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Link layer, LANs: outline

6.1 introduction, services

6.2 error detection, correction

6.3 multiple access protocols

6.4 Switched LANs

- addressing, ARP
- Ethernet
- switches

6.7 a day in the life of a web request *(Self Study)*

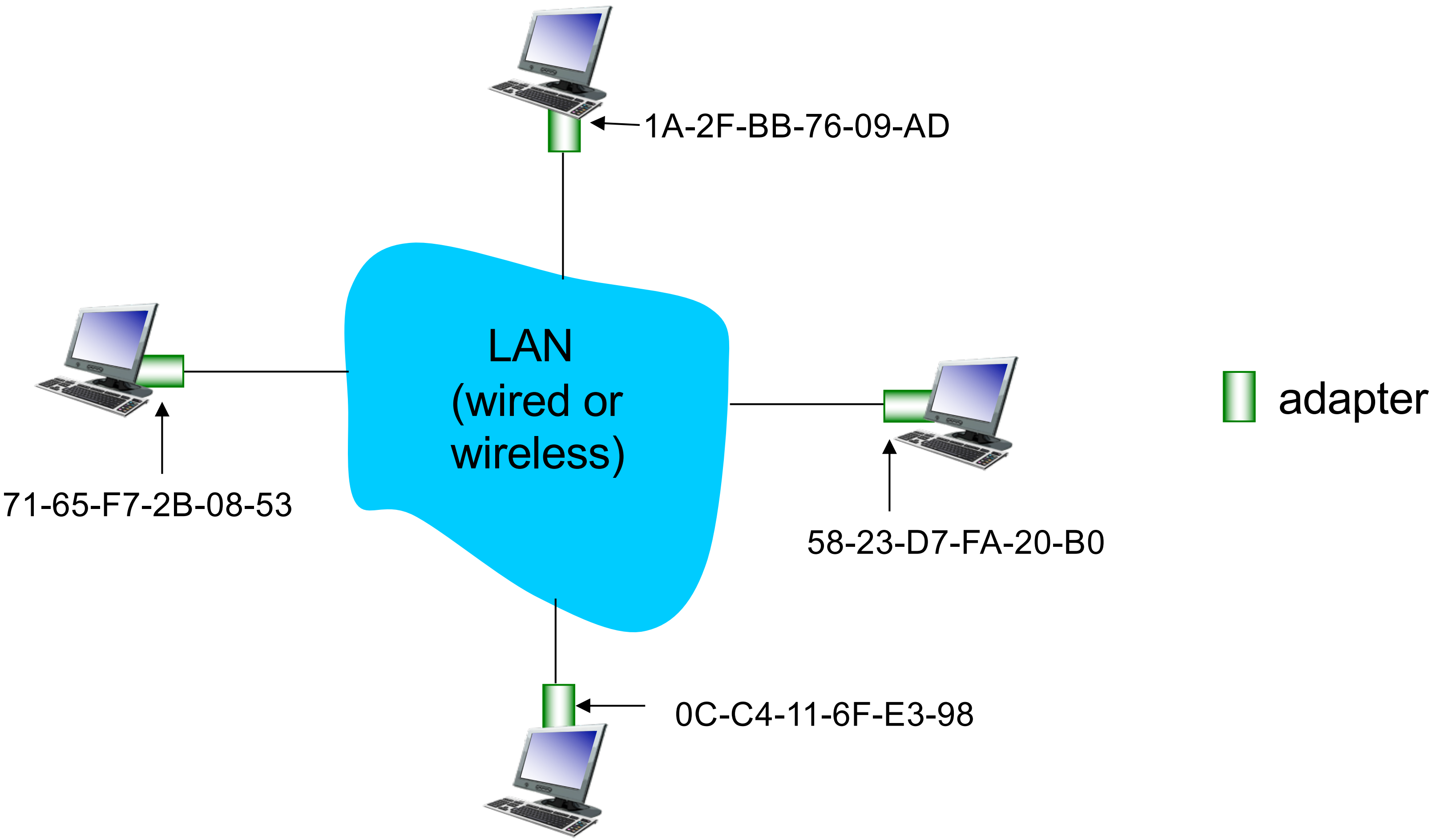
MAC addresses and ARP

- 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



LAN addresses (more)

- MAC address allocation administered by IEEE
- manufacturer buys portion of MAC address space (to assure uniqueness) 24-24 split
- 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

MAC Address vs. IP Address

- MAC addresses (used in link-layer)
  - Hard-coded in read-only memory when adapter is built
  - Flat name space of 48 bits (e.g., 00-0E-9B-6E-49-76)
  - Portable, and can stay the same as the host moves
  - Is used to get a packet between interfaces within the same IP subnet

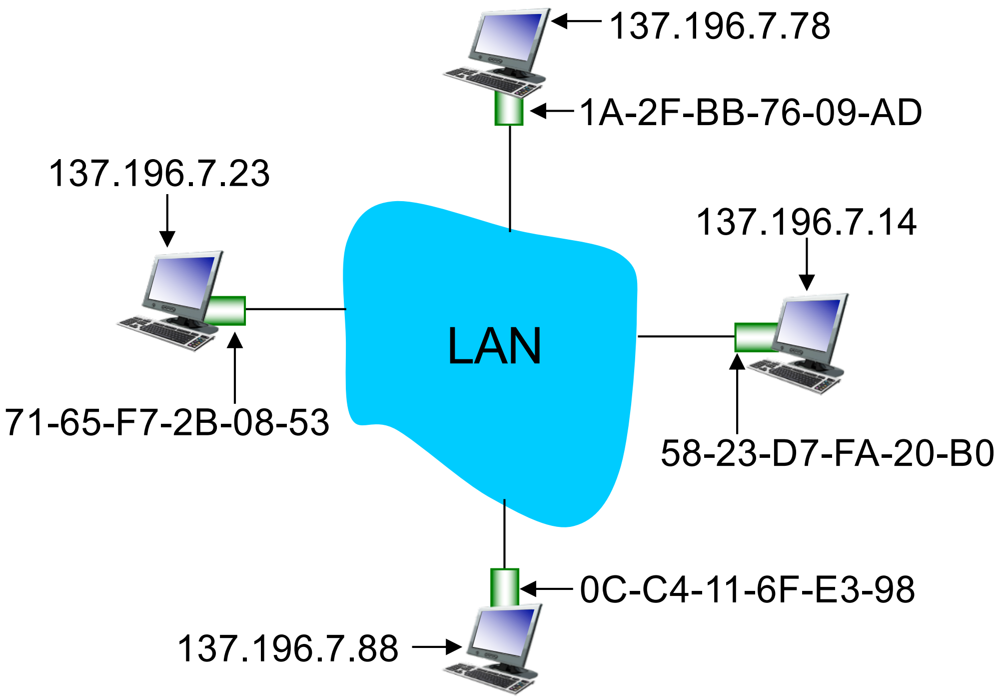
- IP addresses
  - Configured, or learned dynamically
  - Hierarchical name space of 32 bits (e.g., 12.178.66.9)
  - Not portable, and depends on where the host is attached
  - Is used to get a packet to destination IP subnet

