Computer Networks
Link Layer P-2

Computer Networking: A Top-Down Approach
8th edition, Global Edition
Jim Kurose, Keith Ross

Link layer, LANs: outline

LANs

- addressing, ARP
- Ethernet
- switches
- VLANS

MAC addresses and ARP

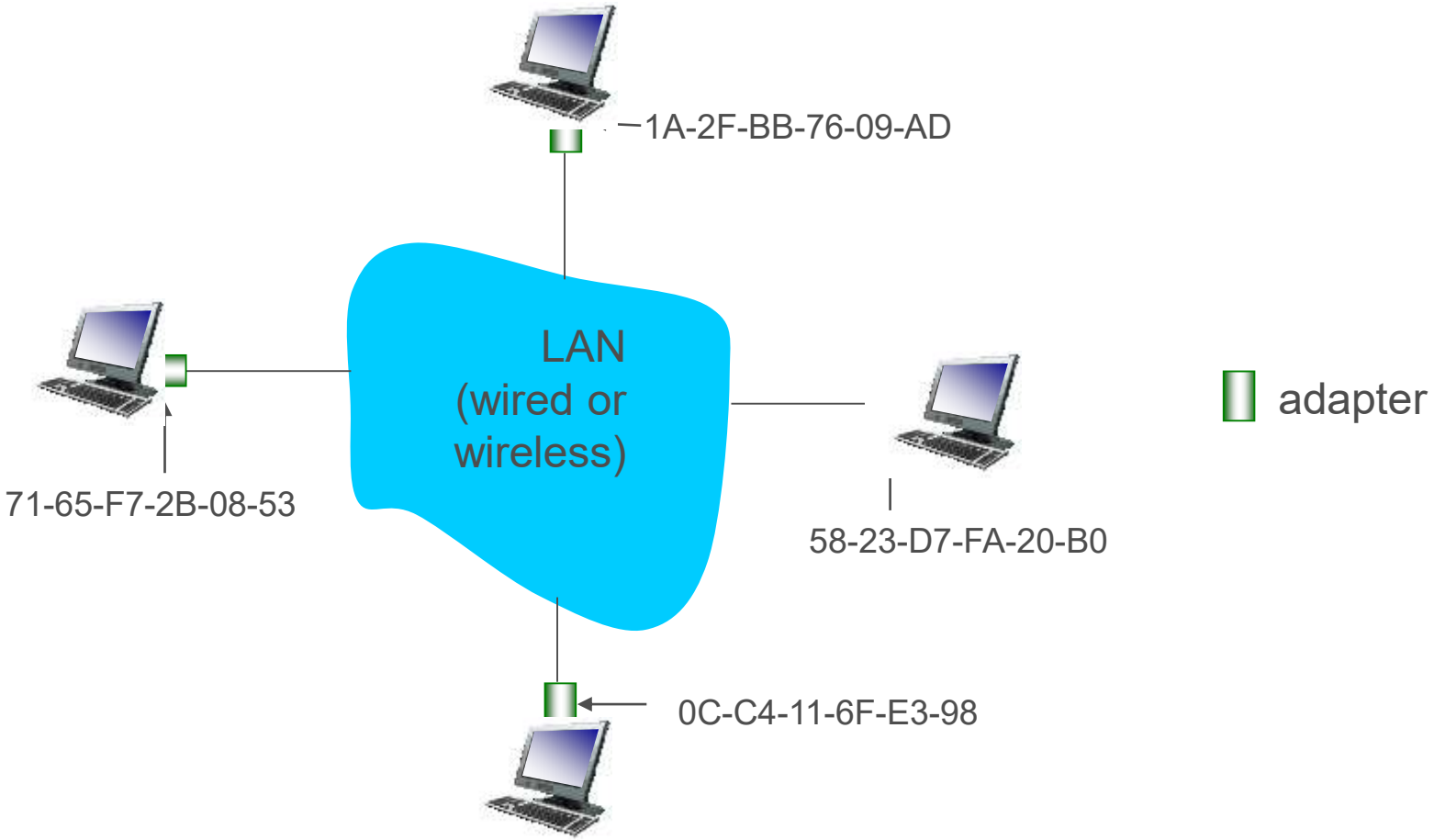
(address resolution protocol)

- **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 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

