Chapter 5
Link Layer

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Thanks and enjoy! JFK/KWR

Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
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Chapter 5: Link layer

our goals:

❖ understand principles behind link layer services:

  ▪ error detection, correction

  ▪ sharing a broadcast channel: multiple access

  ▪ link layer addressing

  ▪ local area networks: Ethernet, VLANs

❖ instantiation, implementation of various link layer technologies

Link layer, LANs: outline

Link layer: introduction

terminology:

❖ hosts and routers: nodes

❖ communication channels that connect adjacent nodes along communication path: links

  ▪ wired links

  ▪ wireless links

  ▪ LANs

❖ layer-2 packet: frame, encapsulates datagram

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

global ISP
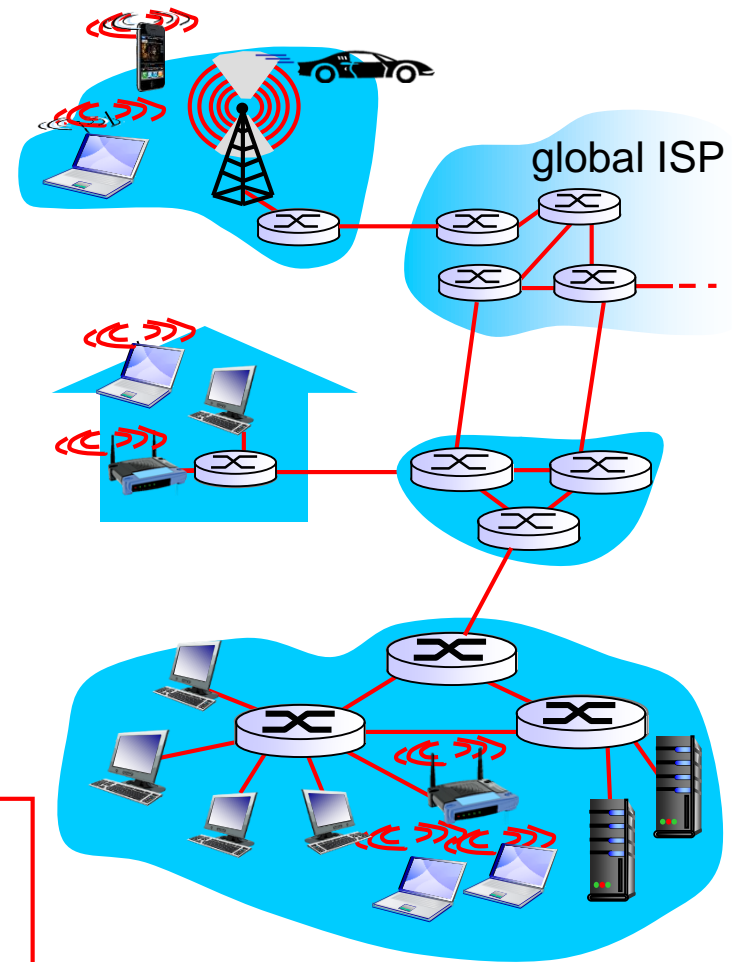
Link layer: context

* datagram transferred by different link protocols over different links:
    * e.g., Ethernet on first link, frame relay on intermediate links, 802.11 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, dest
  - different from IP address!

❖ *reliable delivery between adjacent nodes*
- we learned how to do this already (chapter 3)!
- seldom used on low bit-error link (fiber, some twisted pair)
- wireless links: high error rates
  - *Q:* why both link-level and end-end reliability?

Link layer services (more)