Taking Stock: Naming

Layer	Examples	Structure	Configuration	Resolution Service
App. Layer	www.cse.unsw.edu.au	organizational hierarchy	~ manual	*DNS*
Network Layer	129.94.242.51	topological hierarchy	DHCP	*ARP*
Link layer	45-CC-4E-12-F0-97	vendor (flat)	hard-coded	

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)

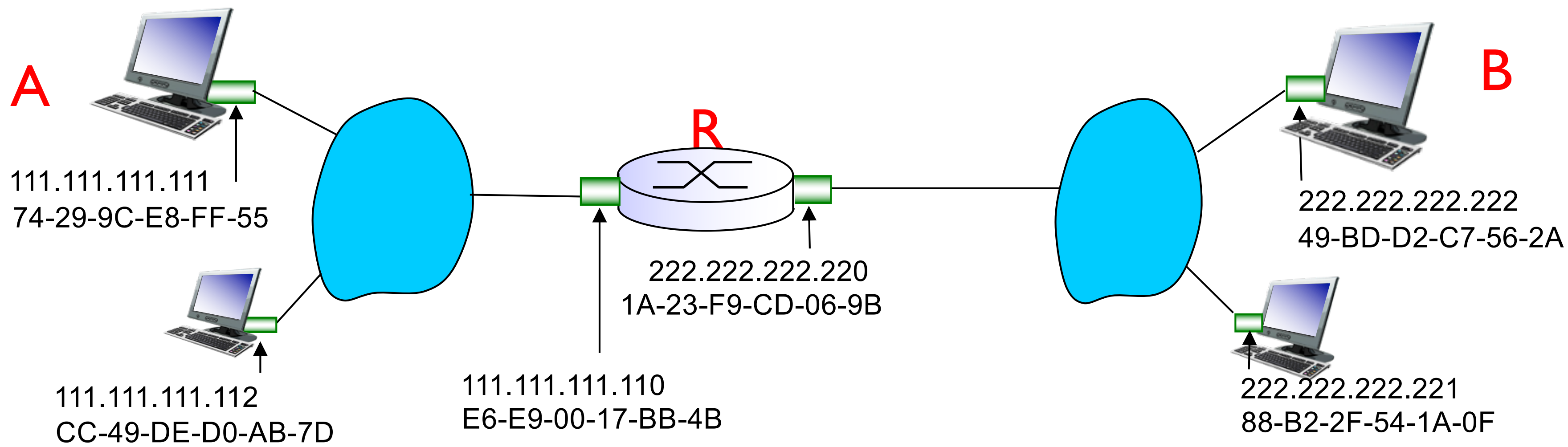
ARP protocol: same LAN

- 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

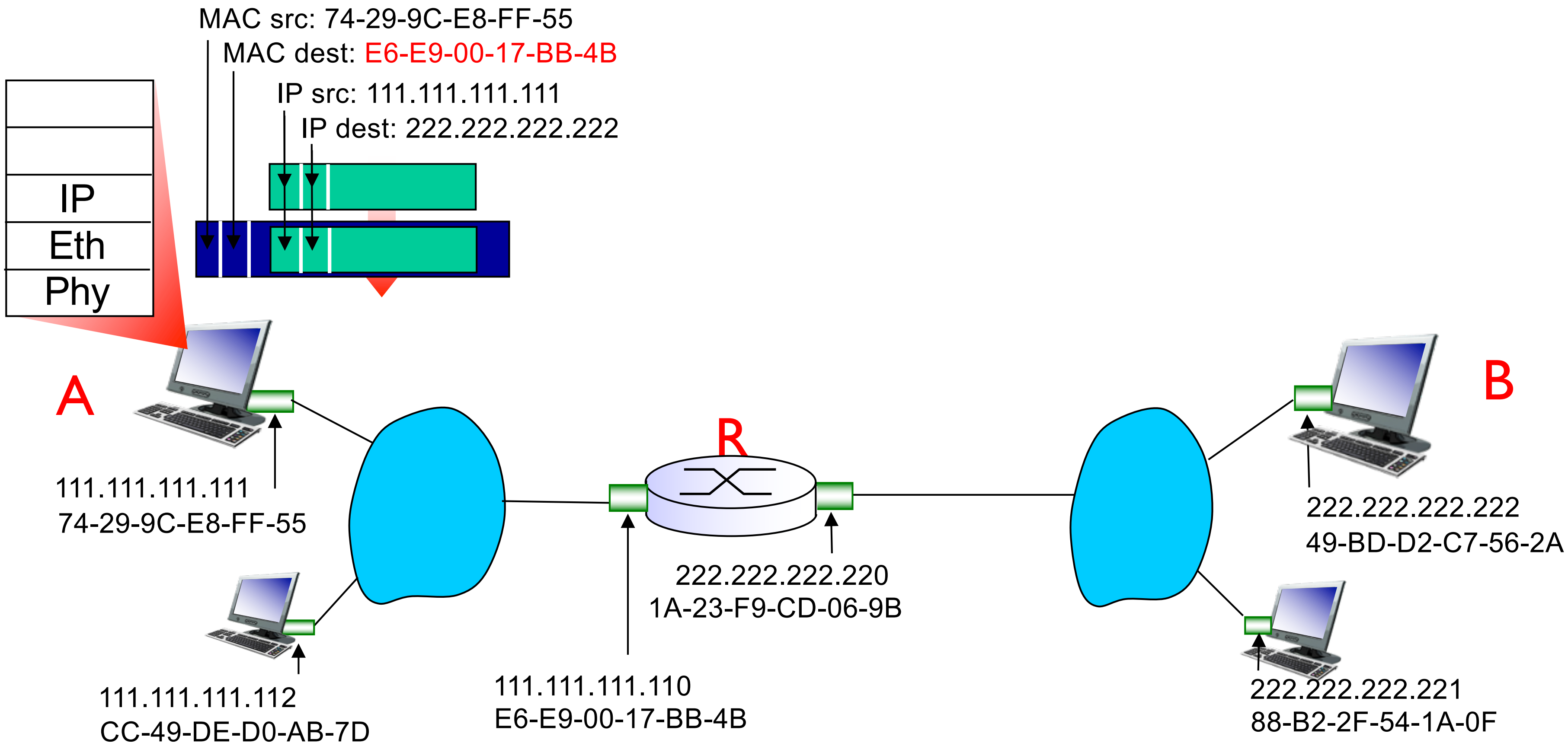
walkthrough: send datagram from A to B via R

- focus on addressing – at IP (datagram) and MAC layer (frame)
- assume A knows B's IP address (how?)
  - How does A know B is not local (i.e. connected to the same LAN as A) ?
    - Subnet Mask (discovered via DHCP)
- assume A knows IP address of first hop router, R (how?)
    - Default router (discovered via DHCP)
- assume A knows R's MAC address (how?)
    - ARP



