Link Layer

CS5700 Fall 2019

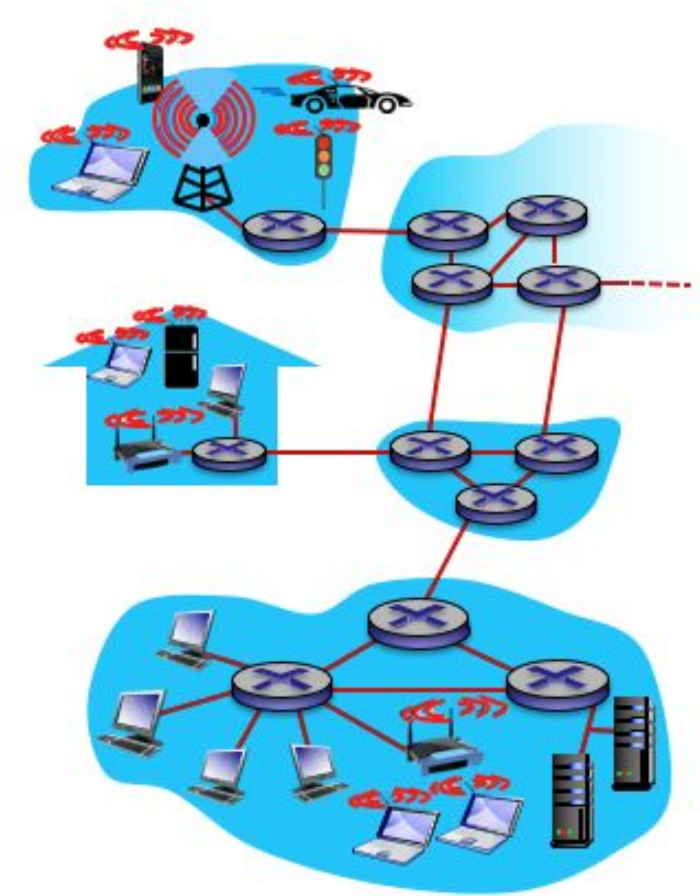
Agenda

- Overview
- Error detection
- Multiple access protocols
- LANs
    - addressing, ARP, Ethernet, switches
- Put everything together!

Overview

Overview

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

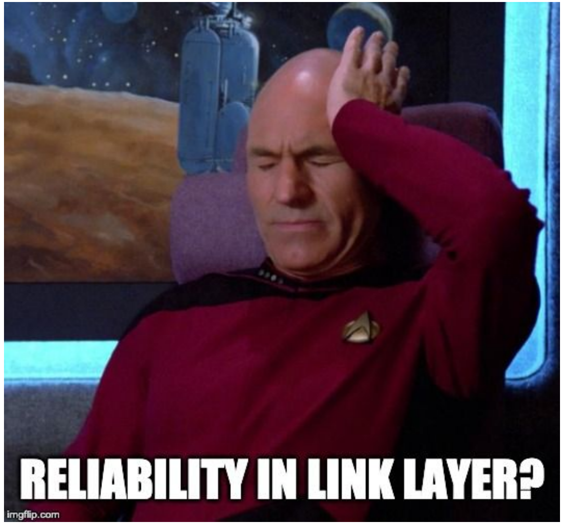


Link layer services

- Framing, link access
    - Encapsulate datagram into frame (header & trailer)
    - Channel access if shared medium
    - MAC address used in frame header to identify source and destination
        - Another address?
- Error detection

Link layer services

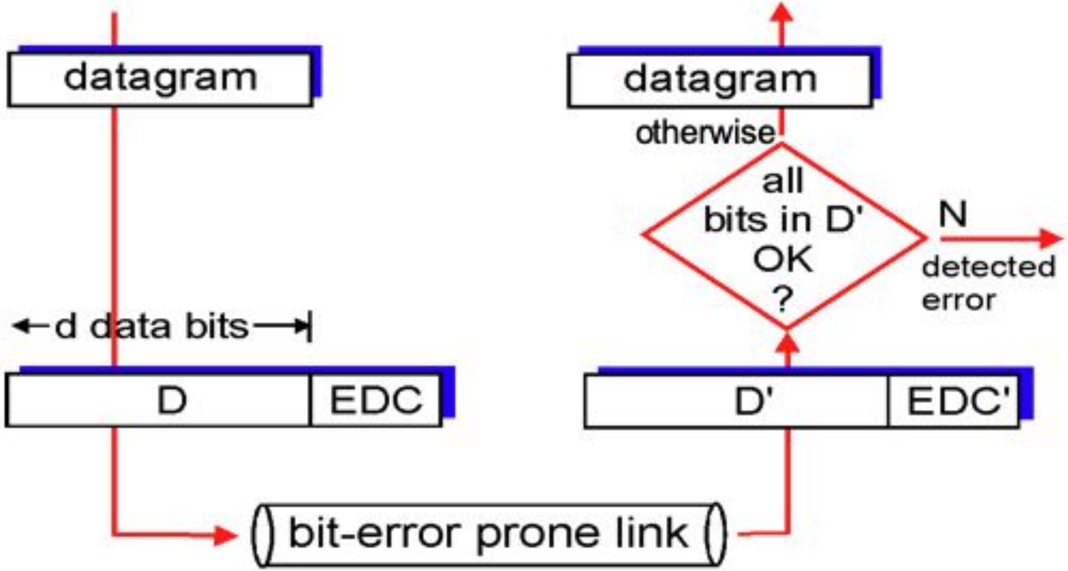
- Reliable delivery between adjacent nodes
  - We learned how to do this in transport layer!
  - Do we need reliability in link layer?



Error detection

Error detection

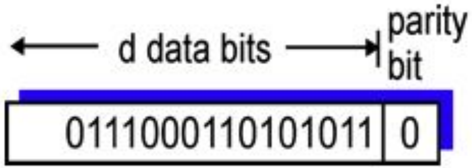
- EDC = Error Detection and Correction bits (redundancy)
- D = Data protected by error checking



Parity checking

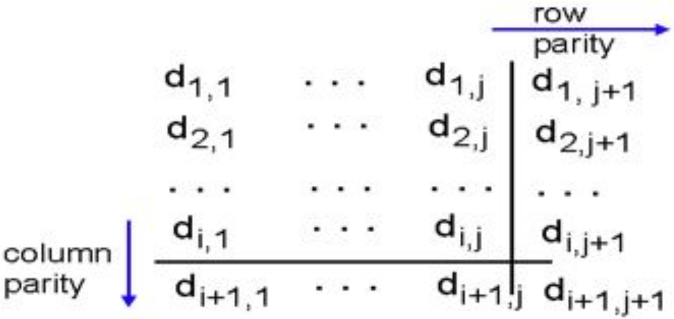
single bit parity:

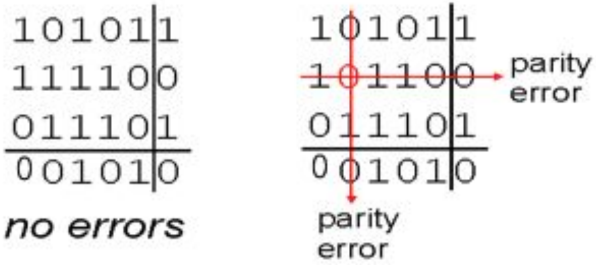
- detect single bit errors



two-dimensional bit parity:

- detect and correct single bit errors



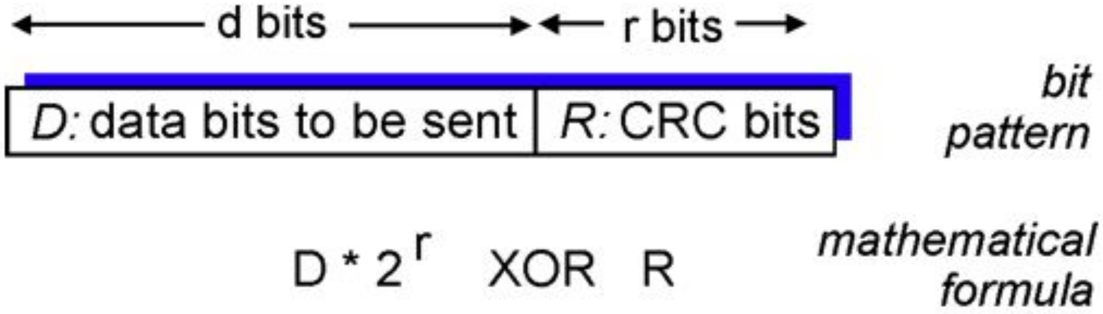


Internet checksum

- Treat data as sequence of 16-bit integers
- Checksum is addition of integers using 1’s complement
- Good to detect burst errors, but not very good in general

CRC

- Cyclic redundancy check
- More powerful error detection coding
- View data bits, D, as a binary number
- Choose r+1 bit pattern G (generator)
- Goal: choose r CRC bits, R



CRC example

want:

$D \cdot 2^r$ XOR $R = nG$

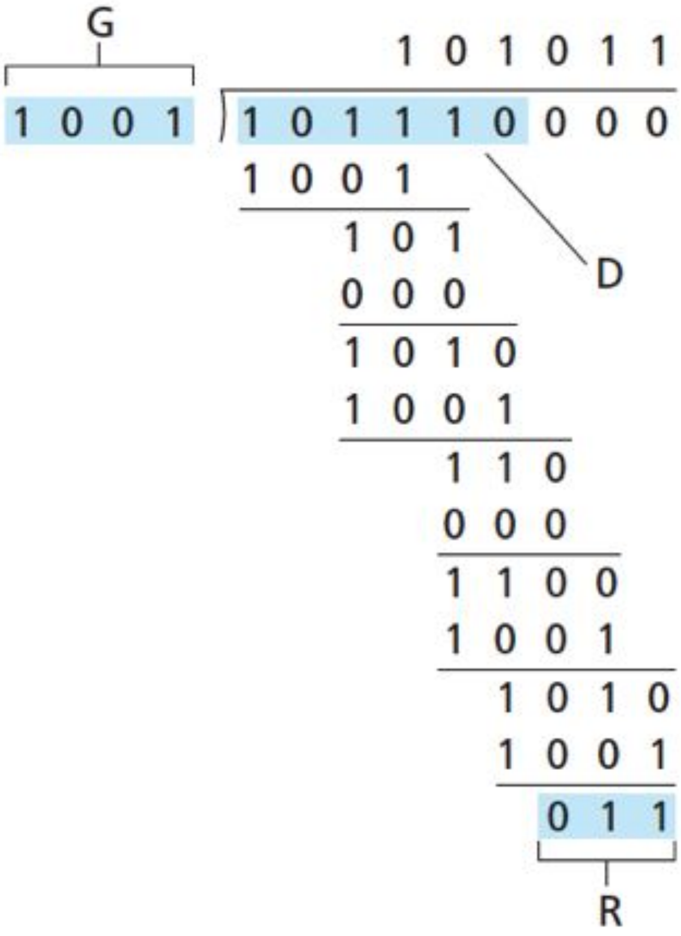
equivalently:

