Link layer, LANs: roadmap

- introduction
- error detection, correction
- multiple access protocols
- LANs
  - addressing, ARP
  - Ethernet
  - switches
  - VLANs
- link virtualization: MPLS
- data center networking

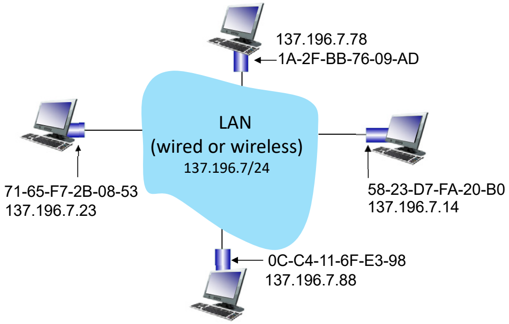
- a day in the life of a web request

MAC addresses

- IP address:
  - *network-layer* address for interface
    - used for layer-3 (network layer) forwarding
  - 32-bit (in IPv4)
    - e.g.: 128.119.40.136
- MAC (or LAN or physical or Ethernet) address:
  - function: used "locally" to get frame from one interface to another physically-connected interface in link layer (within same subnet)
  - 48-bit MAC address (for most LANs) burned in NIC ROM, also sometimes software settable
    - e.g.: 1A-2F-BB-76-09-AD (or 1A:2F:BB:76:09:AD)

Each interface (at host or router)

- has unique 48-bit MAC address
- has a locally unique 32-bit IP address (as we've seen)

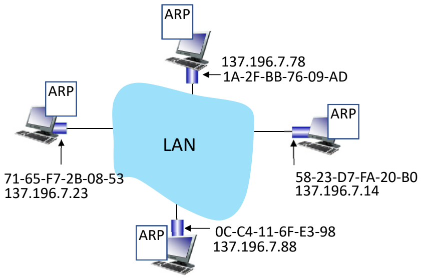


MAC addresses

- 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 interface from one LAN to another LAN
  - recall IP address *not* portable: 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 (layer-3) node (host, router) on LAN has table

- IP/MAC address mappings for some LAN nodes:

  < IP address; MAC address; TTL>

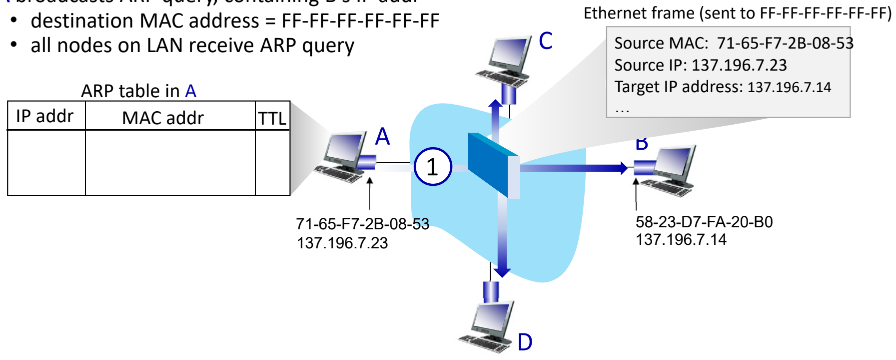
- TTL (Time To Live): time after which address mapping will be forgotten (typically 20 min)

ARP protocol 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

1 A broadcasts ARP query, containing B's IP addr
- destination MAC address = FF-FF-FF-FF-FF-FF
- all nodes on LAN receive ARP query



ARP protocol in action

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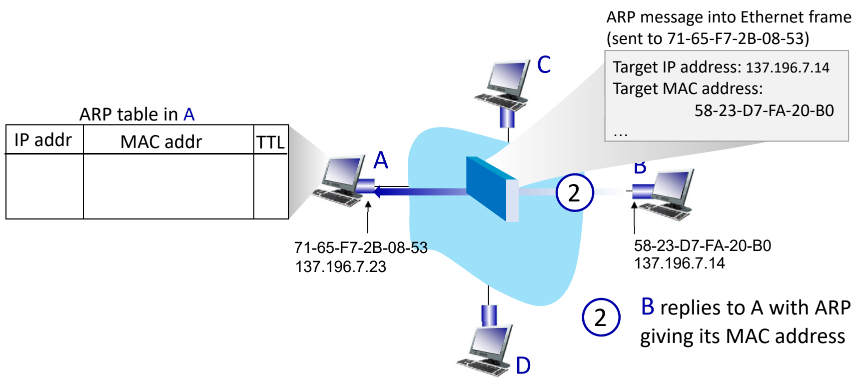

