
  - with half duplex, nodes at both ends of link can transmit, but not at same time

Multiple access protocols

- single shared broadcast channel
- two or more simultaneous transmissions by nodes: interference
  - *collision* if node receives two or more signals at the same time

multiple access protocol

- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

An ideal multiple access protocol

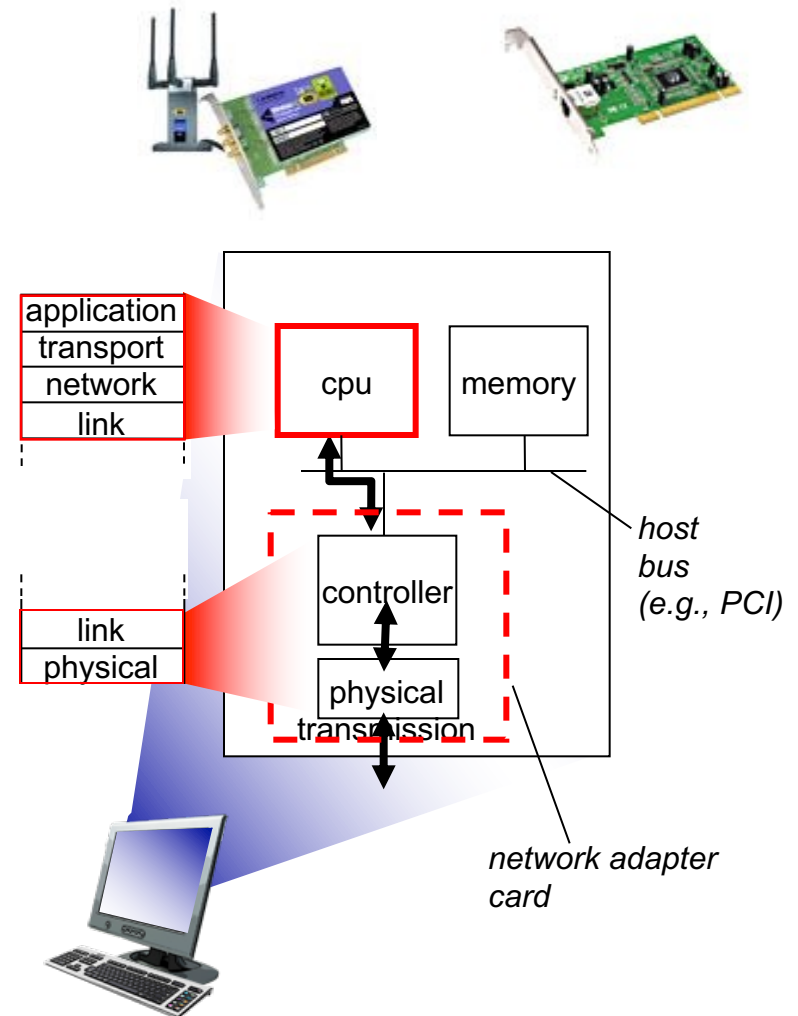*given:* broadcast channel of rate R bps

desiderata:

1. when 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
3. fully decentralized:
   - no special node to coordinate transmissions
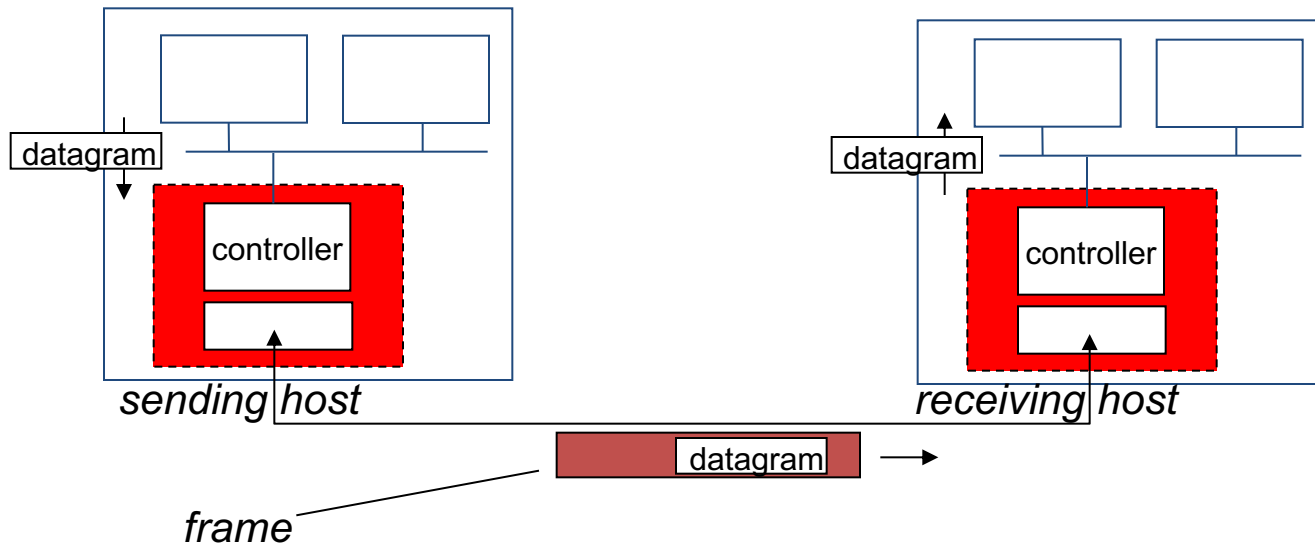   - no synchronization of clocks, slots
4. Simple

We will discuss about MAC protocol in more details when we talk about Wi-Fi

Where is the link layer implemented?

- in each and every host
- link layer implemented in "adaptor" (aka *network interface card* NIC) or on a chip
  - Ethernet card, 802.11 card; Ethernet chipset
  - implements link, physical layer
- attaches into host's system buses
- combination of hardware, software, firmware

application
transport
network
link

cpu   memory

link
physical

controller

physical

transmission

host bus (e.g., PCI)

network adapter card

Adaptors communicating

datagram

controller

sending host

datagram

controller

receiving host

datagram

frame

- sending side:
  - encapsulates datagram in frame
  - adds error checking bits, rdt, flow control, etc.

