

Chapter 6(Review)

The Link Layer and LANs

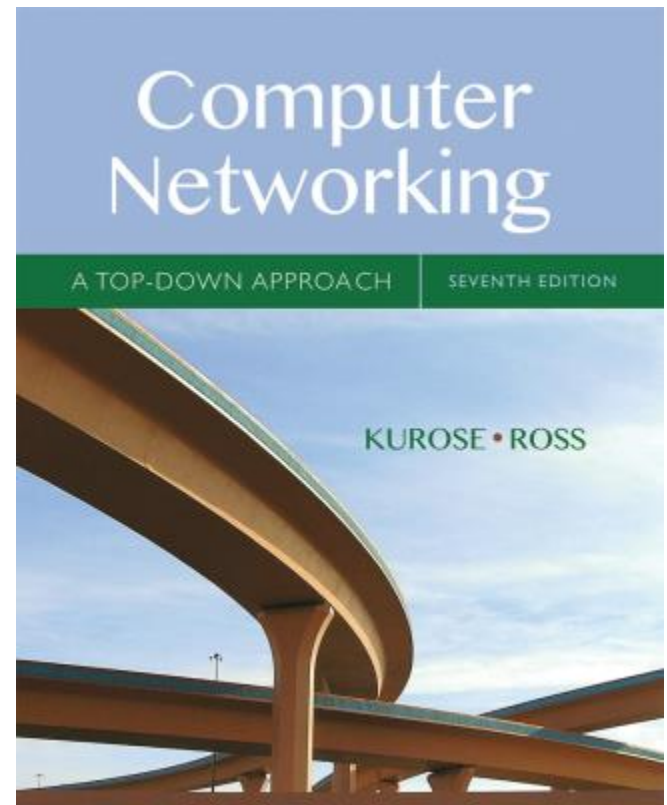
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Computer Networking: A Top Down Approach

7th edition

Jim Kurose, Keith Ross

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Link layer, LANs: outline

6.1 introduction, services

6.2 error detection,
correction

6.3 multiple access
protocols

6.4 LANs

- addressing, ARP
- Ethernet
- switches
- VLANs

6.5 link virtualization:
MPLS

6.6 data center
networking

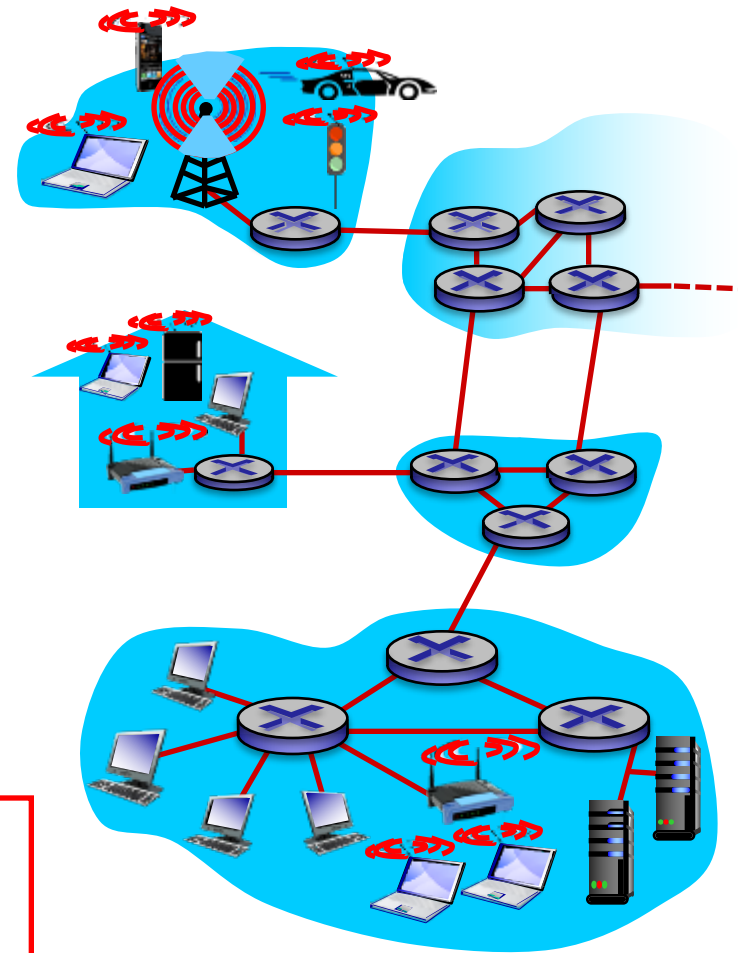
6.7 a day in the life of a
web request

Link layer: introduction

terminology:

- hosts and routers: **nodes**
- communication channels that connect adjacent nodes along communication path: **links**
 - wired links
 - wireless links
- layer-2 packet: **frame**, encapsulates datagram

data-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, adding header, trailer
- channel access if shared medium
- “MAC” addresses used in frame headers to identify source, destination
 - different from IP address!