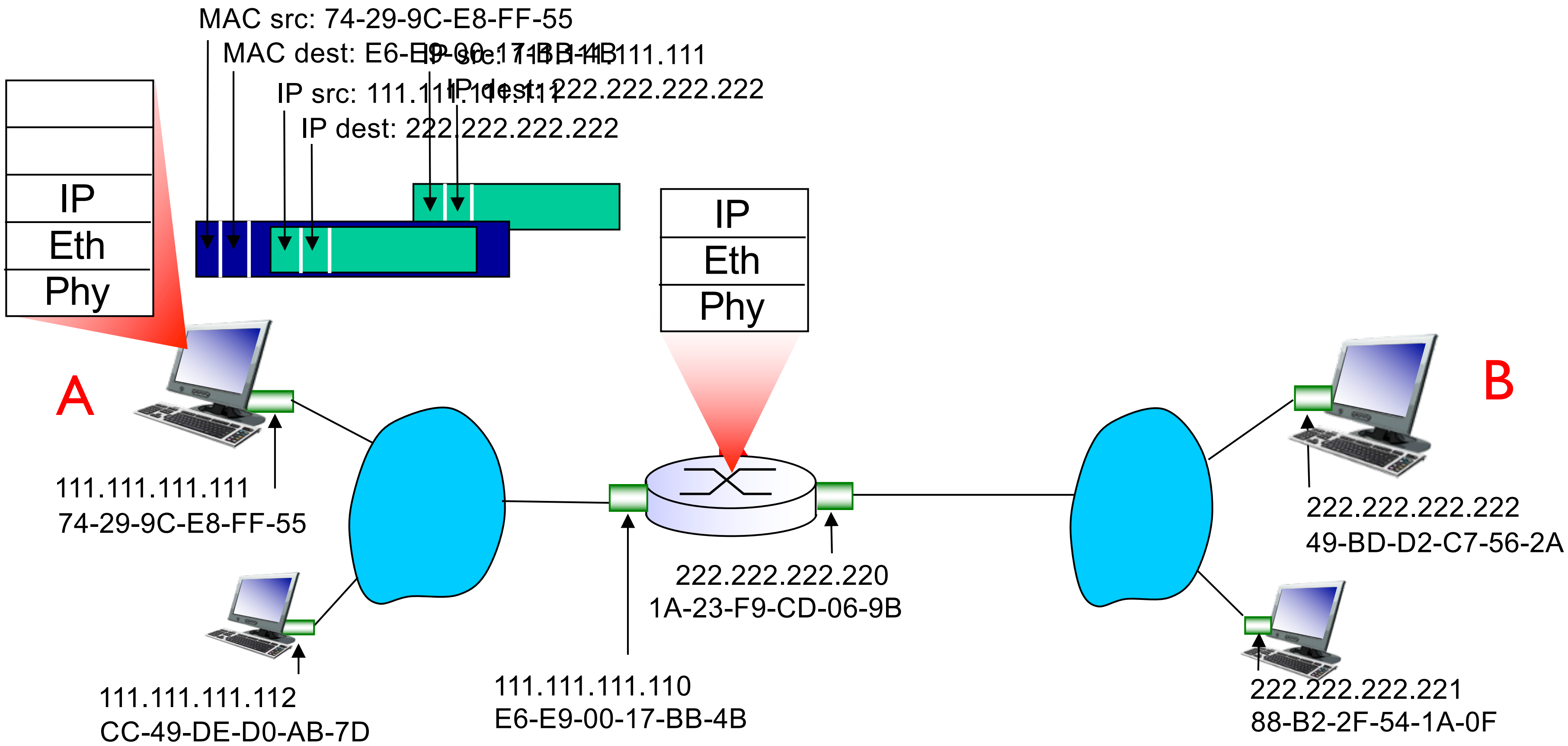
Addressing: routing to another LAN

- 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



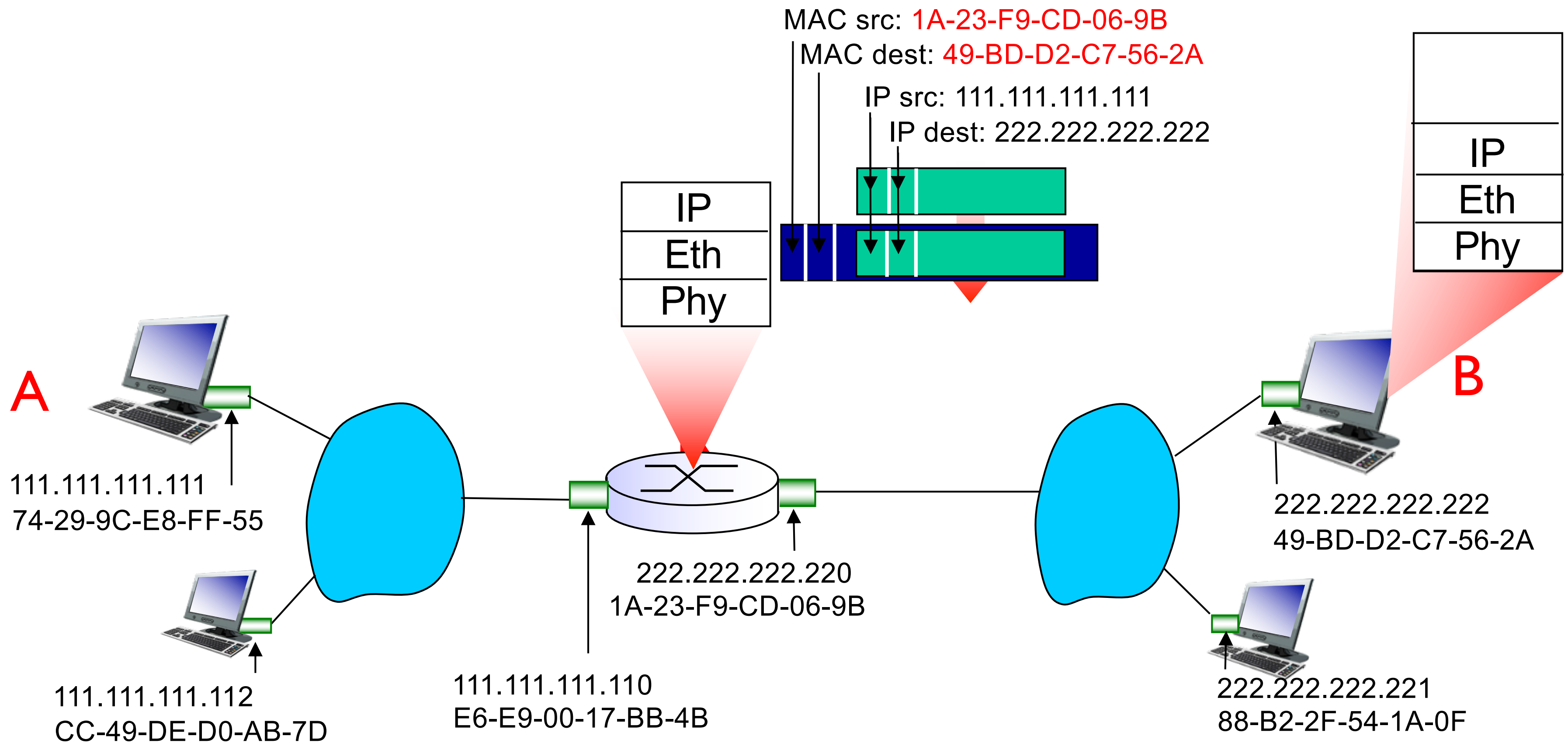
Addressing: routing to another LAN

- 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 (forwarding table)
- R creates link-layer frame with B's MAC address as dest, frame contains A-to-B IP datagram