- receiving side
  - looks for errors, rdt, flow control, etc.
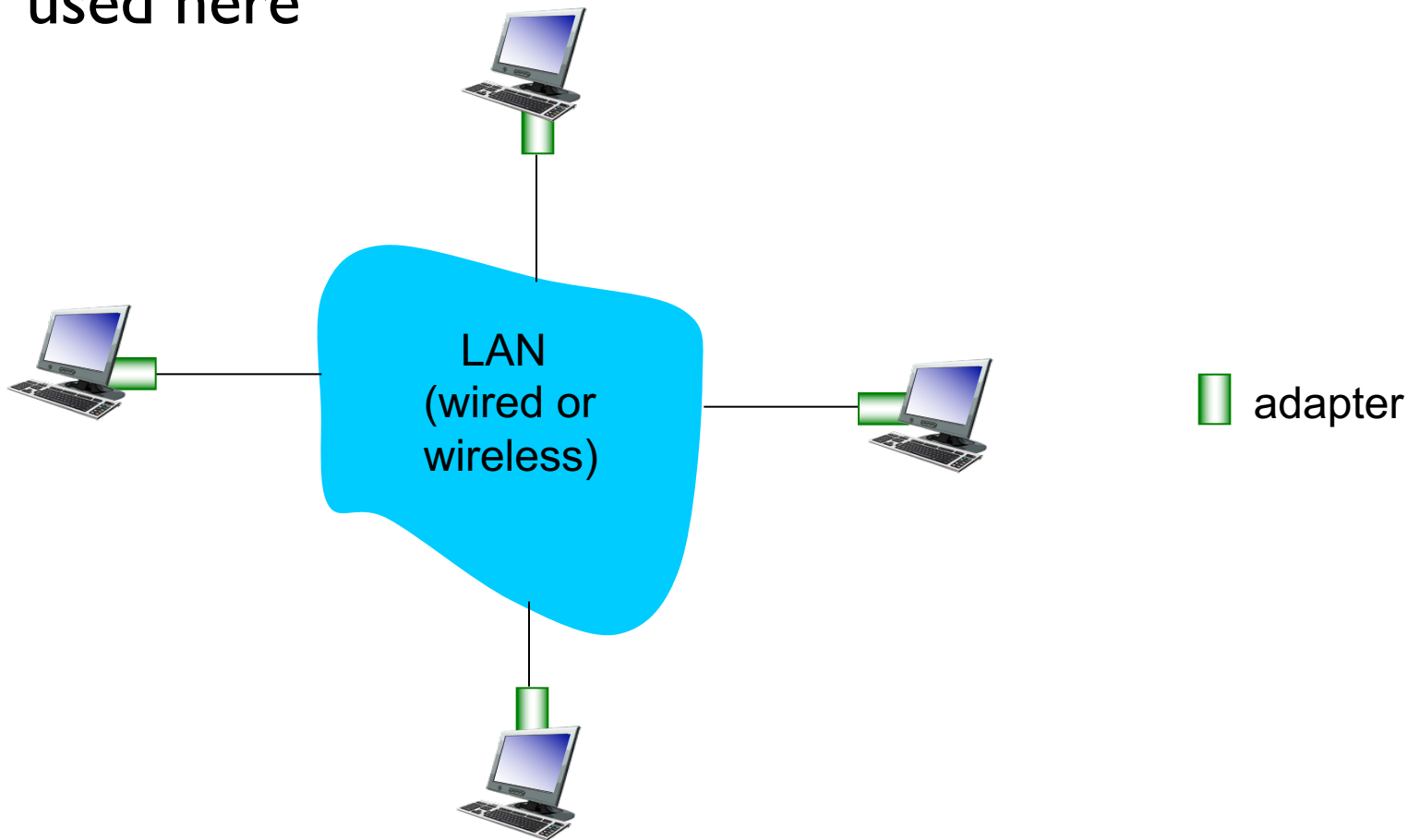 - extracts datagram, passes to upper layer at receiving side

Outline

Introduction to Link Layer

LANs
– addressing, ARP
– Ethernet

LAN (Local area network)

Ethernet and 802.11 are the two common technologies used here

LAN
(wired or
wireless)

adapter

MAC addresses and ARP

- 32-bit IP address:
  - *network-layer* address for interface
  - used for layer 3 (network layer) forwarding
- MAC (or LAN 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) 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)

LAN addresses and ARP

each adapter on LAN has unique *LAN* address

1A-2F-BB-76-09-AD

LAN
(wired or
wireless)

71-65-F7-2B-08-53

58-23-D7-FA-20-B0

0C-C4-11-6F-E3-98

adapter
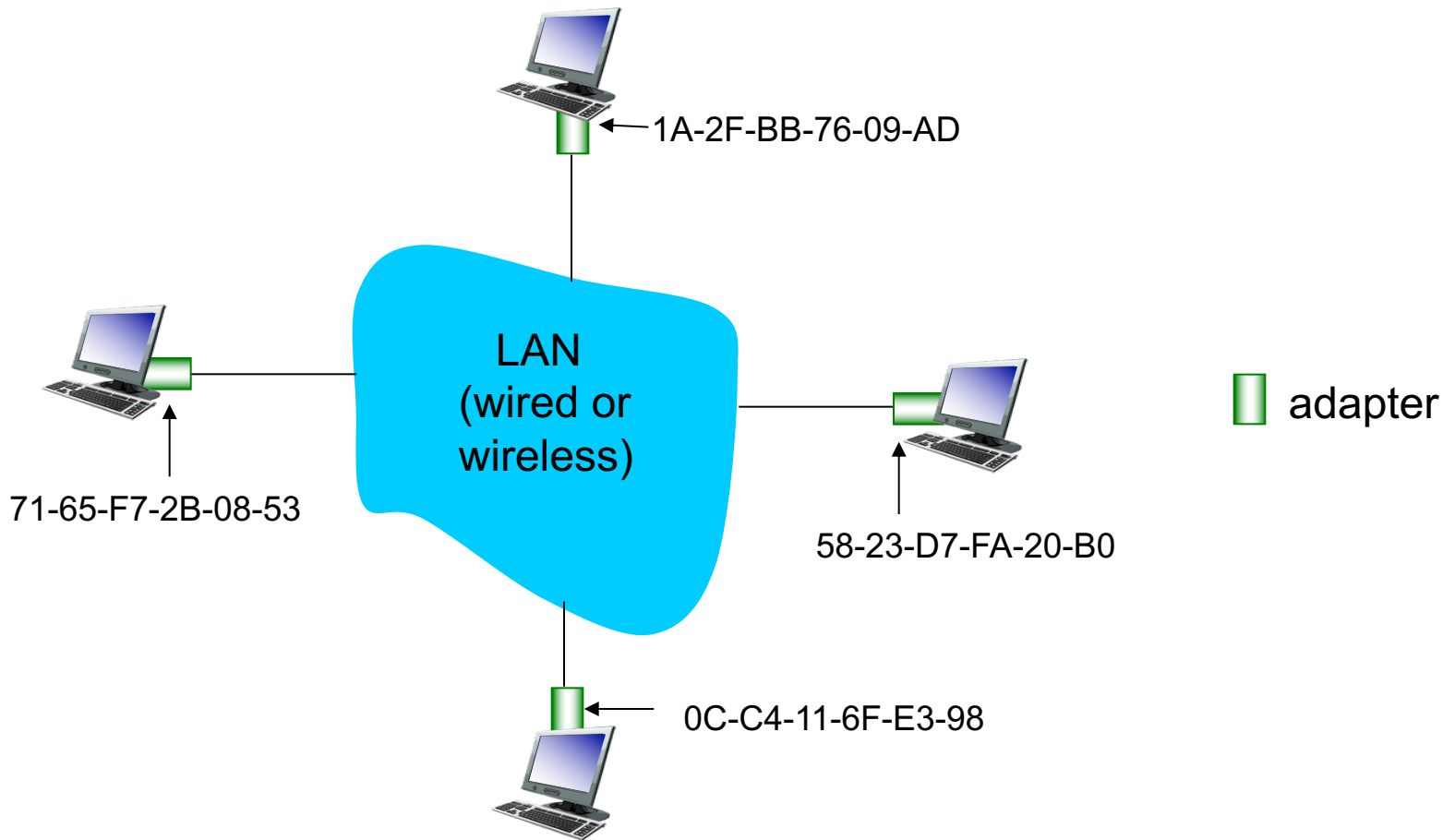
LAN addresses (more)