■ *reliable delivery between adjacent nodes*

- we learned how to do this already (chapter 3)!
- 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)

- *flow control:*
 - pacing between adjacent sending and receiving nodes
- *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
- *half-duplex and full-duplex*
 - with half duplex, nodes at both ends of link can transmit, but not at same time

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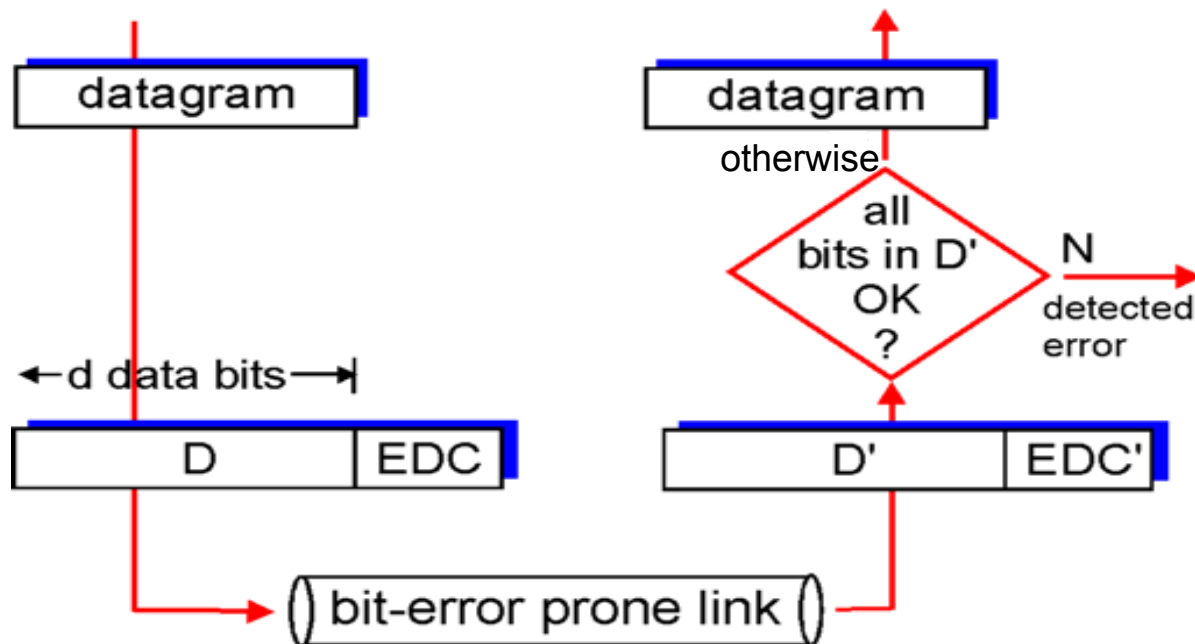
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Error detection

EDC= **Error Detection and Correction** bits (redundancy)

D = Data protected by error checking, may include header fields

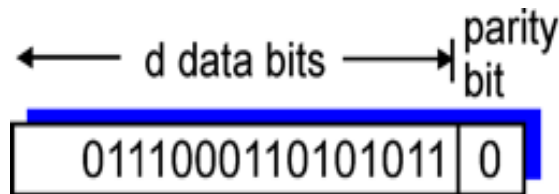
- Error detection not 100% reliable!
 - protocol may miss some errors, but rarely
 - larger EDC field yields better detection and correction



Parity checking

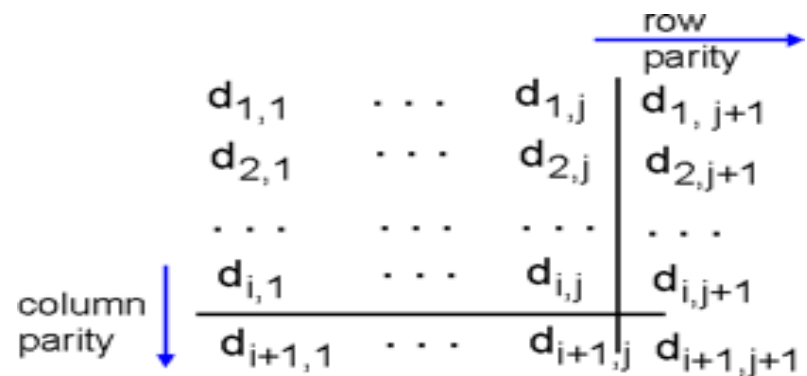
single bit parity:

- detect single bit errors



two-dimensional bit parity:

- detect and correct single bit errors



1	0	1	0	1	1
1	1	1	1	0	0
0	1	1	1	0	1
0	0	1	0	1	0

no errors

1	0	1	0	1	1
1	1	1	0	0	0
0	1	1	1	0	1
0	0	1	0	1	0

parity error

*correctable
single bit error*

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

Internet checksum (review)

goal: detect “errors” (e.g., flipped bits) in transmitted packet
(note: used at transport layer only)

sender:

- treat segment contents as sequence of 16-bit integers
- checksum: addition (1's complement sum) of segment contents
- sender puts checksum value into UDP checksum field

receiver:

- compute checksum of received segment
- check if computed checksum equals checksum field value:
 - NO - error detected
 - YES - no error detected.
But maybe errors nonetheless?