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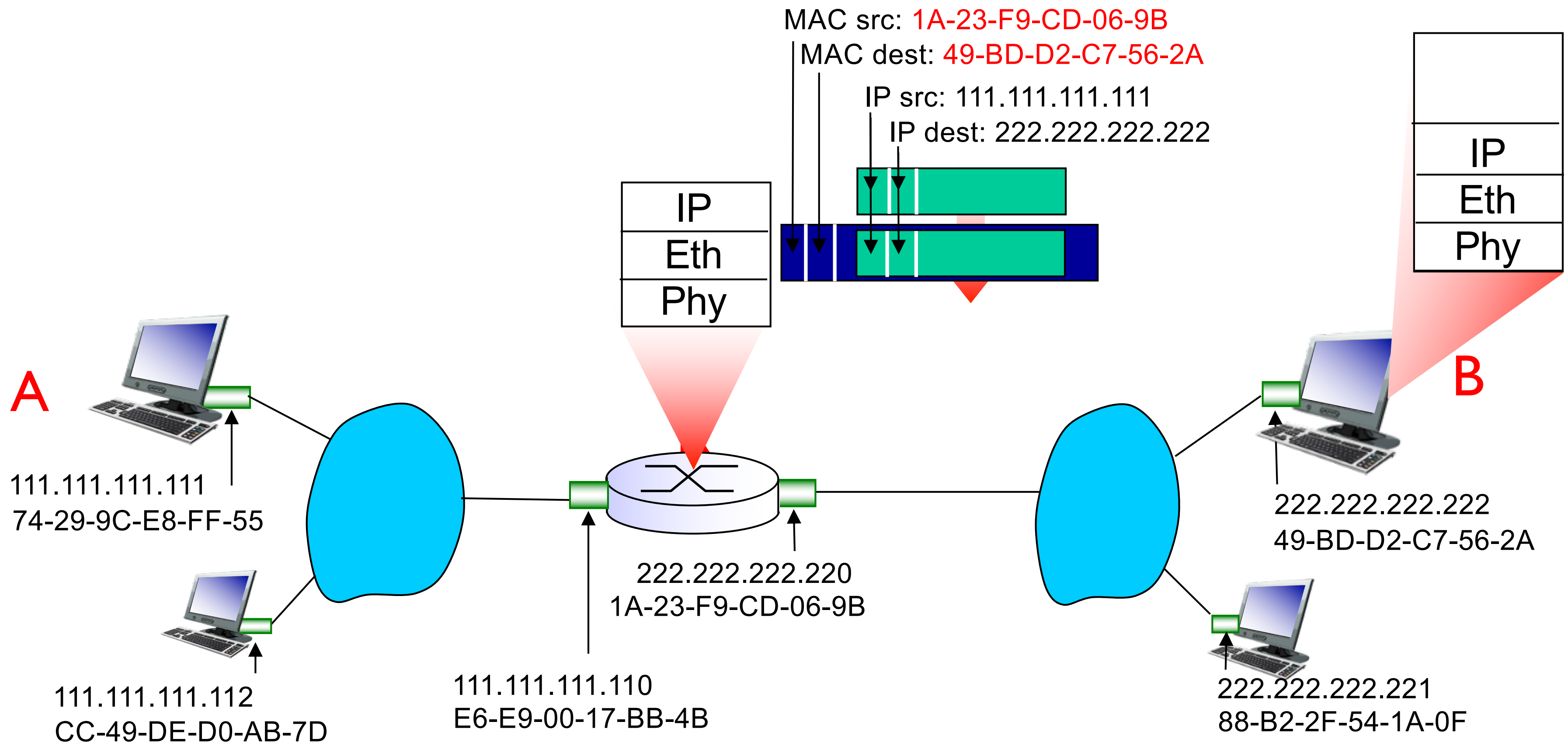

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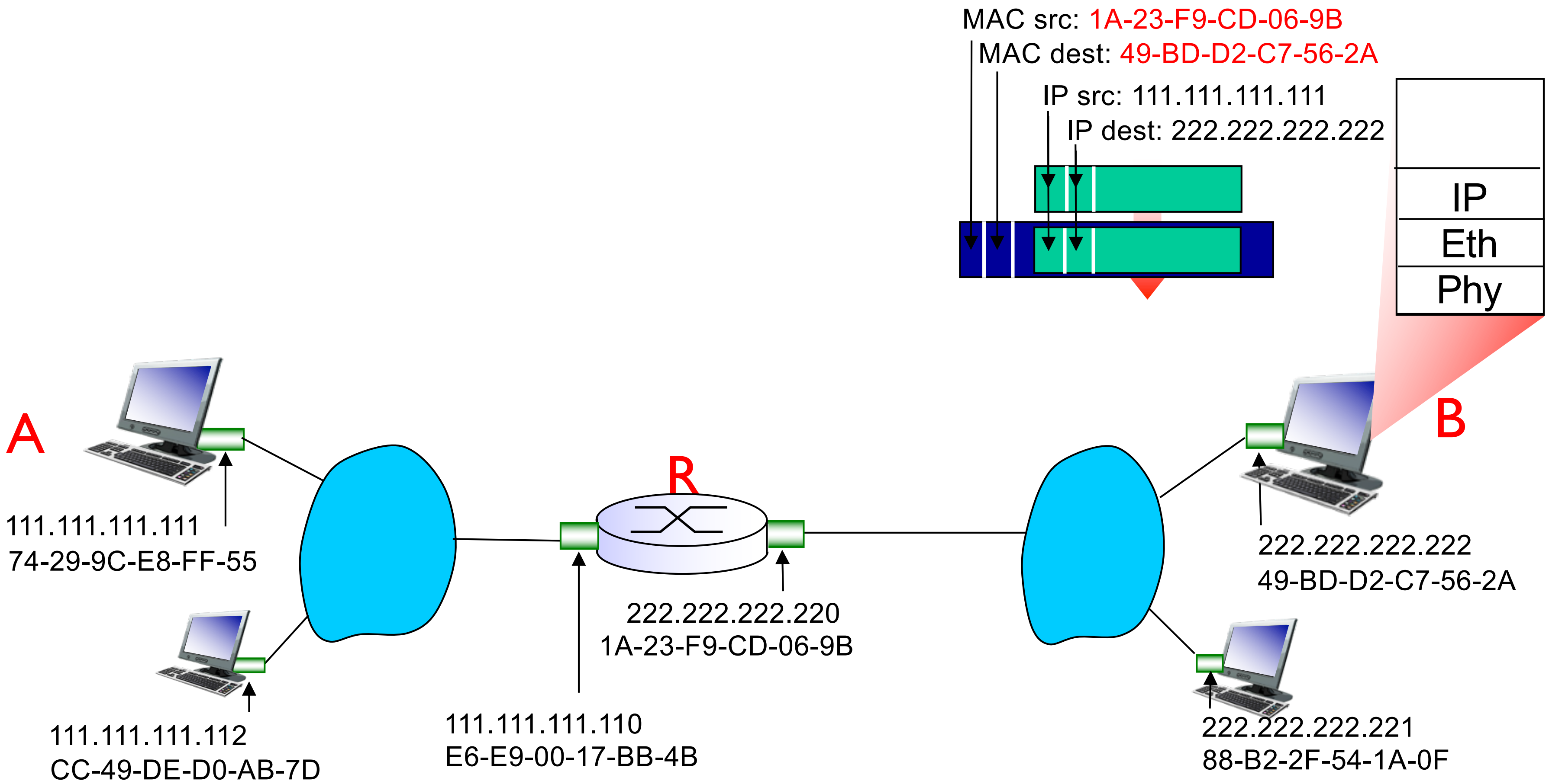


