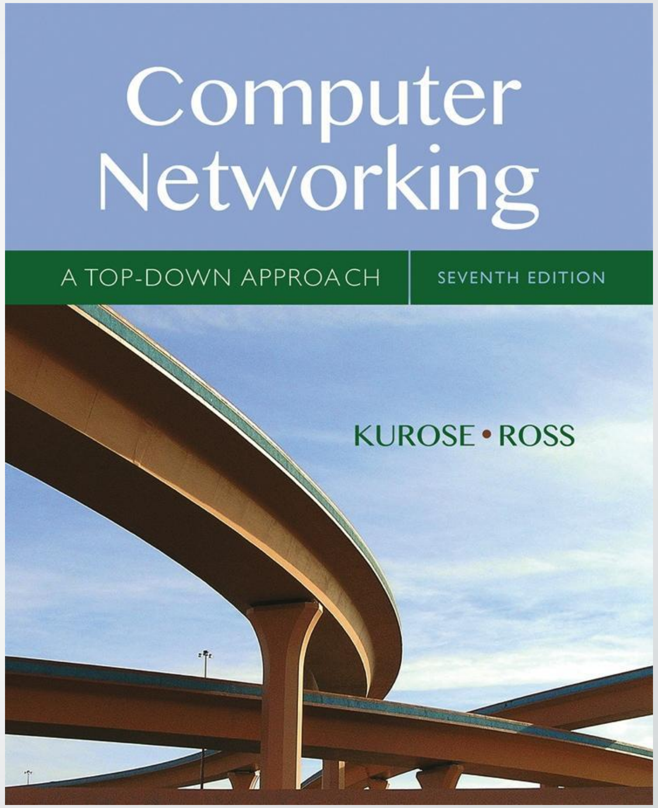
Data Link Layer

Lecture 15 | CSE421 –Computer Networks

Department of Computer Science and Engineering
School of Data & Science

Based on Chapter 6
The Link Layer and LANs

- *The slides are adapted from Kurose and Ross, Computer Networks 7th edition, Kurose and Ross.*

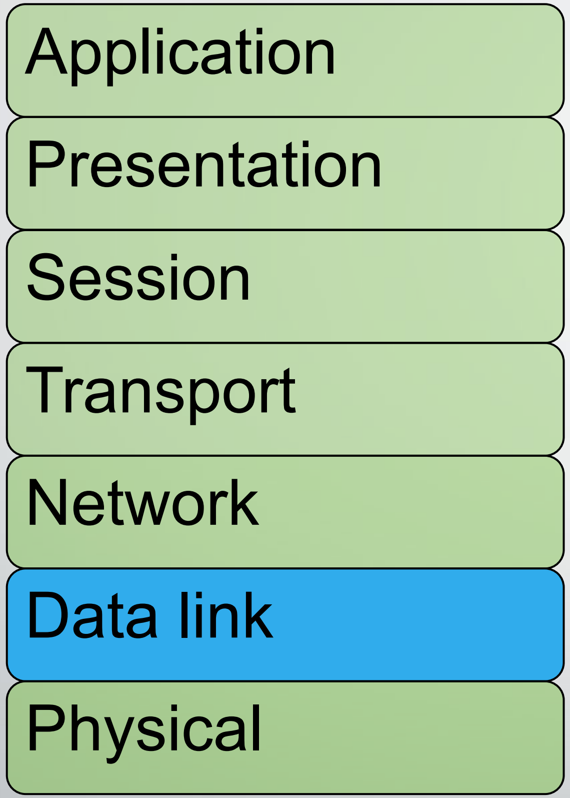


Computer Networking: A Top Down Approach
7th edition
Jim Kurose, Keith Ross
Pearson/Addison Wesley
April 2016

Chapter 6: Link layer and LANs

Objectives:

- understand principles behind link layer services:
  - error detection, correction (done in CSE320)
  - sharing a broadcast channel: multiple access (done in CSE320)
  - Framing - link layer addressing
  - ARP
  - local area networks: Ethernet

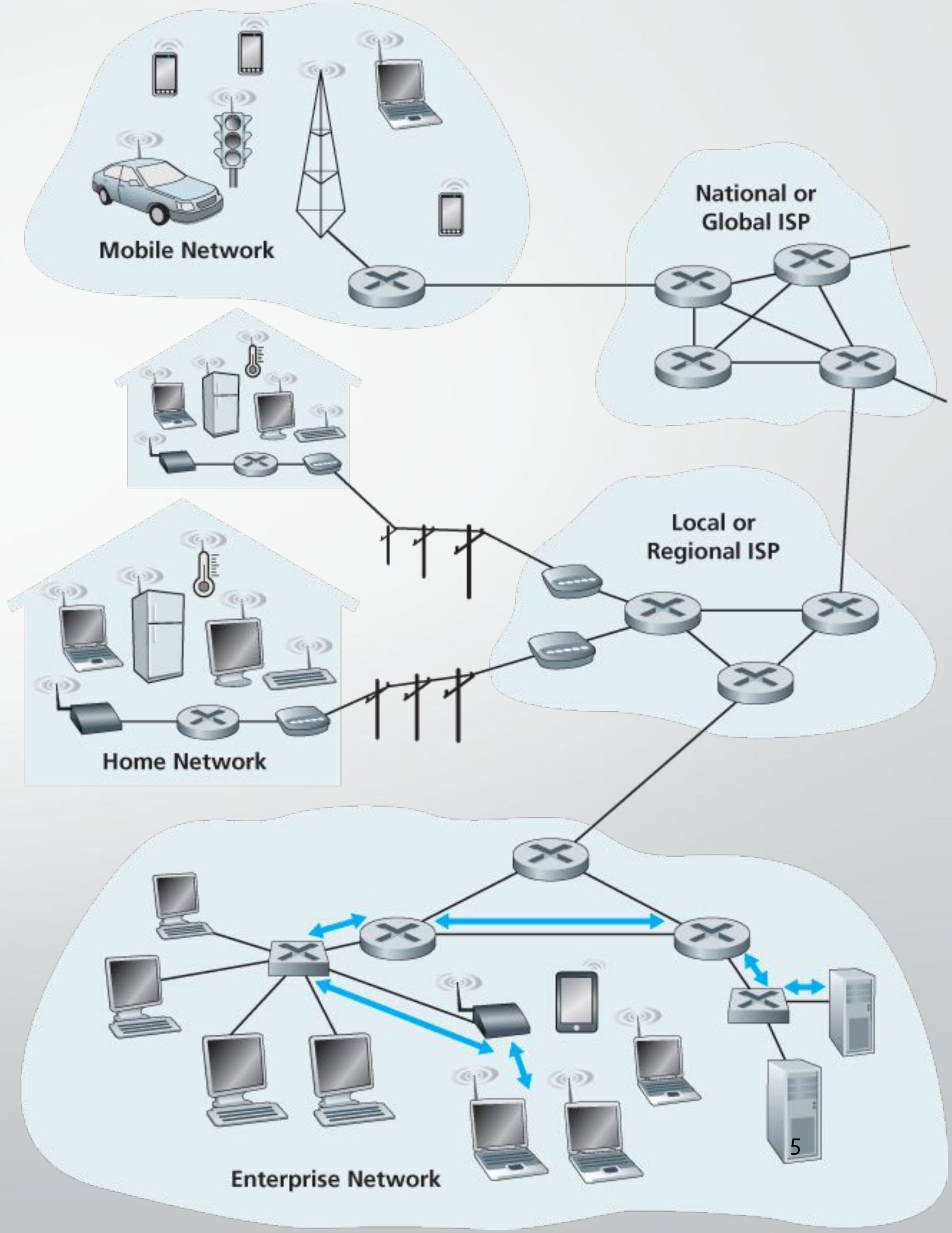


Introduction to Link Layer

Link Layer Terminology

- Nodes : hosts and routers
- Links:
  - wired links
  - wireless links
- Frame : layer-2 packet

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



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

Transportation analogy:

- trip from Home to Cox's Bazaar
  - Uber Car : Home to Dhaka Airport
  - Plane: Dhaka to Chittagong
  - Bus: Chittagong to Cox's Bazaar
- tourist = datagram
- transport segment = communication link
- transportation mode = link layer protocol
- travel agent = routing algorithm

Link layer functions/services

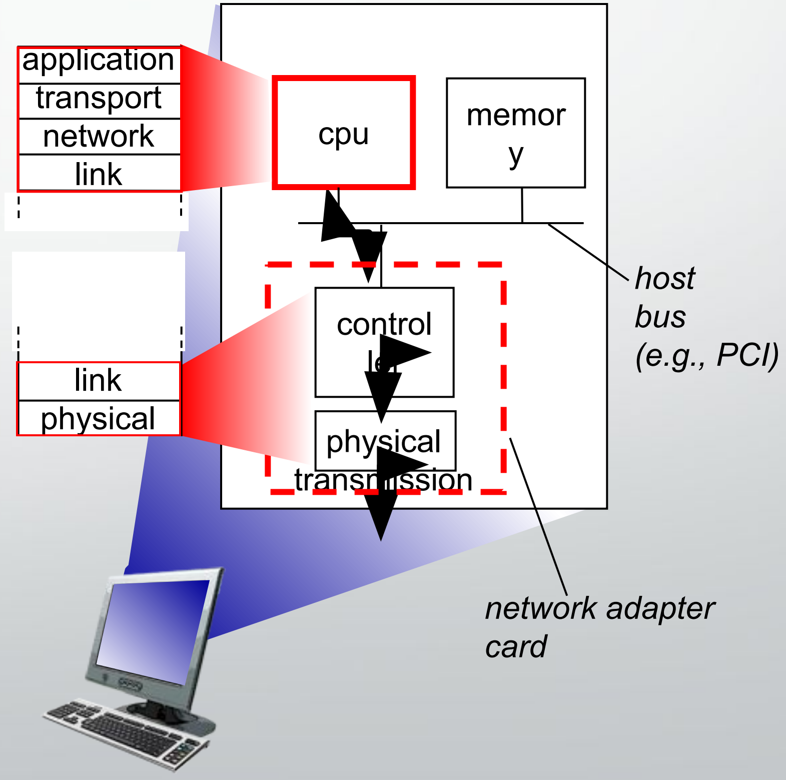
- *Framing*
  - encapsulate datagram into frame, adding header, trailer
    - Various information added such as the various protocols
  - "MAC" addresses used in frame headers to identify source, destination
    - different from IP address!
- *Link access:*
  - how to send a frame to the link
  - channel access if shared medium
    - Control/Avoid clashes in multi-access networks!
  - rules to follow when sending the link
- *Reliable delivery between adjacent nodes*
  - we learned how to do this already (Transport Layer)
  - 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)

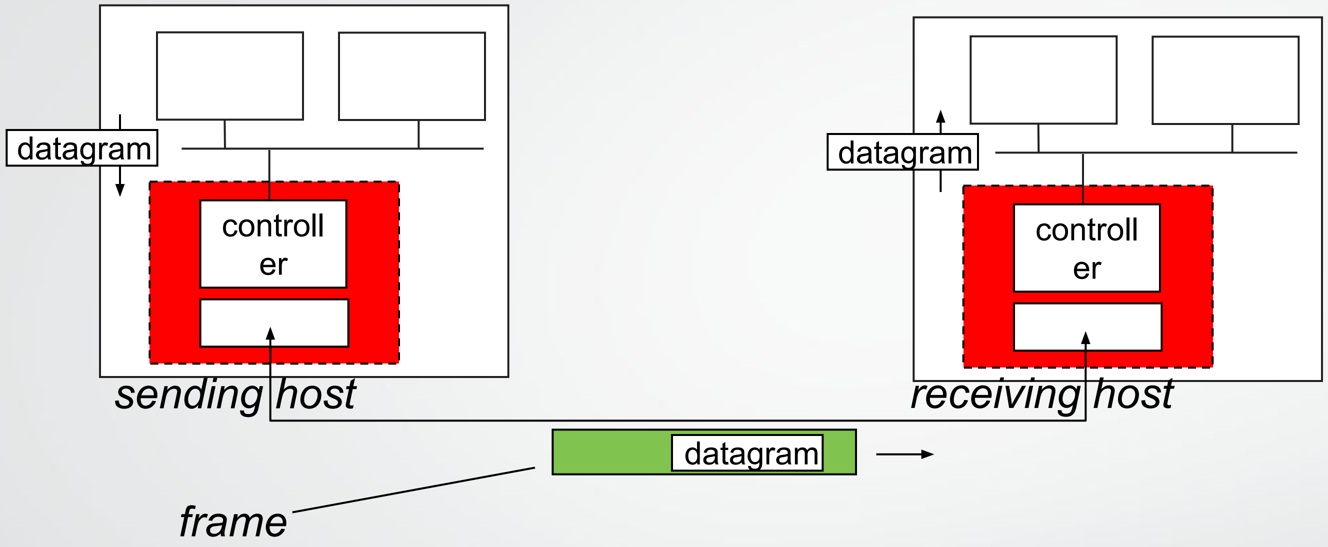
- *error detection*:
  - errors caused by signal attenuation, noise.
  - receiver detects presence of errors:
    - signals sender for retransmission or drops frame
- *error correction:*
  - receiver identifies *and corrects* bit error(s) without resorting to retransmission (there are various protocols)
- *flow control:*
  - pacing between adjacent sending and receiving nodes
- *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