❖ *flow control:*
  ▪ pacing between adjacent sending and receiving nodes

❖ *error detection:*
  ▪ errors caused by signal attenuation, noise.
  ▪ receiver detects presence of errors:
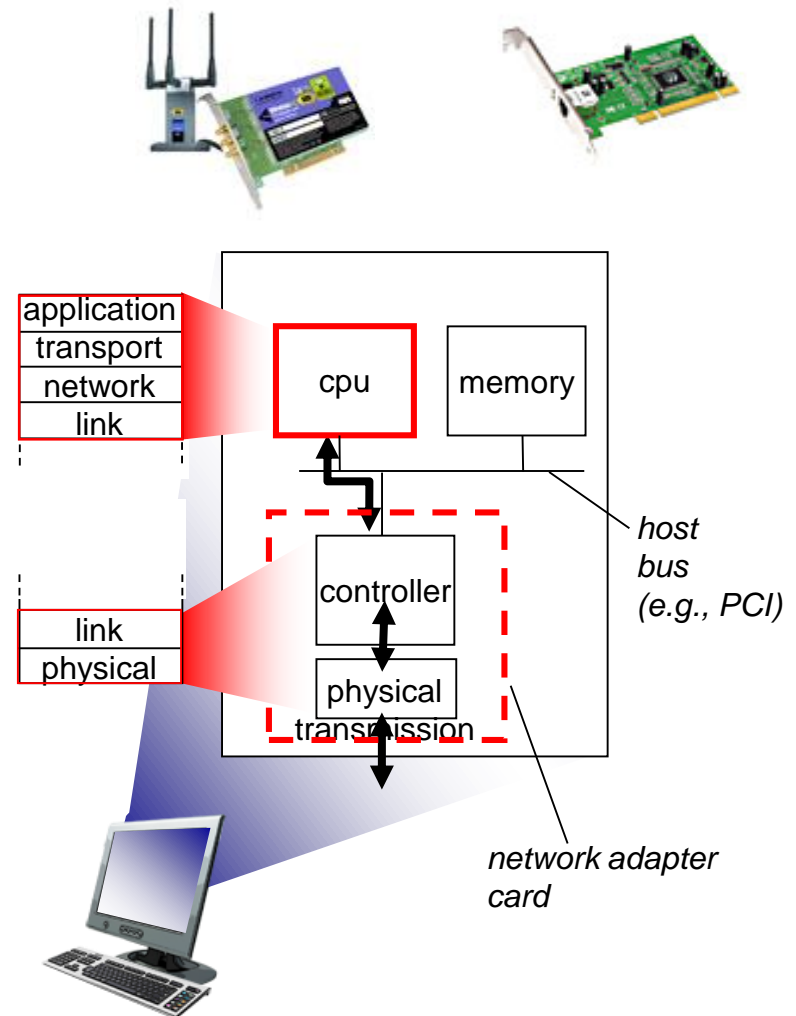   • signals sender for retransmission or drops frame

❖ *error correction:*
  ▪ receiver identifies *and corrects* bit error(s) without resorting to retransmission
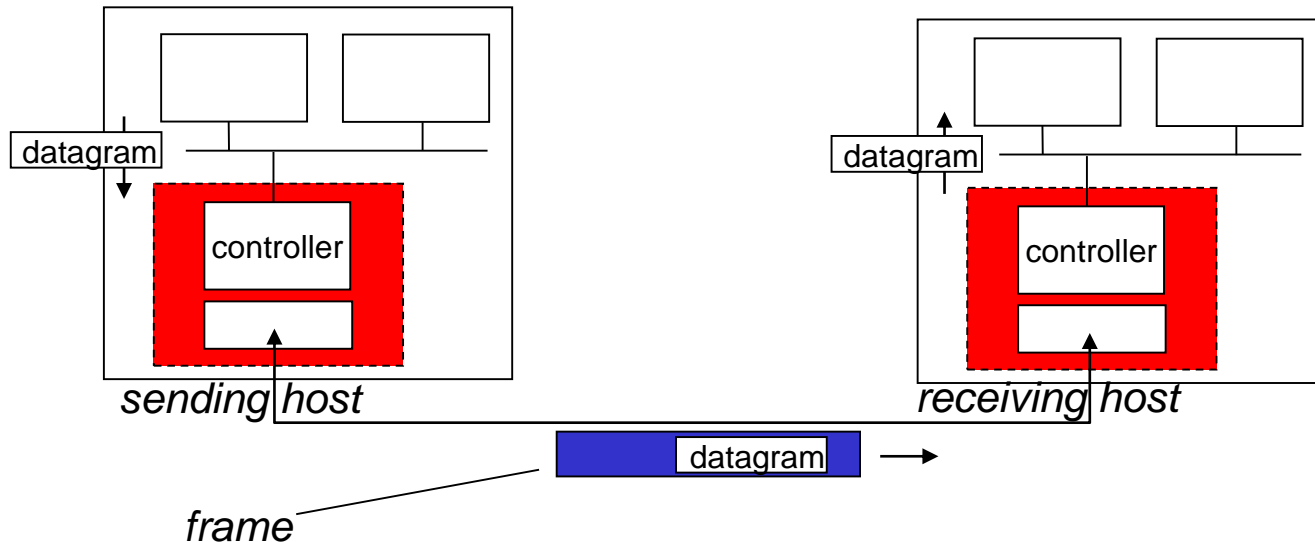
❖ *half-duplex and full-duplex*
  ▪ with half duplex, nodes at both ends of link can transmit, but not at same time