Example ARP Table

C:\Windows\system32\cmd.exe

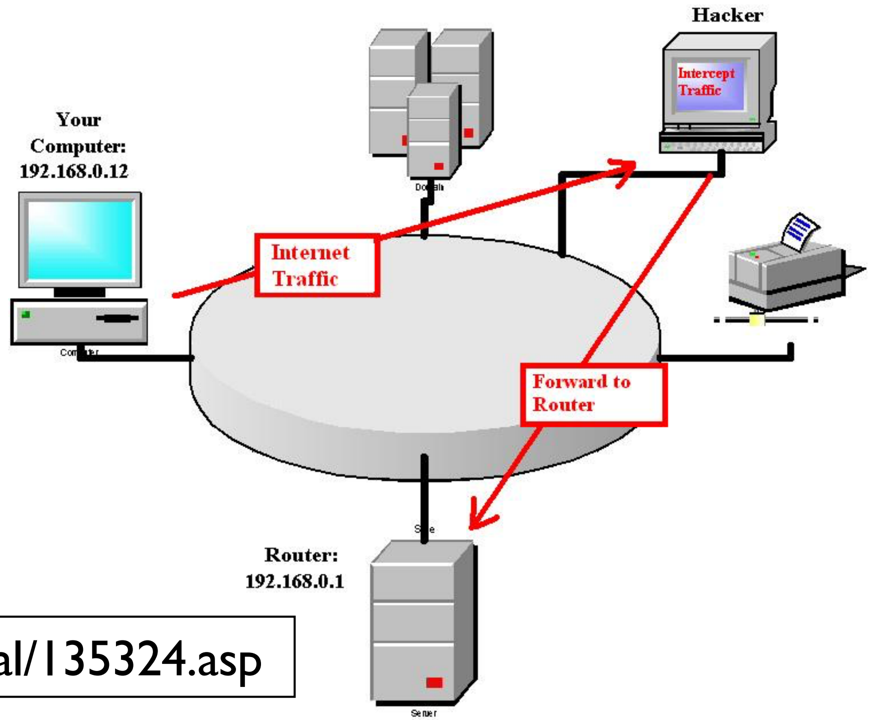
```
C:\Users\admin>arp -a

Interface: 192.168.150.155 --- 0xb
  Internet Address      Physical Address      Type
  192.168.150.2         00-10-db-82-4d-52     dynamic
  192.168.150.10        00-0e-7f-af-6d-b8     dynamic
  192.168.150.24        00-0f-fe-25-74-40     dynamic
  192.168.150.32        00-0b-cd-6e-b8-2c     dynamic
  192.168.150.36        00-0f-fe-3a-aa-3f     dynamic
  192.168.150.42        00-0f-fe-87-1e-98     dynamic
  192.168.150.48        00-0e-7f-63-8d-d1     dynamic
  192.168.150.54        00-16-35-ae-3b-a9     dynamic
  192.168.150.58        00-16-35-ae-39-53     dynamic
  192.168.150.60        00-21-63-68-e9-29     dynamic
  192.168.150.62        00-0f-fe-9b-e8-38     dynamic
  192.168.150.78        00-0f-fe-3a-a7-d7     dynamic
  192.168.150.90        00-0e-7f-f2-f8-e8     dynamic
  192.168.150.92        00-0f-fe-3a-a7-96     dynamic
  192.168.150.98        00-0f-fe-85-8d-6b     dynamic
  192.168.150.114       00-0e-7f-6c-81-25     dynamic
  192.168.150.144       00-22-5f-12-67-a2     dynamic
  192.168.150.156       00-0f-fe-d1-7e-1e     dynamic
  192.168.150.157       00-0f-fe-d1-7e-1e     dynamic
  192.168.150.159       00-06-1b-c2-e1-f3     dynamic
  192.168.150.208       00-19-66-32-53-25     dynamic
  192.168.150.219       00-00-aa-8c-be-07     dynamic
  192.168.150.221       00-0e-7f-64-5f-d0     dynamic
  192.168.150.255       ff-ff-ff-ff-ff-ff     static
  224.0.0.22            01-00-5e-00-00-16     static
  224.0.0.251           01-00-5e-00-00-fb     static
  224.0.0.252           01-00-5e-00-00-fc     static
  224.0.1.134           01-00-5e-00-01-86     static
  239.255.255.250       01-00-5e-7f-ff-fa     static
```

Security Issues: ARP Cache Poisoning

- Denial of Service - Hacker replies back to an ARP query for a router NIC with a fake MAC address
- Man-in-the-middle attack - Hacker can insert his/her machine along the path between victim machine and gateway router
- Such attacks are generally hard to launch as hacker needs physical access to the network