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

Objectives – Part 1

~~*Our objectives*~~

- Link Layer Addressing
  - MAC Address
  - Types of MAC Addresses
- ARP
- ARP within LAN
- LAN Protocol
  - Ethernet
- LAN Switch

Link Layer Addressing

IP Address vs MAC Address

IP address

- 32 bits
- Dotted decimal notation
  - Example : 192.168.10.1
- *Network-layer* address for interface
- Hierarchal
  - Not portable
- Function

MAC address

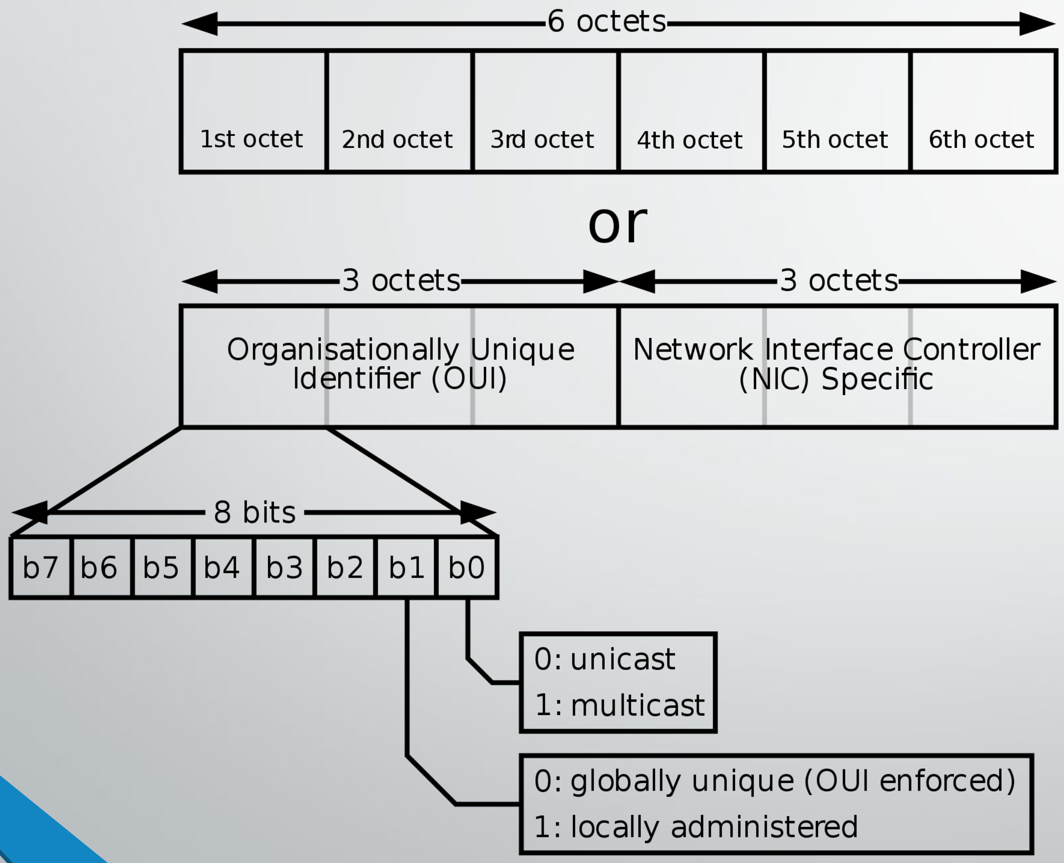
- 48 bits
- 12 Hexadecimal digits
  - Example : 1A-2F-BB-76-09-AD
- *Data Link-layer* address for interface
- Flat
  - portable
- Function

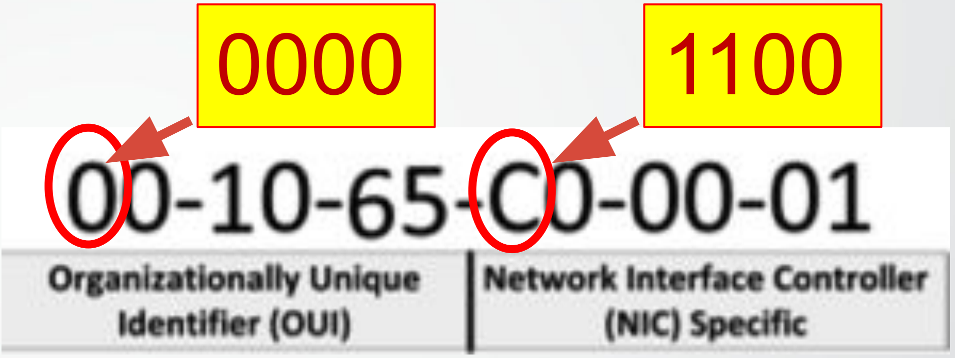
MAC or LAN or Physical or Ethernet addresses (more)

- 48 bits MAC address (for most LANs) burned in NIC ROM, also sometimes software settable
- MAC address allocation administered by IEEE
- Manufacturer buys portion of MAC address space (to assure uniqueness)
- Analogy:
  - MAC address: like National ID
  - IP address: like Postal Address

MAC Address

- 48 bits MAC address (for most LANs) burned in NIC ROM, also sometimes software settable





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

Different display formats:

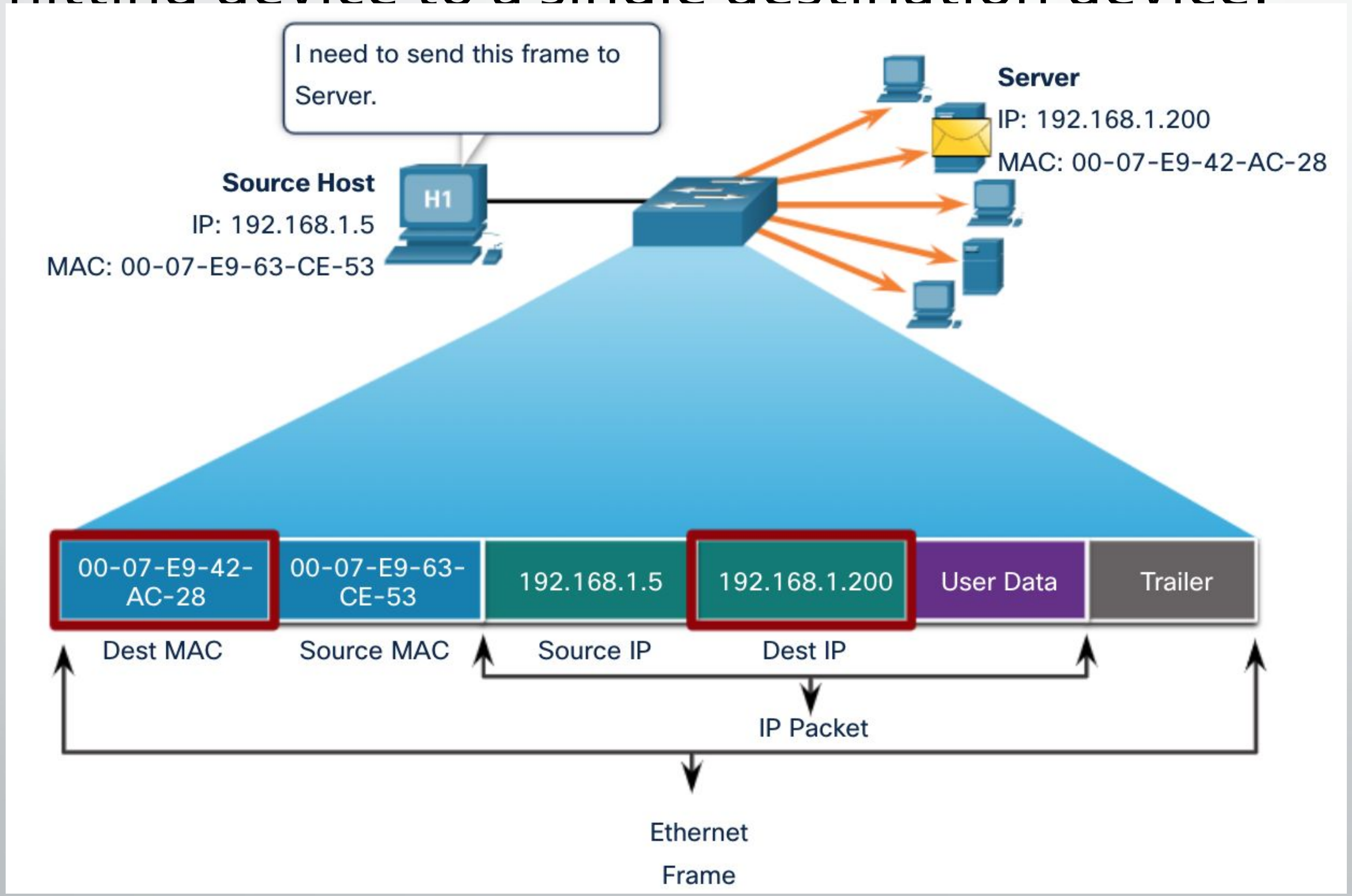
- 0000.0c43.2e08
- 00:00:0c:43:2e:08
- 00-00-0C-43-2E-08

Types of MAC Address

- MAC Address
  - Unicast
  - Multicast
  - Broadcast

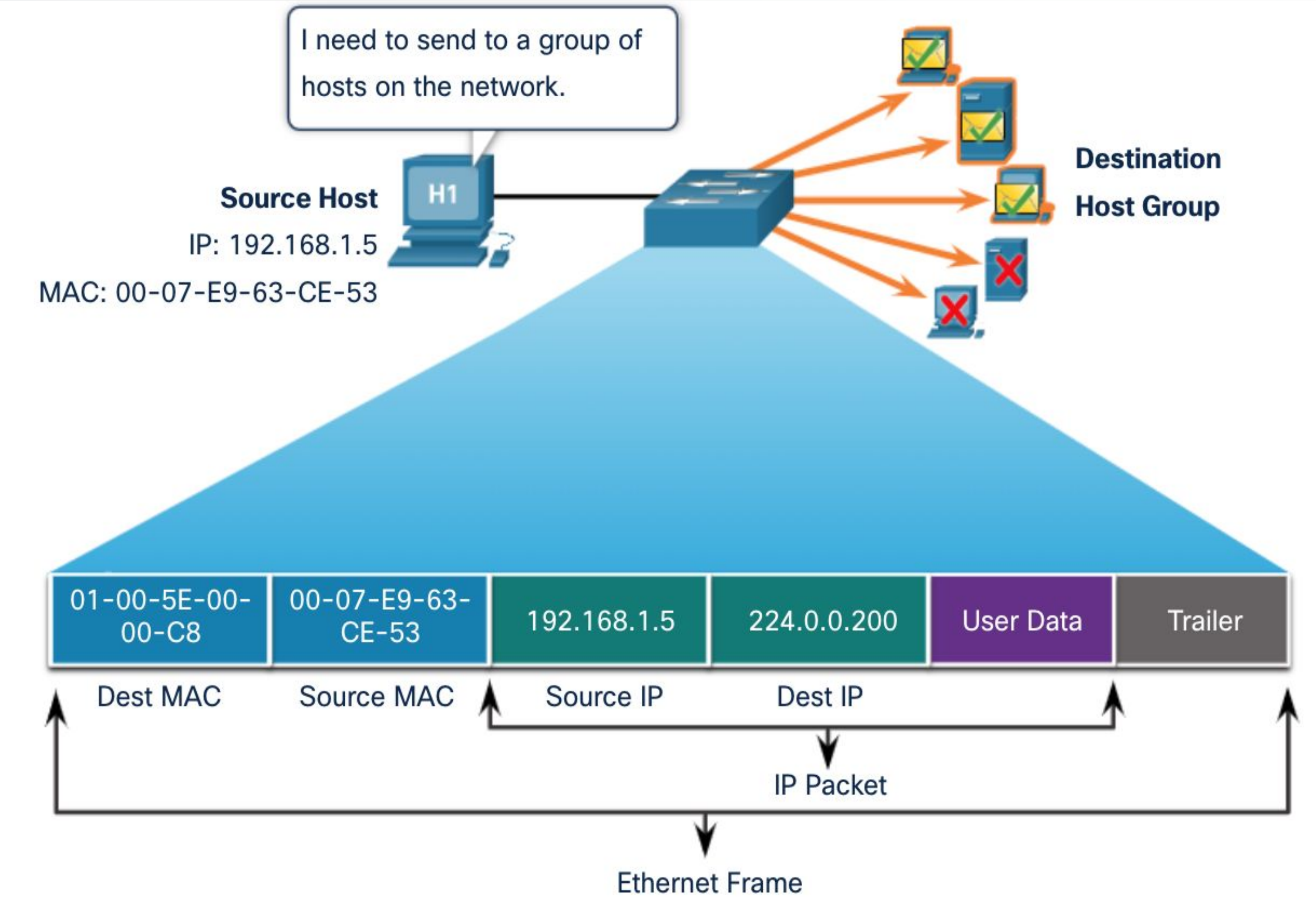
Unicast MAC Addresses

- The unique address used when a frame is sent from a single transmitting device to a single destination device.