Cyclic redundancy check

- more powerful error-detection coding
- view data bits, **D**, as a binary number
- choose $r+1$ bit pattern (generator), **G**
- goal: choose r CRC bits, **R**, such that
 - $\langle D, R \rangle$ exactly divisible by G (modulo 2)
 - receiver knows G , divides $\langle D, R \rangle$ by G . If non-zero remainder: error detected!
 - can detect all burst errors less than $r+1$ bits
- widely used in practice (Ethernet, 802.11 WiFi, ATM)



$$D * 2^r \text{ XOR } R$$

mathematical formula

CRC example

want:

$$D \cdot 2^r \text{ XOR } R = nG$$

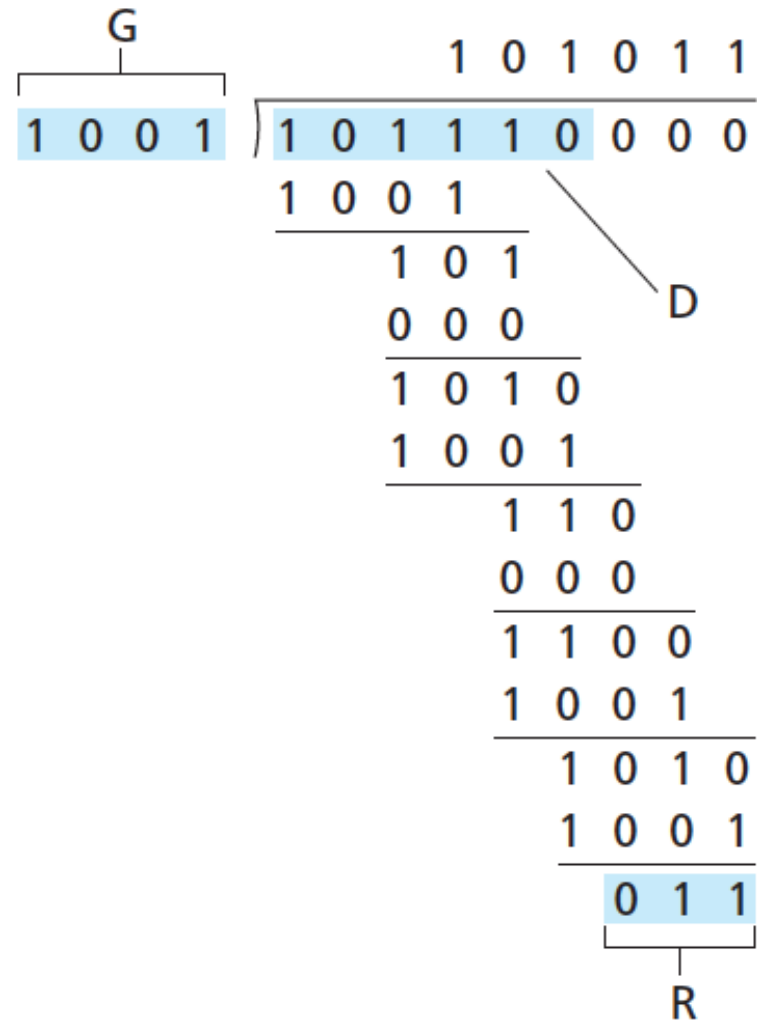
equivalently:

$$D \cdot 2^r = nG \text{ XOR } R$$

equivalently:

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

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



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MAC protocols: taxonomy

three broad classes:

- *channel partitioning*
 - divide channel into smaller “pieces” (time slots, frequency, code)
 - allocate piece to node for exclusive use
- *random access*
 - channel not divided, allow collisions
 - “recover” from collisions
- *“taking turns”*
 - nodes take turns, but nodes with more to send can take longer turns

Ethernet CSMA/CD algorithm

1. NIC receives datagram from network layer, creates frame
2. If NIC senses channel idle, starts frame transmission. If NIC senses channel busy, waits until channel idle, then transmits.
3. If NIC transmits entire frame without detecting another transmission, NIC is done with frame !
4. If NIC detects another transmission while transmitting, aborts and sends jam signal
5. After aborting, NIC enters *binary (exponential) backoff*:
 - after m th collision, NIC chooses K at random from $\{0, 1, 2, \dots, 2^m - 1\}$. NIC waits $K \cdot 512$ bit times, returns to Step 2
 - longer backoff interval with more collisions