2 B replies to A with ARP response, giving its MAC address

ARP protocol in action

example: A wants to send datagram to B

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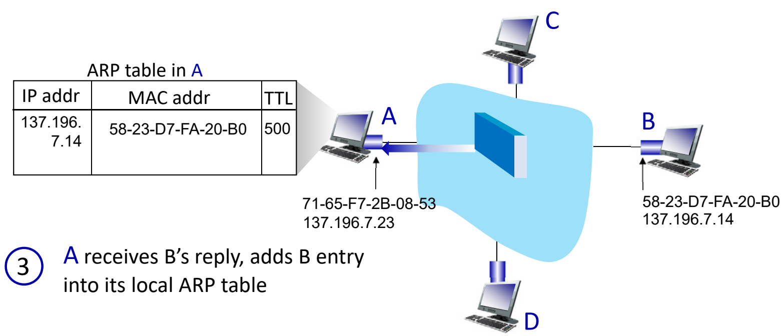
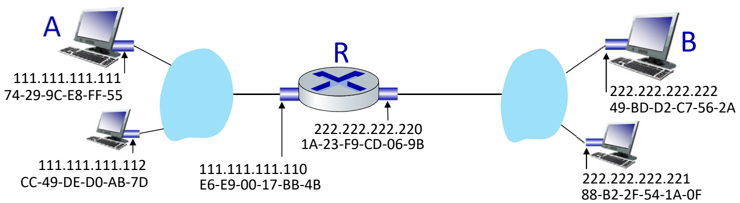


3 A receives B's reply, adds B entry into its local ARP table

Routing to another subnet: addressing

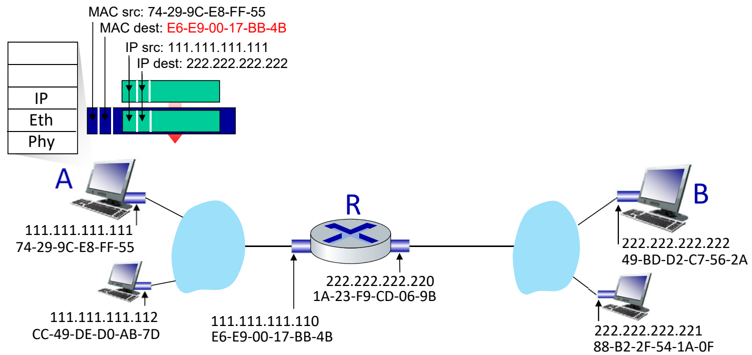
walkthrough: sending a datagram from *A* to *B* via *R*