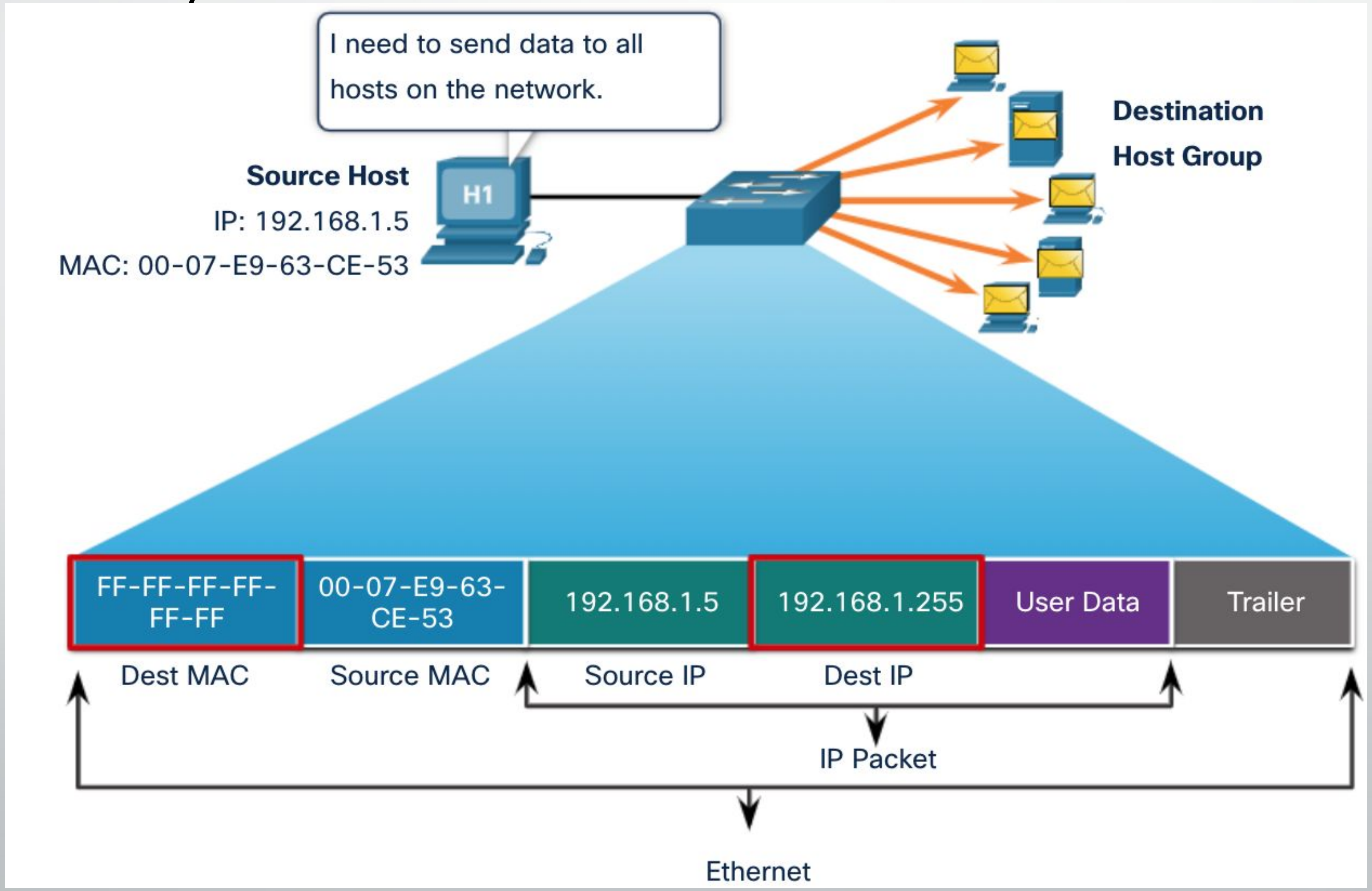
Multicast MAC Addresses

- " 01-00-5E" in an IPv4 multicast packet



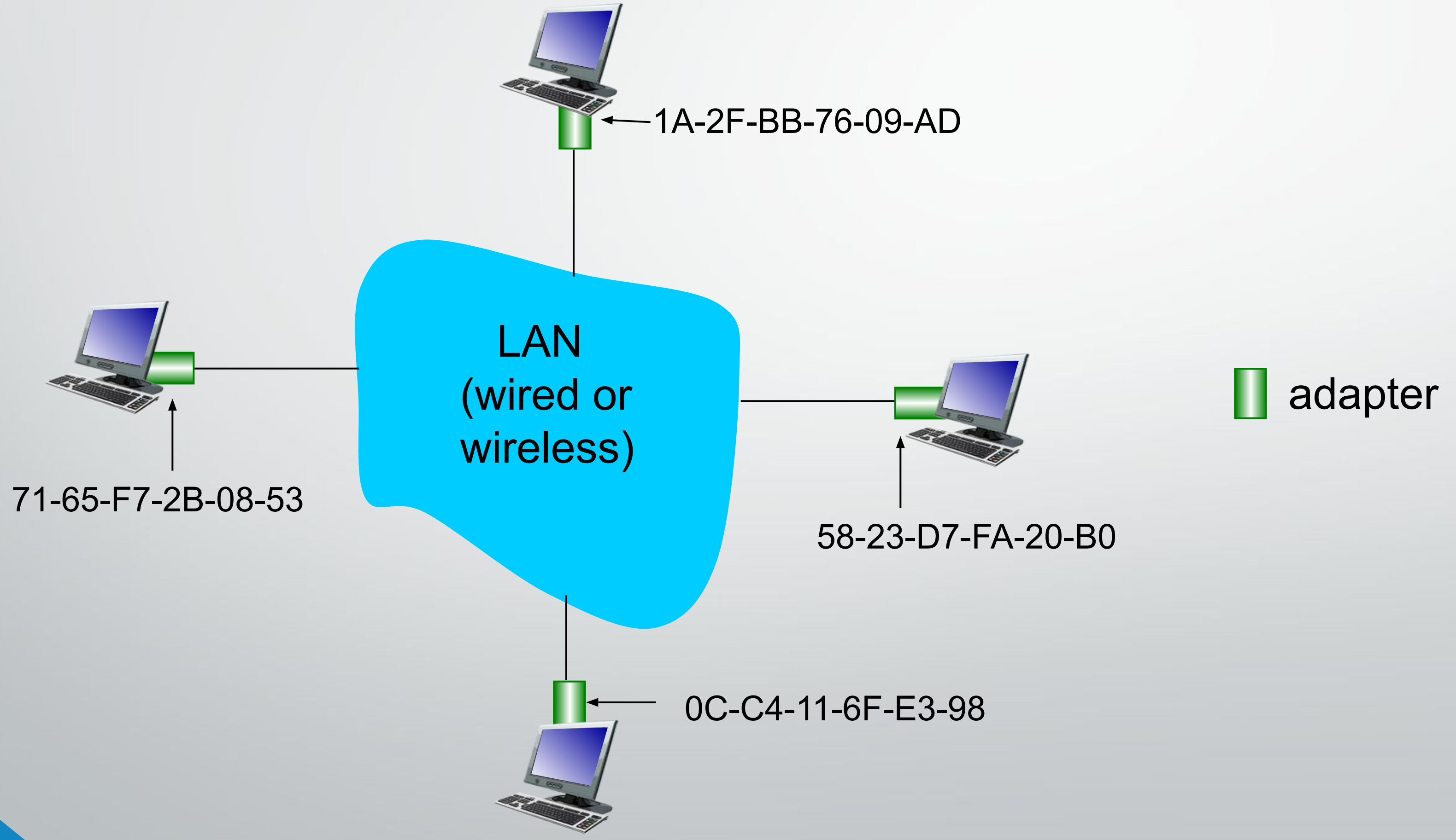
Broadcast MAC Address

- A destination MAC address of FF-FF-FF-FF-FF-FF
- To be processed by all devices in the network



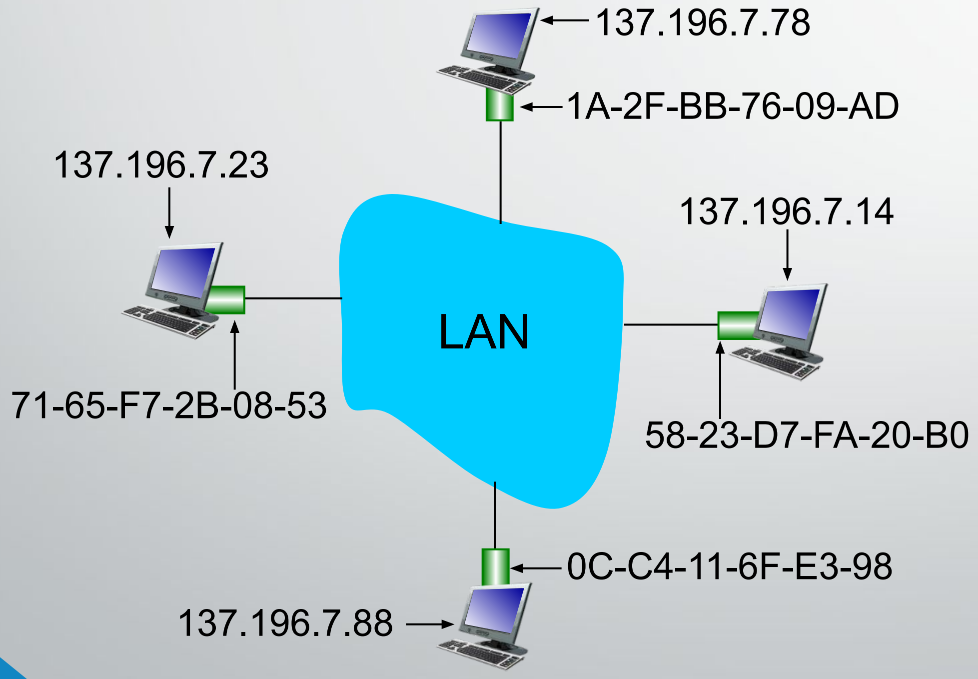
LAN addresses and ARP

each adapter on LAN has unique *LAN* address



ARP: address resolution protocol

Question: how to determine interface's MAC address, knowing its IP address?