Summary of MAC protocols

- **channel partitioning**, by time, frequency or code
 - Time Division, Frequency Division
- **random access** (dynamic),
 - ALOHA, S-ALOHA, CSMA, CSMA/CD
 - carrier sensing: easy in some technologies (wire), hard in others (wireless)
 - CSMA/CD used in Ethernet
 - CSMA/CA used in 802.11
- **taking turns**
 - polling from central site, token passing
 - Bluetooth, FDDI, token ring

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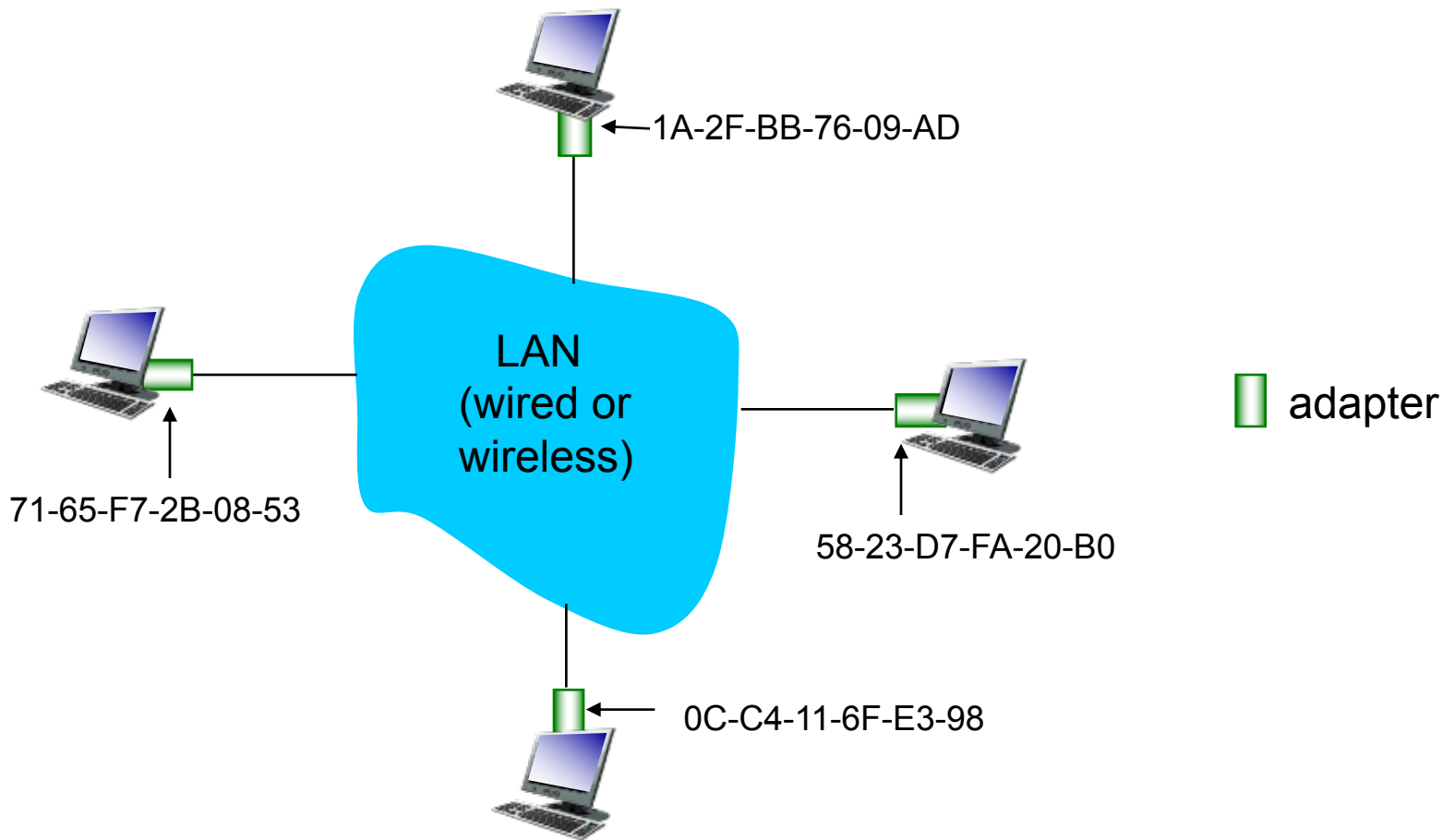
MAC addresses and ARP

- 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 “numeral” represents 4 bits)