$D \cdot 2^r = nG$ XOR R

equivalently:

if we divide $D \cdot 2^r$ by G, want remainder R to satisfy:

$$\boxed{R = remainder[\frac{D \cdot 2^r}{G}]}$$



Multiple access protocols

Multiple access protocols

- Two types of links
  - point-to-point
    - e.g. PPP for dial-up access
  - broadcast
    - e.g. wireless LAN
    - two or more simultaneous transmissions can cause interference
    - need to deal with collision

Multiple access protocols

- Distributed algorithm that determines how nodes share channel
- Communication about channel sharing must use channel itself
    - no out-of-band channel for coordination

An ideal multiple access protocol

- Given broadcast channel of rate R bps
- Desired criteria
  - When one node wants to transmit, it can send at rate R
  - When M nodes want to transmit, each can send at average rate R/M
  - Fully decentralized (no special node to coordinate)
  - Simple

Multiple access protocol taxonomy

- Channel partitioning
  - divide channel into smaller “pieces” (e.g. by time or frequency)
- Random access
  - channel not divided, allow collisions
  - “recover” from collisions

Random access protocols

- When node has packet to send
  - transmit at full channel data rate R
  - no a priori coordination among nodes
- Two or more transmitting nodes means “collision”
- Random access protocol specifies
  - how to detect collisions
  - how to recover from collisions

Random access protocols

- Slotted ALOHA
- Pure ALOHA
- CSMA
- CSMA/CD

Slotted ALOHA

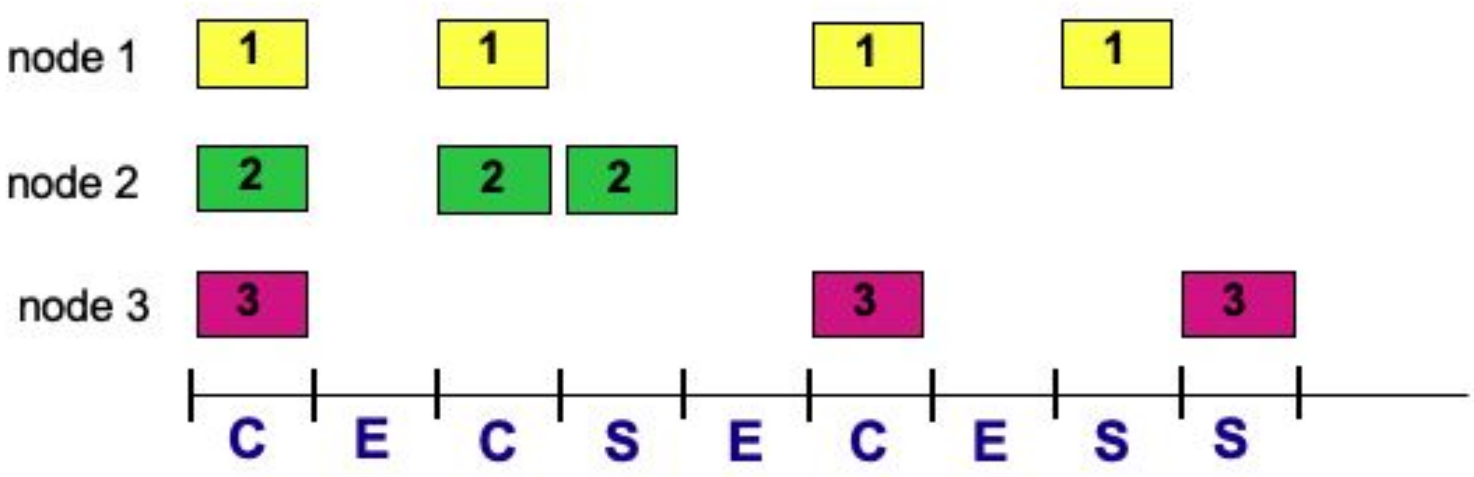
- Assumptions
  - All frames same size
  - Time divided into equal size slots
  - Nodes start to transmit only slot beginning
  - Nodes are synchronized
  - If 2 or more nodes transmit in slot, all nodes detect collision

Slotted ALOHA

- Operation
  - When node obtains fresh frame, transmit in next slot
  - If no collision, node can send new frame in next slot
  - If collision, node retransmits frame in each subsequent slot with probability p until success

Slotted ALOHA

- How good is this protocol?



Slotted ALOHA

- Pros
  - Single active node can continuously transmit at full rate of channel
  - Highly decentralized (but synchronization needed)
- Cons
  - Collisions, wasting slots
  - Clock synchronization
- How efficient is slotted ALOHA

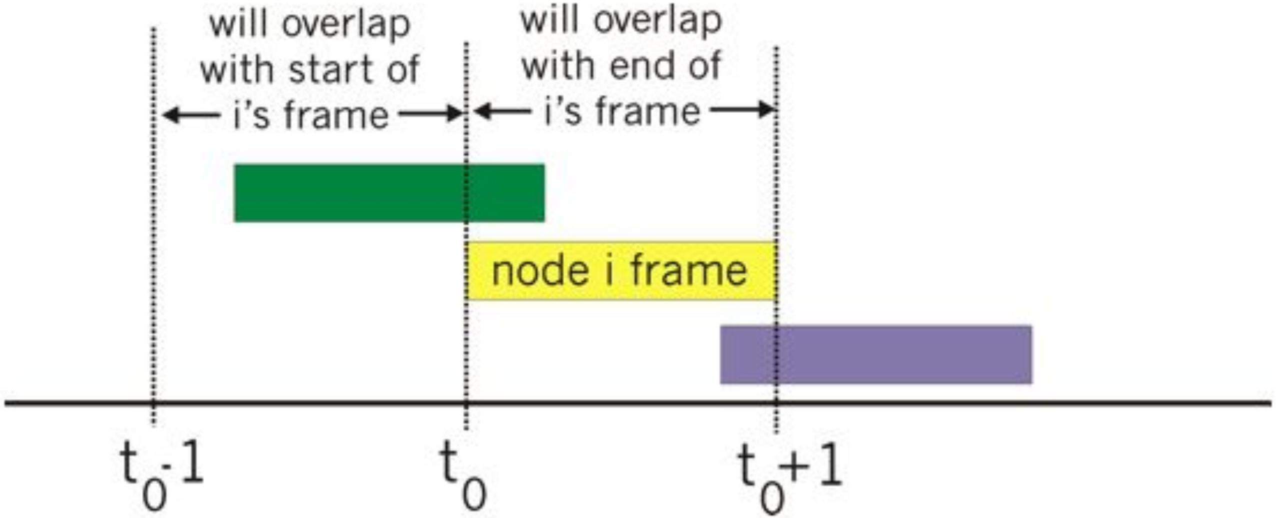
Slotted ALOHA efficiency

at best: channel used for useful transmissions 37% of time!

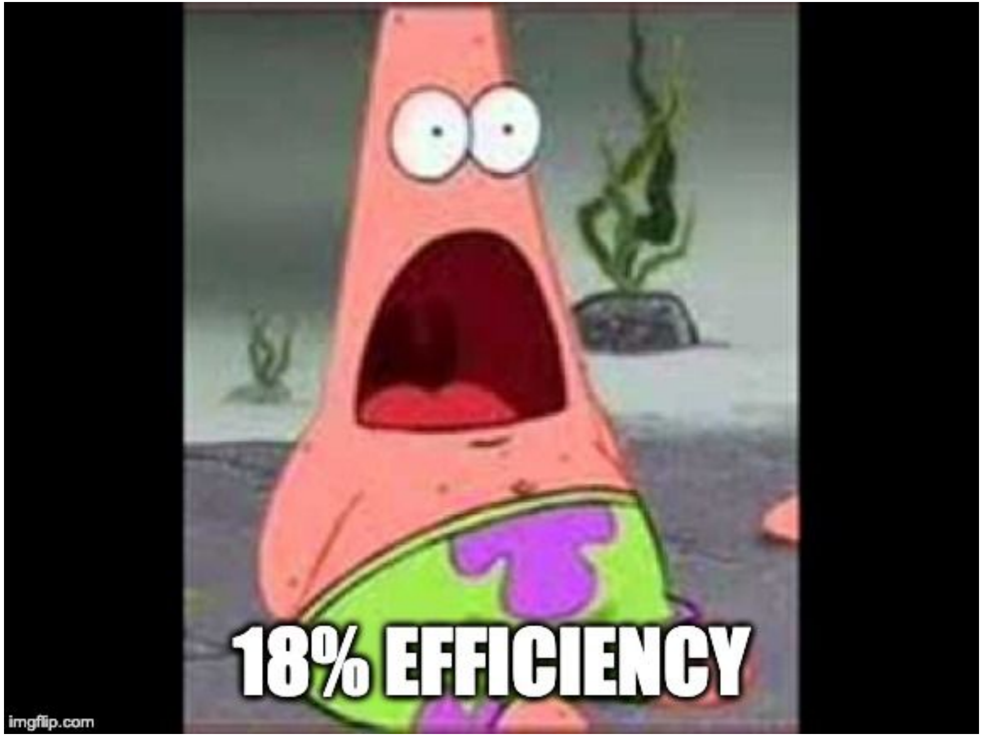
!

Pure (unslotted) ALOHA

- Unslotted ALOHA is simpler, no synchronization
- When frame first arrives, transmit immediately



Pure ALOHA efficiency



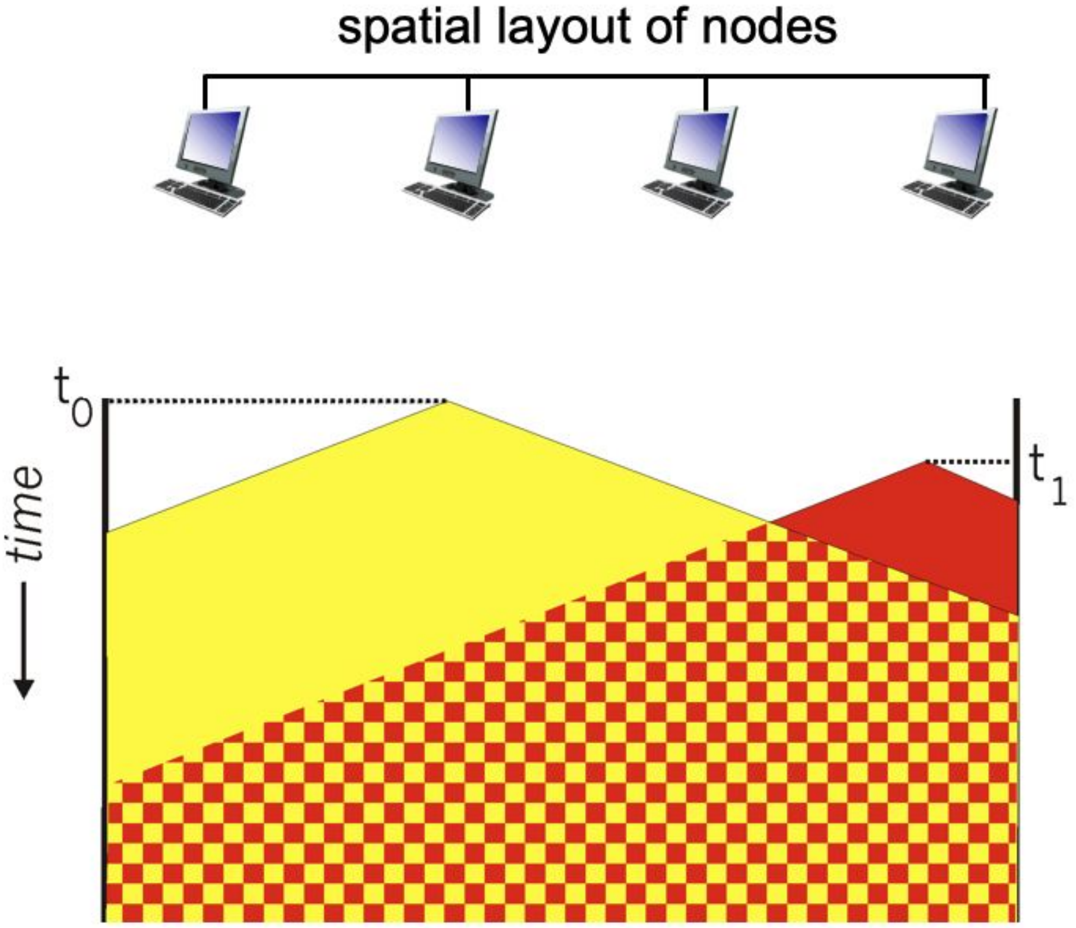
How to improve?