- *ARP*
- *Mapping _IP Add___ to _MAC Add_____*
- *ARP table*
  - IP
  - MAC address
  - TTL (Time To Live) Or Age
    - time after which address mapping will be forgotten (typically 20 min)

ARP Tables

C:\WINDOWS\system32\cmd.exe

```
C:\>arp -a

Interface: 192.168.0.2 --- 0x2
  Internet Address      Physical Address      Type
  192.168.0.1           00-0a-cd-00-0d-1d     dynamic

C:\>
```

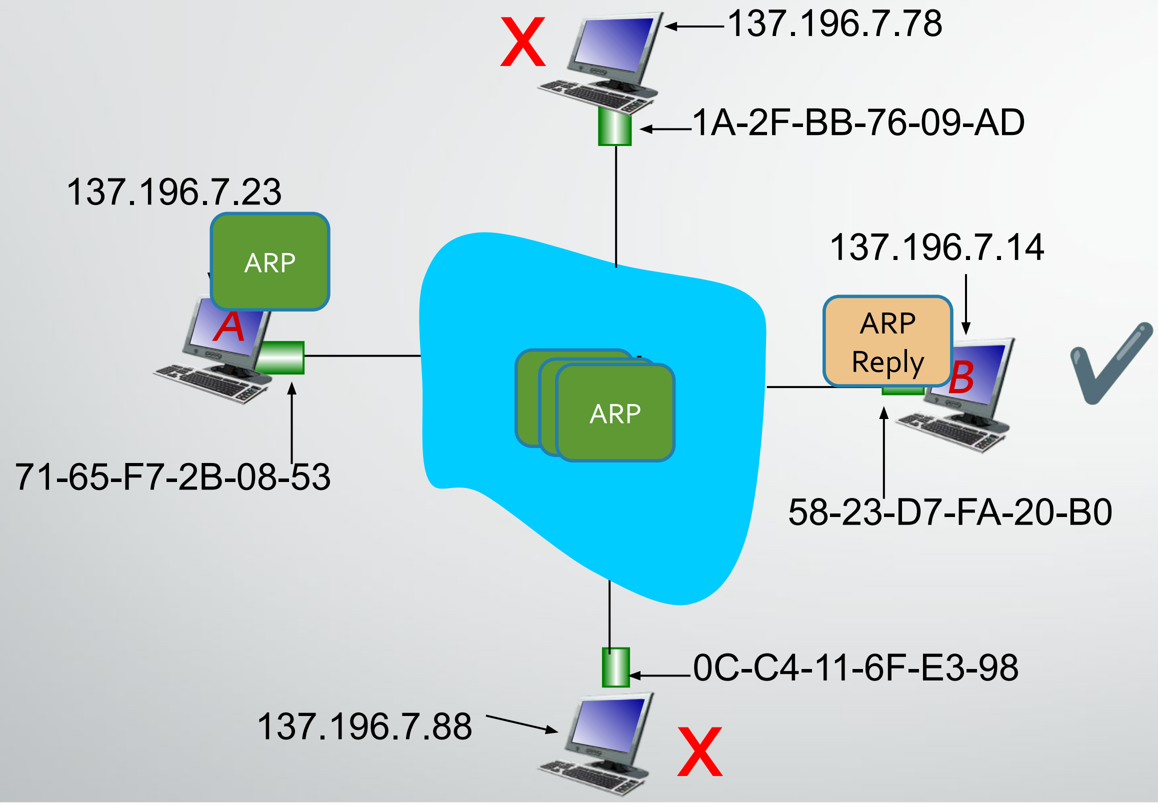
IP Adress | MAC Adress | ARP Type

Host or PC

```
R1#sh ip arp
Protocol  Address          Age (min)  Hardware Addr   Type   Interface
Internet  192.168.1.1             -   ca02.238f.0008  ARPA   FastEthernet0/0
Internet  192.168.1.2             6   0050.7966.6800  ARPA   FastEthernet0/0
Internet  192.168.2.1             -   ca02.238f.0006  ARPA   FastEthernet0/1
Internet  192.168.2.2             6   0050.7966.6801  ARPA   FastEthernet0/1
```


Router

ARP: address resolution protocol



A wants to send datagram to B

71-65-F7-2B-08-53	58-23-D7-FA-20-B0	137.196.7.23	137.196.7.14	ARP Reply
FF-FF-FF-FF-FF-FF	71-65-F7-2B-08-53	137.196.7.14	137.196.7.23	ARP Request
Dest MAC	Source MAC	Dest IP Add	Source IP Add	ARP Req/Reply

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
  - 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*

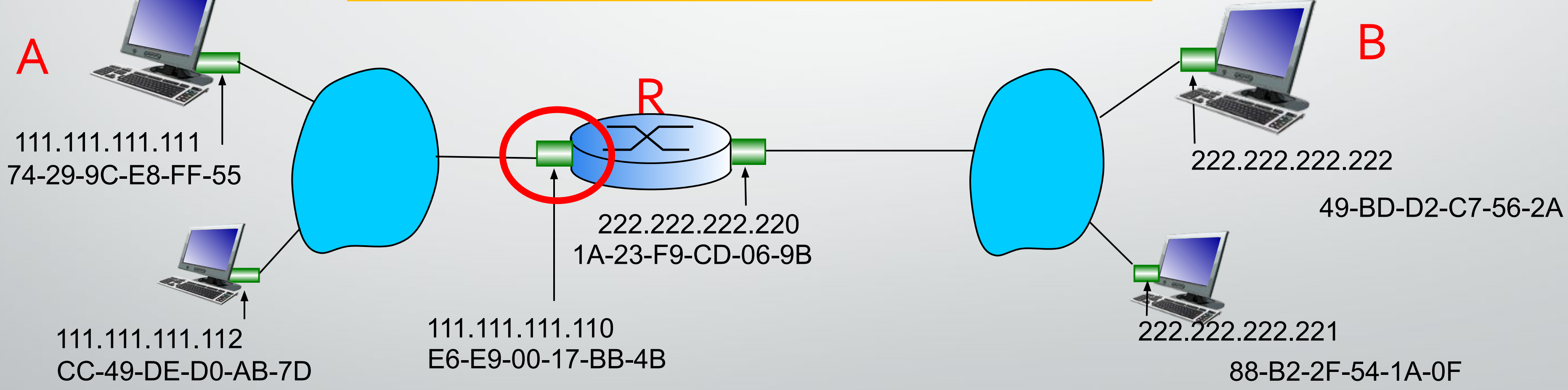
Addressing: routing to another LAN

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
- What will be the destination MAC Address?

Routers never forward broadcast packets!

ARP- To know B's MAC address as B's IP address is known

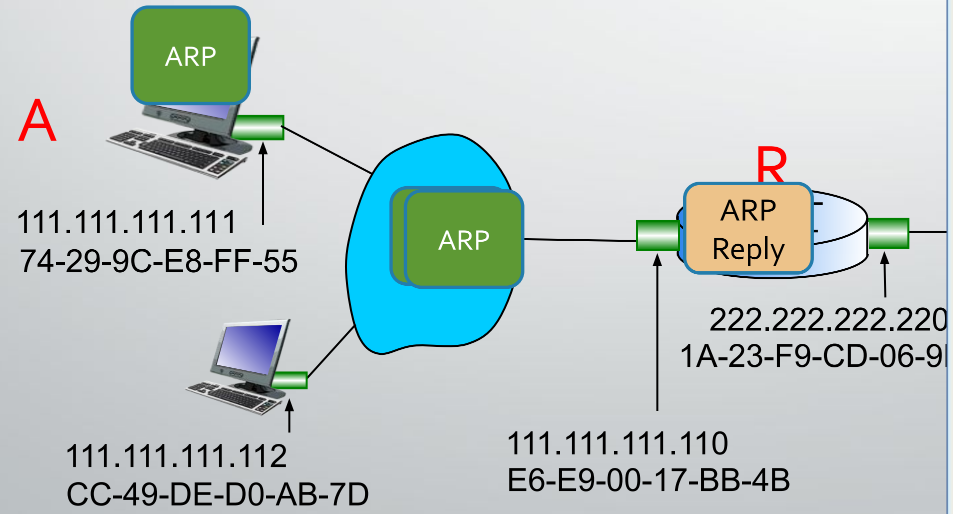


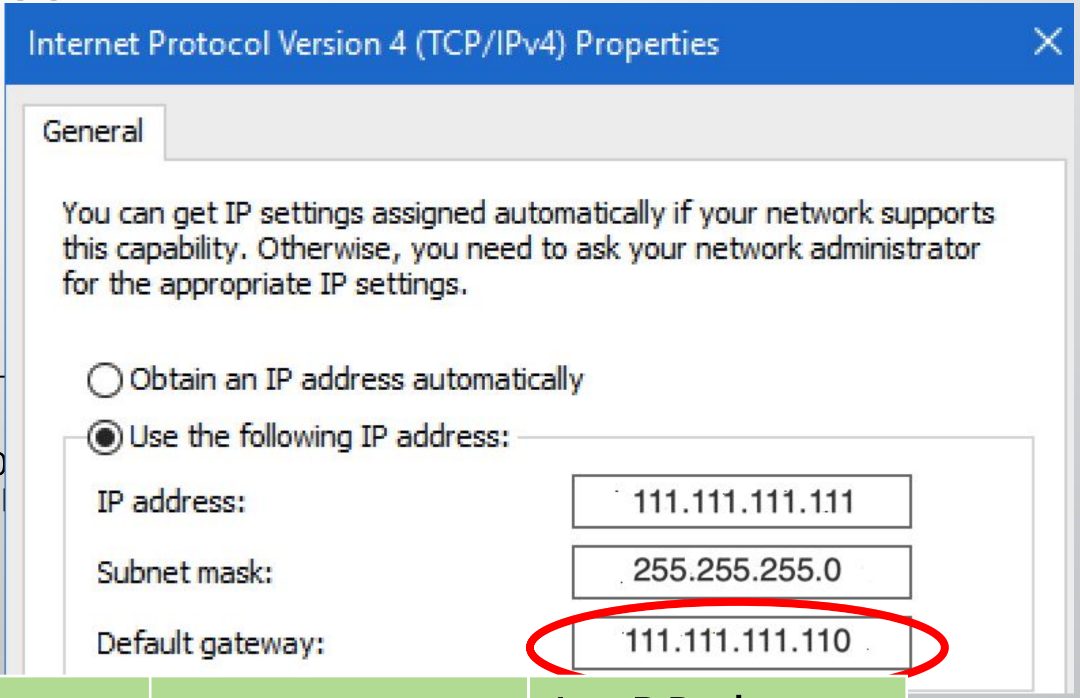
??? Default Gateway's MAC Address	74-29-9C-E8-FF-55	222.222.222.222	111.111.111.111	A to B Packet
Dest MAC	Source MAC	Dest IP Add	Source IP Add	Packet Type

Addressing: routing to another LAN

Send datagram from A to B via R

- Does A know the IP address of first hop router, R which is also known as **Default Gateway**? (how?)
- Will A know R's MAC address?

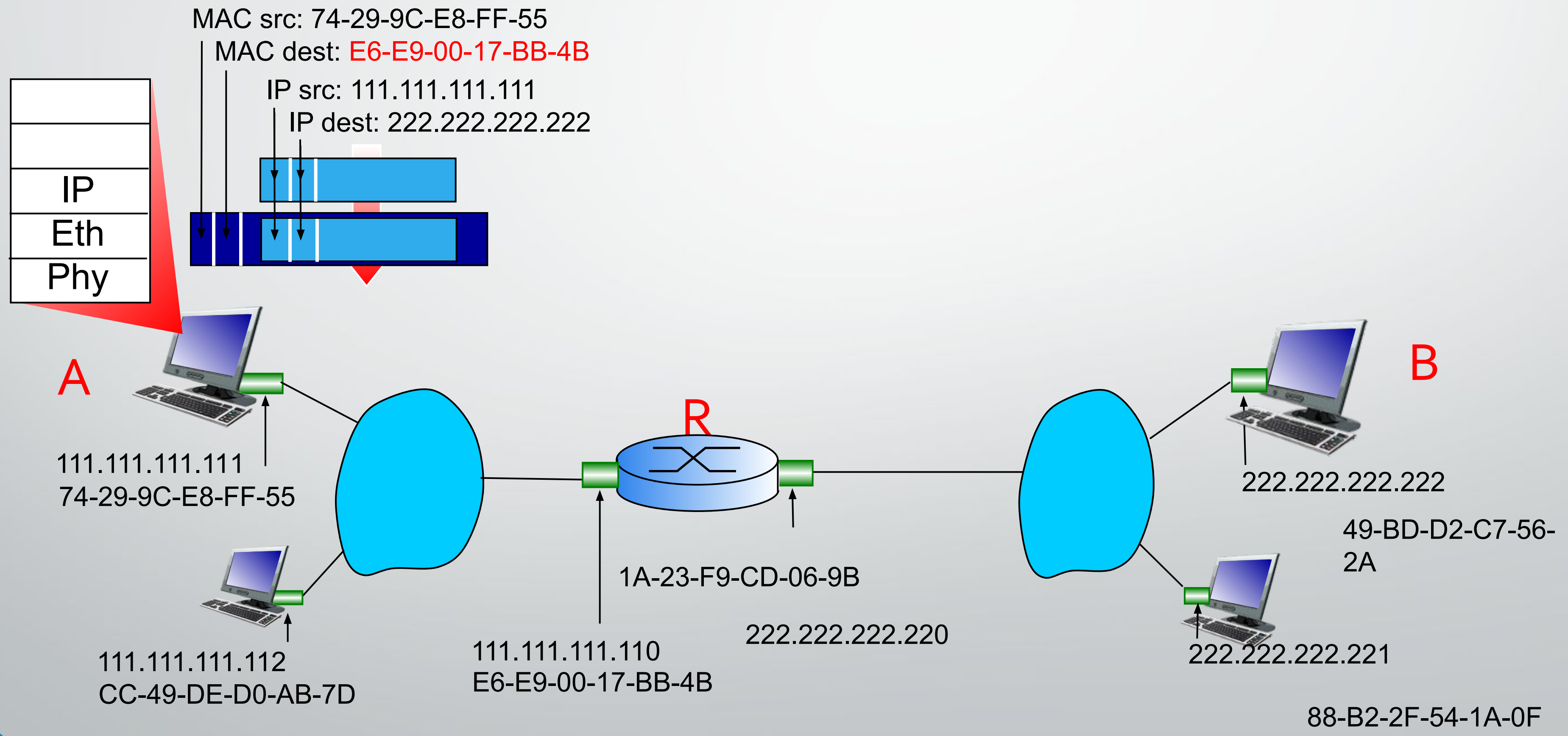




E6-E9-00-17-BB-4B	74-29-9C-E8-FF-55	222.222.222.222	111.111.111.111	A to B Packet