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



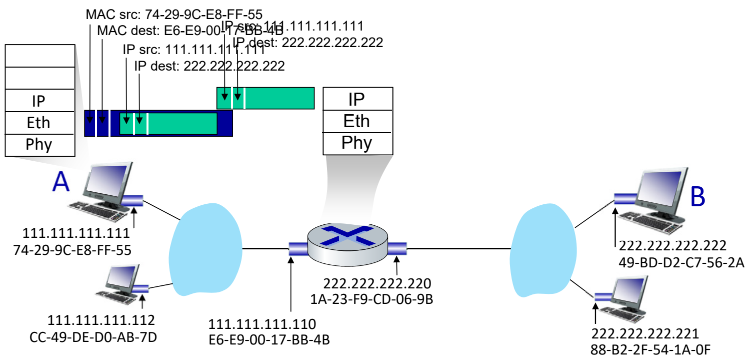
Routing to another subnet: addressing

- 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



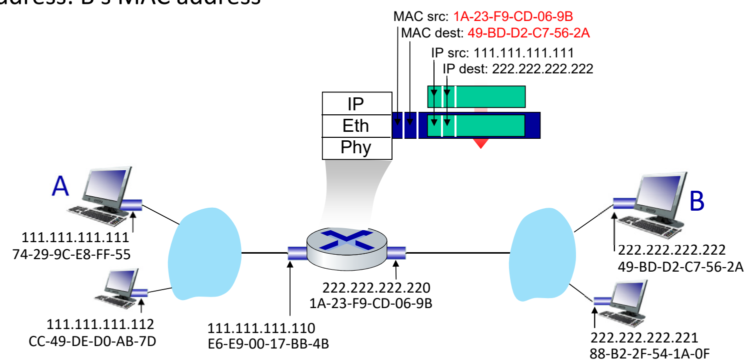
Routing to another subnet: addressing

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



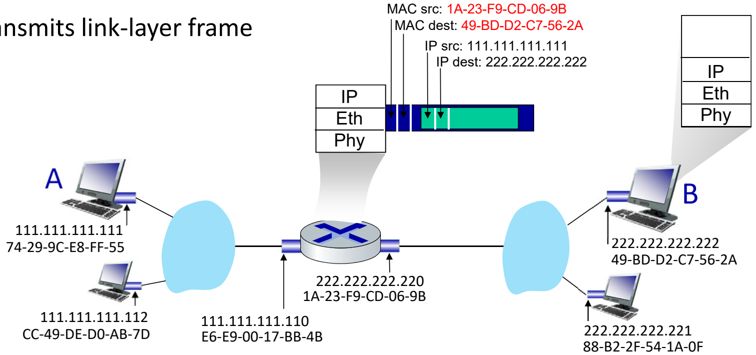
Routing to another subnet: addressing

- 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



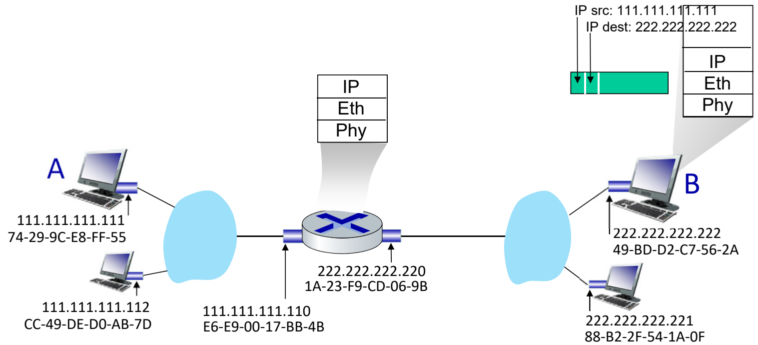
Routing to another subnet: addressing

- 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



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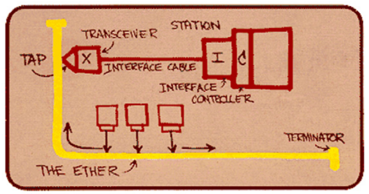
Ethernet

"dominant" wired LAN technology:

- first widely used LAN technology
- simpler, cheap
- kept up with speed race: 10 Mbps – 400 Gbps
- single chip, multiple speeds (e.g., Broadcom BCM5761)

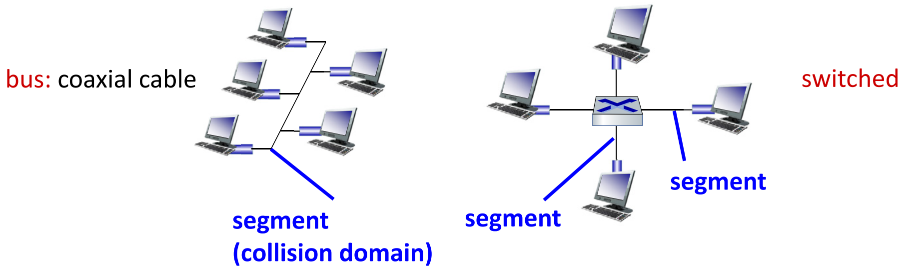


Metcalfe's Ethernet sketch

https://www.uspto.gov/learning-and-resources/journeys-innovation/audio-stories/defying-doubters

Ethernet: physical topology

- bus: popular through mid 90s
  - all nodes in same collision domain (or called "segment" later)
- switched: prevails today
  - *switch* in center (hosts are connected to switches)
  - each segment runs a (separate) Ethernet protocol
    - store-and-forward (frames are stored in a switch and then forwarded)
    - (different) segments do not collide with each other



Ethernet frame structure

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

preamble	dest. address	source address	type	data (payload)	CRC

preamble:

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

Ethernet frame structure (more)

preamble	dest. address	source address	type	data (payload)	CRC

- 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)
  - used to demultiplex up at receiver
- CRC: cyclic redundancy check at receiver
  - error detected: frame is dropped