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

host
bus
(e.g., PCI)

link
physical

controller

physical
transmission

network adapter
card

Adaptors communicating

- ❖ 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

Link layer, LANs: outline

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) burned in NIC ROM, also sometimes software settable
  ▪ e.g.: 1A-2F-BB-76-09-AD

hexadecimal (base 16) notation
(each "number" 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)

adapter

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

58-23-D7-FA-20-B0

0C-C4-11-6F-E3-98
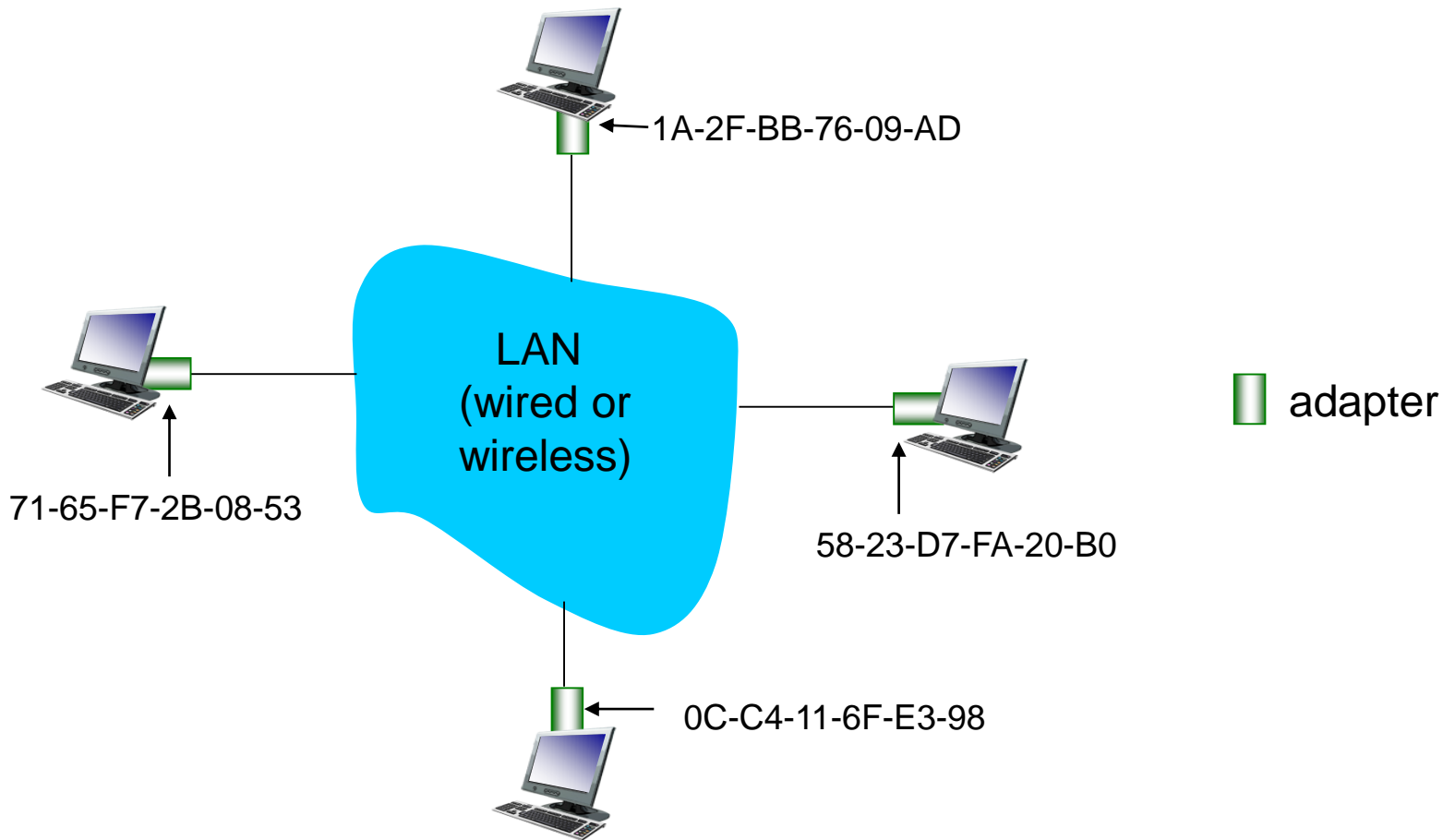
LAN addresses (more)