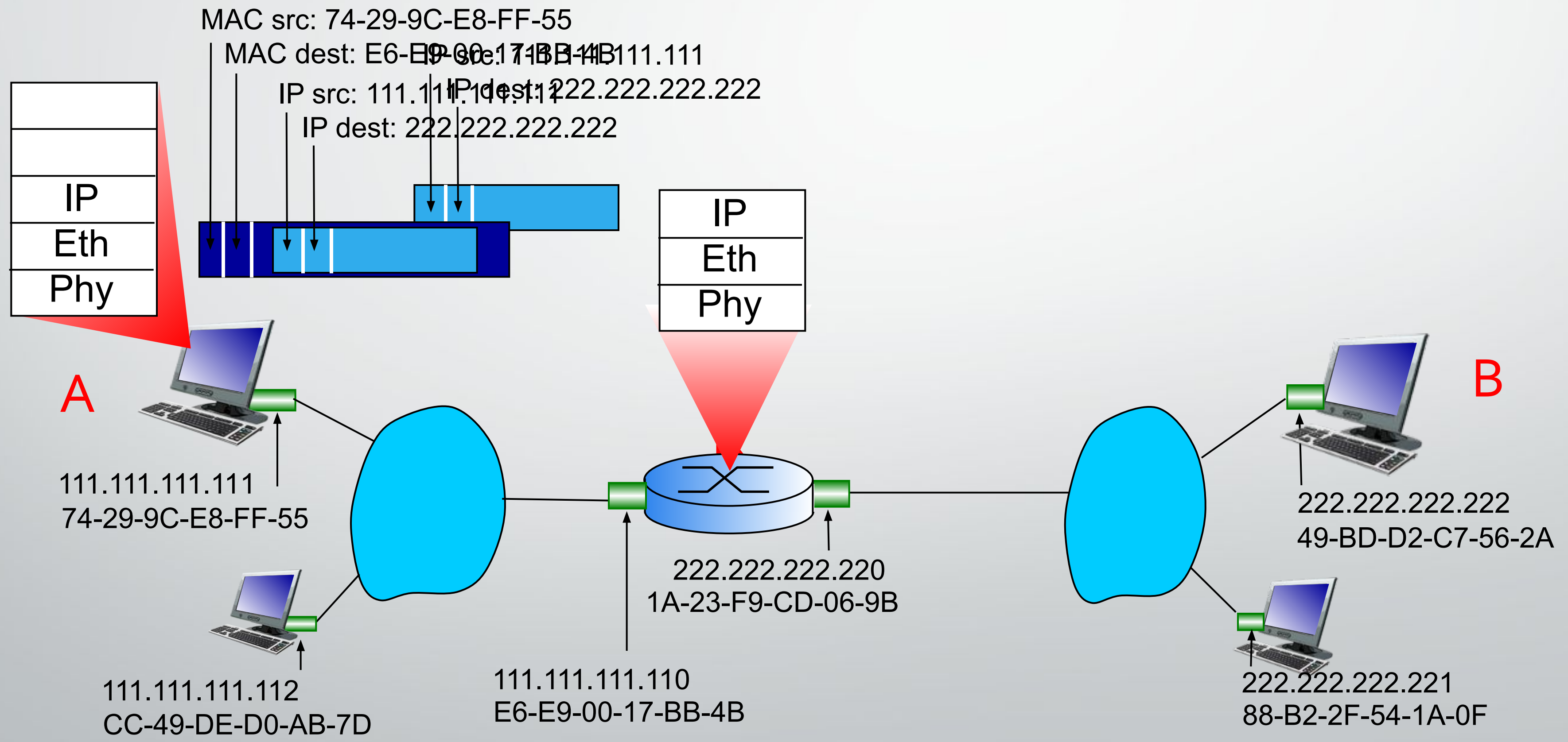
Addressing: routing to another LAN

- 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



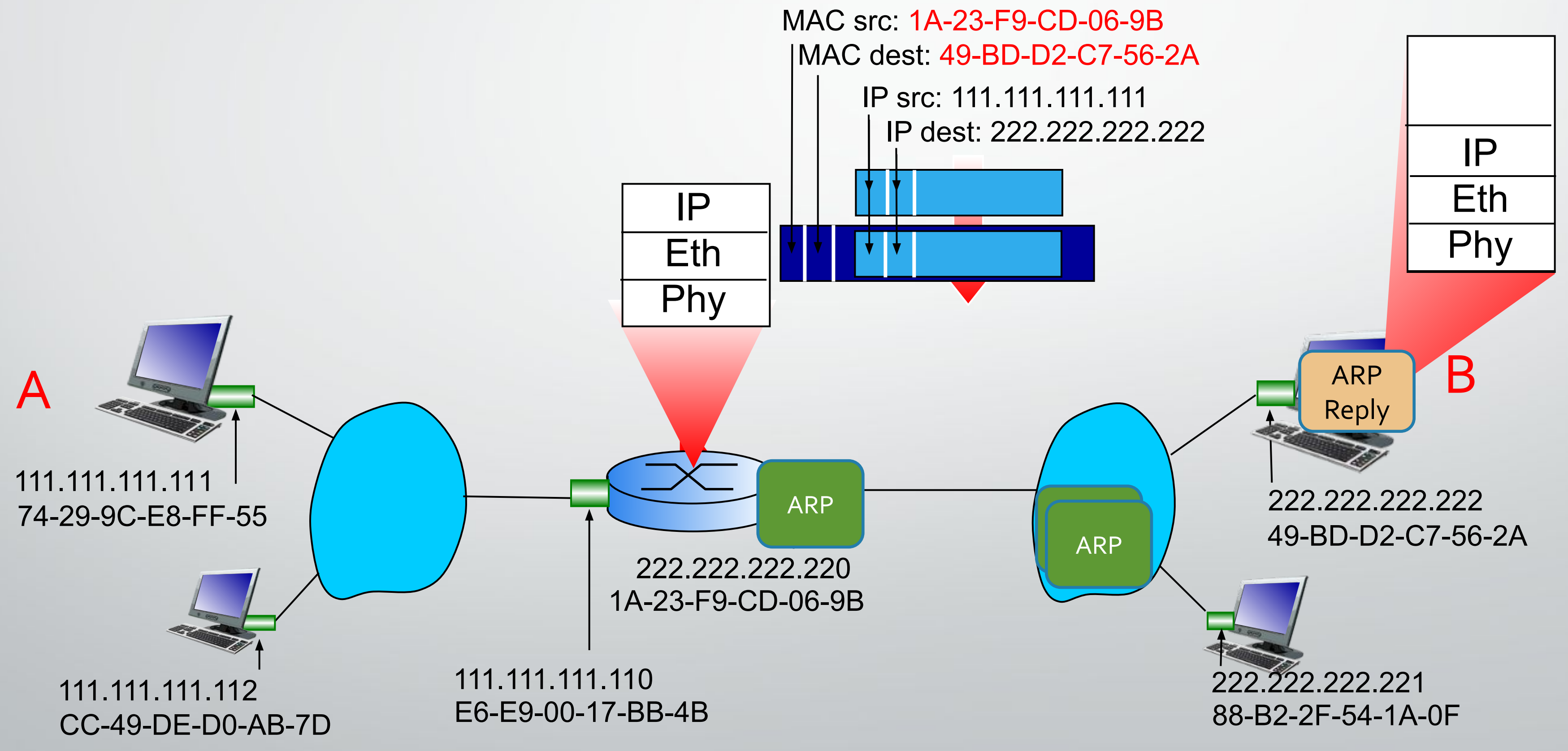
Addressing: routing to another LAN

- 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



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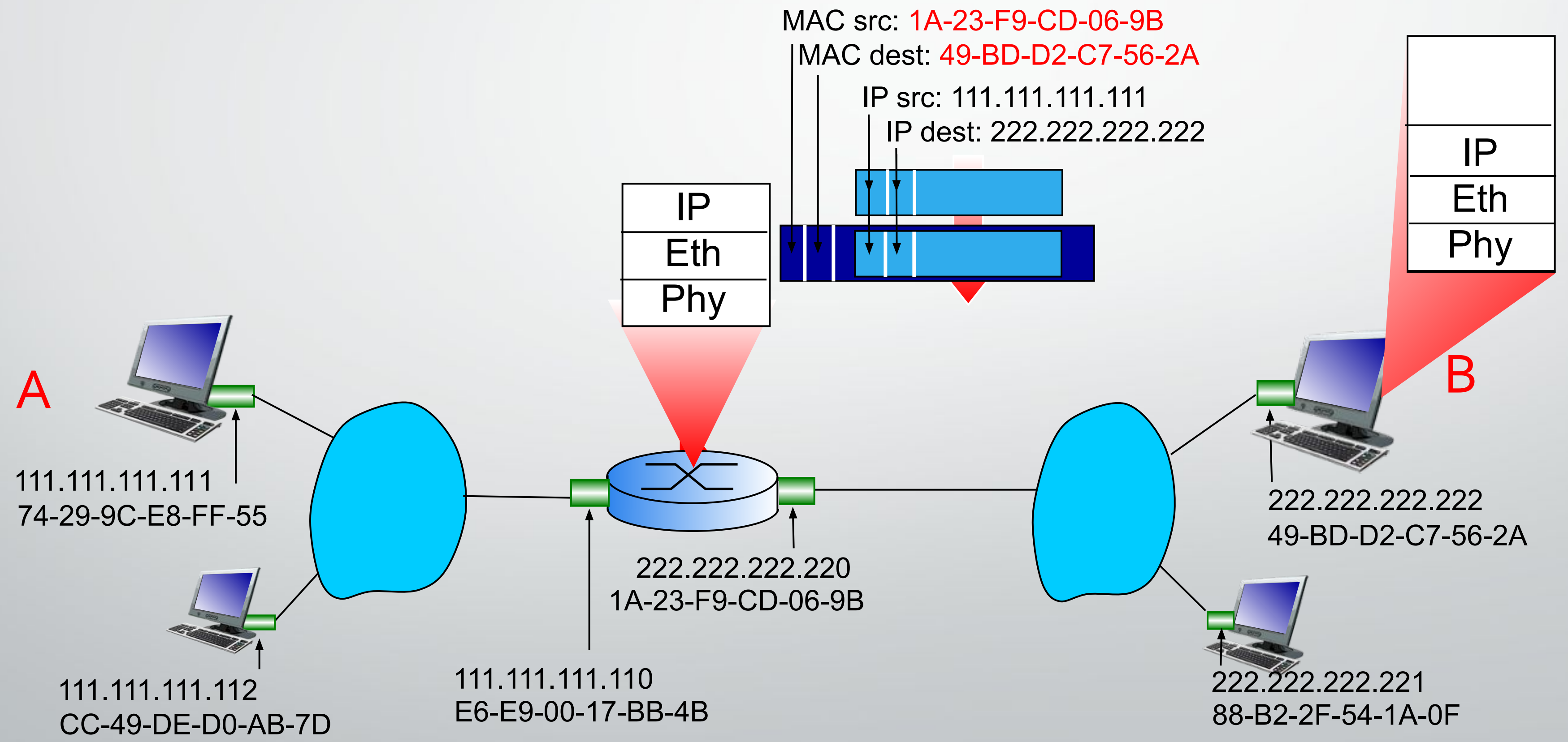