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

LAN addresses and ARP

each adapter on LAN has unique *LAN* address

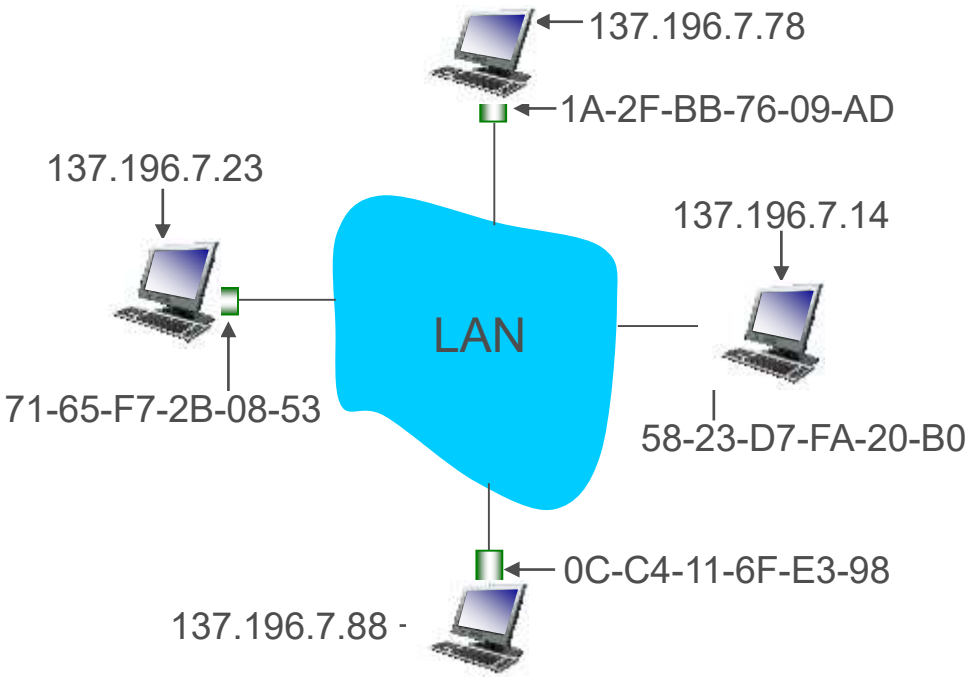


LAN addresses (more)

- **MAC address allocation administered by IEEE**
- **Manufacturer buys portion of MAC address space (to assure uniqueness)**
- **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)

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*

ARP protocol in action

example: A wants to send datagram to B

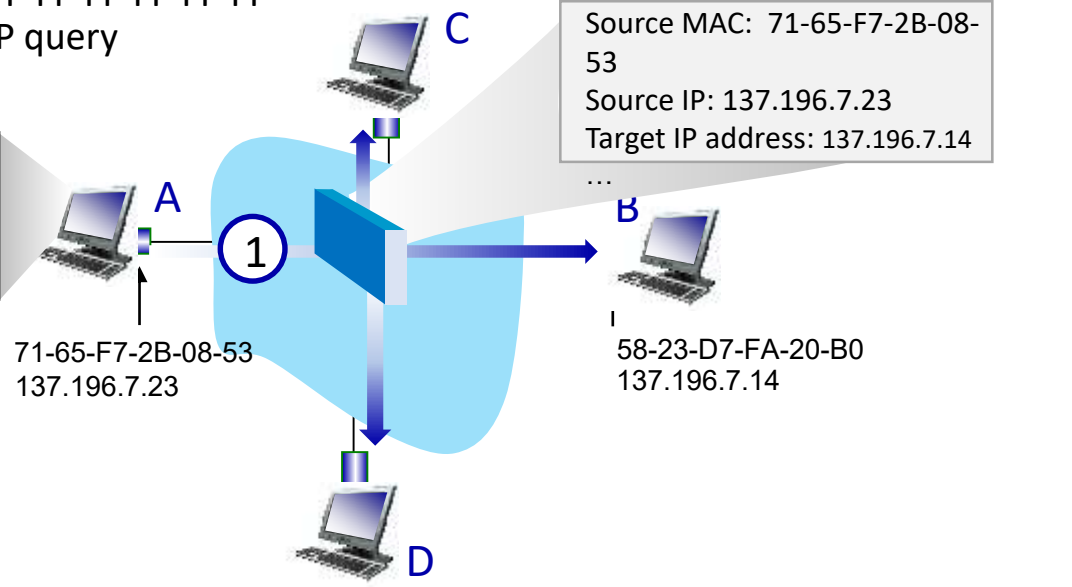
- B's MAC address not in A's ARP table, so A uses ARP to find B's MAC address

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



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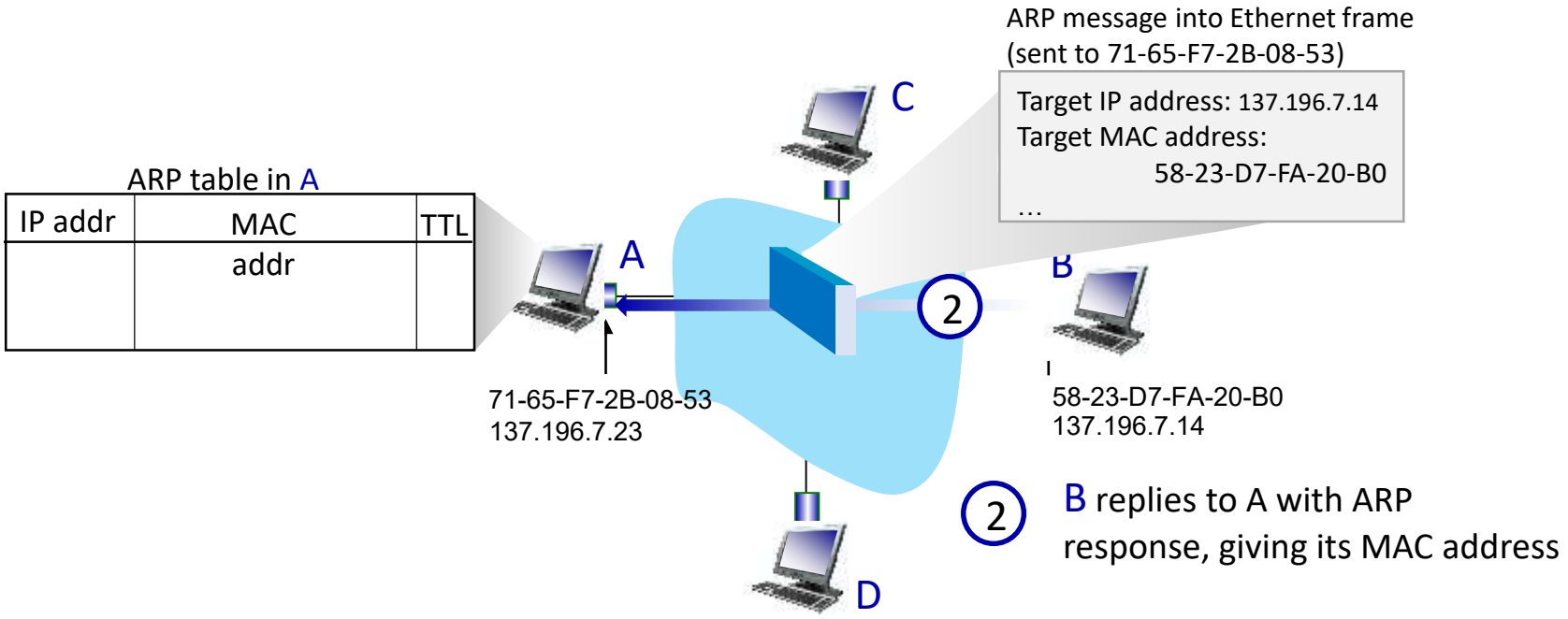