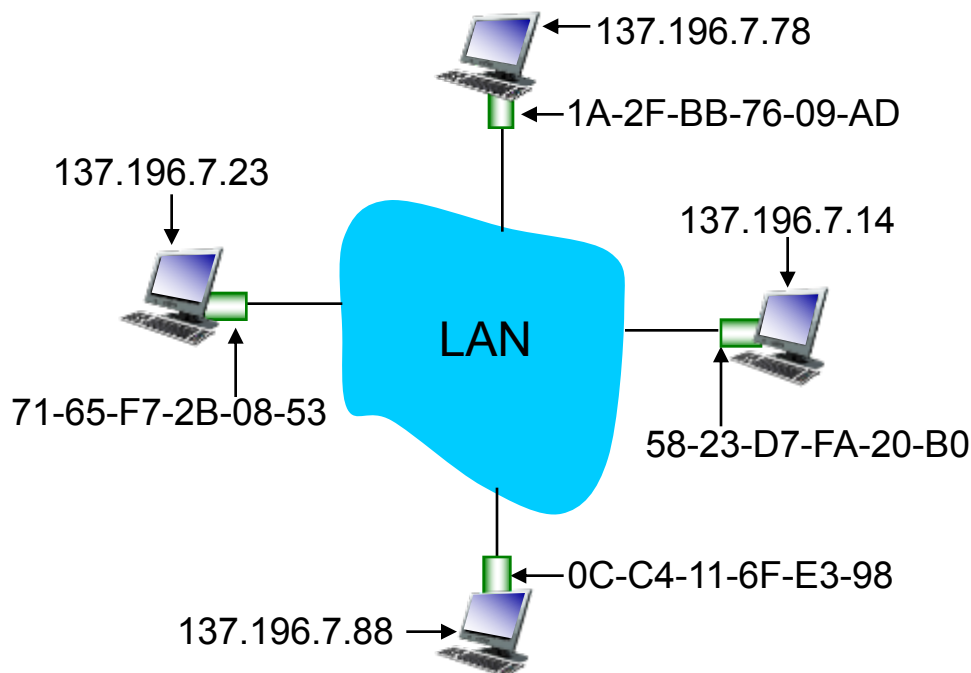
LAN addresses and ARP

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 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)