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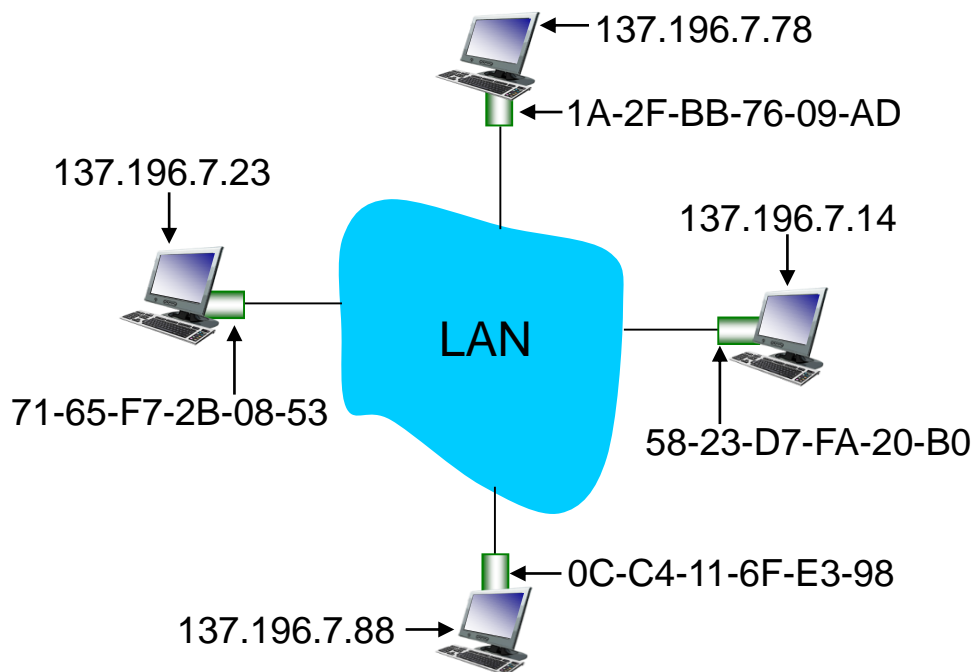 ▪ IP address: like postal address
❖ MAC flat address ➜ portability
  ▪ can move LAN card from one LAN to another
❖ IP hierarchical address *not* portable
  ▪ address depends on IP subnet to which node is attached

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

LAN

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

137.196.7.14

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
  ▪ dest 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
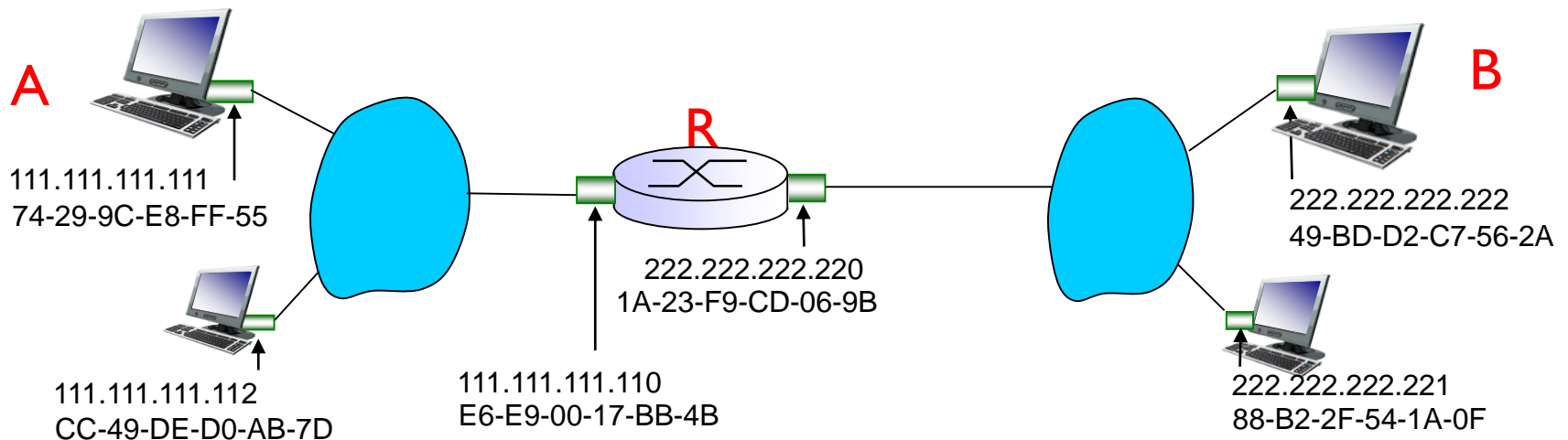
Addressing: routing to another LAN