Addressing: routing to another LAN

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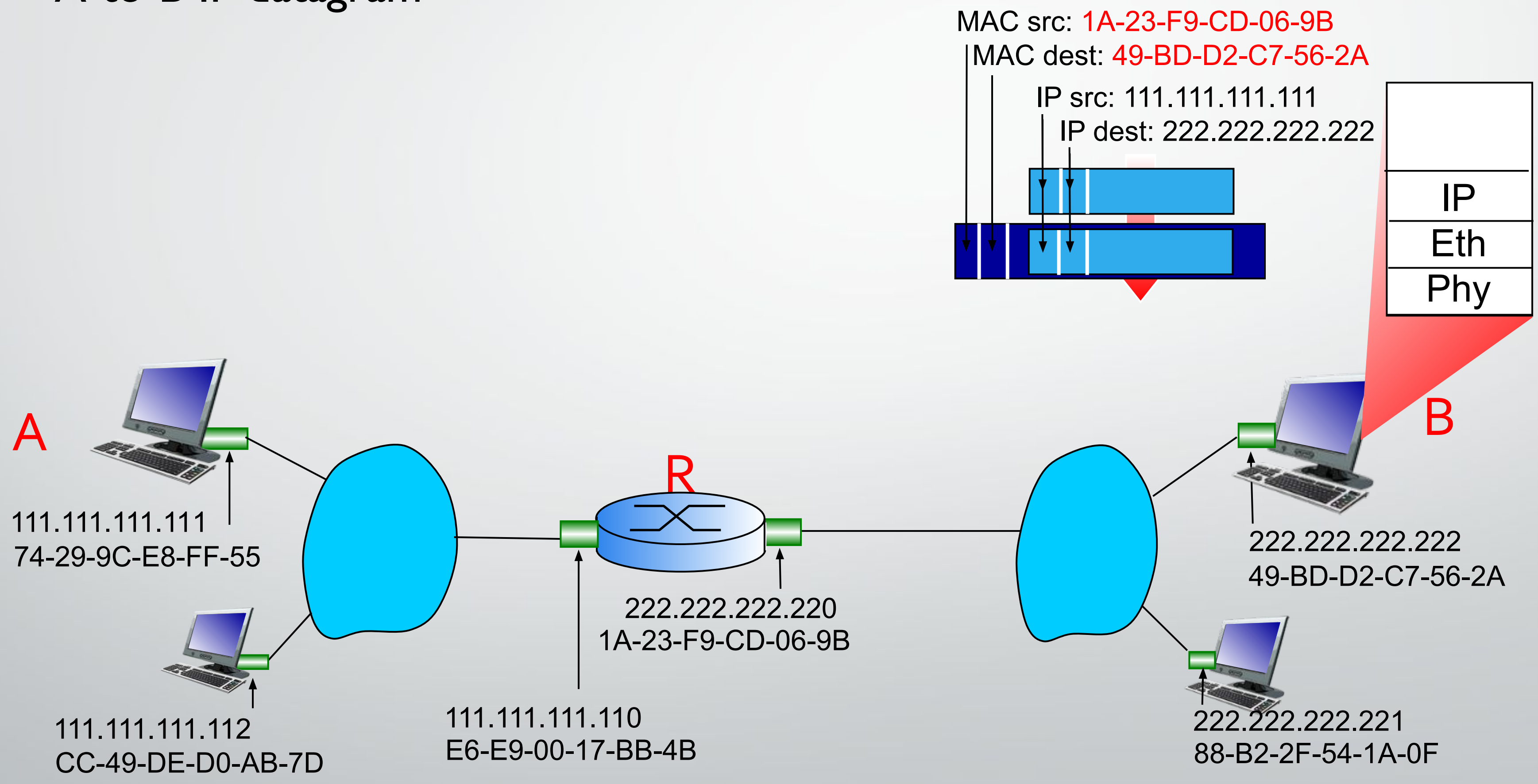


* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

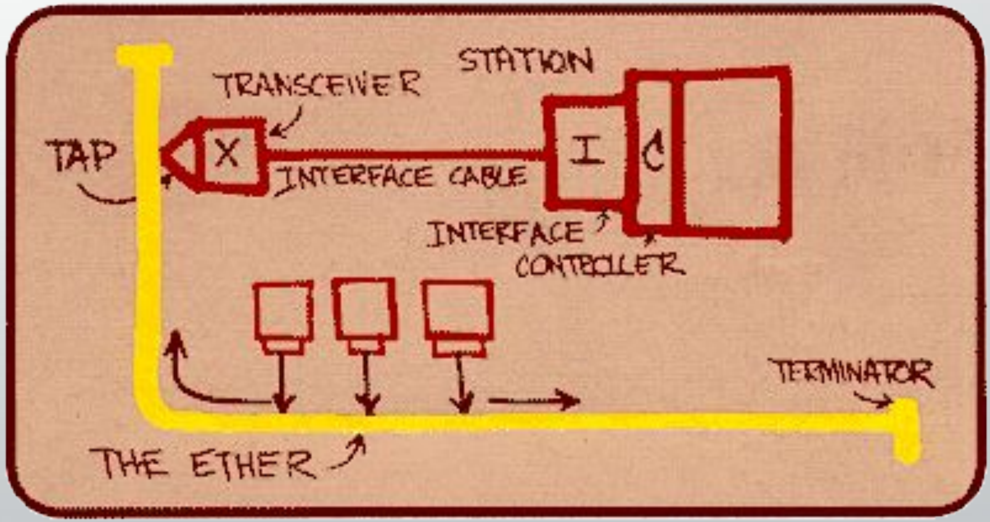
Objectives – Part II

- LAN Protocol : **Ethernet**
  - Ethernet Frame Structure
  - Features of Ethernet
  - Types of Ethernet
  - Switches in Ethernet

Ethernet

"Dominant" wired LAN technology

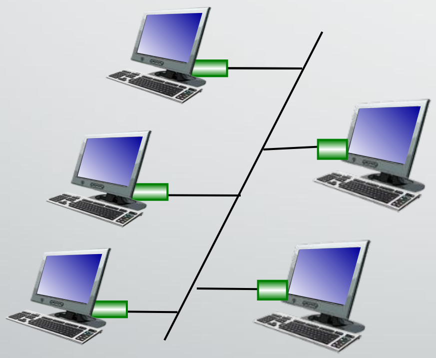
- Cheap
- First
- Simple
- Fast : 10 Mbps – 10 Gbps



Metcalfe's Ethernet sketch

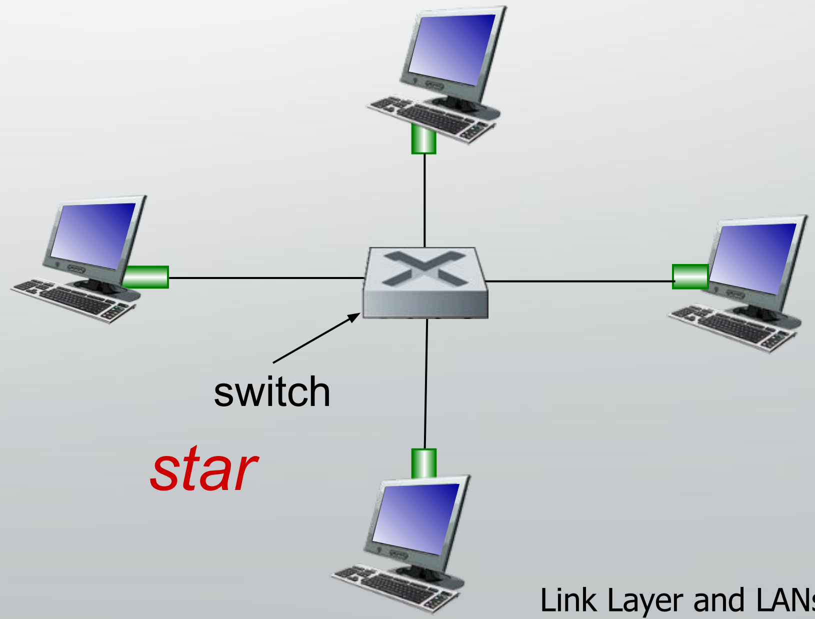
Ethernet: physical topology

- *Bus*
- popular through mid 90s
  - All nodes in same collision domain



bus: coaxial cable

- *Star*
- prevails today
  - Active *switch* in center
  - Nodes do not collide with each other

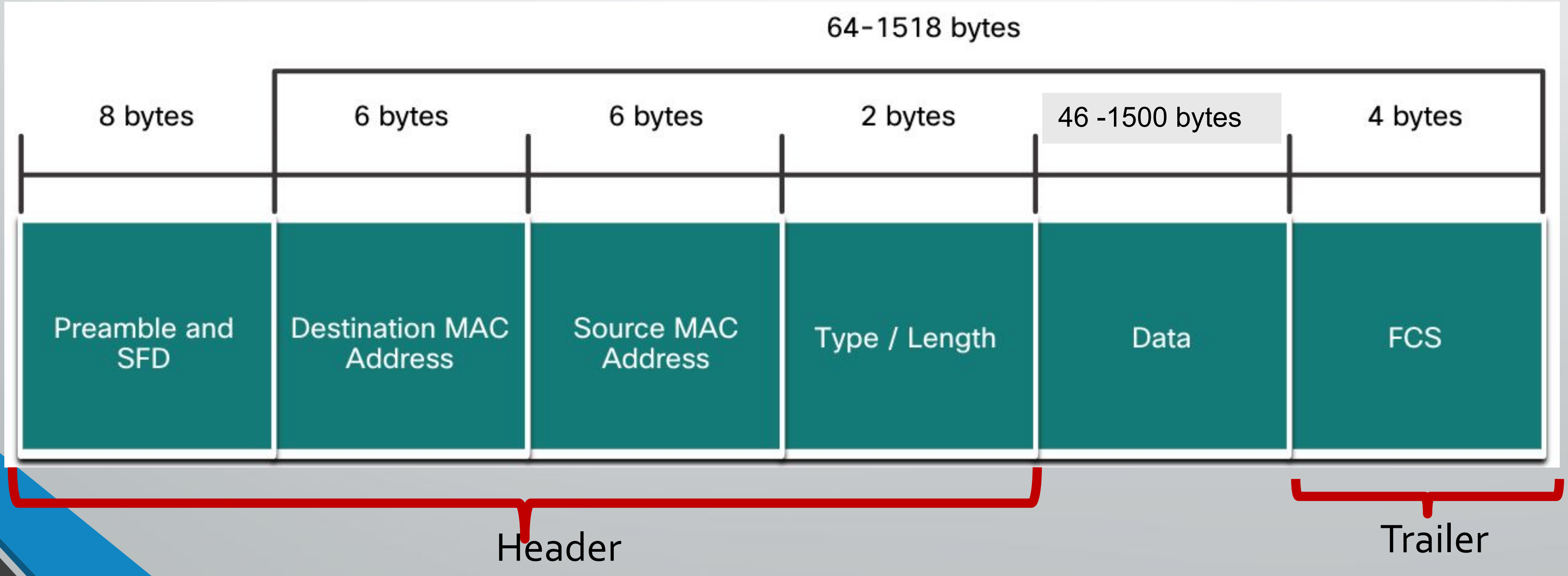


star

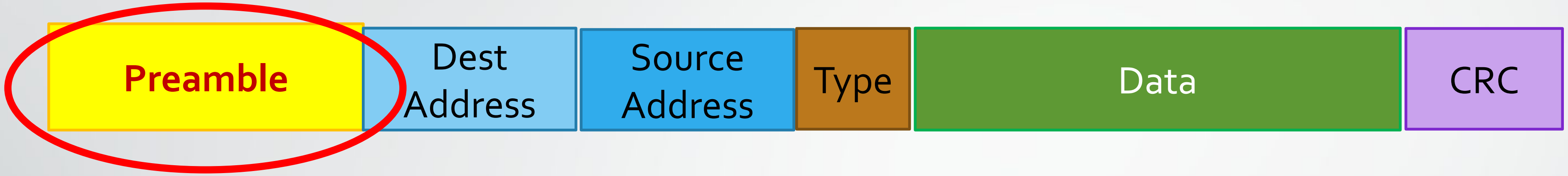
Ethernet Frame Structure

- Ethernet Frame
  - Sending adapter encapsulates IP datagram (or other network layer protocol packet) with header and trailer