- 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 LAN card from one LAN to another
- 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?
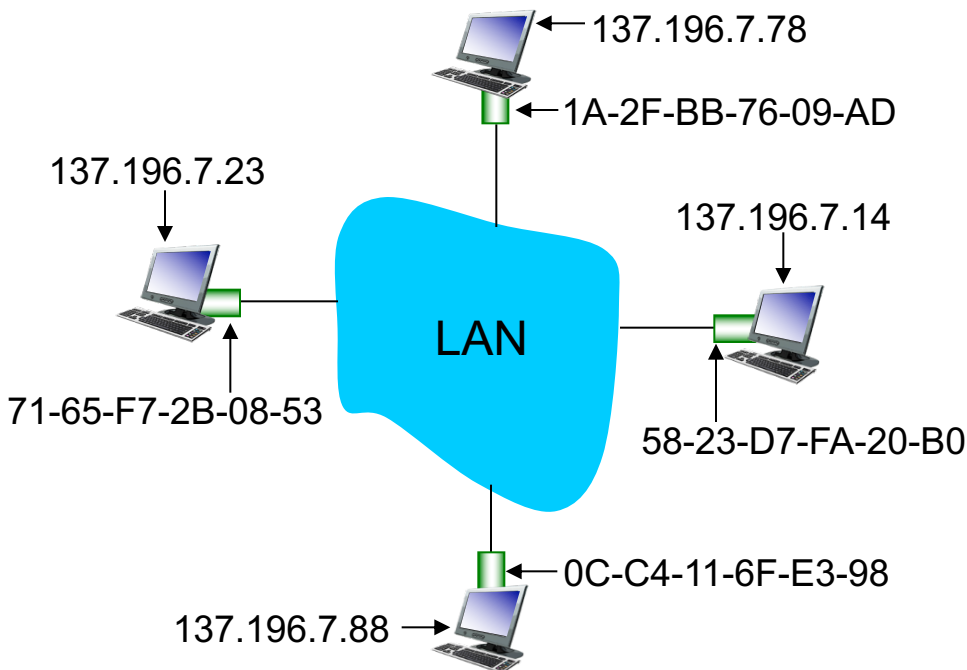
ARP table: each IP node (host, router) on LAN has table

- IP/MAC address mappings for some LAN nodes:

  < IP address; MAC address; TTL>

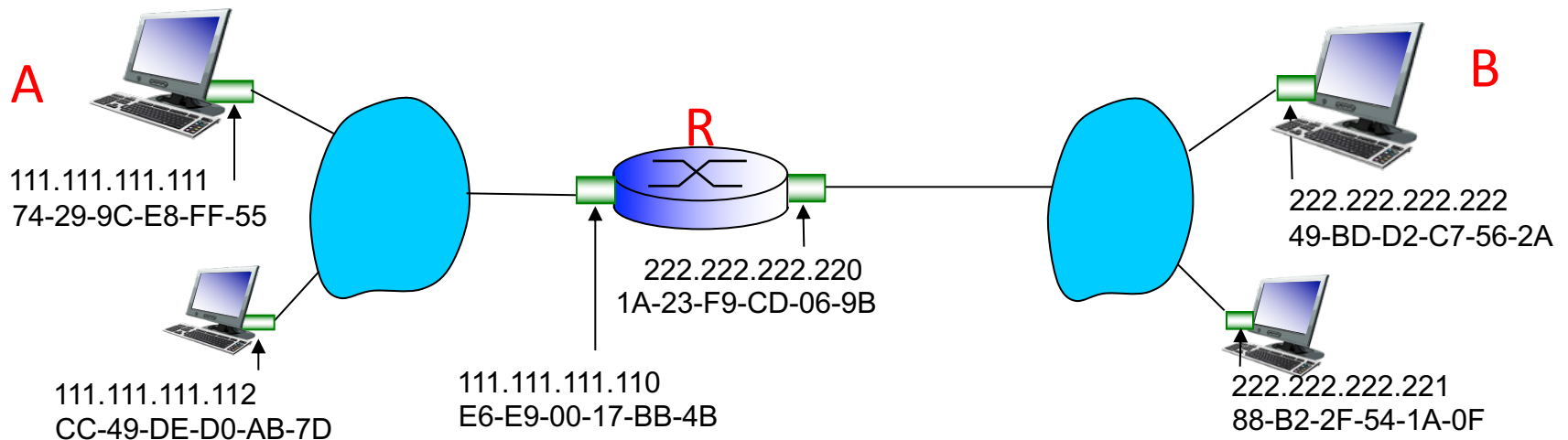- TTL (Time To Live): time after which address mapping will be forgotten (typically 20 min)

137.196.7.78

1A-2F-BB-76-09-AD

137.196.7.23

137.196.7.14

LAN

71-65-F7-2B-08-53

58-23-D7-FA-20-B0

0C-C4-11-6F-E3-98

137.196.7.88

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)
  - soft state: information that times out (goes away) unless refreshed
- ARP is "plug-and-play":
  - nodes create their ARP tables *without intervention from net administrator*

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 (how?)
- assume A knows R's MAC address (how?)