❖ A creates IP datagram with IP source A, destination B

❖ A creates link-layer frame with R's MAC address as dest, 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

B

R

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
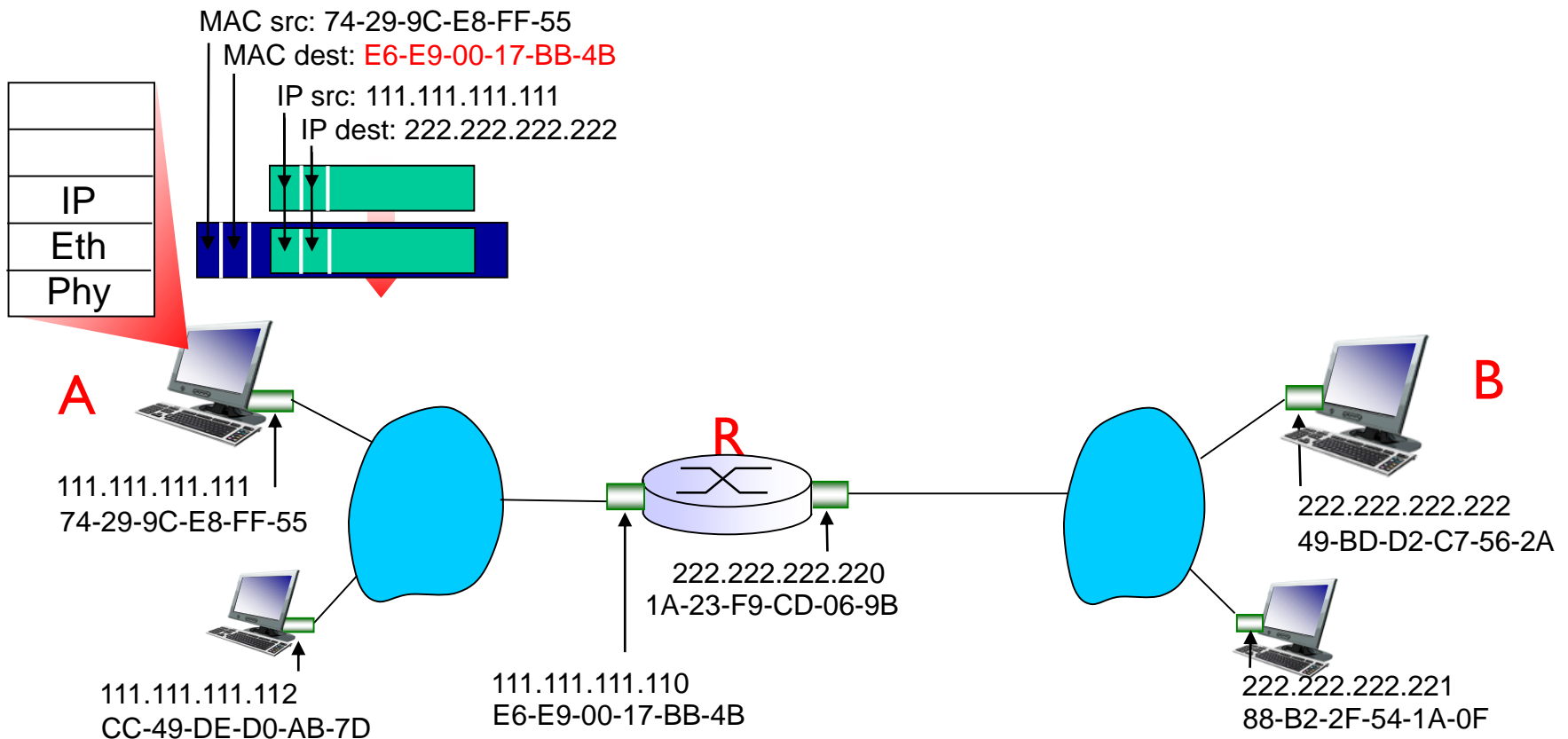
Addressing: routing to another LAN