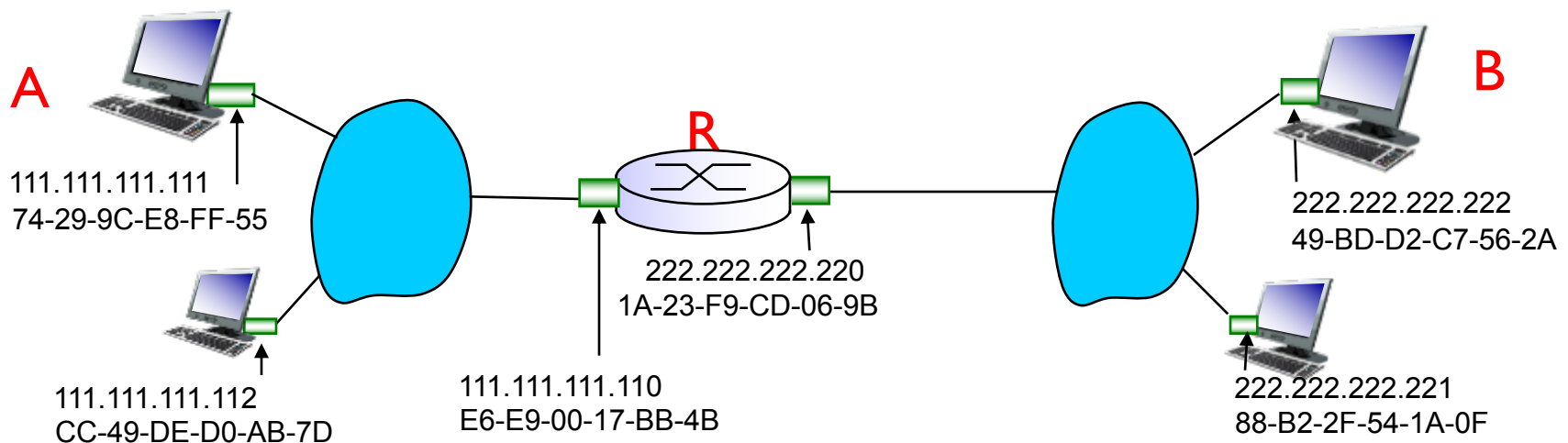
ARP protocol: same LAN

- 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*

Addressing: routing to another LAN

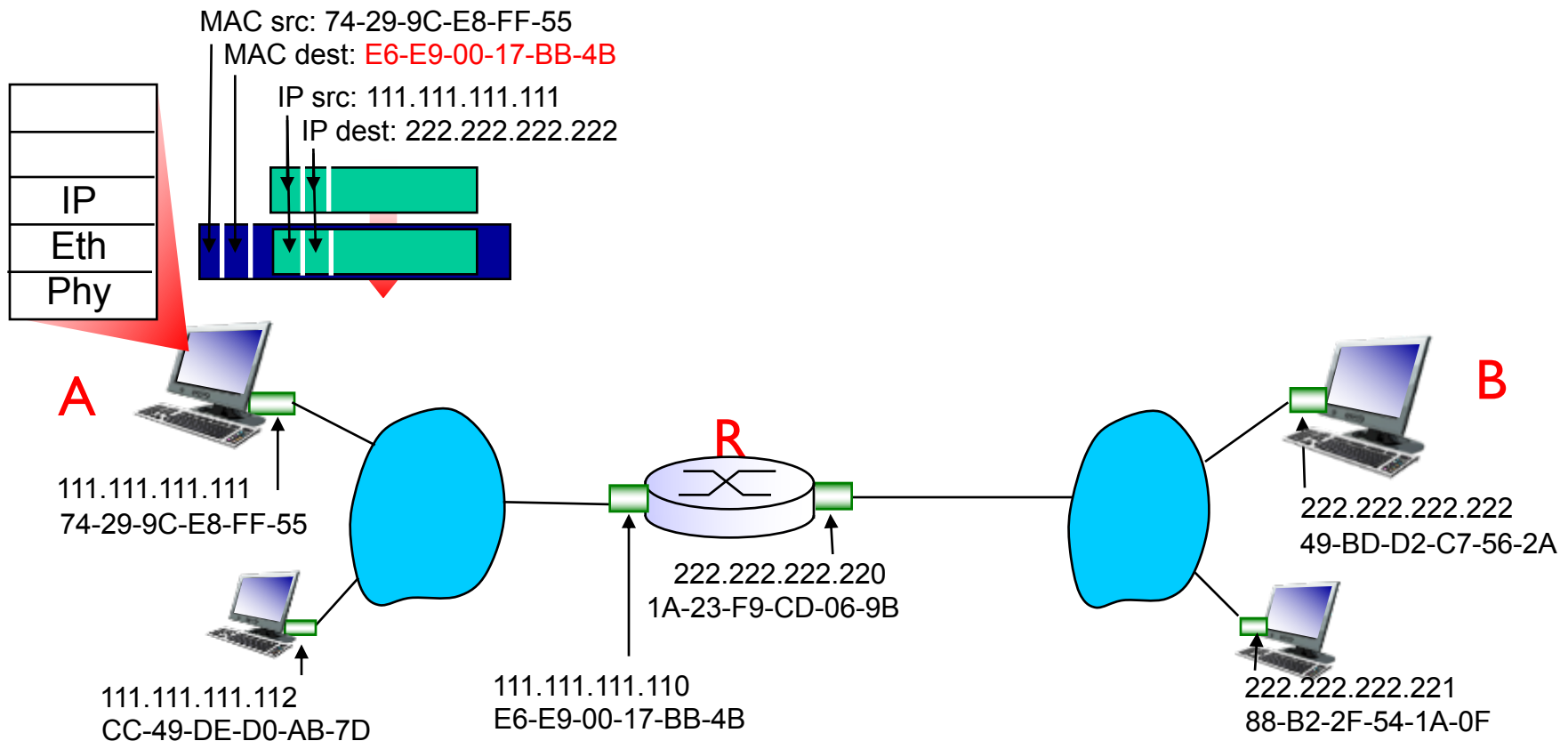
walkthrough: **send datagram from A to B via R**

- focus on addressing – at IP (datagram) and MAC layer (frame)
- assume A knows B's IP address
- assume A knows IP address of first hop router, R (how?)
- assume A knows R's MAC address (how?)