A

111.111.111.111
74-29-9C-E8-FF-55

111.111.111.112
CC-49-DE-D0-AB-7D

R

222.222.222.220
1A-23-F9-CD-06-9B

111.111.111.110
E6-E9-00-17-BB-4B

B

222.222.222.222
49-BD-D2-C7-56-2A

222.222.222.221
88-B2-2F-54-1A-0F

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

MAC src: 74-29-9C-E8-FF-55
MAC dest: E6-E9-00-17-BB-4B
IP src: 111.111.111.111
IP dest: 222.222.222.222

IP
Eth
Phy

A

111.111.111.111
74-29-9C-E8-FF-55

111.111.111.112
CC-49-DE-D0-AB-7D

R

222.222.222.220
1A-23-F9-CD-06-9B

111.111.111.110
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222.222.222.222
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222.222.222.221
88-B2-2F-54-1A-0F
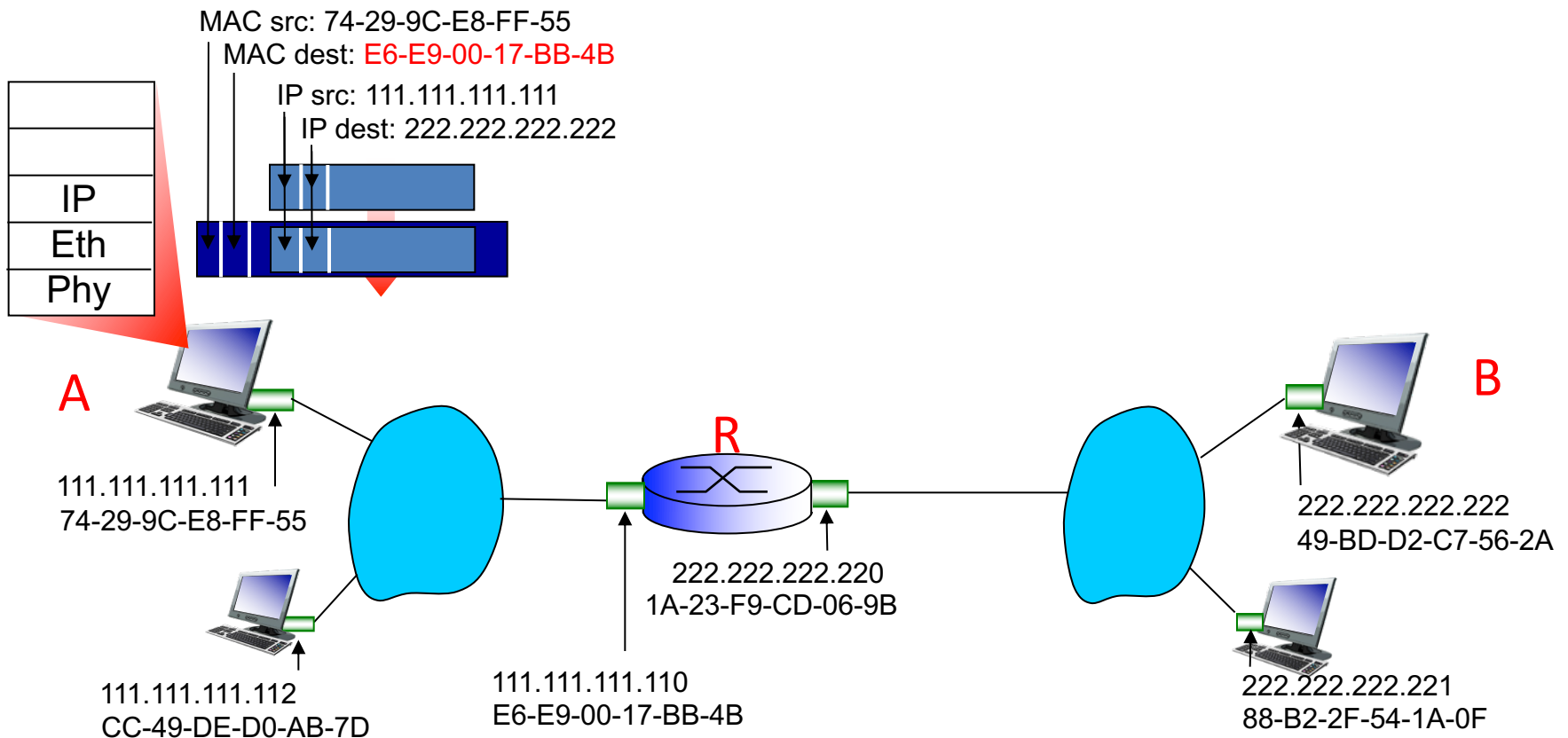
Addressing: routing to another LAN