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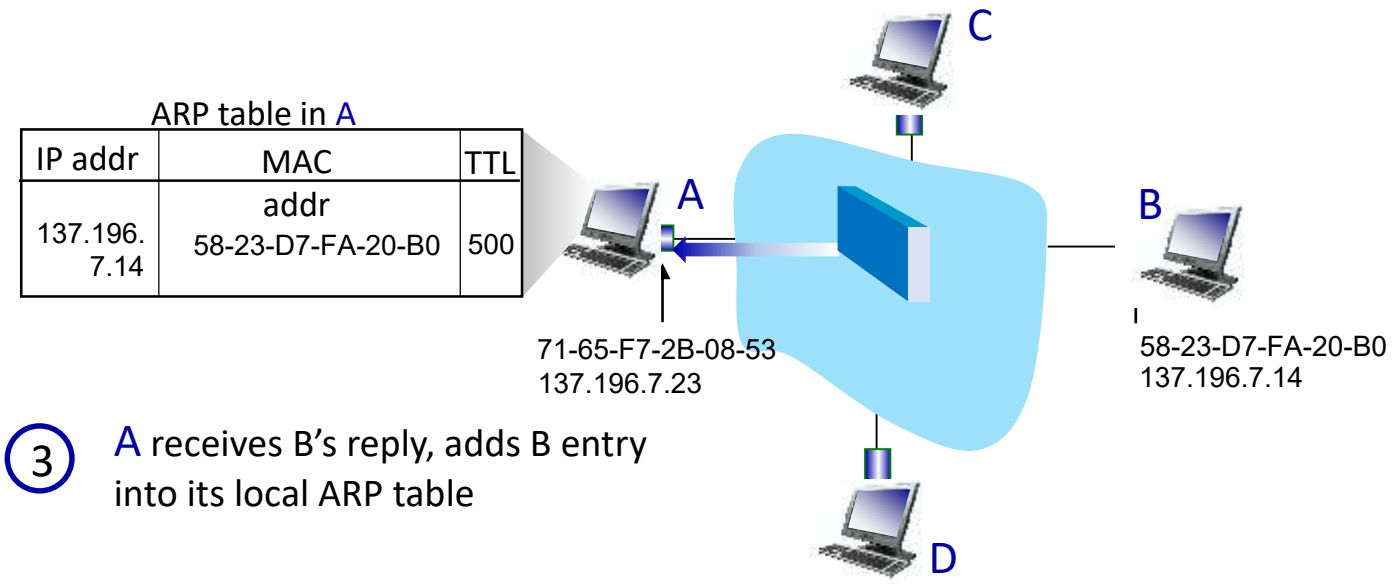
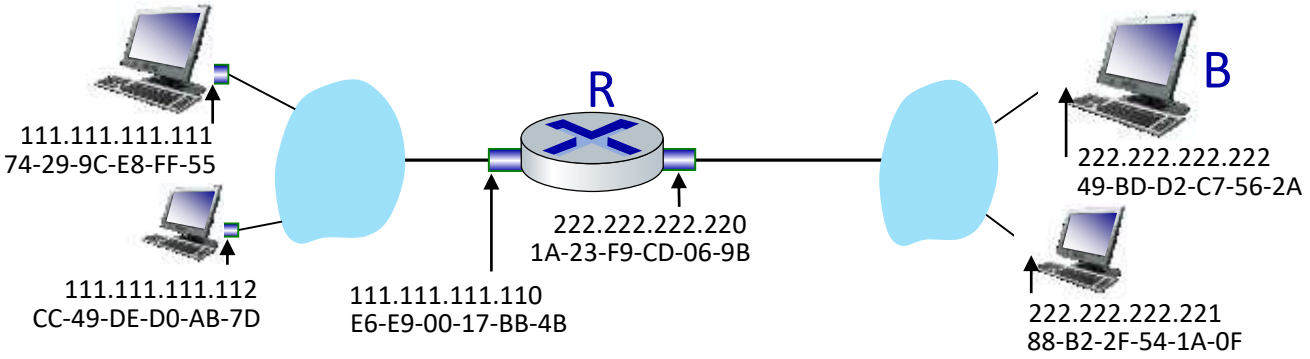