CSMA

- Carrier Sense Multiple Access
- If channel sensed idle, transmit entire frame
- If channel is busy, defer transmission

CSMA collisions

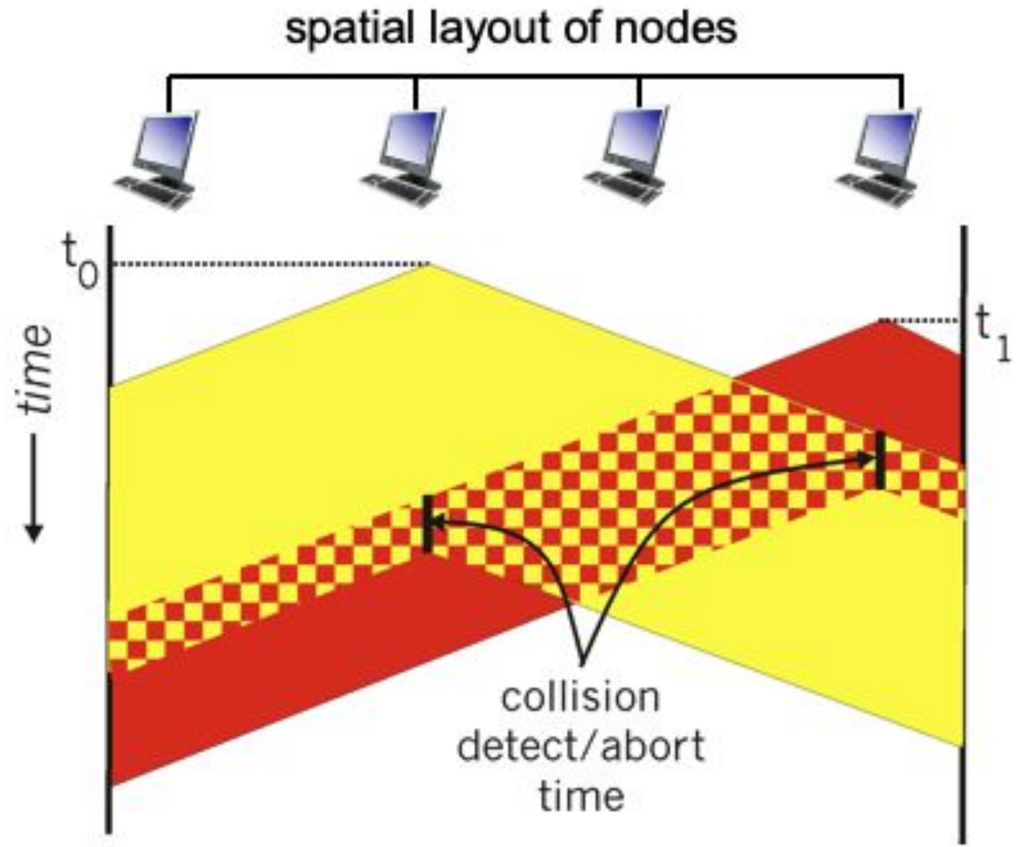
- Collisions can still occur
  - propagation delay



CSMA/CD

- CD stands for collision detection
- When collision is detected, transmissions are aborted to reduce channel wastage

CSMA/CD


spatial layout of nodes
t_0
t_1
time
collision detect/abort time

Ethernet CSMA/CD algorithm

- Receive datagram from network layer, create frame
- If sense channel idle, start frame transmission
- If sense channel busy, wait until channel idle, then start transmission
- If transmit entire frame without detecting another transmission, success!

Ethernet CSMA/CD algorithm

- If detect another transmission while transmitting, abort
- After aborting, retry using exponential backoff
    - after mth collision, choose K at random from $\{0,1,2,\ldots,2^m-1\}$
    - wait K time unit before retransmit (time unit is the time to send 512 bits)
    - longer backoff interval with more collisions

CSMA/CD efficiency

- T_{prop} = max propagation delay between 2 nodes in LAN
- T_{trans} = time to transmit max-size frame
- What happens when T_{prop} increases? Efficiency goes up or down?
- What happens when T_{trans} increases? Efficiency goes up or down?

LANs

MAC address

- 48 bit MAC address burned in NIC ROM, also sometimes software settable
    - e.g. 1A-2F-BB-76-09-AD
    - MAC address allocation administered by IEEE
- Used “locally” to get frame from one interface to another physically-connected interface (aka same network)

ARP

- Address Resolution Protocol
  - determine interface’s MAC address knowing its IP address
- Each node maintains ARP table
  - IP to MAC address mappings for nodes in the same LAN (<IP address, MAC address, TTL>)

Packet delivery in the same LAN

- A wants to send datagram to B
- A checks its ARP table using B’s IP address
  - assume this mapping is in ARP table
- A use B’s MAC address to create link layer frame and transmit
- B’s NIC detects this frame has its MAC address as destination, will pick it up and deliver to upper layer protocol


WHAT IF IT'S NOT IN ARP TABLE?
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Discover MAC address

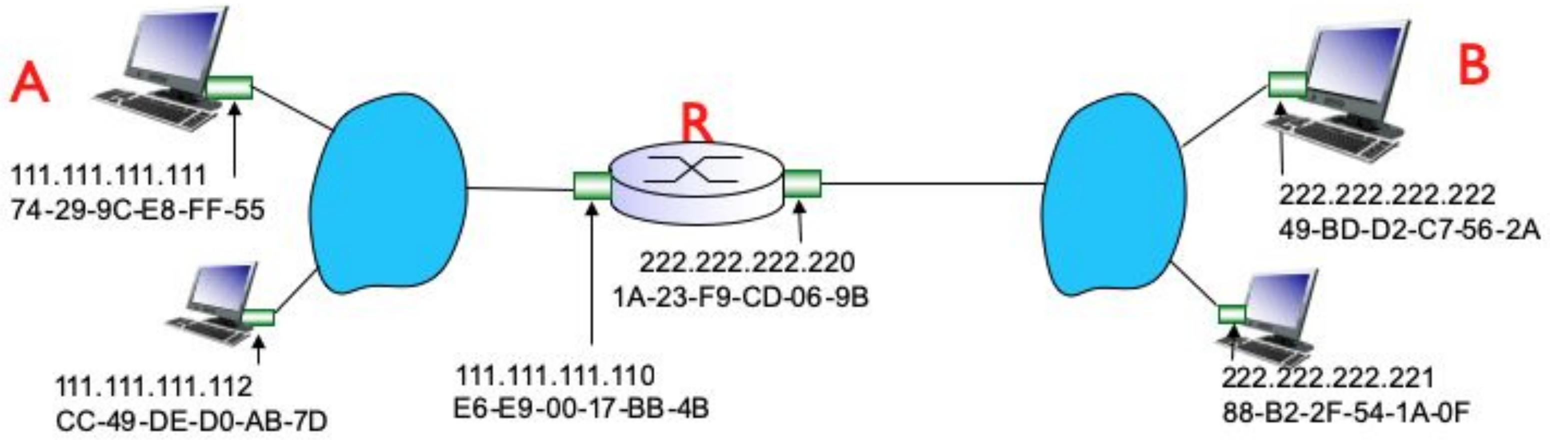
- A wants to find out B’s MAC address
- A broadcasts ARP query packet, containing B’s IP address
  - destination MAC address is FF-FF-FF-FF-FF-FF
  - all nodes on the same LAN will receive ARP query
- B receives ARP packet, replies to A with MAC address
- A saves IP-to-MAC address to ARP table

Packet delivery in the same LAN

- No routing involved
- No need to look up forwarding table
- Use ARP table lookup MAC address and send frame directly

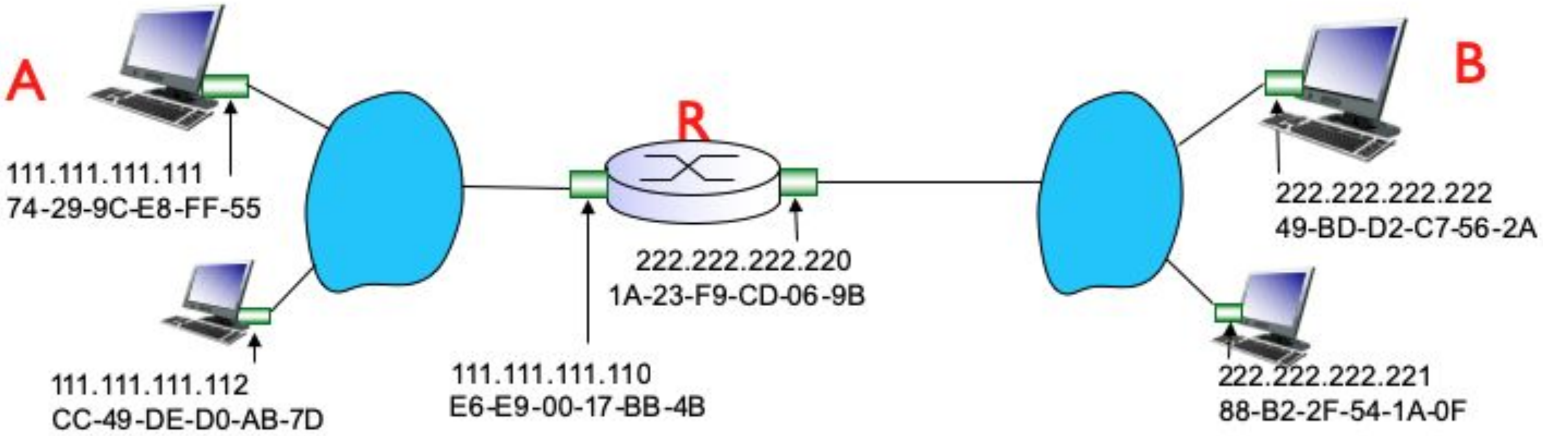
Packet delivery to another LAN

- A sends datagram to B



Packet delivery to another LAN

- Assume A knows IP address of first hop router R (how?)
- Assume A knows the MAC address of R (how?)