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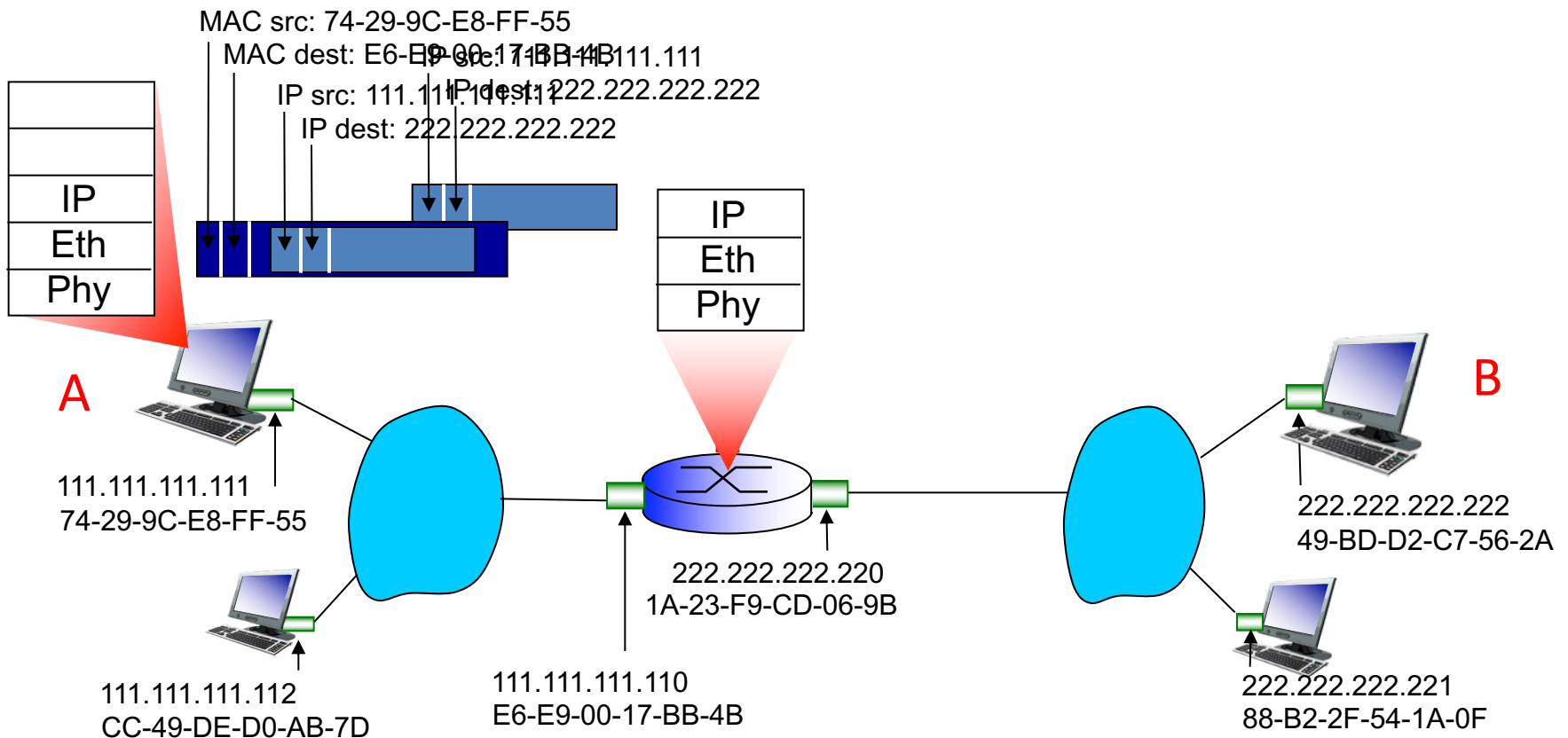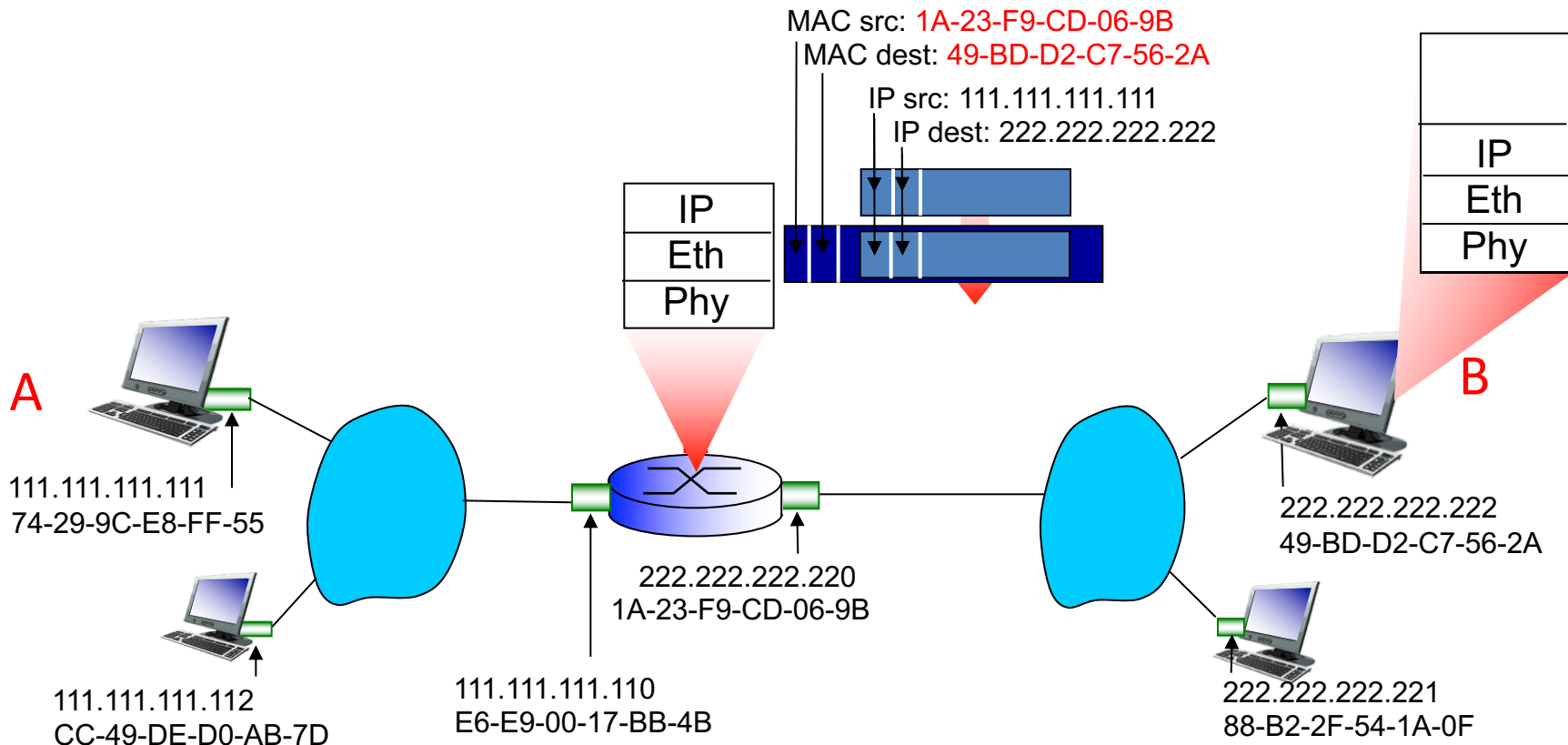- frame received at R, datagram removed, passed up to IP