3 A receives B's reply, adds B entry into its local ARP table

Routing to another subnet: addressing

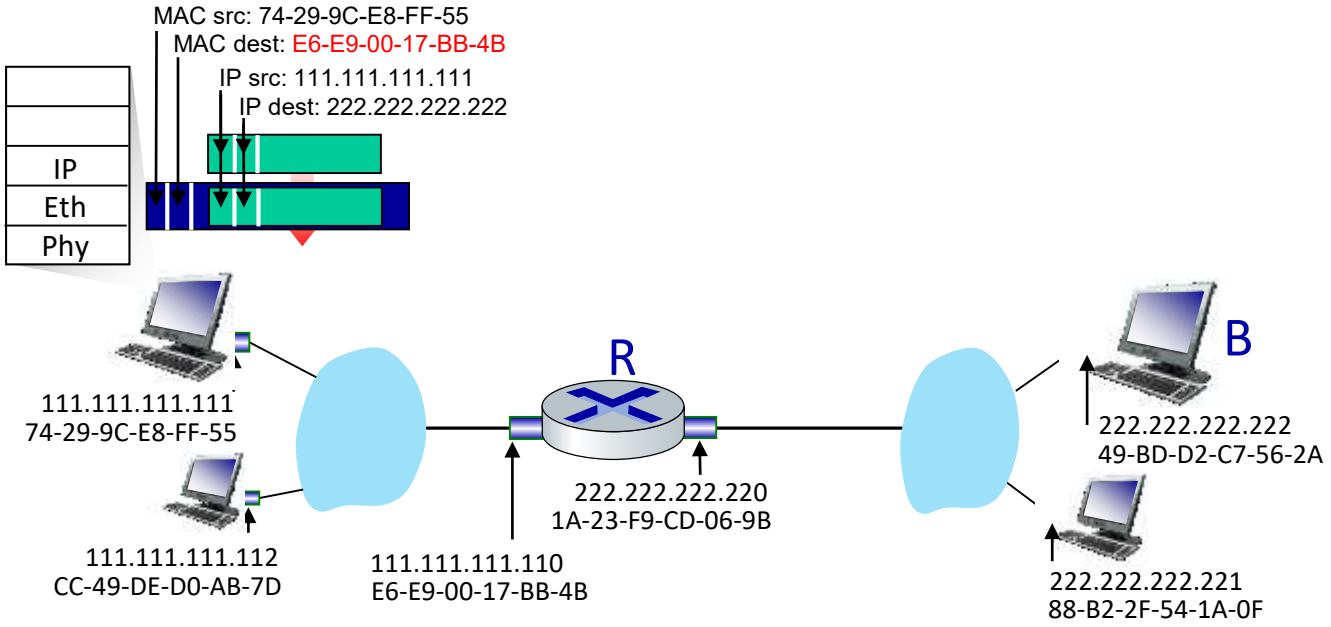
walkthrough: sending a datagram from *A* to *B* via *R*