PAY ATTENTION!
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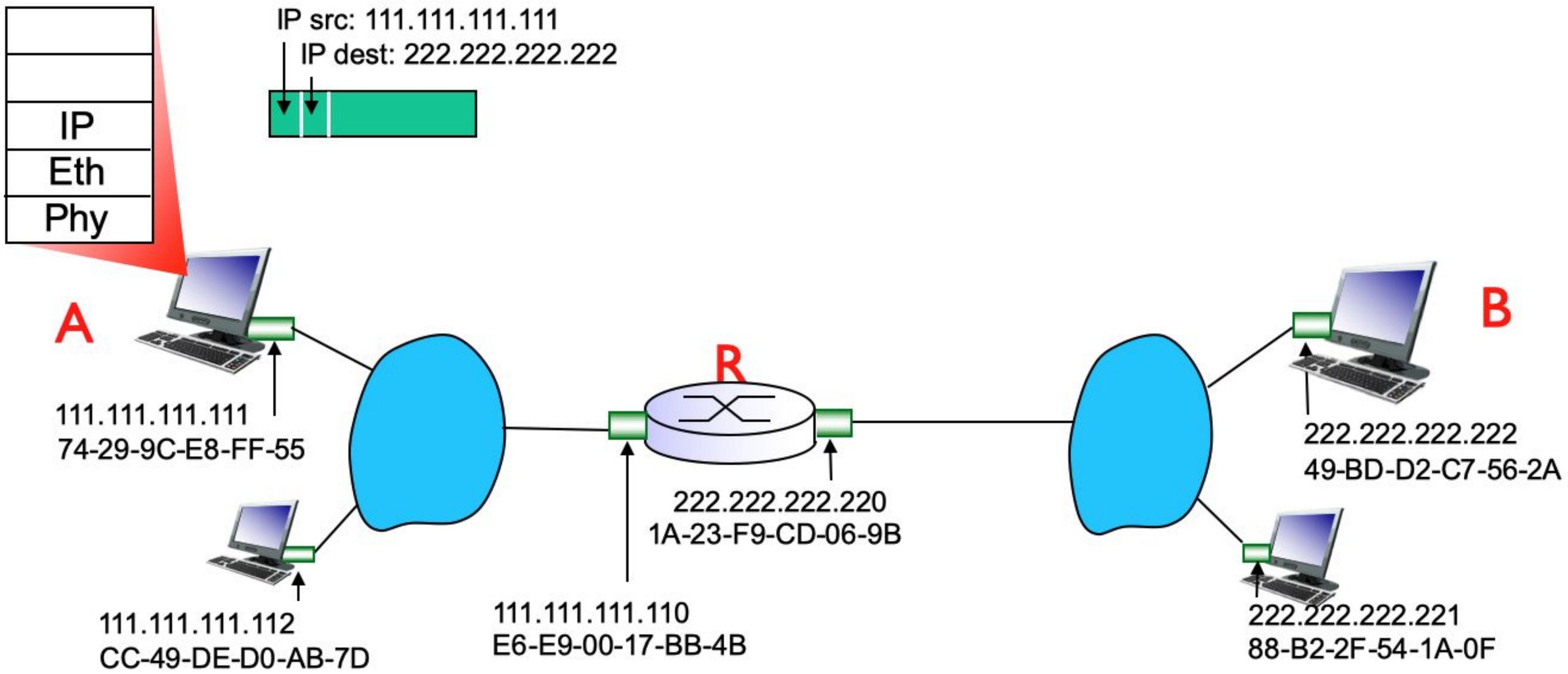
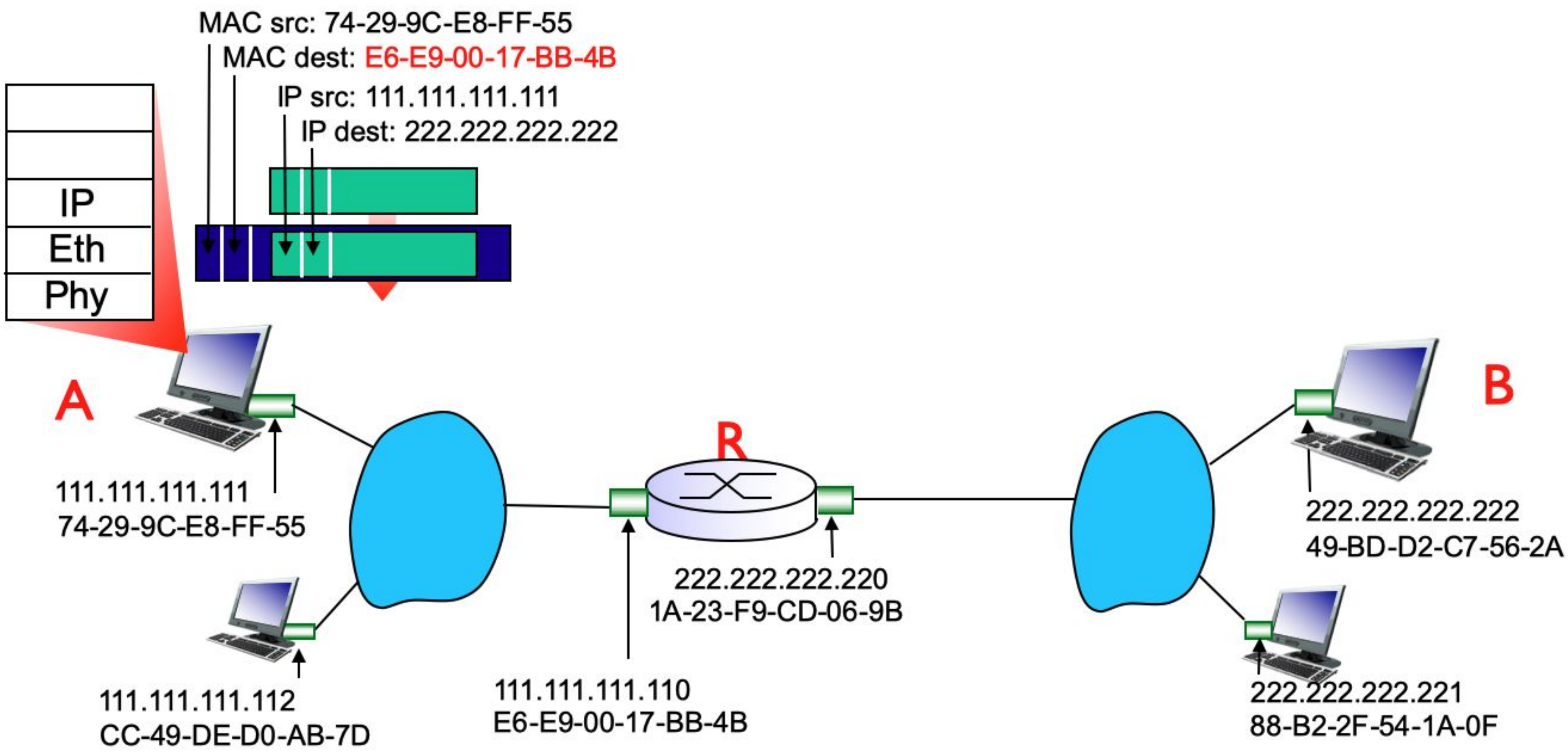