Header	Data	Trailer



Ethernet Frame Structure



Preamble:

- 8 bytes
- Seven of '10101010' patterns
- One '10101011' pattern -> SFD (Start Frame Delimiter)
- used to synchronize receiver, sender clock rates

Ethernet Frame Structure

Preamble	Dest Address	Source Address	Type	Data	CRC

- *Destination and Source addresses*
  - 6 bytes source & destination MAC addresses
- *Type*
  - Indicates higher layer protocol (E.g. mostly IP)
    - IPv4? IPv6? Any other?
  - Allows to multiplex network layer protocols or ARP

Ethernet Frame Structure

Preamble	Dest Address	Source Address	Type	Data	CRC

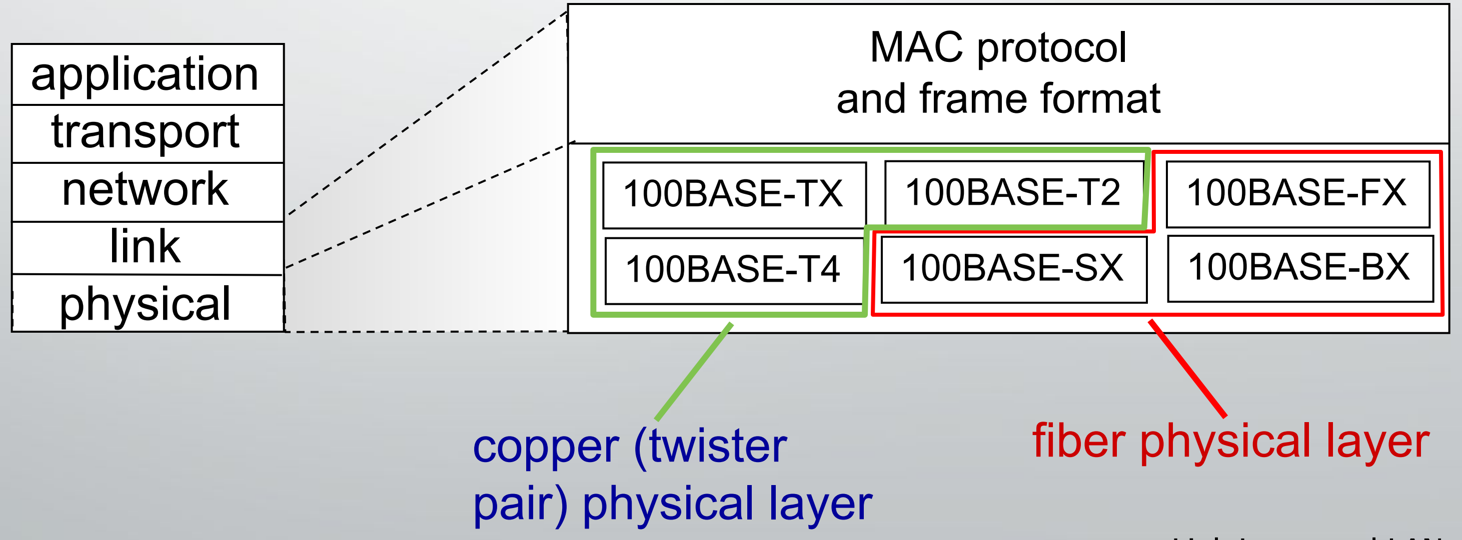
- *Data field*
  - Contains IP datagram
  - Min 46 bytes and max 1500 bytes
- *CRC/FCS/Checksum*
  - Cyclic redundancy check at receiver
  - error detected: frame is dropped

Ethernet: unreliable, connectionless

- *Connectionless:* no handshaking between sending and receiving NICs
- *unreliable:* receiving NIC doesn't send acks or nacks 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*
  - *Hub has collision domains, switch doesn't.*

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



Ethernet Type	Bandwidth	Cable Type	Maximum Distance
10Base-T	10Mbps	Cat 3/Cat 5 UTP	100m
100Base-TX	100Mbps	Cat 5 UTP	100m
100Base-TX	200Mbps	Cat 5 UTP	100m
100Base-FX	100Mbps	Multi-mode fiber	400m
100Base-FX	200Mbps	Multi-mode fiber	2Km
1000Base-T	1Gbps	Cat 5e UTP	100m
1000Base-TX	1Gbps	Cat 6 UTP	100m
1000Base-SX	1Gbps	Multi-mode fiber	550m
1000Base-LX	1Gbps	Single-mode fiber	2Km
10GBase-T	10Gbps	Cat 6a/Cat 7 UTP	100m
10GBase-LX	10Gbps	Multi-mode fiber	100m
10GBase-LX	10Gbp	Single-mode fiber	10Km

Objectives – Part III

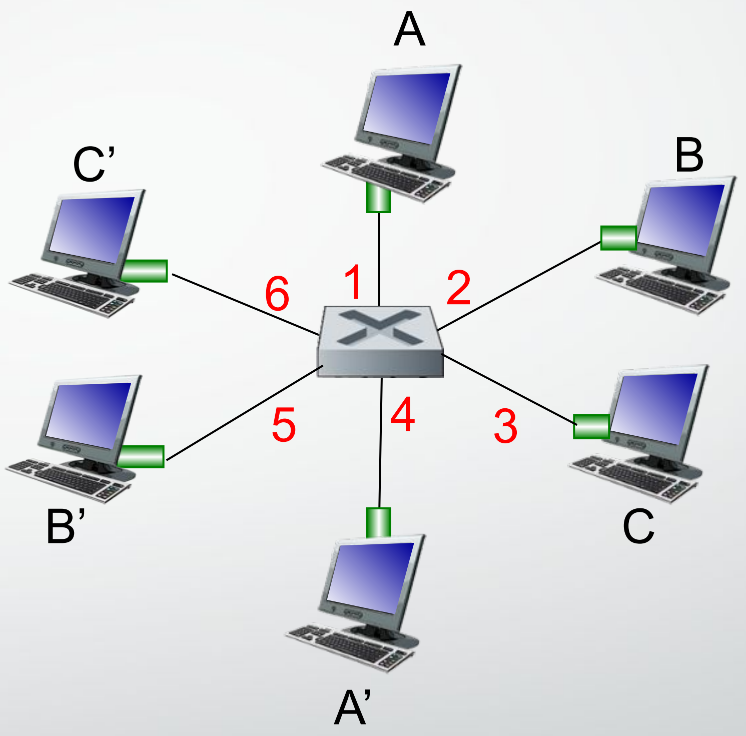
- Switch
  - Characteristics of a switch
  - Role of switch in a LAN

Ethernet switch

- ~~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 are 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, but 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)

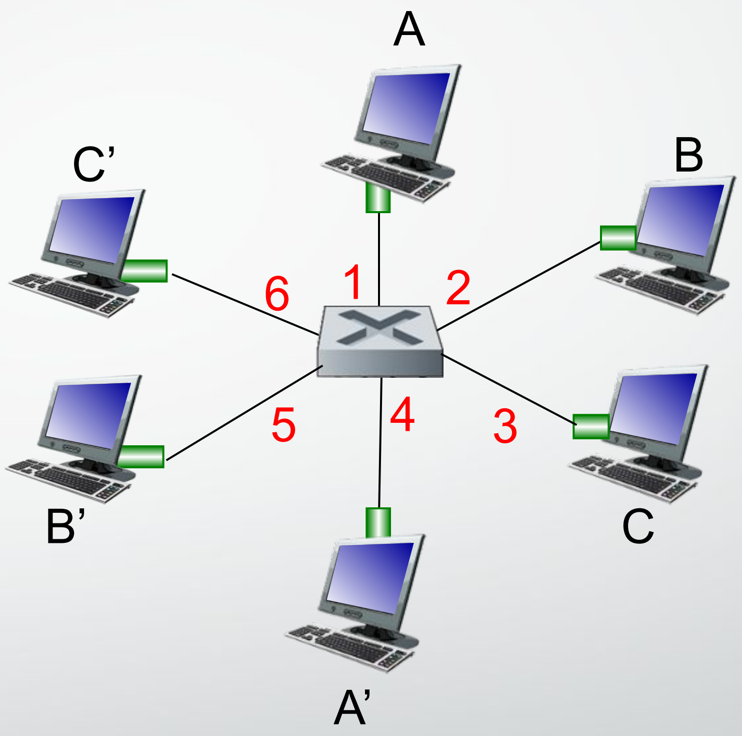
Switch forwarding table

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?

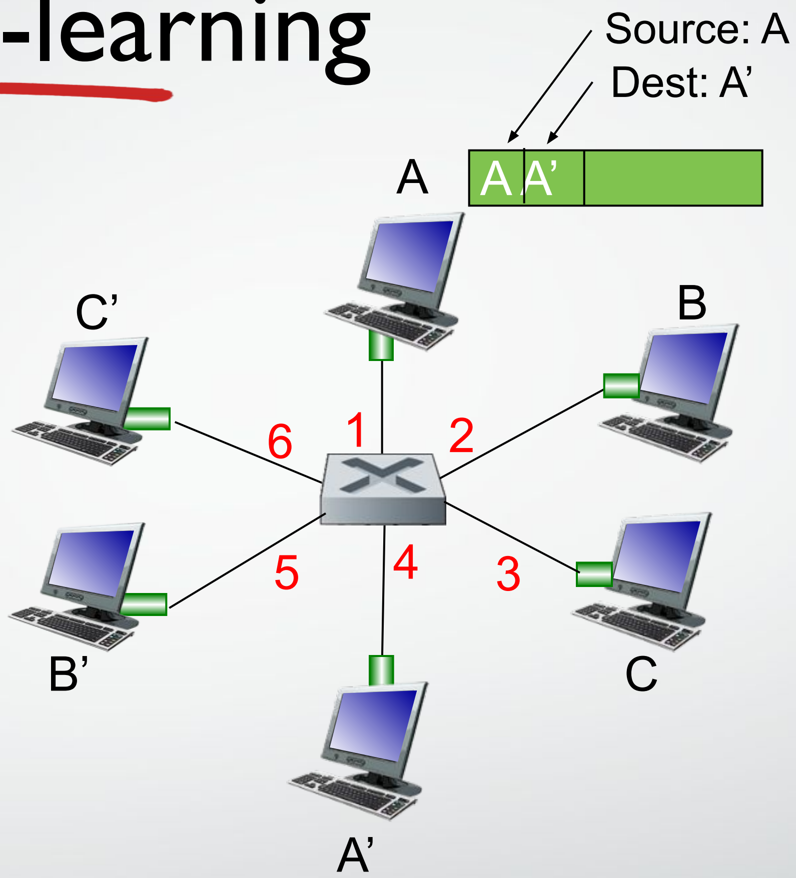
- something like a routing protocol?