Solutions -
• Use Switched Ethernet with port security enabled (i.e. one host MAC address per switch port)
• Adopt static ARP configuration for small size networks
• Use ARP monitoring tools such as ARPWatch



http://www.watchguard.com/infocenter/editorial/135324.asp

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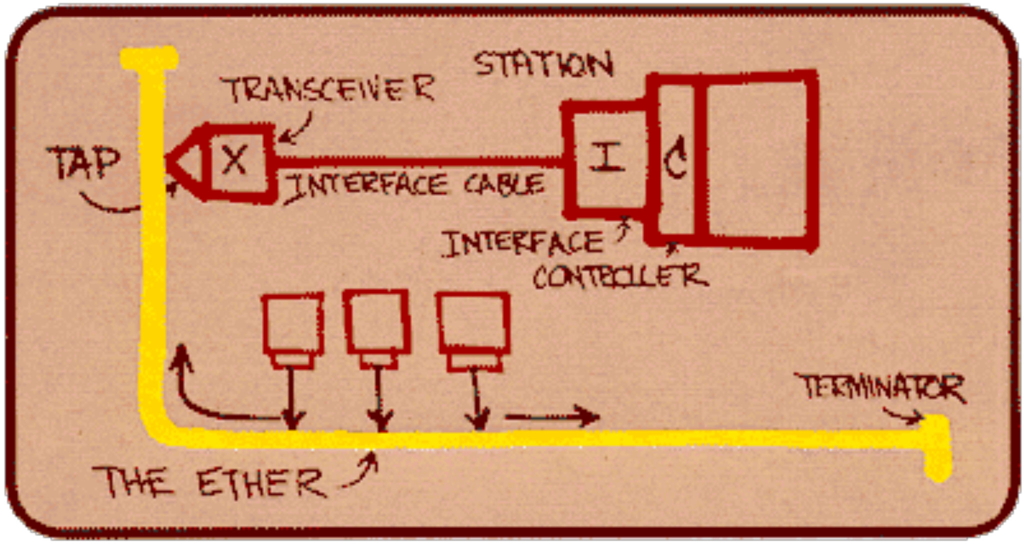
Ethernet

Bob Metcalfe, Xerox PARC, visits Hawaii and gets an idea!



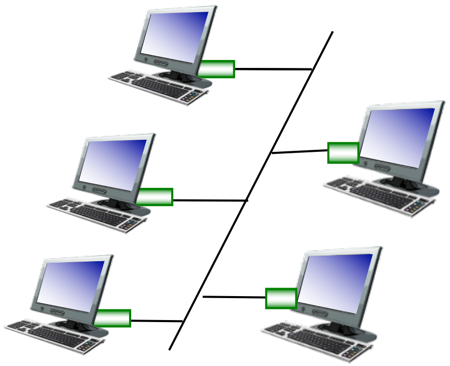
Metcalfe's Ethernet sketch

"dominant" wired LAN technology:

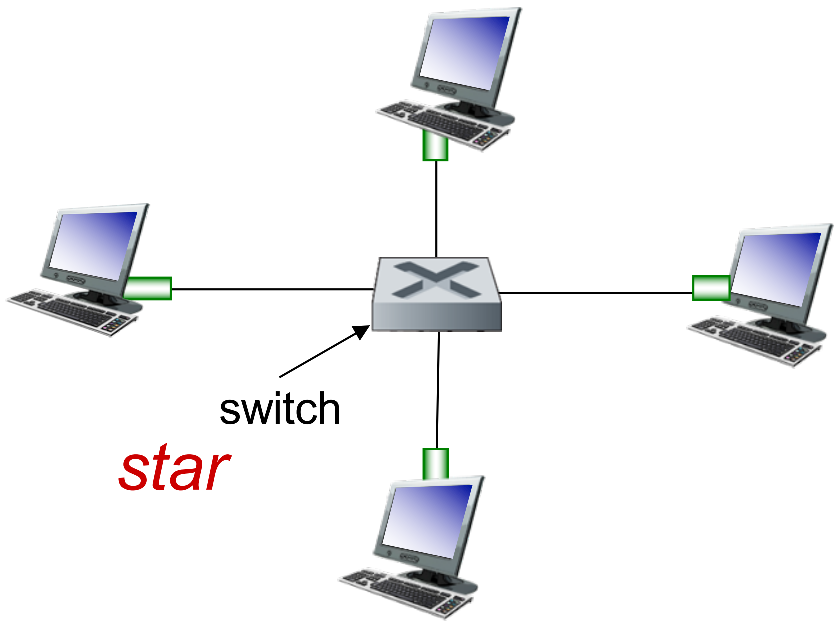
- first widely used LAN technology
- simpler, cheaper than token LANs and ATM
- kept up with speed race: 10 Mbps – 10 Gbps

Ethernet: physical topology

- *bus:* popular through mid 90s
  - all nodes in same collision domain (can collide with each other)
  - CSMA/CD for media access control
- *star:* prevails today
  - active *switch* in center
  - each "spoke" runs a (separate) Ethernet protocol (nodes do not collide with each other)
  - No sharing, no CSMA/CD



bus: coaxial cable



star

Ethernet frame structure

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

Preamble 7 Bytes	SFD 1 Byte	Dest MAC 6 Bytes	Source MAC 6 Bytes	Type/Length 2 Bytes	Payload 46-1500 Bytes	FCS/CRC 4 Bytes	Inter Frame Gap

preamble:

- Start of frame is recognized by
  - Preamble : Seven bytes with pattern 10101010
  - Start of Frame Delimiter (SFD) : 10101011
- used to synchronize receiver, sender clock rates
- Inter Frame Gap is 12 Bytes (96 bits) of idle state
  - 0.96 microsec for 100 Mbit/s Ethernet
  - 0.096 microsec for Gigabit/s Ethernet

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., ARP, Novell IPX, AppleTalk)
- *CRC:* cyclic redundancy check at receiver
  - error detected: frame is dropped

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

Ethernet: unreliable, connectionless

- *connectionless:* no handshaking between sending and receiving NICs
- *unreliable:* receiving NIC does not 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*

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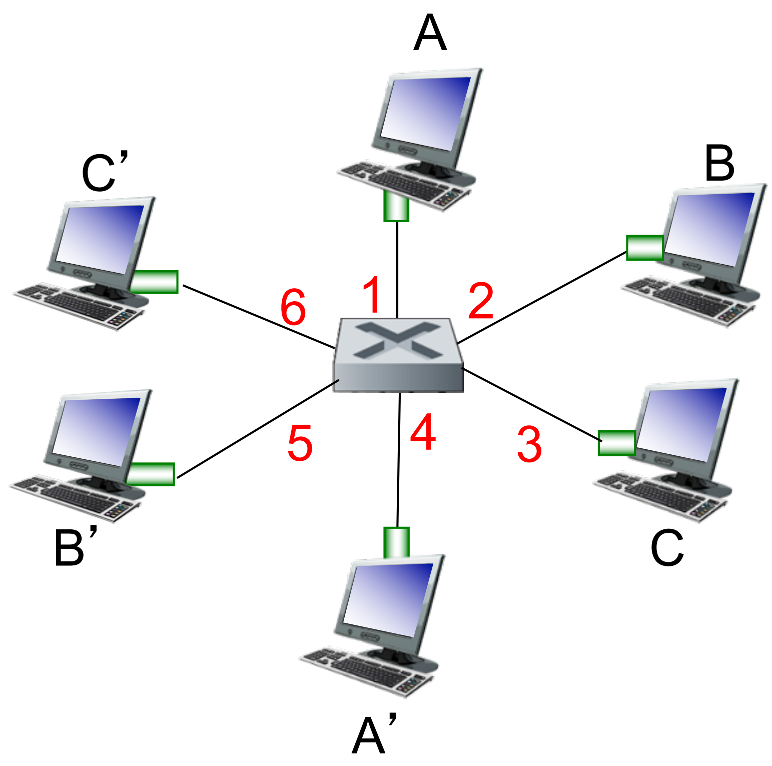
Ethernet switch