IP src: 111.111.111.111
IP dest: 222.222.222.222
IP
Eth
Phy
A
R
B
111.111.111.111
74-29-9C-E8-FF-55
111.111.111.112
CC-49-DE-D0-AB-7D
111.111.111.110
E6-E9-00-17-BB-4B
222.222.222.220
1A-23-F9-CD-06-9B
222.222.222.222
49-BD-D2-C7-56-2A
222.222.222.221
88-B2-2F-54-1A-0F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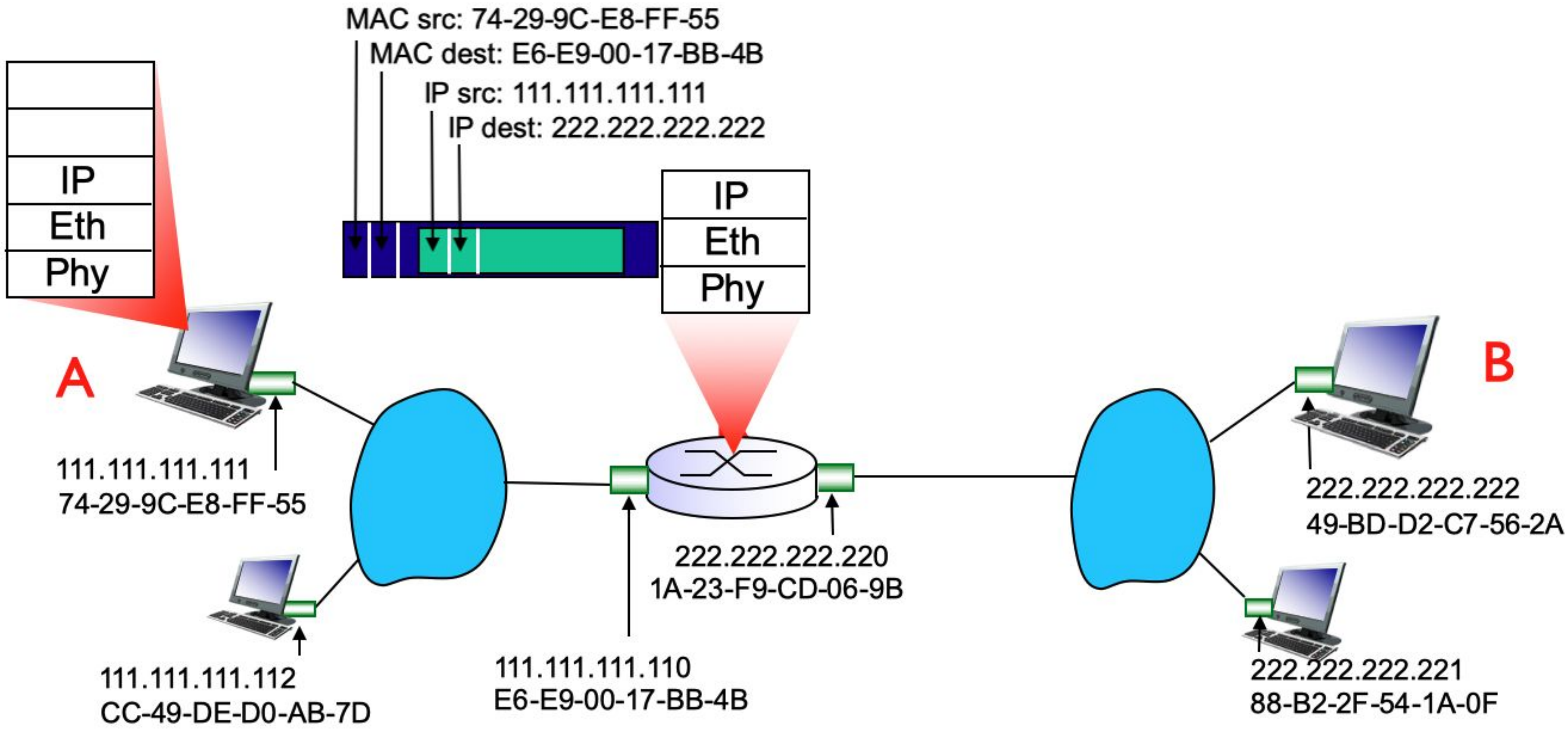
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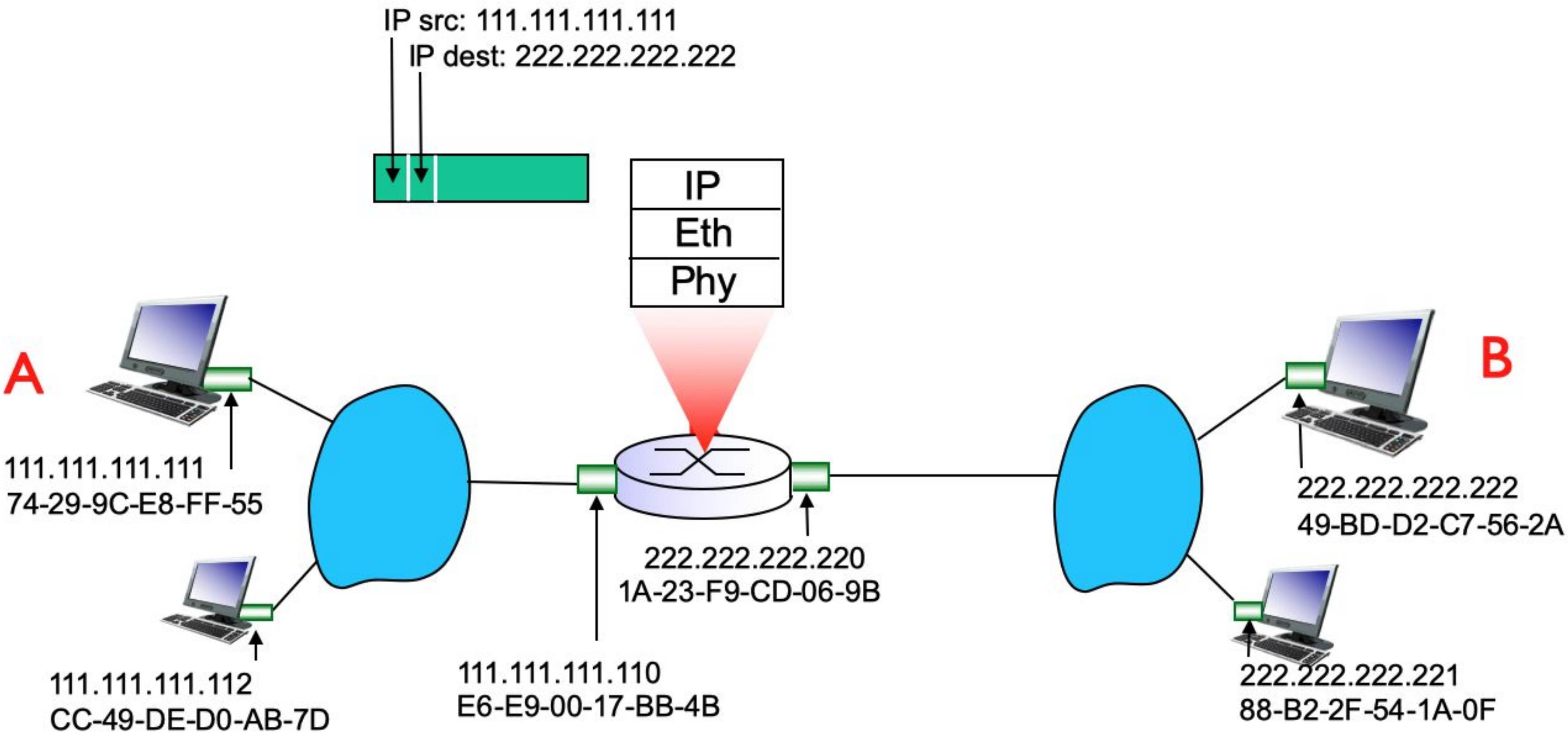
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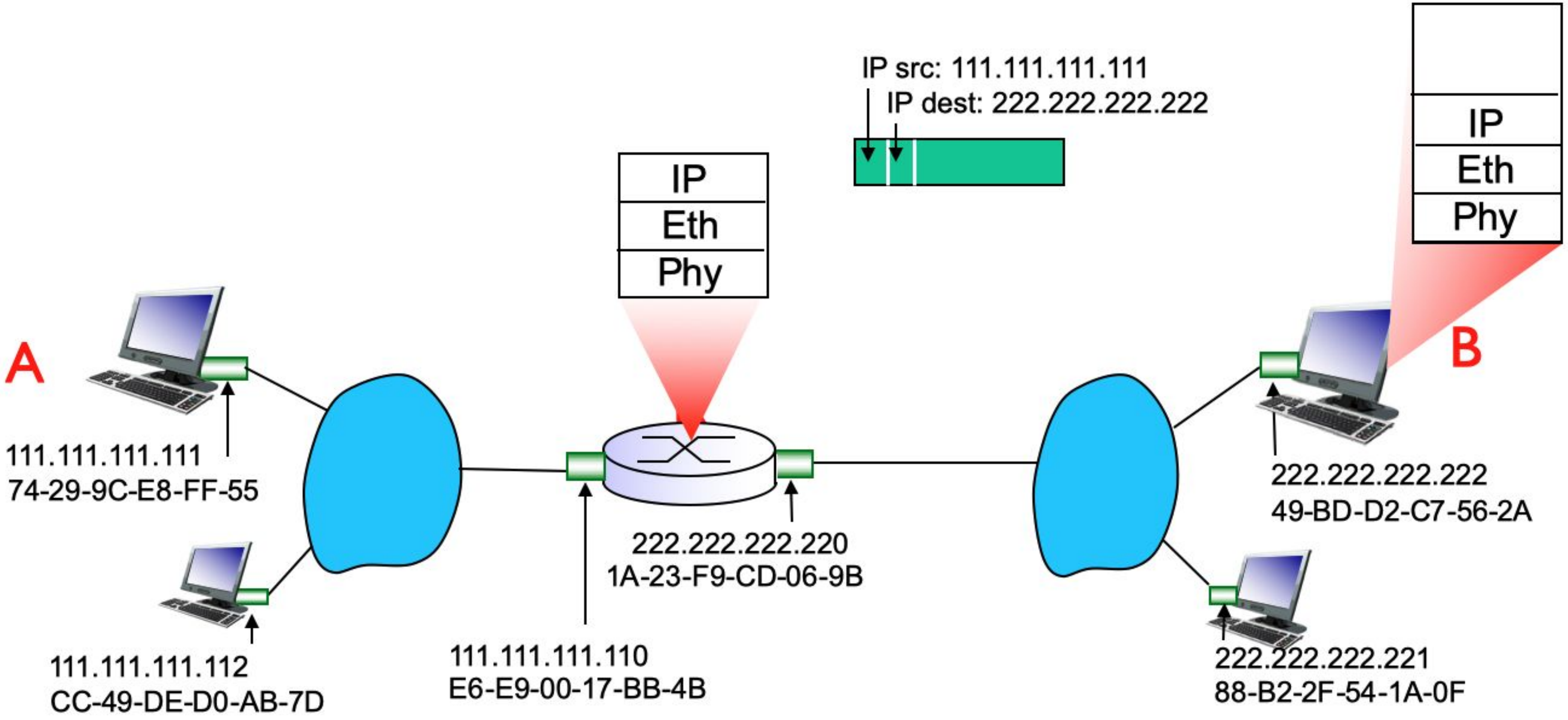
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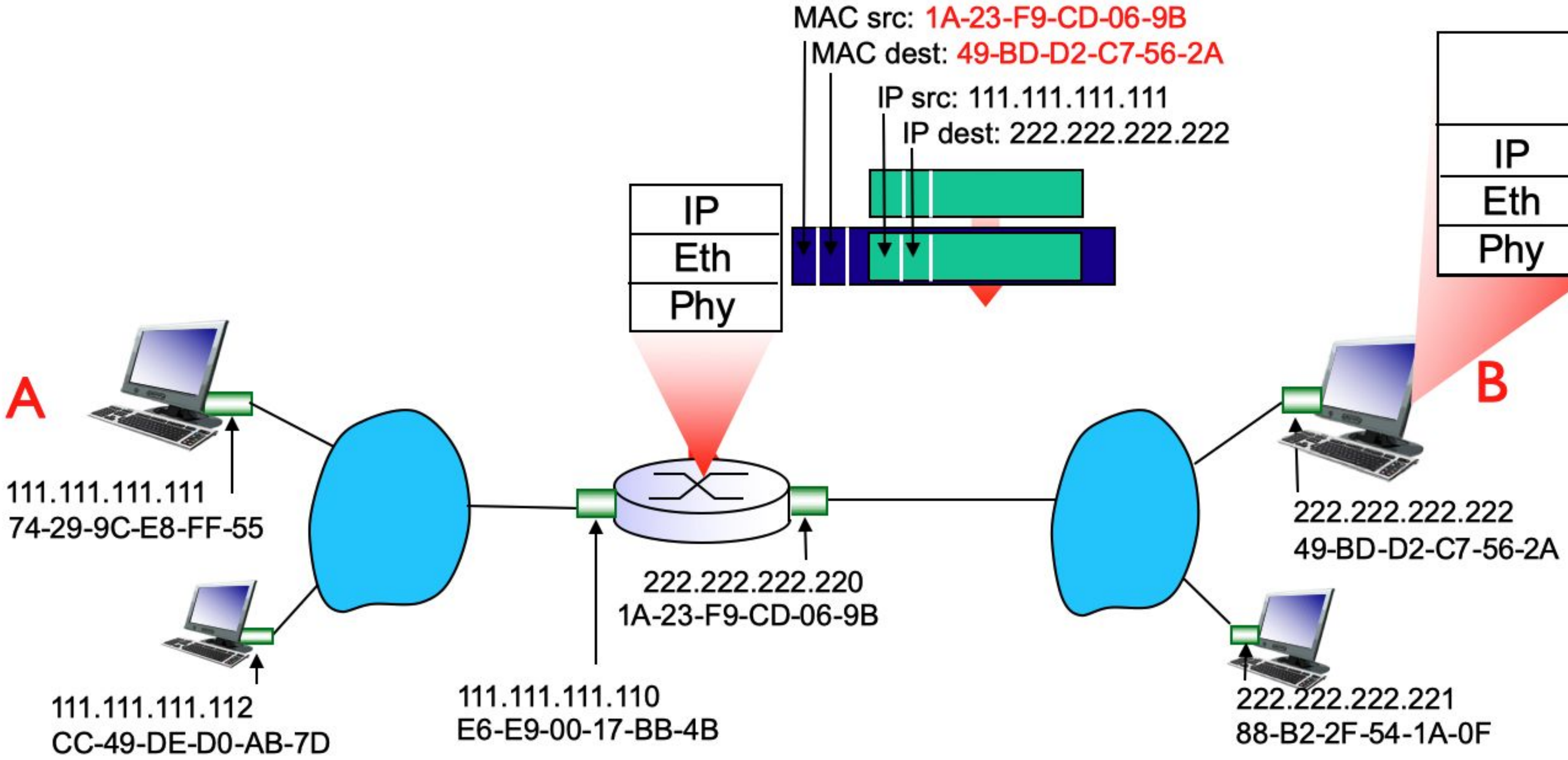
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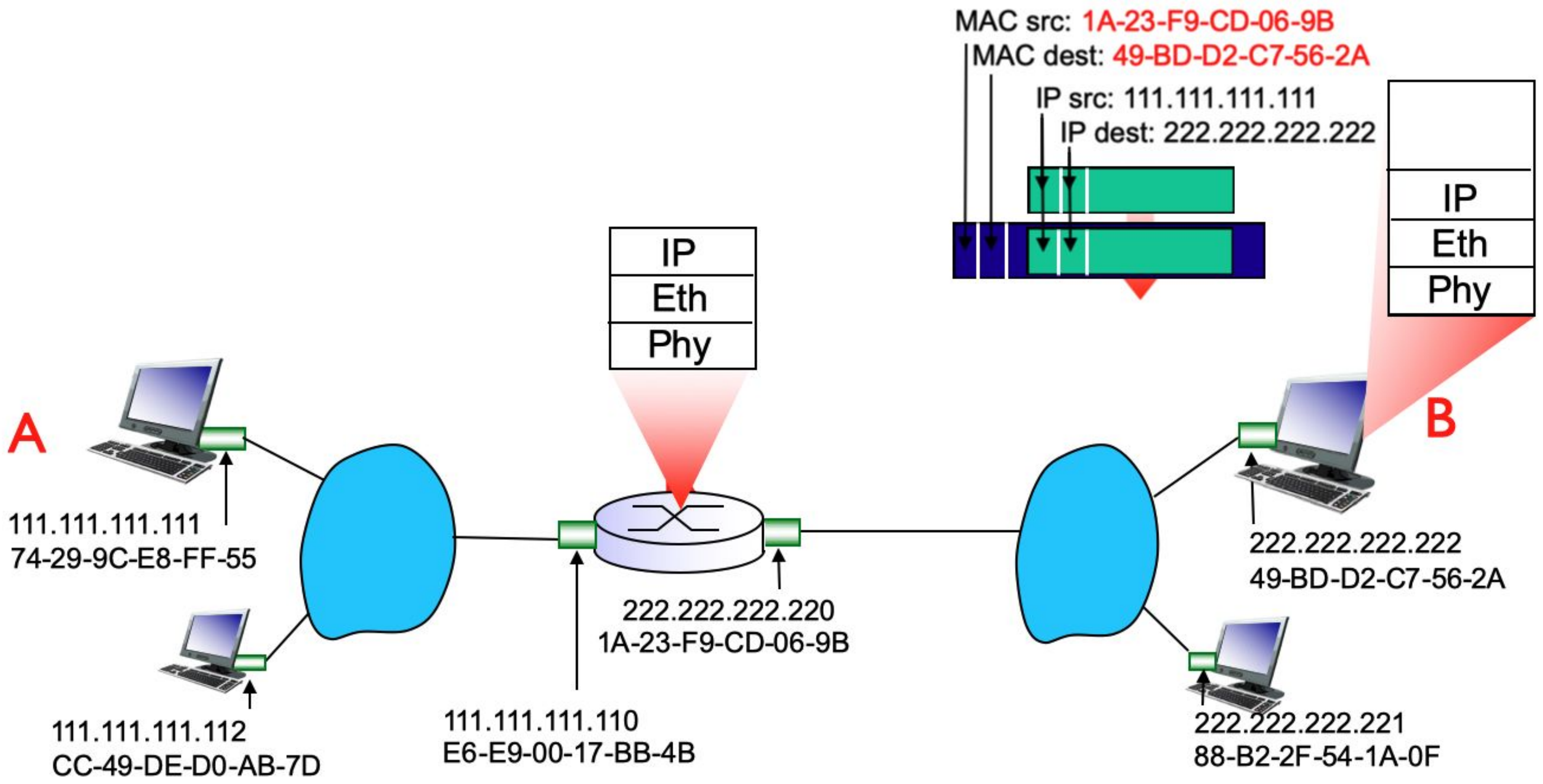