- 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



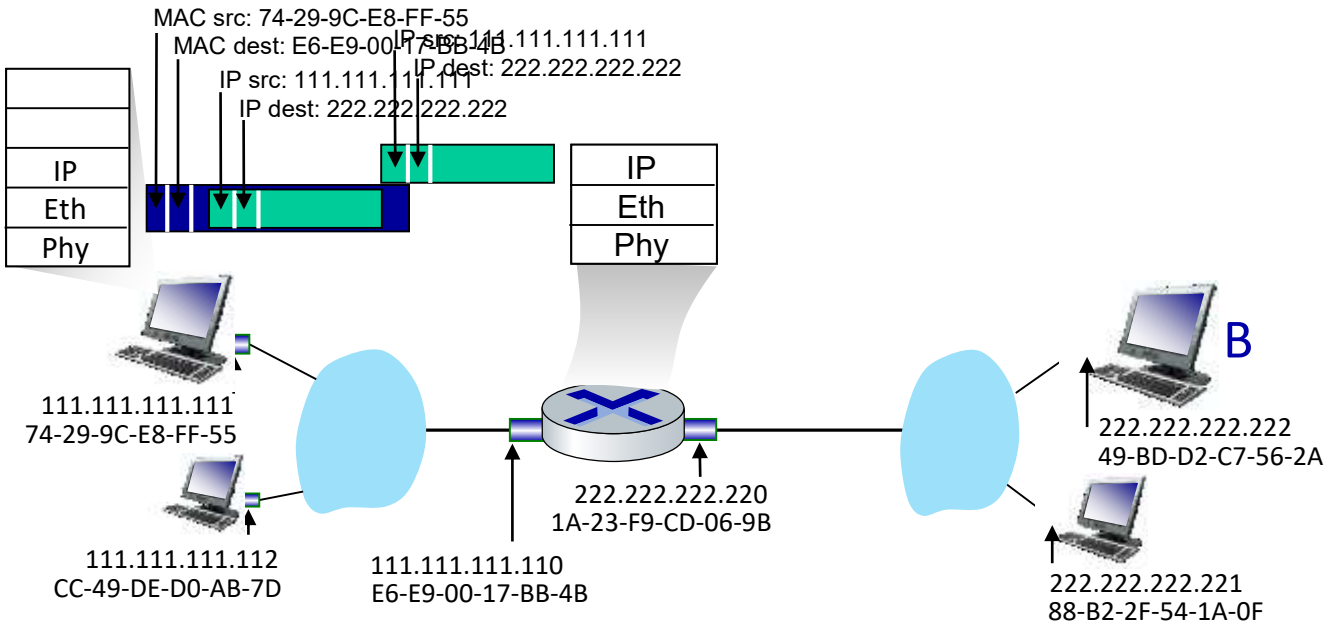
Routing to another subnet: addressing

- 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



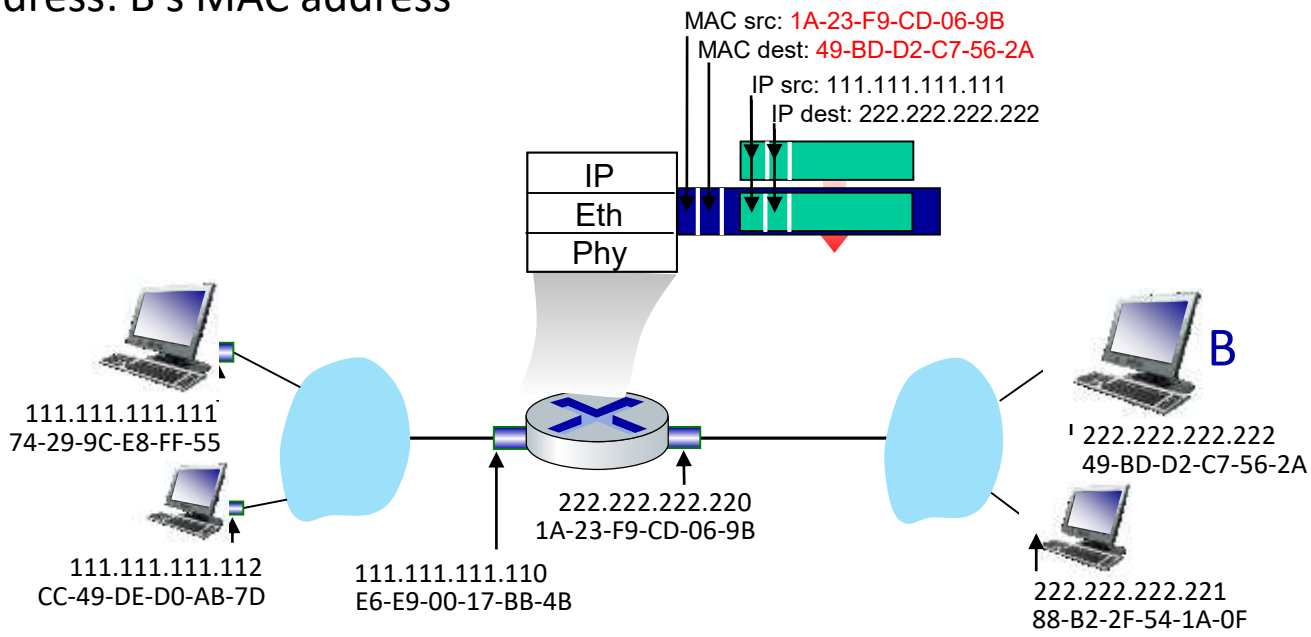
Routing to another subnet: addressing

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



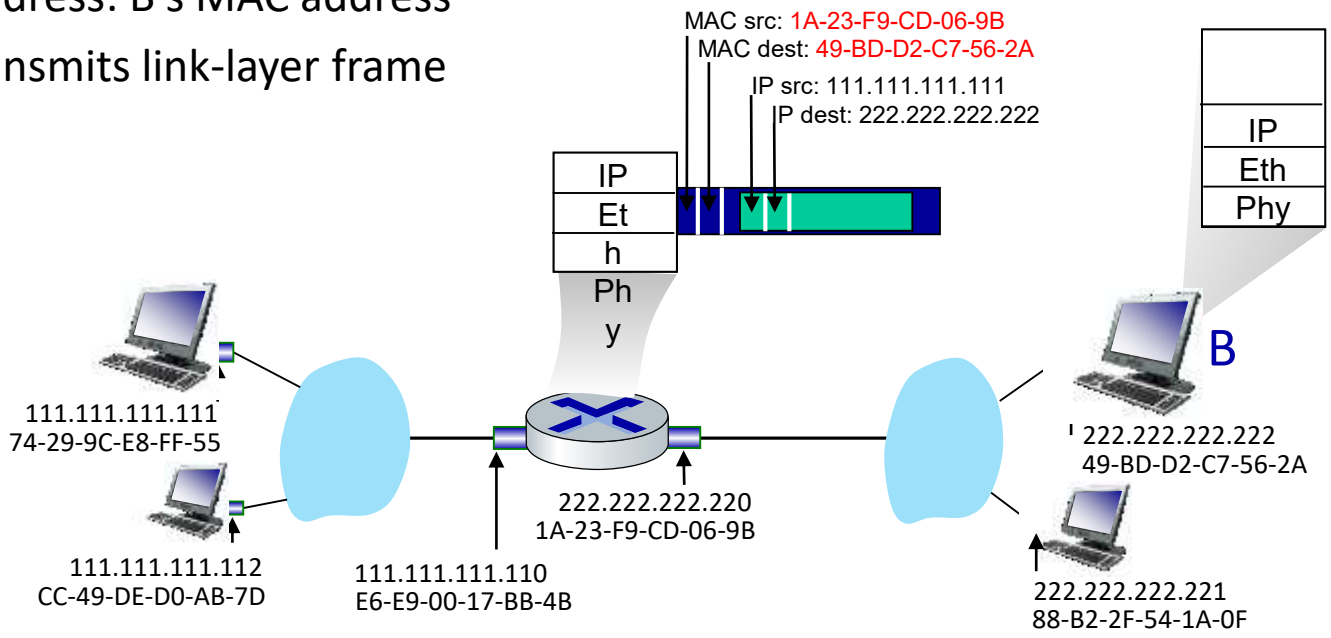
Routing to another subnet: addressing

- 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



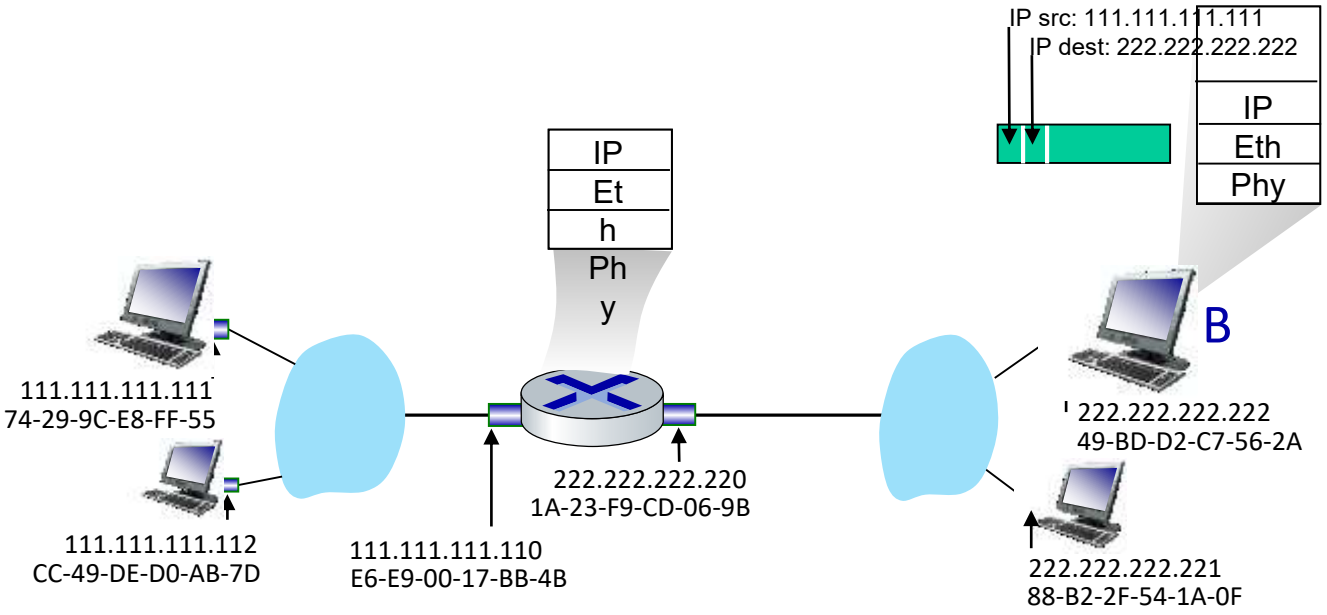
Routing to another subnet: addressing

- 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: outline

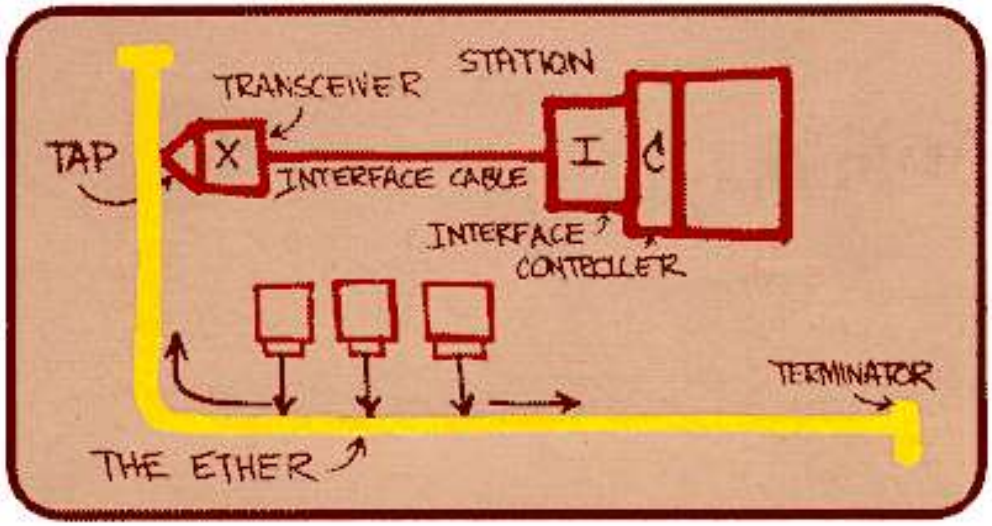
LANs

- Ethernet

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 – 400 Gbps