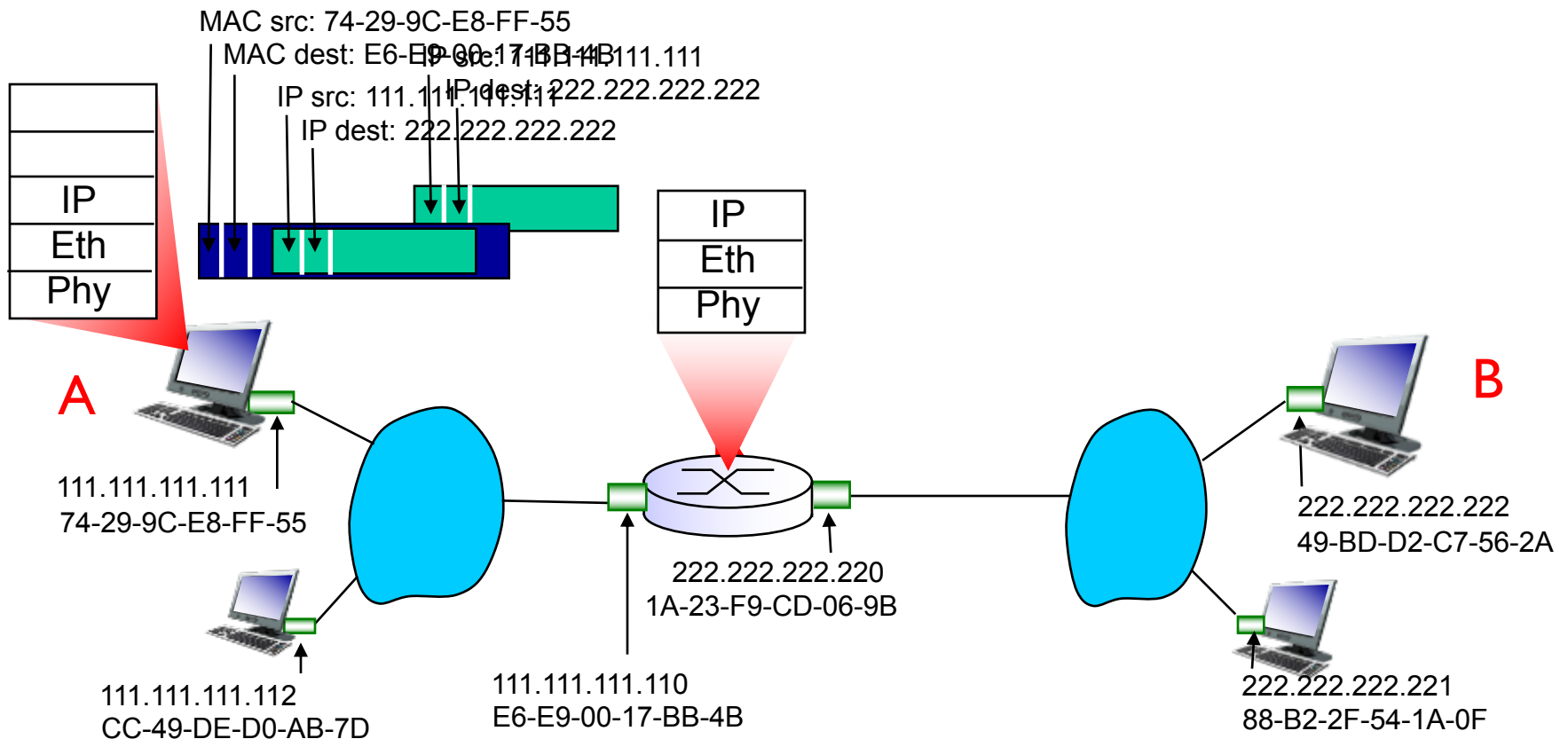
Addressing: routing to another LAN

- 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



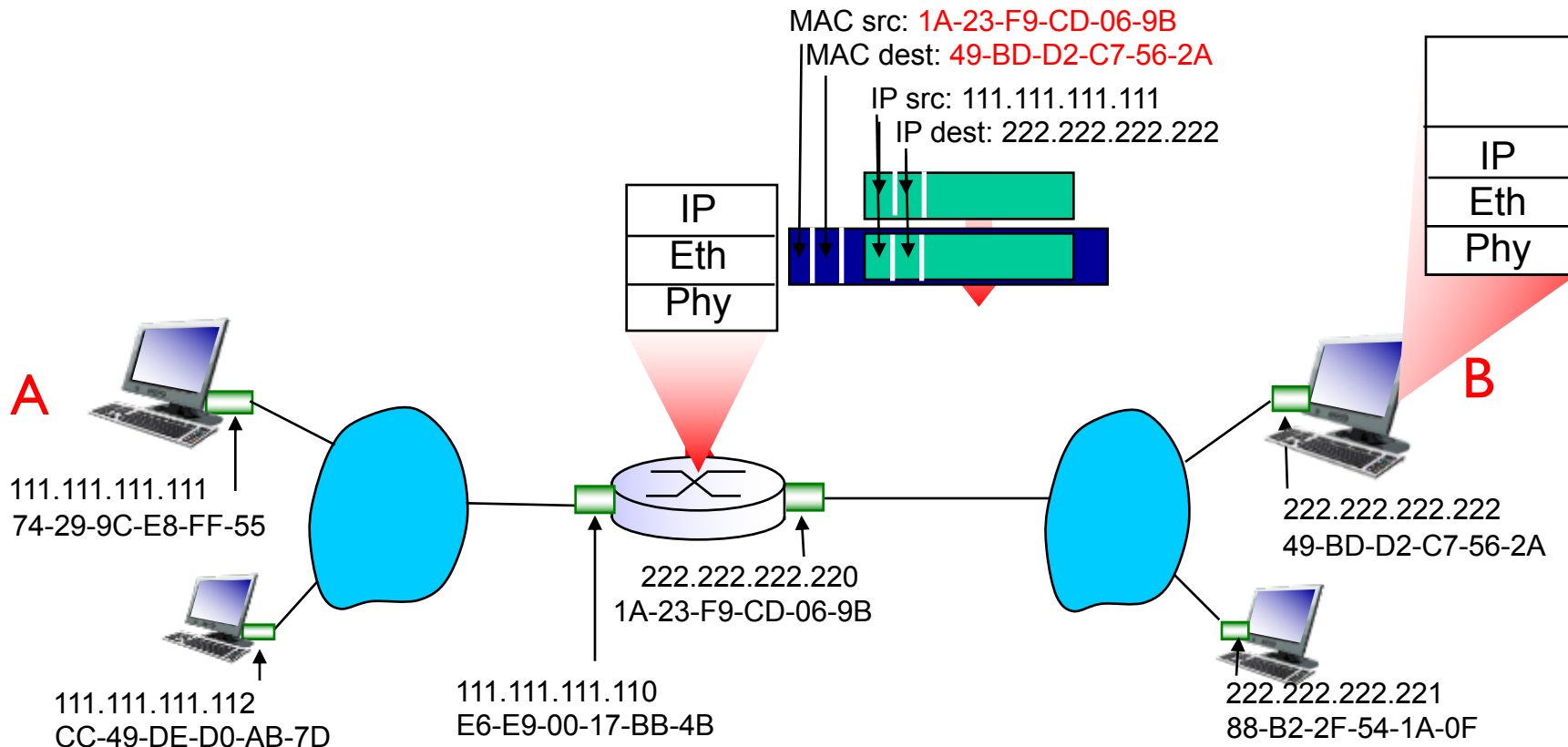
Addressing: routing to another LAN