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

MAC src: 1A-23-F9-CD-06-9B
MAC dest: 49-BD-D2-C7-56-2A
IP src: 111.111.111.111
IP dest: 222.222.222.222

IP
Eth
Phy

IP
Eth
Phy

A

B

111.111.111.111
74-29-9C-E8-FF-55

222.222.222.222
49-BD-D2-C7-56-2A

222.222.222.220
1A-23-F9-CD-06-9B

111.111.111.112
CC-49-DE-D0-AB-7D

111.111.111.110
E6-E9-00-17-BB-4B
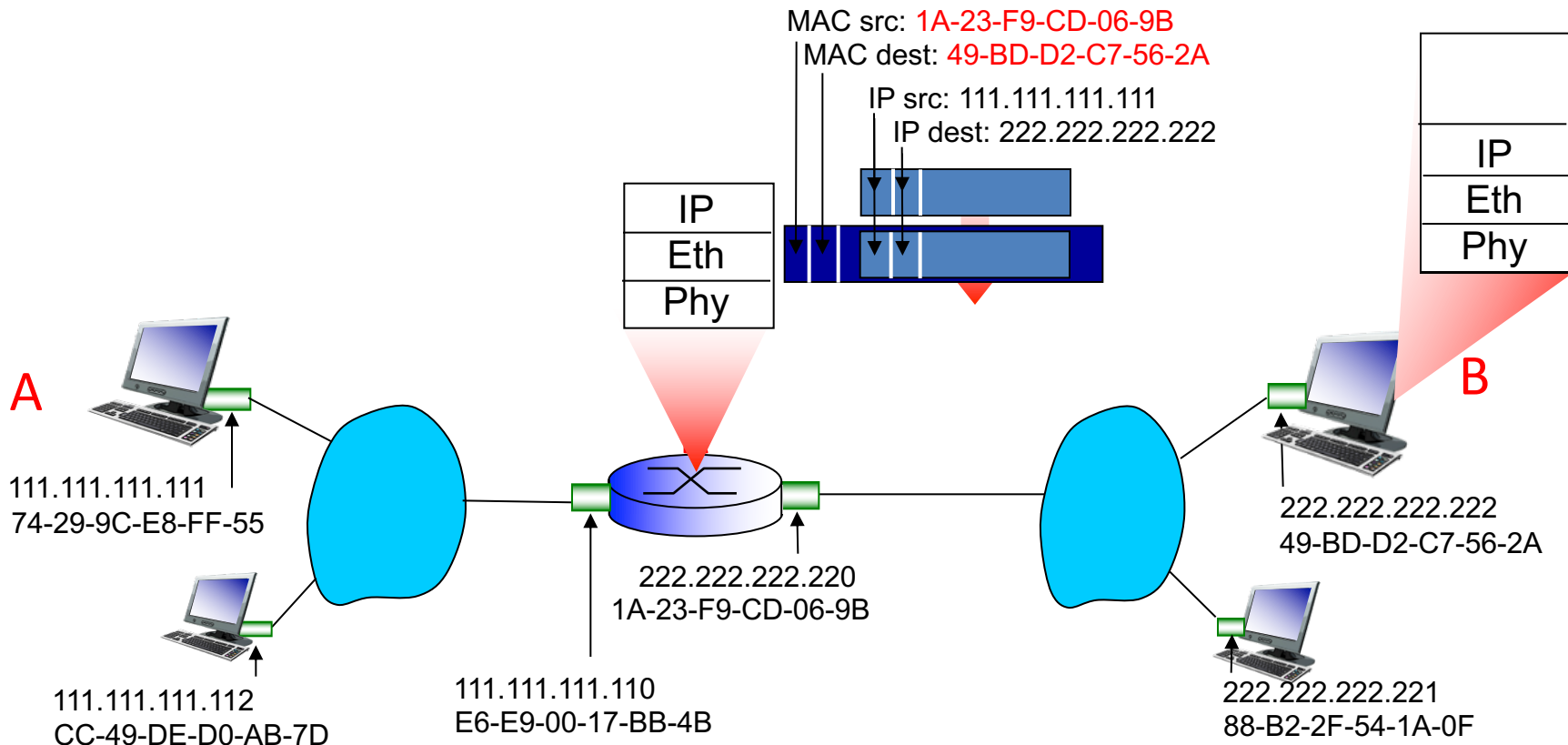
222.222.222.221
88-B2-2F-54-1A-0F

Addressing: routing to another LAN

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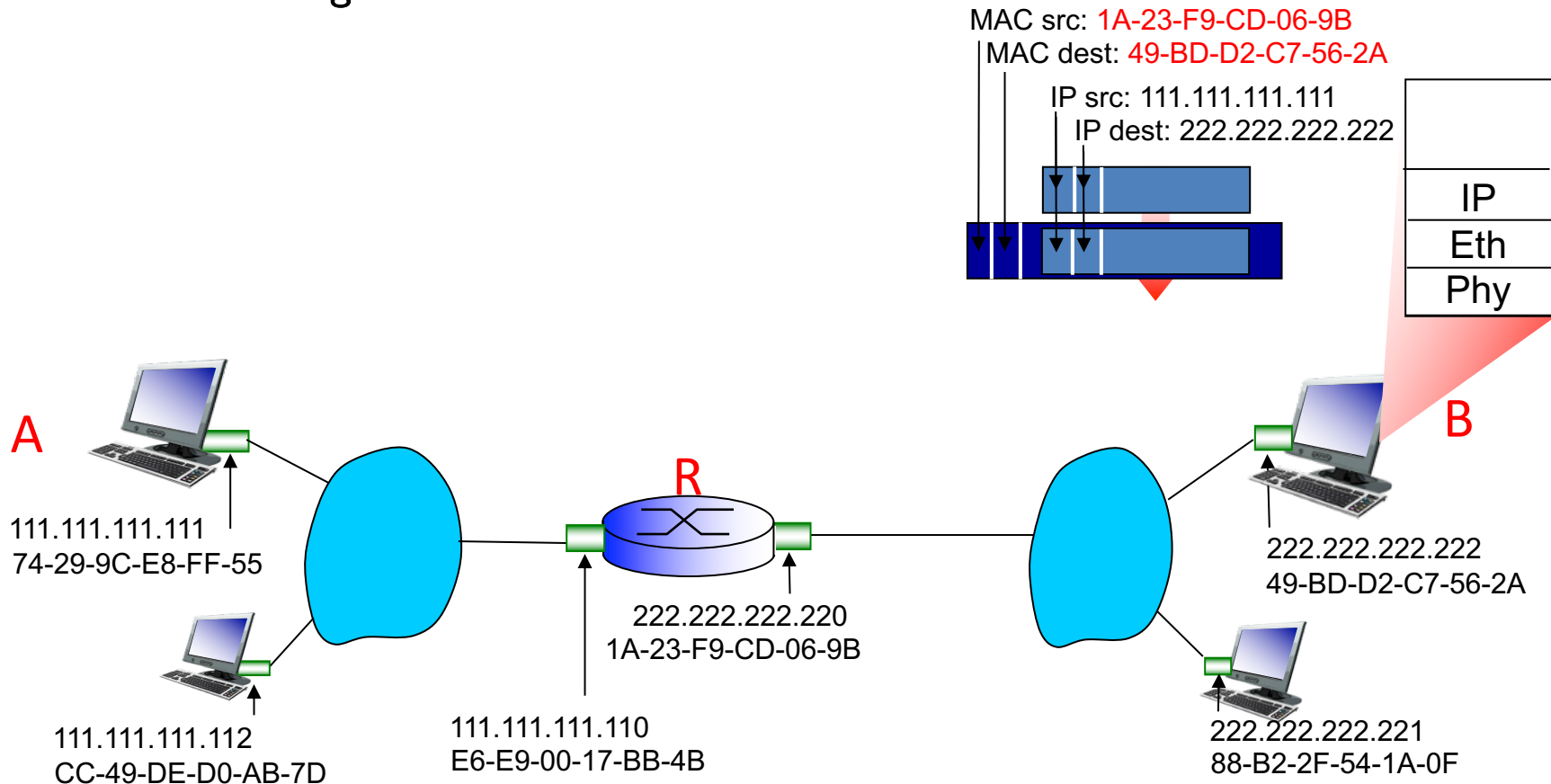- R creates link-layer frame with B's MAC address as destination address, frame contains A-to-B IP datagram

MAC src: 1A-23-F9-CD-06-9B
MAC dest: 49-BD-D2-C7-56-2A

IP src: 111.111.111.111
IP dest: 222.222.222.222

IP
Eth
Phy

IP
Eth
Phy

A

B

111.111.111.111
74-29-9C-E8-FF-55

222.222.222.220
1A-23-F9-CD-06-9B

222.222.222.222