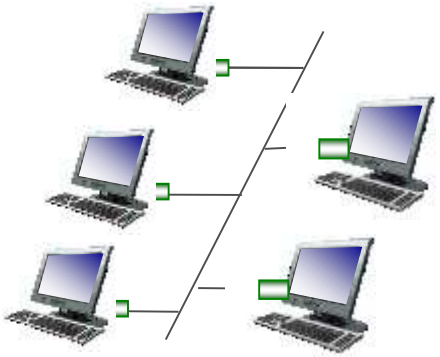


Metcalfe's Ethernet sketch

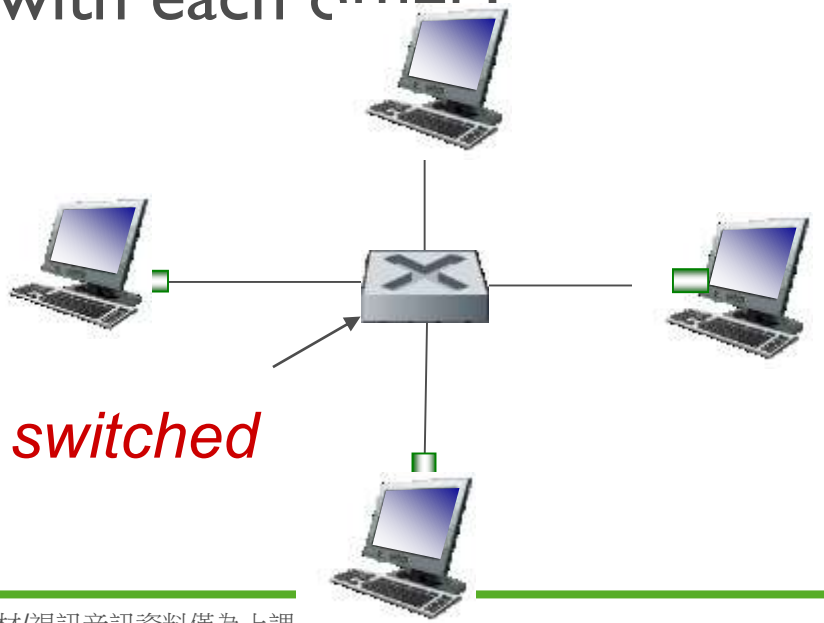
Bob Metcalfe: Ethernet co-inventor, 2022 ACM Turing Award recipient

Ethernet: physical topology

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



bus: coaxial cable



switched

Ethernet frame structure

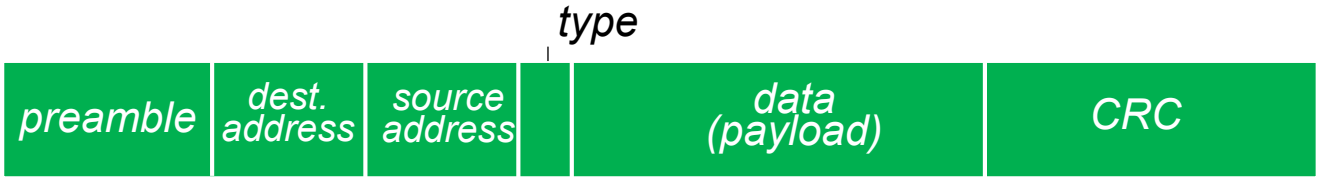
sending interface encapsulates IP datagram (or other network layer protocol packet) in **Ethernet frame**

preamble:

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

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



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***

Link layer, LANs: outline

6.4 LANs

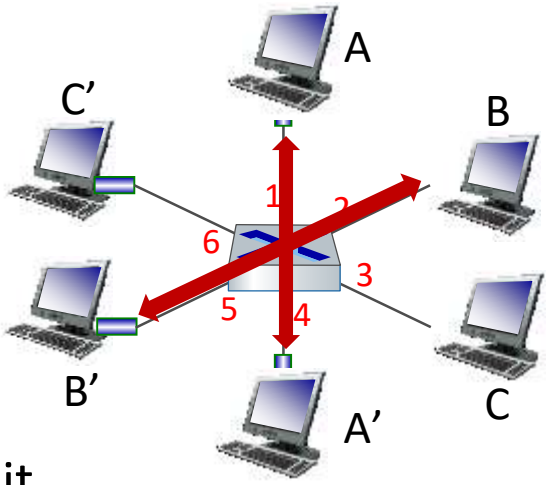
- addressing, ARP
- Ethernet
- switches