Ethernet: unreliable, connectionless

- connectionless: no handshaking between sending and receiving NICs
- Ethernet's MAC protocol: unslotted CSMA/CD with binary backoff
  - backoff and retransmit
- unreliable: receiving NIC doesn't send ACKs or NAKs to sending NIC
  - data in dropped frames recovered only if initial sender uses higher layer rdt (e.g., TCP), otherwise dropped data lost

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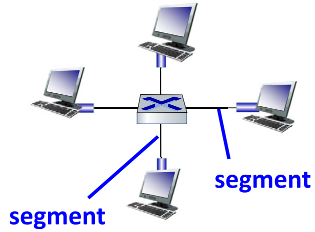
Ethernet switch



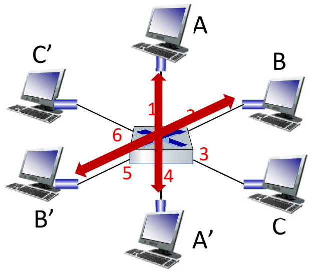
- switch is a link-layer device
  - store and forward Ethernet frames
    - based on incoming frame's destination MAC address
  - when frame is to be forwarded on a segment, uses CSMA/CD to access the segment
- switch is transparent:
  - in layer 3, hosts unaware of the presence of switches
- switch is plug-and-play, self-learning
  - switches do not need to be configured

Switch: multiple simultaneous transmissions

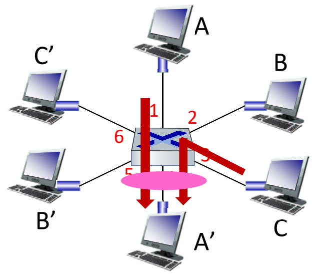
- hosts often have dedicated, direct connection to switch
- switches buffer packets
- Ethernet's MAC protocol used on *each* incoming link, so:
  - each link is its own collision domain
  - de facto collision-free and full-duplex
    - since 10Base-T (10Mbps rate)

Switch: multiple simultaneous transmissions

- A-to-A' and B-to-B' can transmit simultaneously, without collisions



- but A-to-A' and C to A' *can't* happen simultaneously



Switch forwarding table

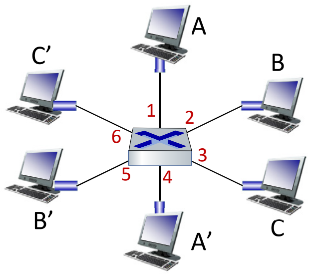
Q: how does switch know A' reachable via interface 4, B' reachable via interface 5?

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

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

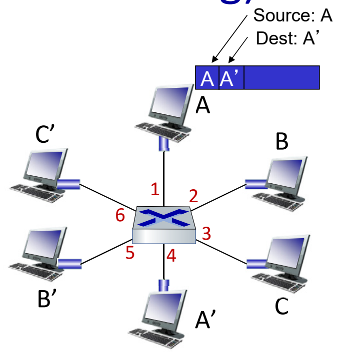
Q: how are entries created, maintained in switch table?

- something like a routing protocol? No!



Switch: self-learning (backward 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

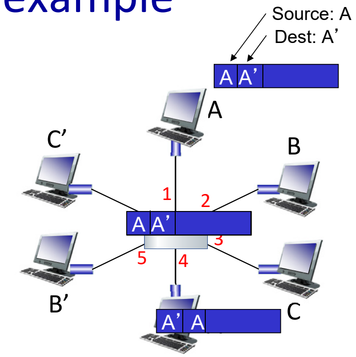


MAC addr	interface	TTL
A	*1*	*60*

Switch table (initially empty)

Self-learning, forwarding: example

- if switch table has no entry for the frame destination (e.g. A') → flood (except the incoming link)
- if switch table has an entry for the frame destination → send on just one link

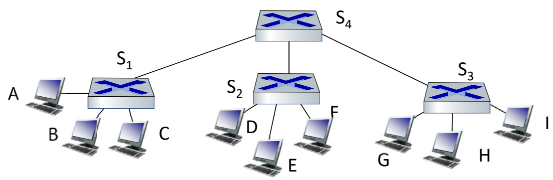


MAC addr	interface	TTL
A *A'*	*1* *4*	*60* *60*

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!)
  - no loop (because in a LAN, all links that cause loops are disabled)