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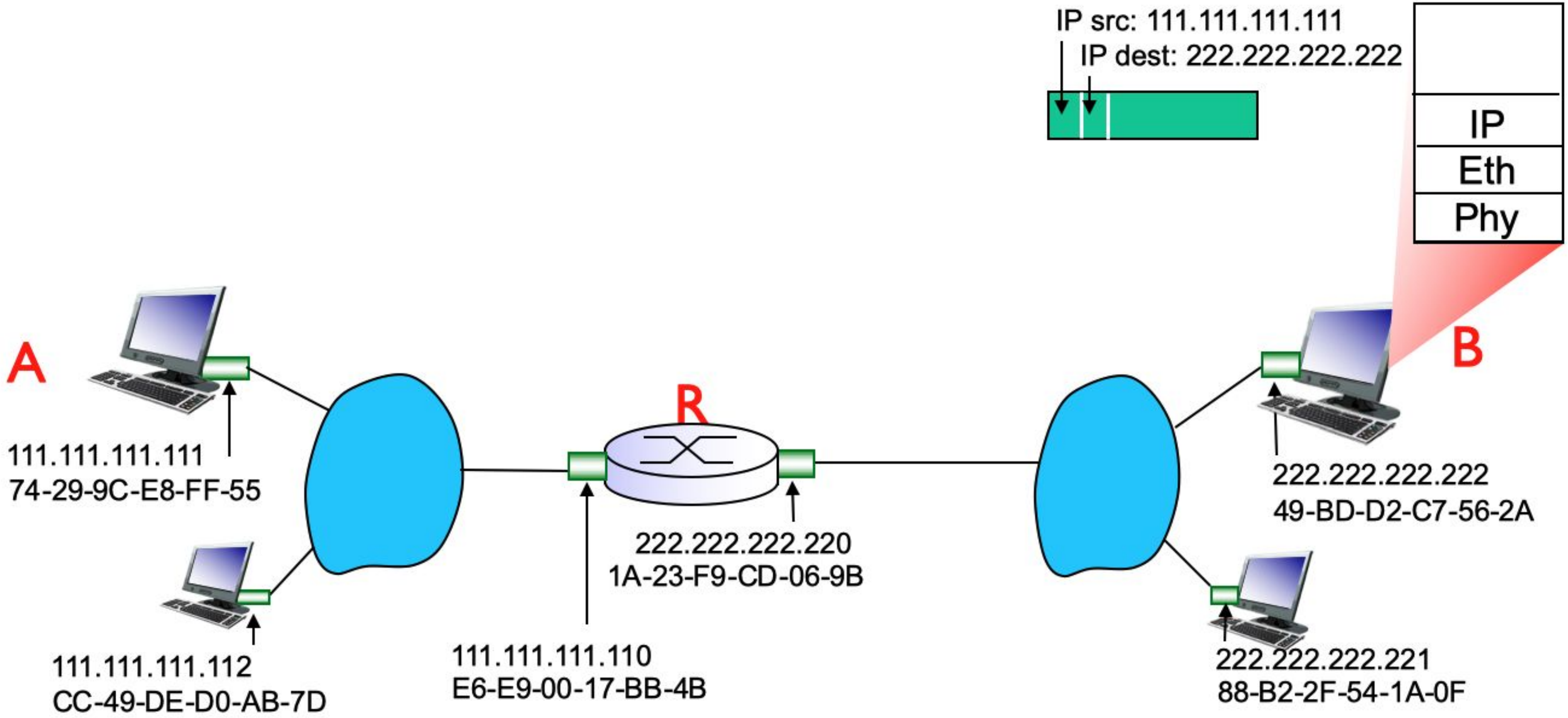
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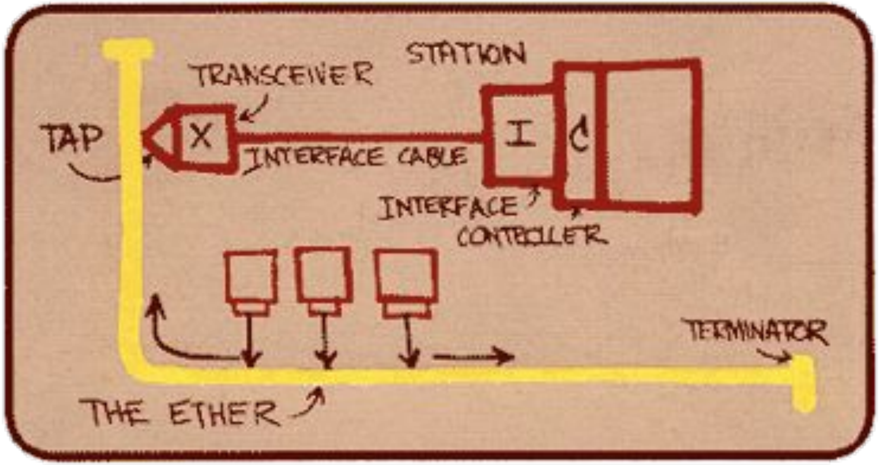
222.222.222.222
49-BD-D2-C7-56-2A
222.222.222.221
88-B2-2F-54-1A-0F

Any questions?