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

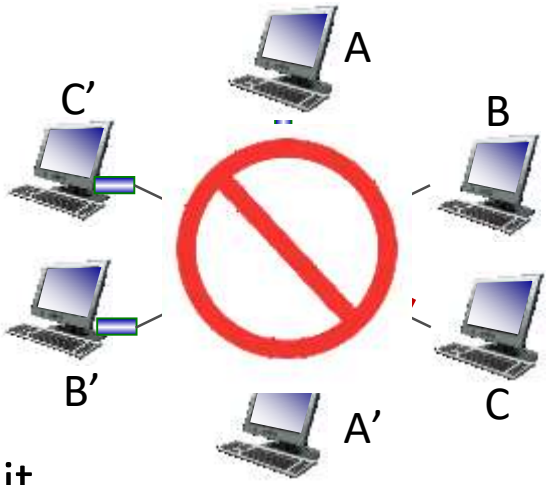
- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol used on *each* incoming link, so:
  - no collisions; full duplex
  - each link is its own collision domain
- switching: A-to-A' and B-to-B' can transmit simultaneously, without collisions



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

Switch: multiple simultaneous transmissions

- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol used on *each* incoming link, so:
  - no collisions; full duplex
  - each link is its own collision domain
- switching: A-to-A' and B-to-B' can transmit simultaneously, without collisions
  - but A-to-A' and C to A' can *not* happen simultaneously