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111.111.111.112
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E6-E9-00-17-BB-4B

222.222.222.221
88-B2-2F-54-1A-0F

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 dest, frame contains A-to-B IP datagram

MAC src: 1A-23-F9-CD-06-9B
MAC dest: 49-BD-D2-C7-56-2A

IP src: 111.111.111.111
IP dest: 222.222.222.222

IP
Eth
Phy

A

111.111.111.111
74-29-9C-E8-FF-55

R

111.111.111.112
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222.222.222.220
1A-23-F9-CD-06-9B

111.111.111.110
E6-E9-00-17-BB-4B

B

222.222.222.222
49-BD-D2-C7-56-2A

222.222.222.221
88-B2-2F-54-1A-0F

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

Ethernet

"dominant" wired LAN technology:

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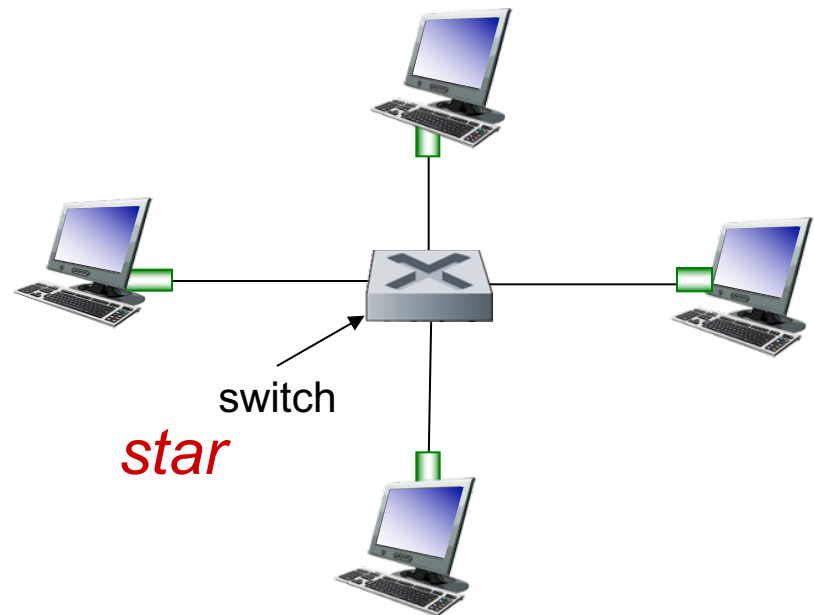- kept up with speed race: 10 Mbps – 10 Gbps
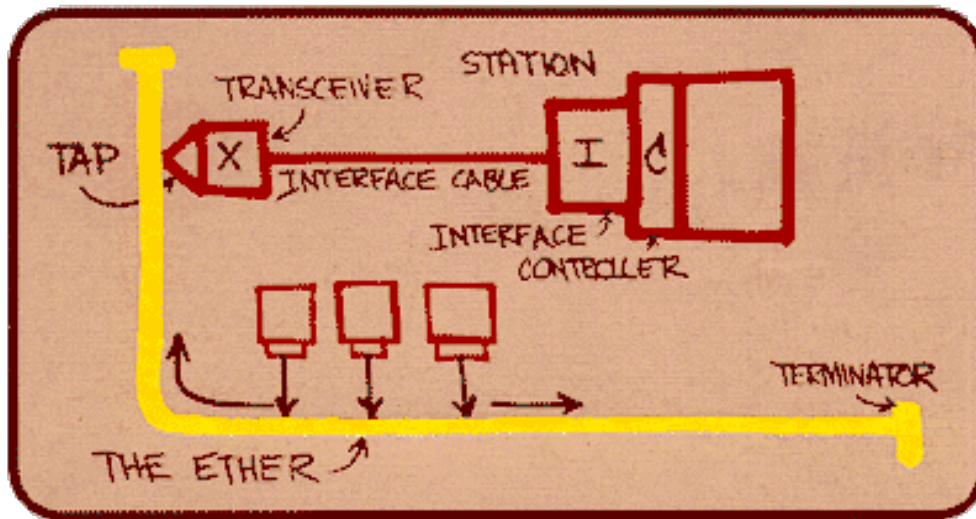
Metcalfe's Ethernet sketch