Ethernet

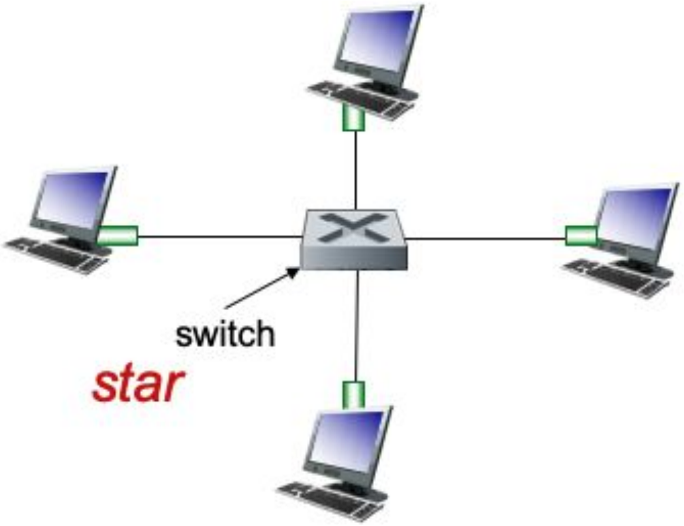
- Dominant wired LAN technology
- Simple, cheap
- Kept up with speed race: 10 Mbps - 10 Gbps



Physical topology

- bus: popular through mid 90s
- star: prevails today

bus: coaxial cable



star

Ethernet frame structure

- preamble: used synchronize sender/receiver clock
- address: MAC addresses for source and destination
- type: upper layer protocol
- CRC: error detection

Ethernet

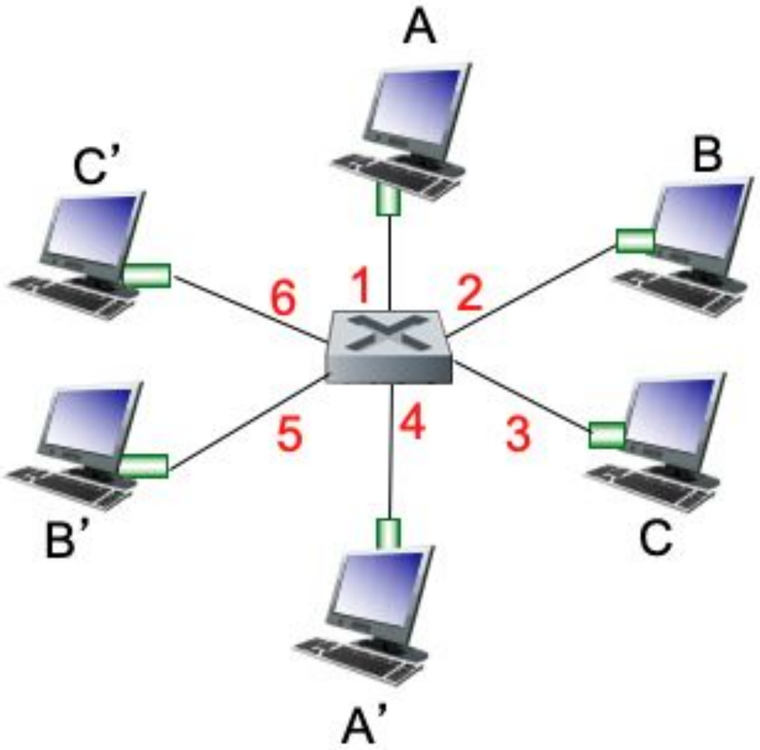
- Connectionless: no handshake between sending and receiving NICs
- Unreliable: receiving NIC doesn’t send ACK or NACK to sending NIC
- Use CSMA/CD

Switch

- Link layer device
  - Store and forward Ethernet frames
  - Examine incoming frame's MAC address, selectively forward frame to one or more outgoing links
- Transparent
  - Hosts are unaware of presence of switches
- Plug-and-play
  - Switches do not need to be configured

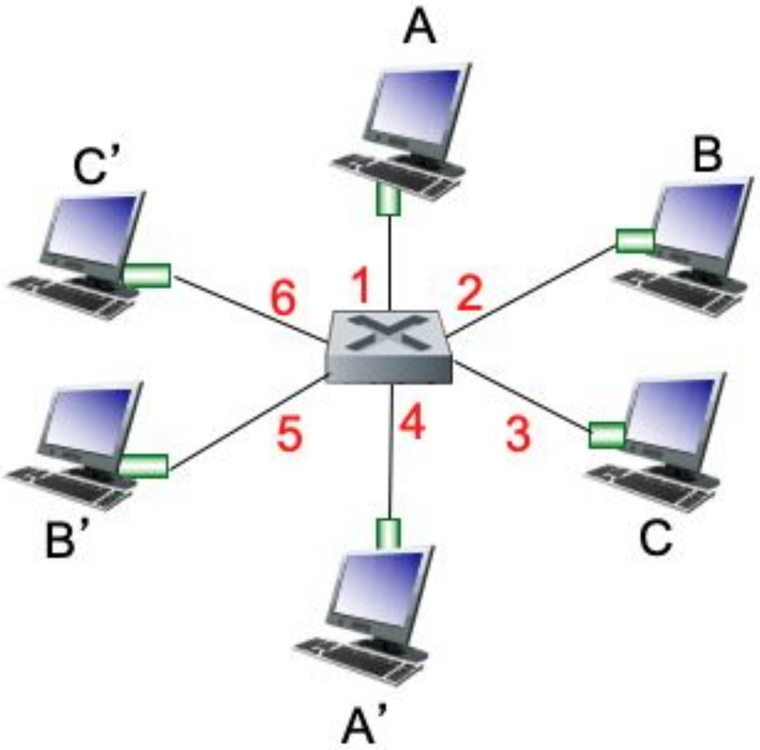
Switch

- Hosts have dedicated, direct connection to switch
- Switch buffers packets



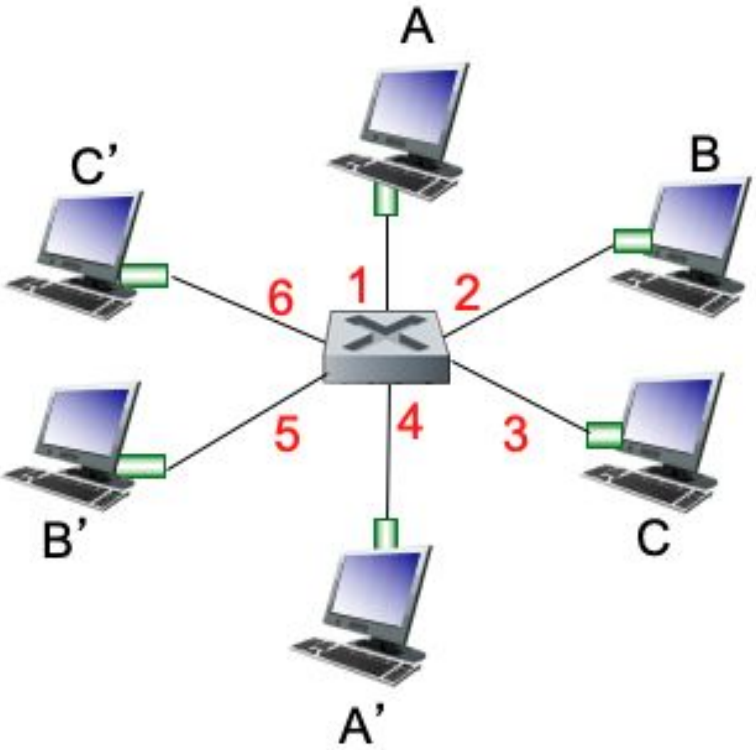
Switch

- Ethernet protocol is used on each link
  - each link is its own collision domain
  - A-to-A’ and B-to-B’ can transmit simultaneously without collisions



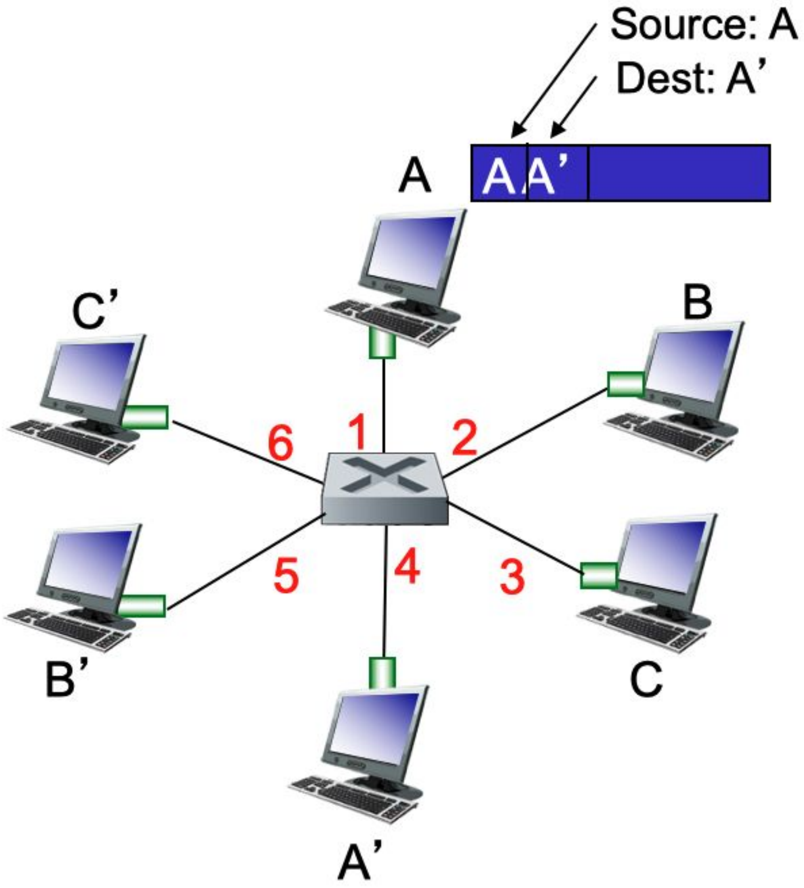
Switch forwarding table

- How does switch know A' reachable via interface 4, B' reachable via interface 5?
- There is a switch forwarding table with MAC address to host mapping
- How is table created and maintained?