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

Switch forwarding table

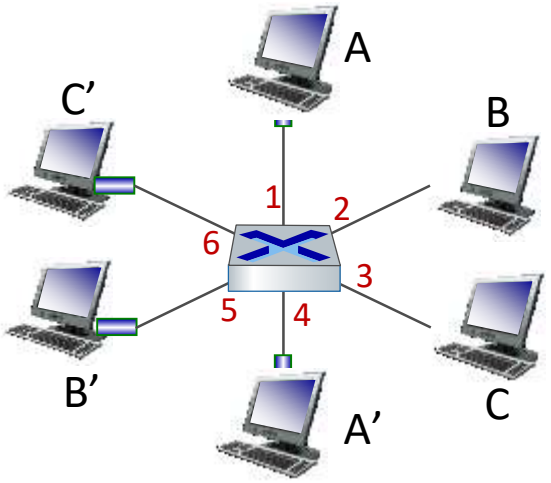
Q: how does switch know A' reachable via interface 4, B' reachable via interface 5?

A: each switch has a switch table, each entry:

- (MAC address of host, interface to reach host, time stamp)
- looks like a routing table!

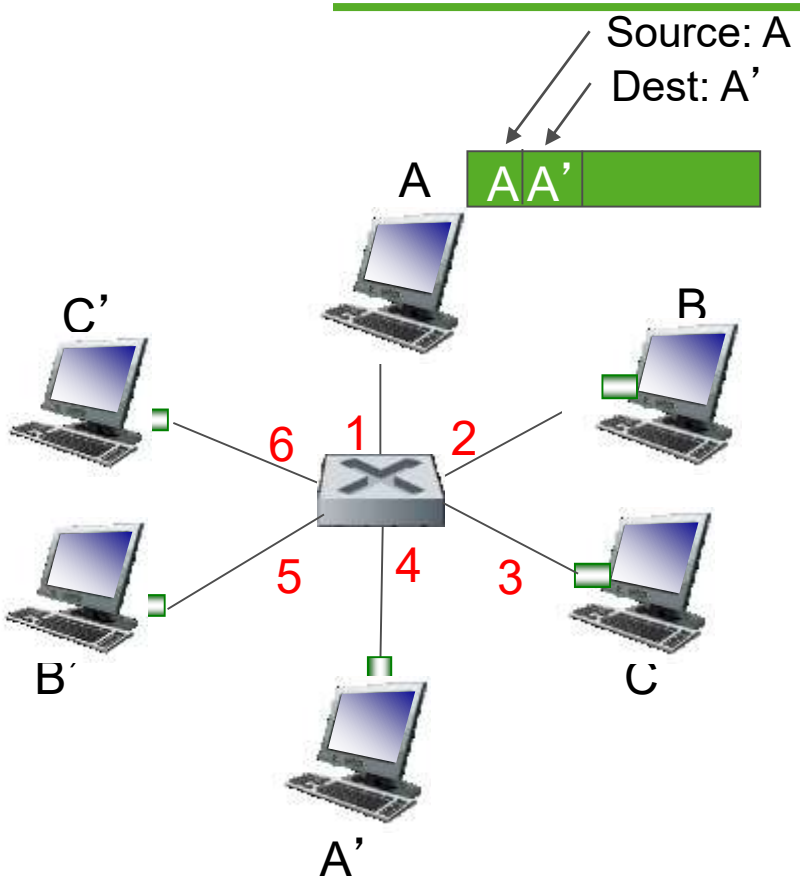
Q: how are entries created, maintained in switch table?

- something like a routing protocol?



Switch: 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

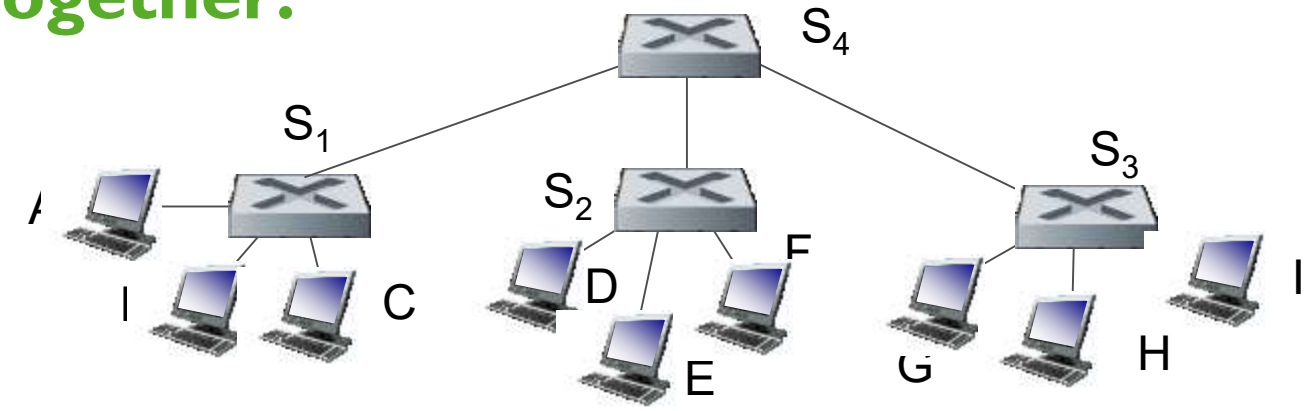
when frame received at switch:

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 */
```

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!)

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