- 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
- *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

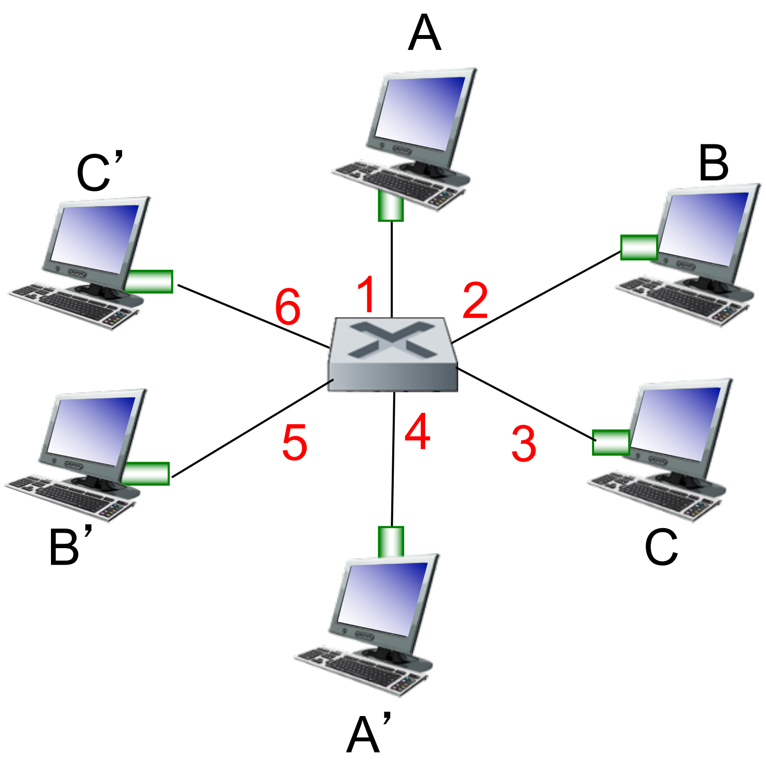


switch with six interfaces (1,2,3,4,5,6)

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!*



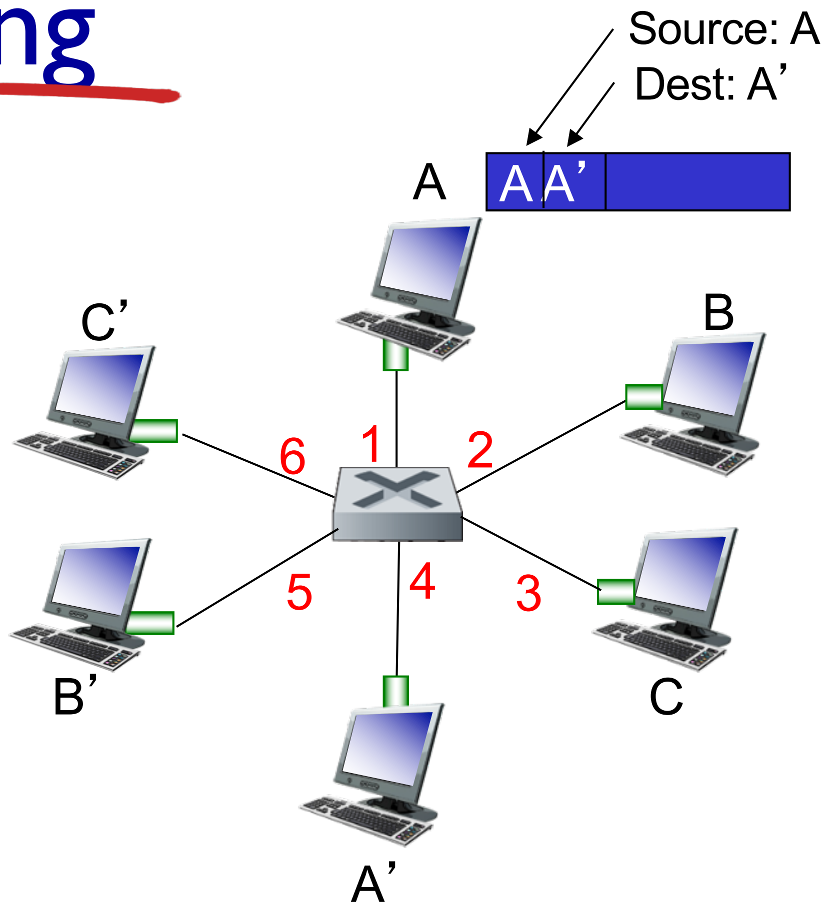
switch with six interfaces (1,2,3,4,5,6)

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)

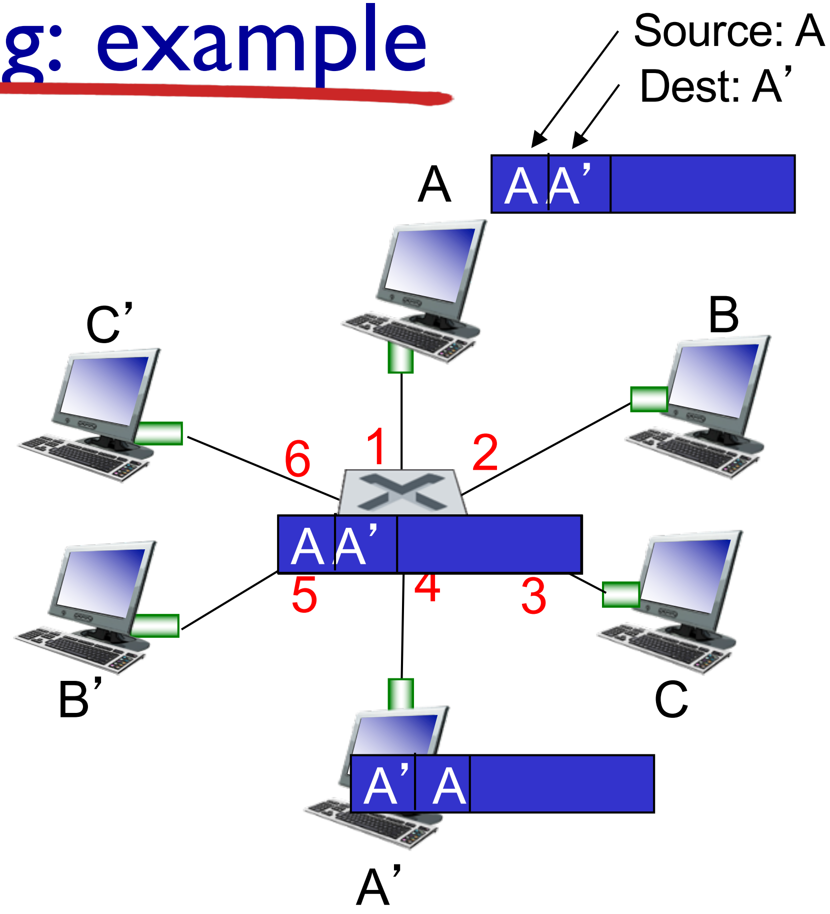
Switch: frame filtering/forwarding

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', locaton unknown: *flood*
- destination A location known: *selectively send on just one link*