Ethernet: physical topology

- *bus:* popular through mid 90s
  - all nodes in same collision domain (can collide with each other)
- *star:* prevails today
  - active *switch* in center
  - each "spoke" runs a (separate) Ethernet protocol (nodes do not collide with each other)

bus: coaxial cable

switch

star
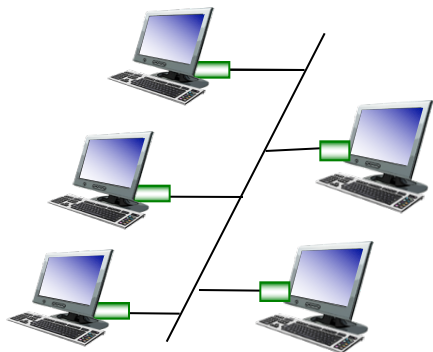
Ethernet frame structure

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

type

| *preamble*	*dest. address*	*source address*	*data (payload)*	*CRC*

preamble:

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

Cyclic redundancy check

- more powerful error-detection coding
- view data bits, D, as a binary number
- choose r+1 bit pattern (generator), G
- goal: choose r CRC bits, R, such that
  - <D,R> exactly divisible by G (modulo 2)
  - receiver knows G, divides <D,R> by G. If non-zero remainder: error detected!
  - can detect all burst errors less than r+1 bits
- widely used in practice (Ethernet, 802.11 WiFi, ATM)

← d bits → ← r bits →

| D: data bits to be sent | R: CRC bits |

bit pattern
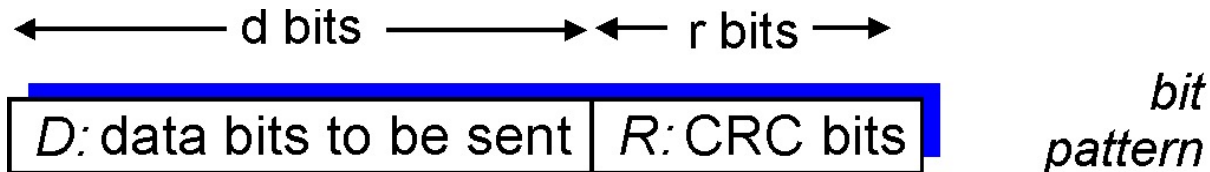
$$D * 2^r \;\; XOR \;\; R$$

mathematical formula

CRC example

want:

   $D \cdot 2^r$ XOR R = nG

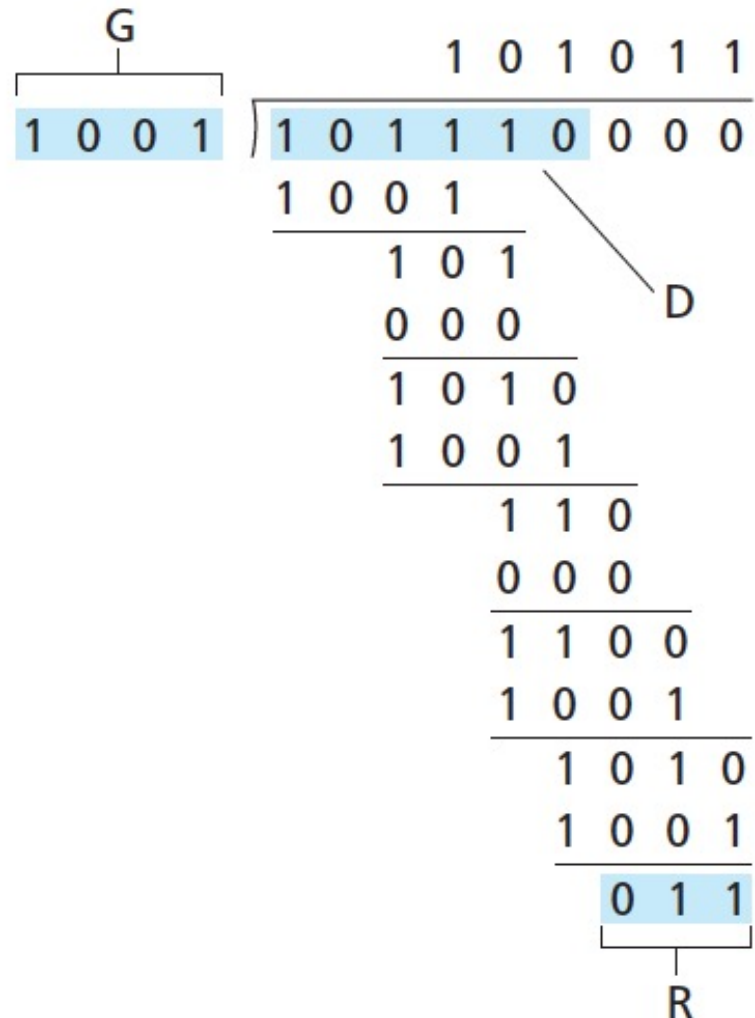*equivalently:*

   $D \cdot 2^r$ = nG XOR R

equivalently:

   if we divide $D \cdot 2^r$ by G, want remainder R to satisfy:

$$R = remainder[\frac{D \cdot 2^r}{G}]$$


```
                          1 0 1 0 1 1
G
1 0 0 1 ) 1 0 1 1 1 0 0 0 0
          1 0 0 1
            1 0 1
            0 0 0          D
            1 0 1 0
            1 0 0 1
              1 1 0
              0 0 0
              1 1 0 0
              1 0 0 1
                1 0 1 0
                1 0 0 1
                  0 1 1
                    R
```

* Check out the online interactive exercises for more examples:
http://gaia.cs.umass.edu/kurose_ross/interactive/

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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

type

preamble	dest. address	source address		data (payload)	CRC

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 rdt (e.g., TCP), otherwise dropped data lost

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

| application |
| transport |
| network |
| link |
| physical |

| MAC protocol and frame format |
| 100BASE-TX | 100BASE-T2 | 100BASE-FX |
| 100BASE-T4 | 100BASE-SX | 100BASE-BX |

copper (twister pair) physical layer

fiber physical layer