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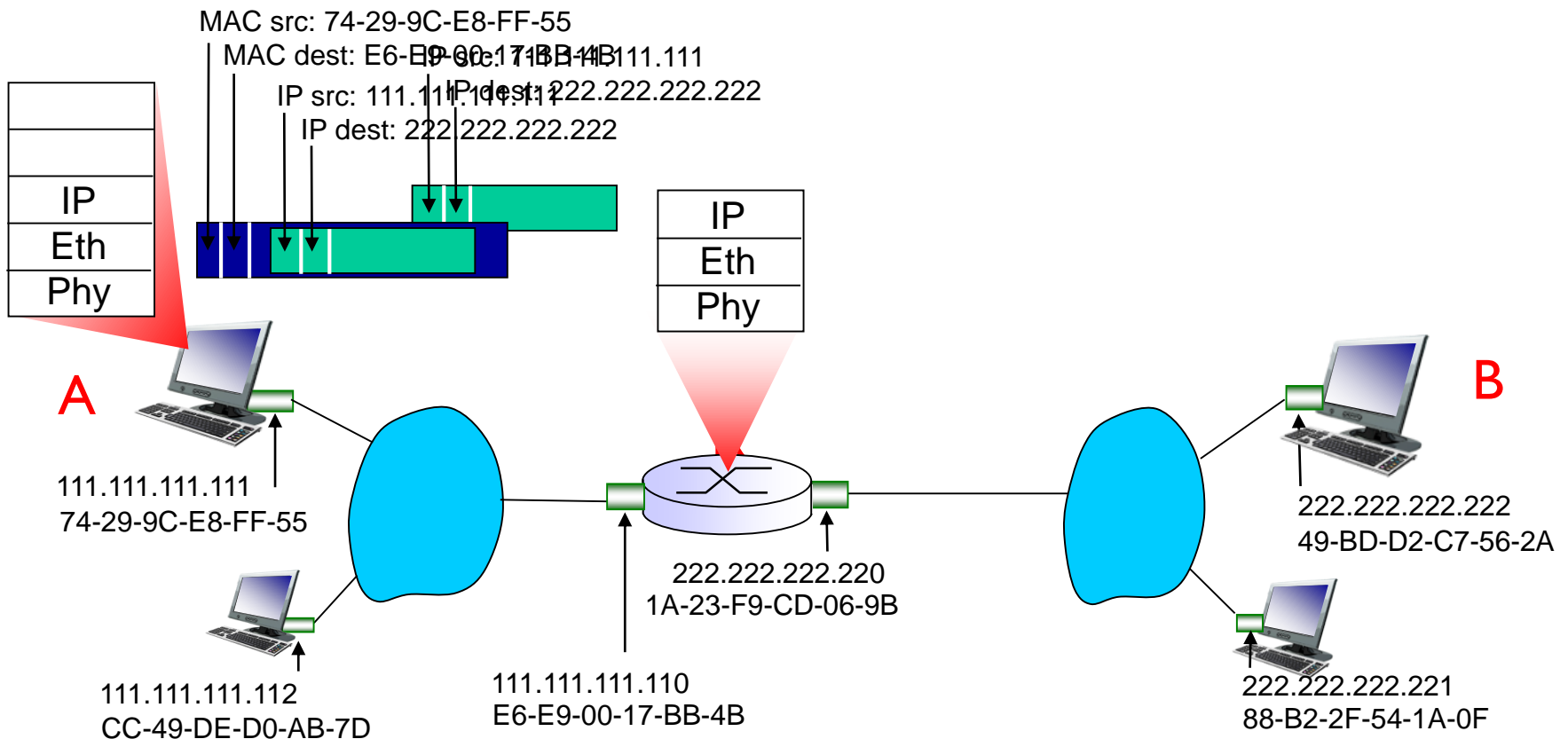- frame received at R, datagram removed, passed up to IP