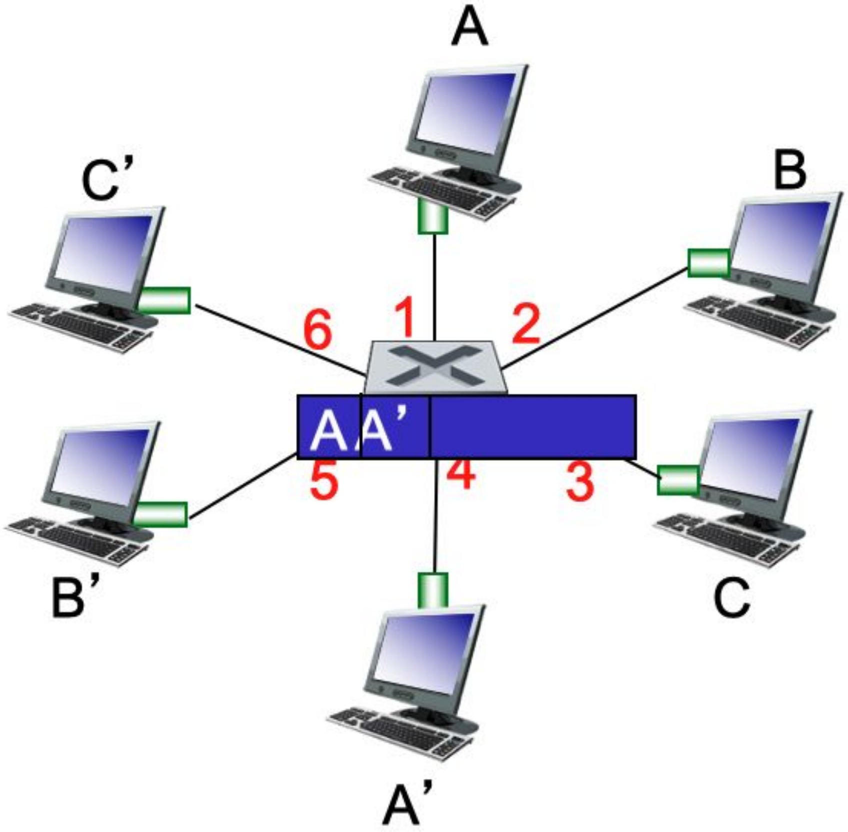
Self-learning

MAC addr	interface	TTL



Self-learning

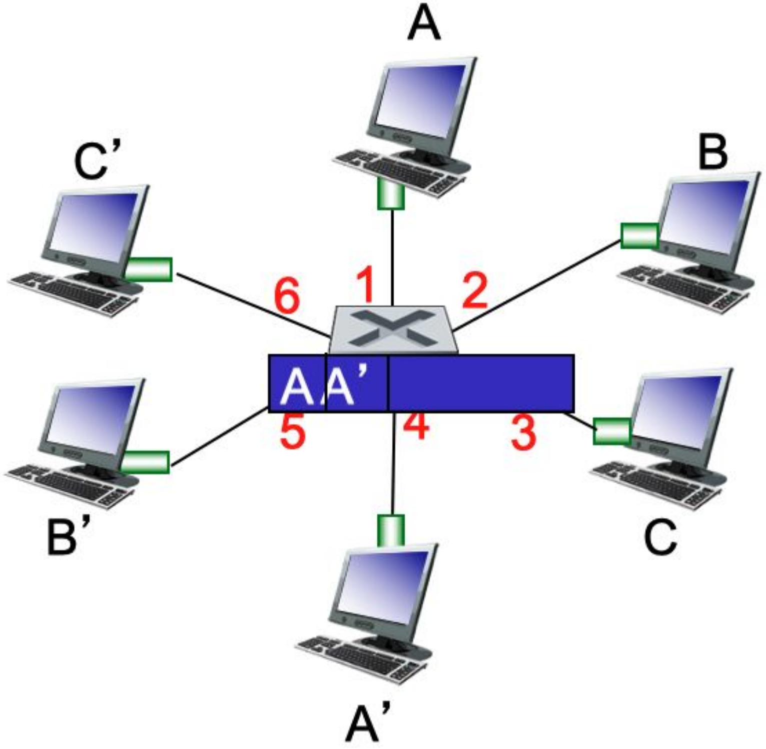
MAC addr	interface	TTL
A	*1*	*60*



Forwarding

- Destination is A’. What to do?

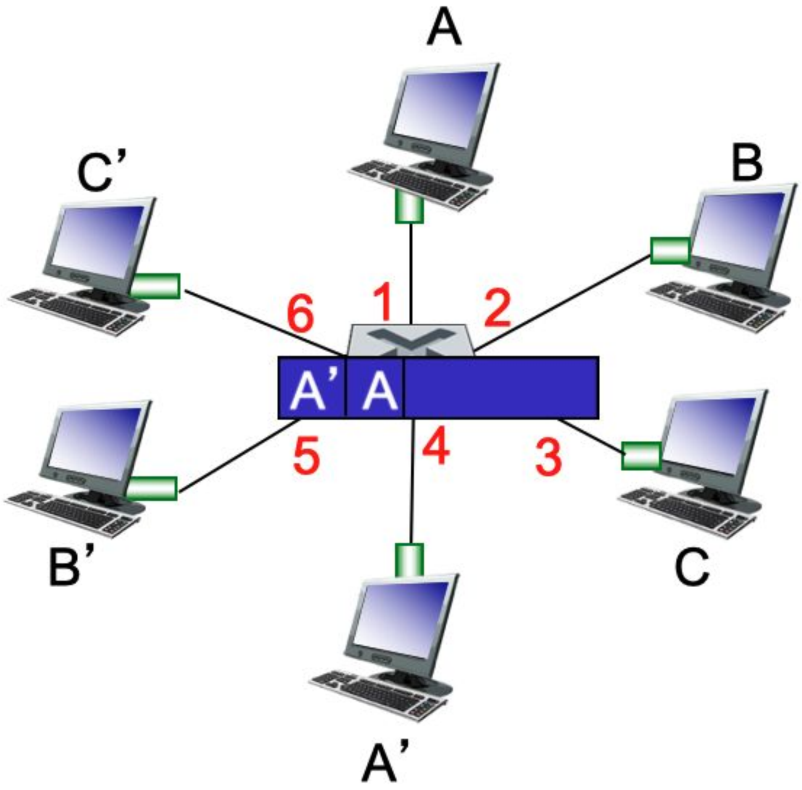
MAC addr	interface	TTL
A	*1*	*60*



Forwarding

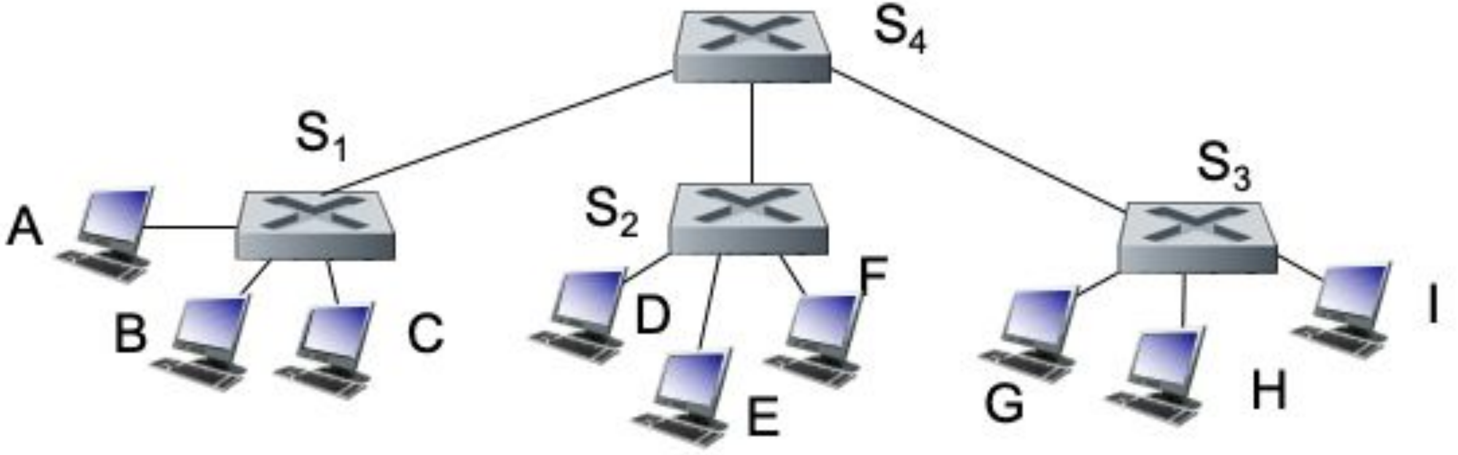
- Destination is A. What to do?

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



Interconnecting switches

- Self-learning switches can be connected together

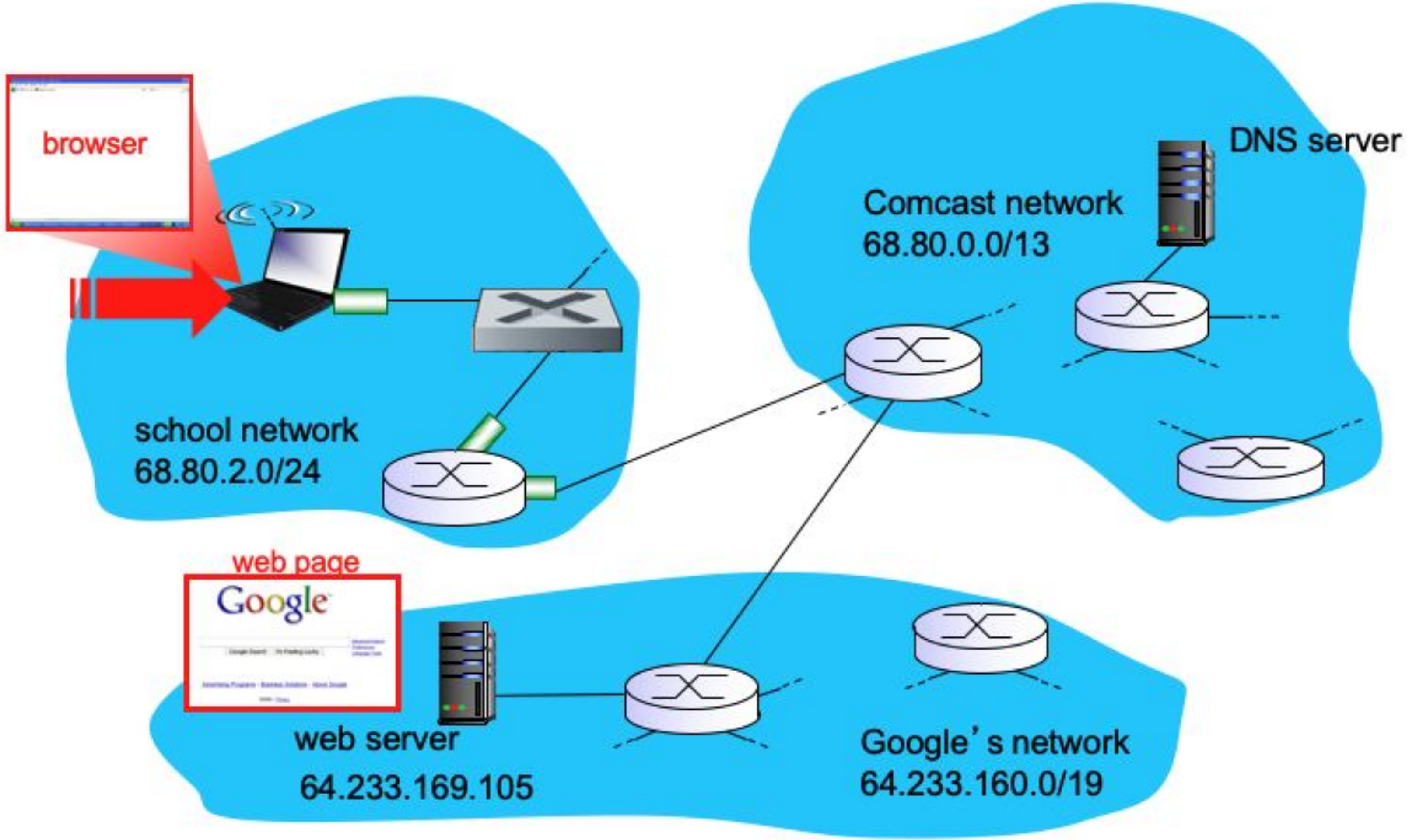


Switch vs router

- Both are store-and-forward
    - router: network layer device, examine IP header
    - switch: link layer device, examine Ethernet header
- Both have forwarding table
    - router: compute tables using routing algorithms using IP address
    - switch: self-learned

Put everything together

Goal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DNS server
Comcast network
68.80.0.0/13
school network
68.80.2.0/24
web page
Google
web server
64.233.169.105
Google's network
64.233.160.0/19

That's all folks!