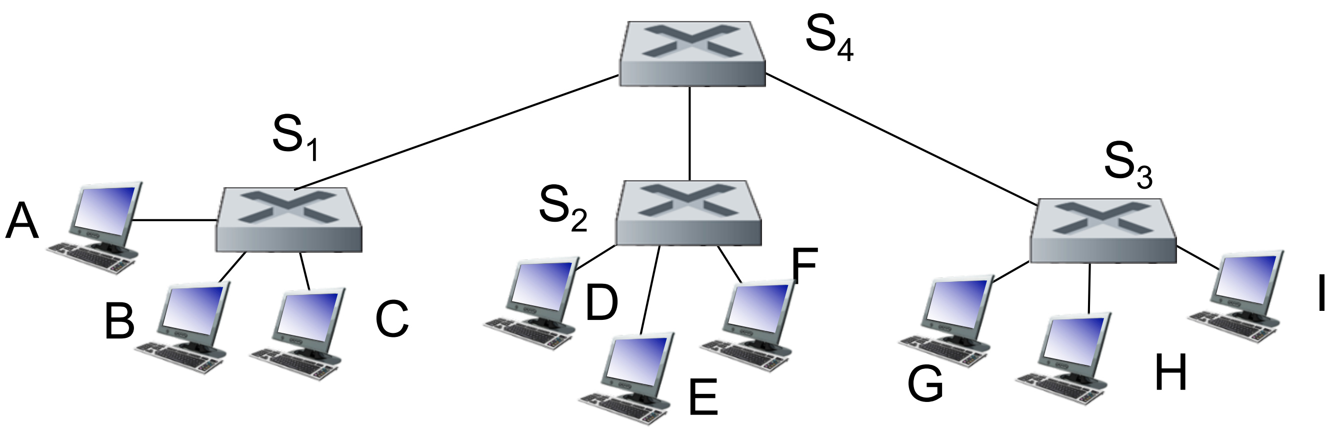


MAC addr	interface	TTL
A	*1*	*60*
A'	*4*	*60*

switch table (initially empty)

Interconnecting switches

- 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!)

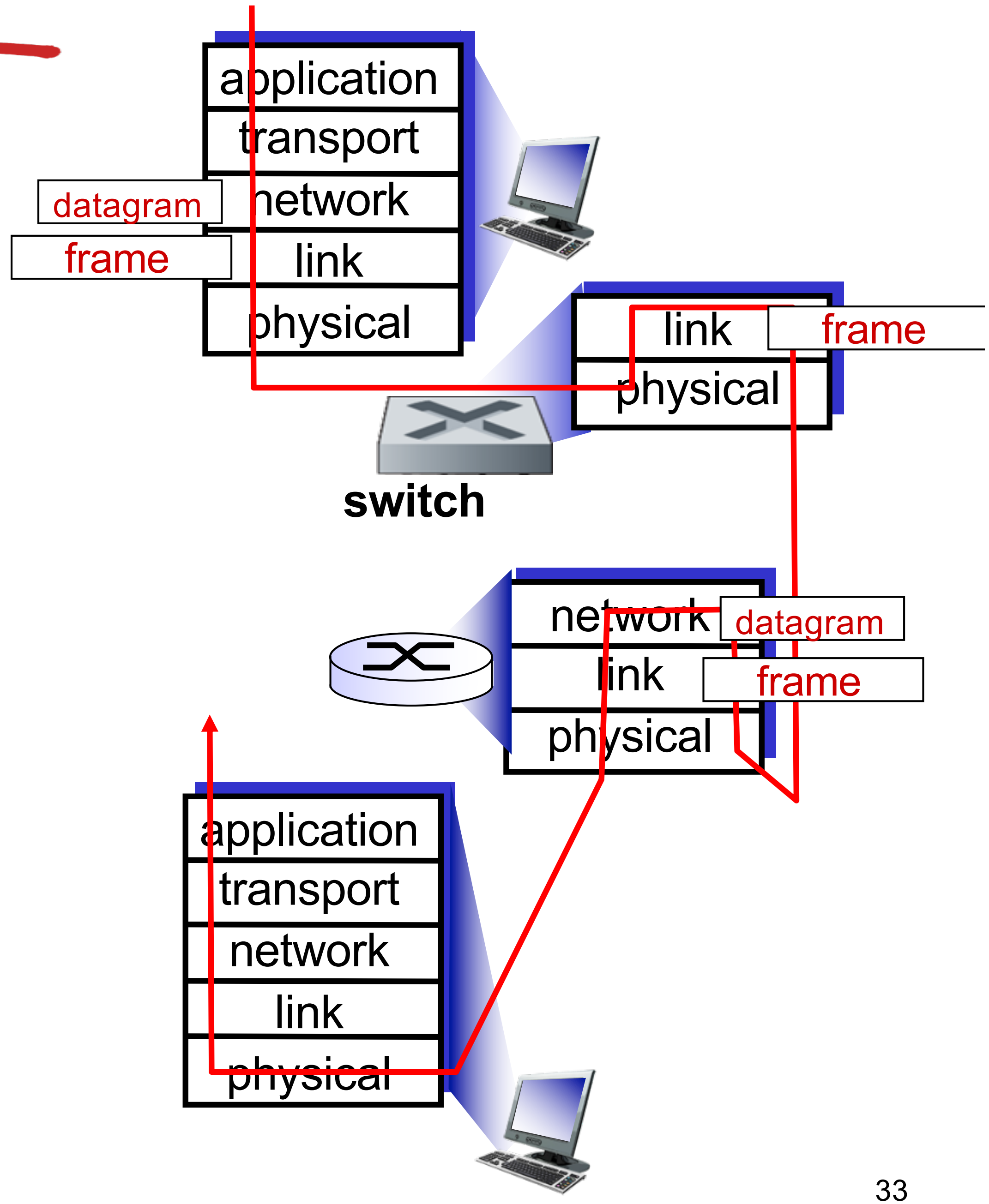
Switches vs. routers

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



Security Issues

- In a switched LAN once the switch table entries are established frames are not broadcast
  - Sniffing frames is harder than pure broadcast LANs
  - Note: attacker can still sniff broadcast frames and frames for which there are no entries (as they are broadcast)
- Switch Poisoning: Attacker fills up switch table with bogus entries by sending large # of frames with bogus source MAC addresses
- Since switch table is full, genuine packets frequently need to be broadcast as previous entries have been wiped out

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Link Layer: Summary

- principles behind data link layer services:
  - error detection, correction
  - sharing a broadcast channel: multiple access
  - link layer addressing
- instantiation and implementation of various link layer technologies
  - Ethernet
  - switched LANS

Link Layer: let's take a breath

- journey down protocol stack *complete* (except PHY)
- solid understanding of networking principles, practice
- ….. could stop here …. but *we have not covered wireless yet!*
  - *Next week: Wireless in the link layer*