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 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 |

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

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 dest, frame contains A-to-B IP datagram

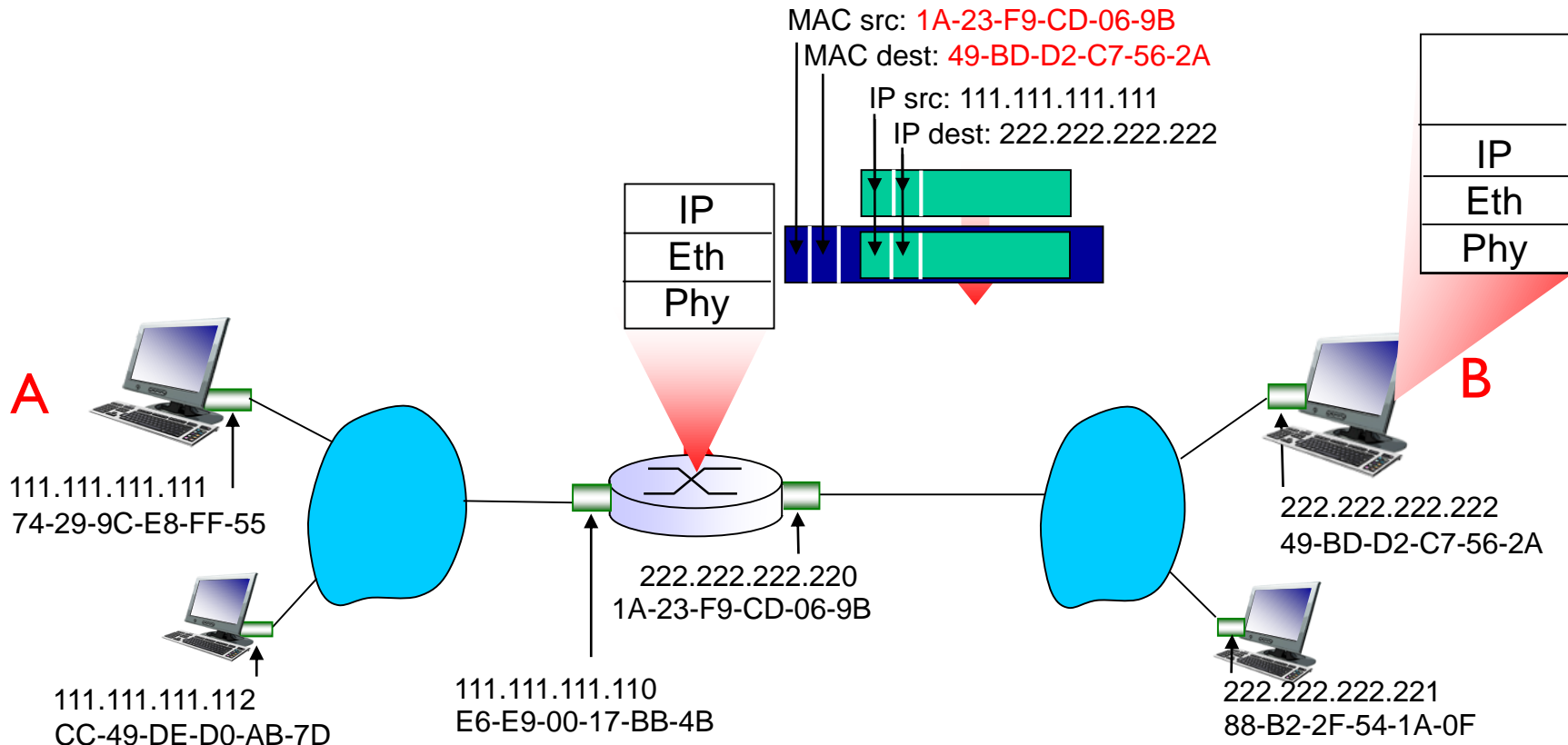MAC src: 1A-23-F9-CD-06-9B
MAC dest: 49-BD-D2-C7-56-2A
IP src: 111.111.111.111
IP dest: 222.222.222.222