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

Switch: self-learning

- The table is empty initially
- 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)

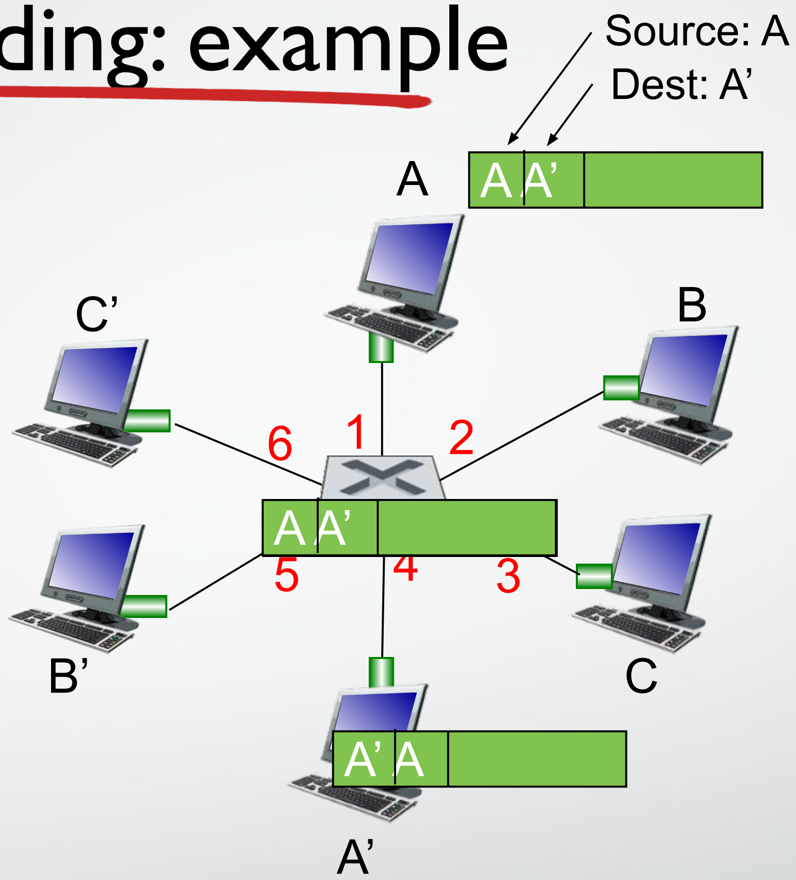
Switch: frame filtering/forwarding

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

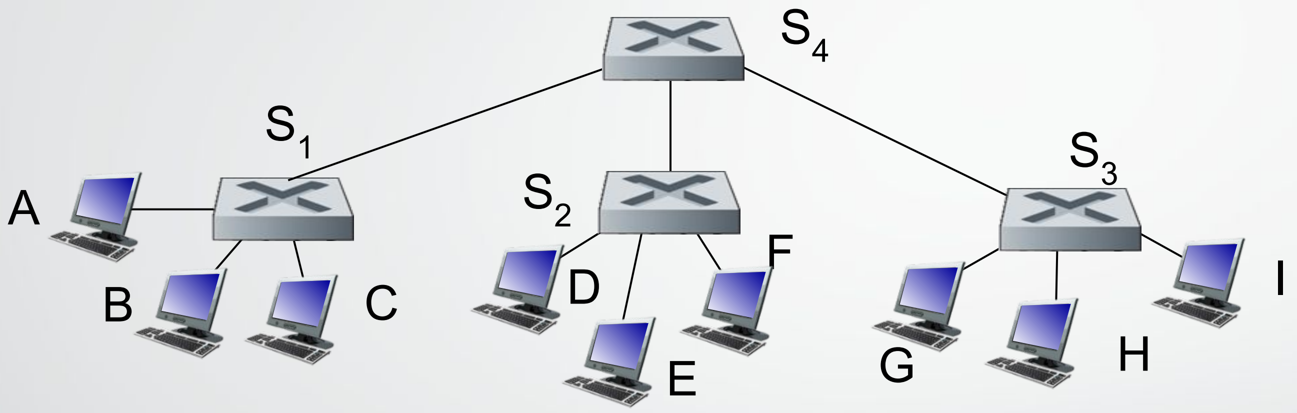


MAC addr	interface	TTL
A	*1*	*60*
A'	*4*	*60*

switch table (initially empty)

Interconnecting switches

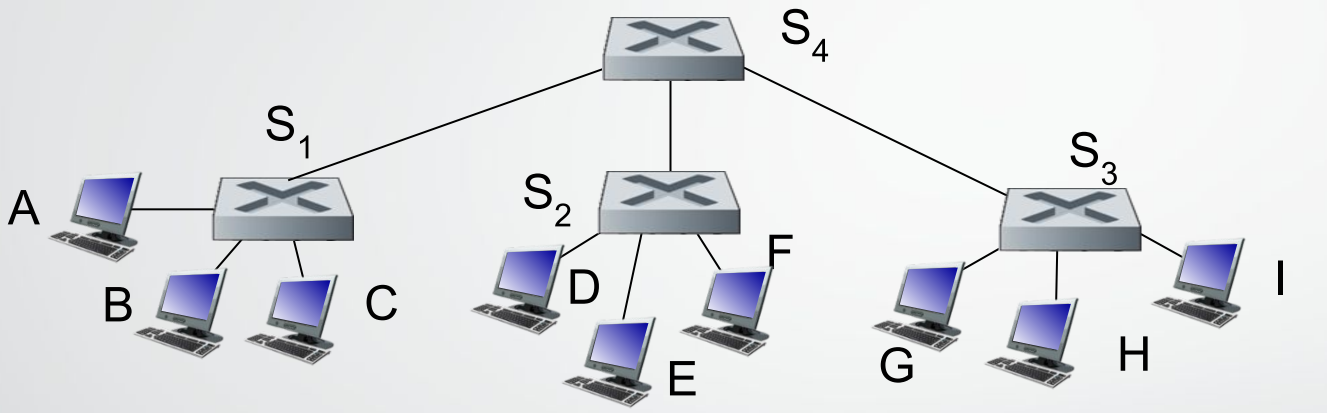
self-learning switches can be connected together:



Q: sending from A to G - how does S_1 know to forward frame destined to G via S_4 and S_3?

- *A:* self learning! (works exactly the same as in single-switch case!)

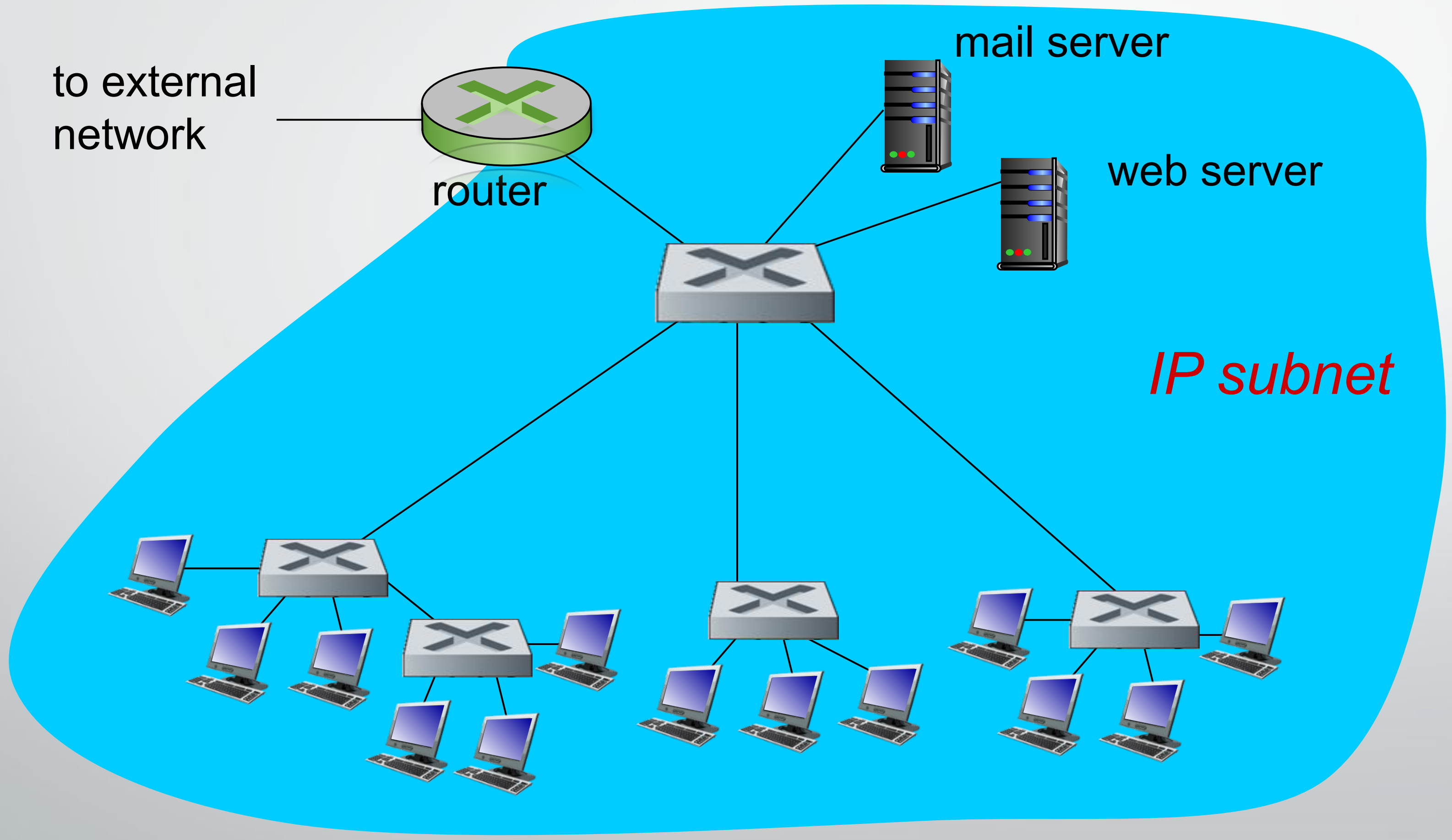
Self-learning multi-switch example



Suppose C sends frame to I, I responds to C

- Q: show switch tables and packet forwarding in S_1, S_2, S_3, S_4

Institutional network



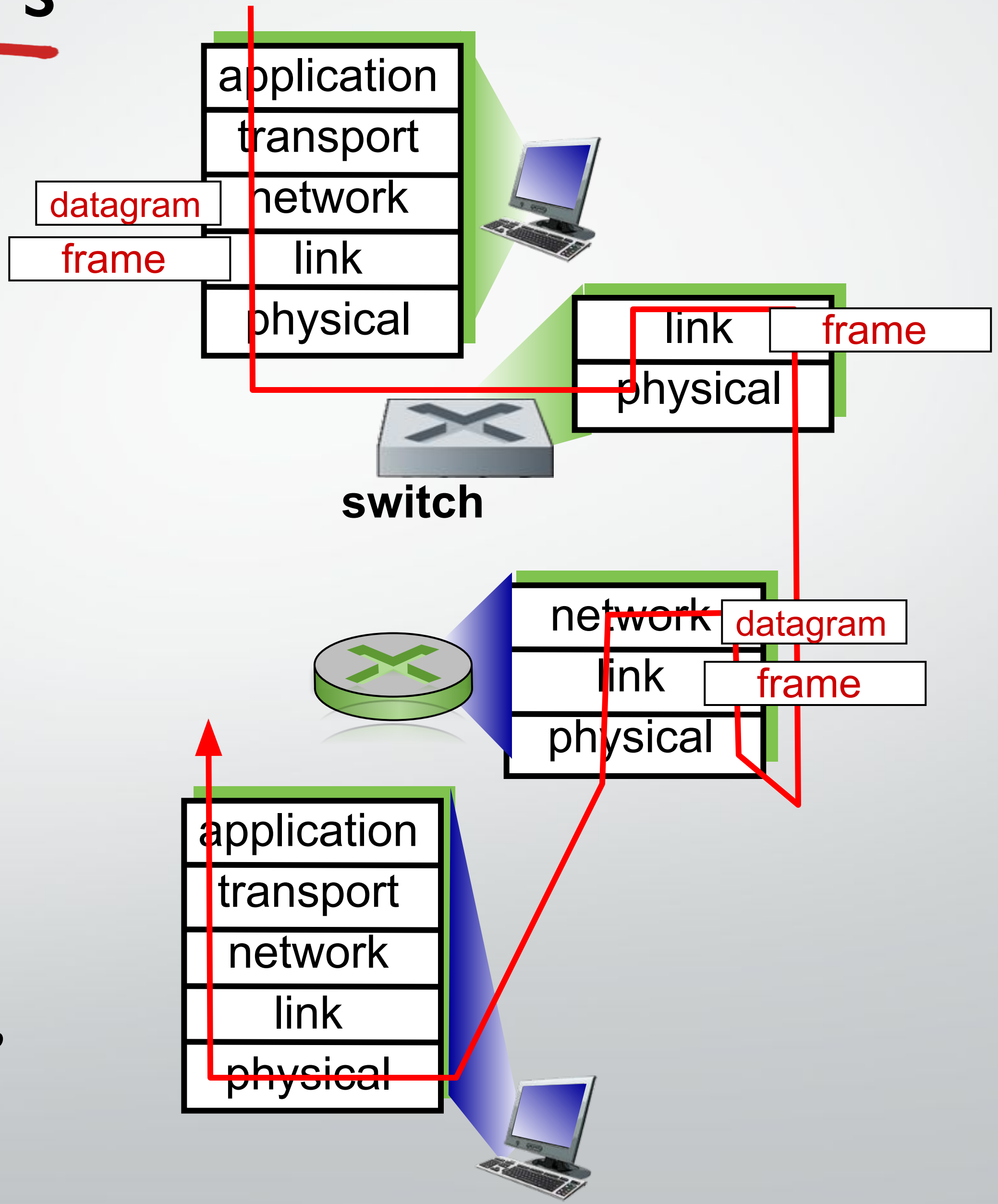
Switches vs. routers

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



THE END!