A

B

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

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

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

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

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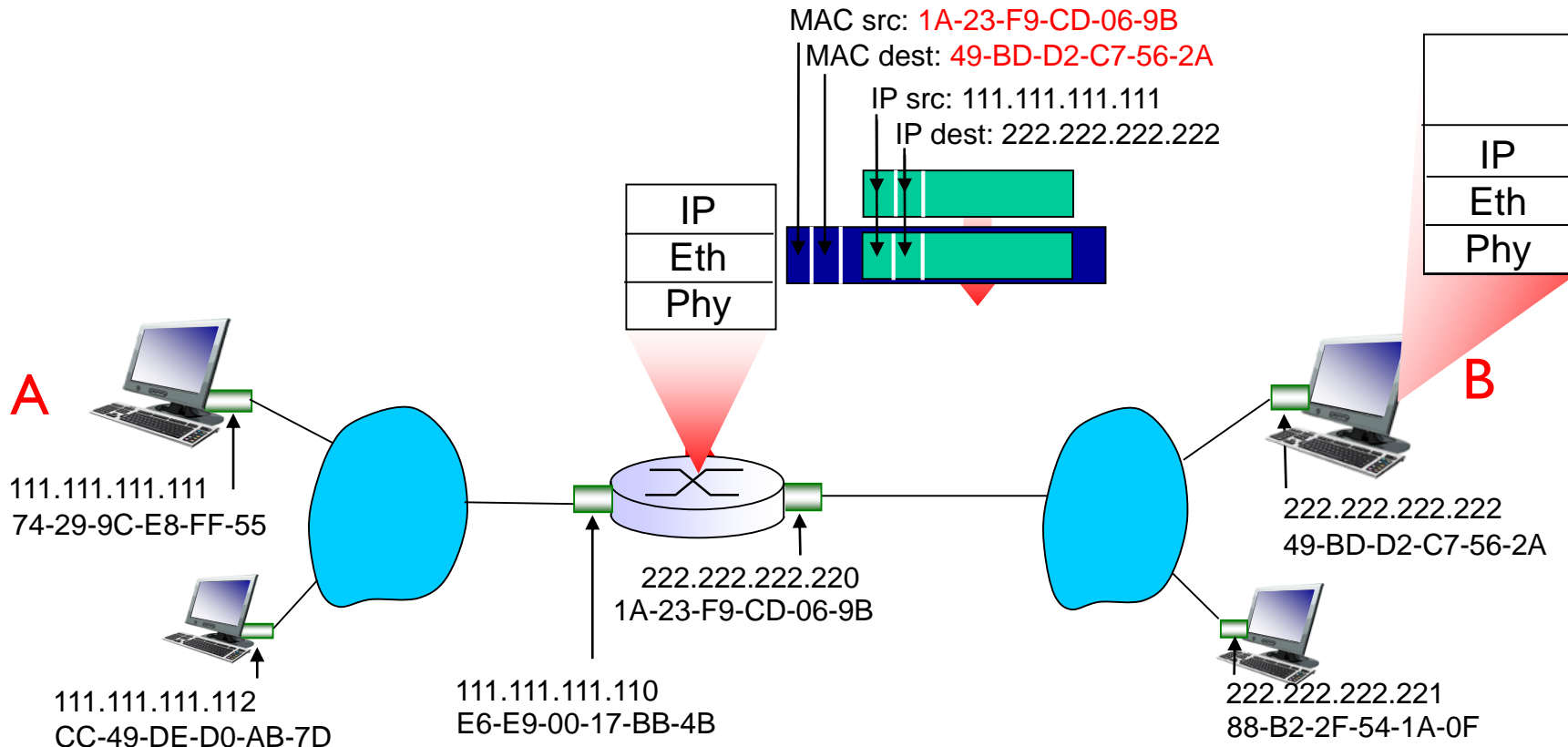49-BD-D2-C7-56-2A

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

Addressing: routing to another LAN

❖ 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

R

B

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

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

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

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

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

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