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



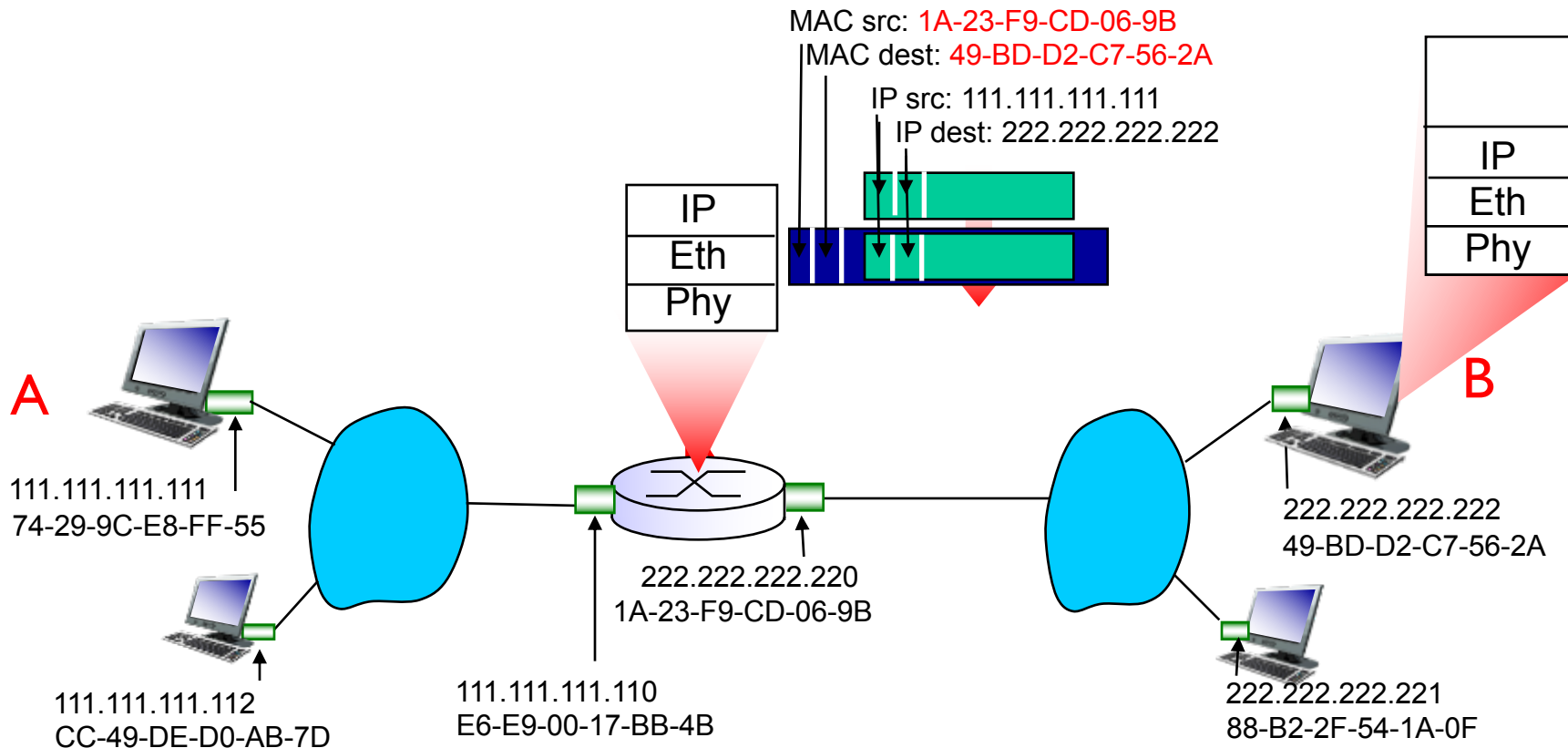
Addressing: routing to another LAN

- 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



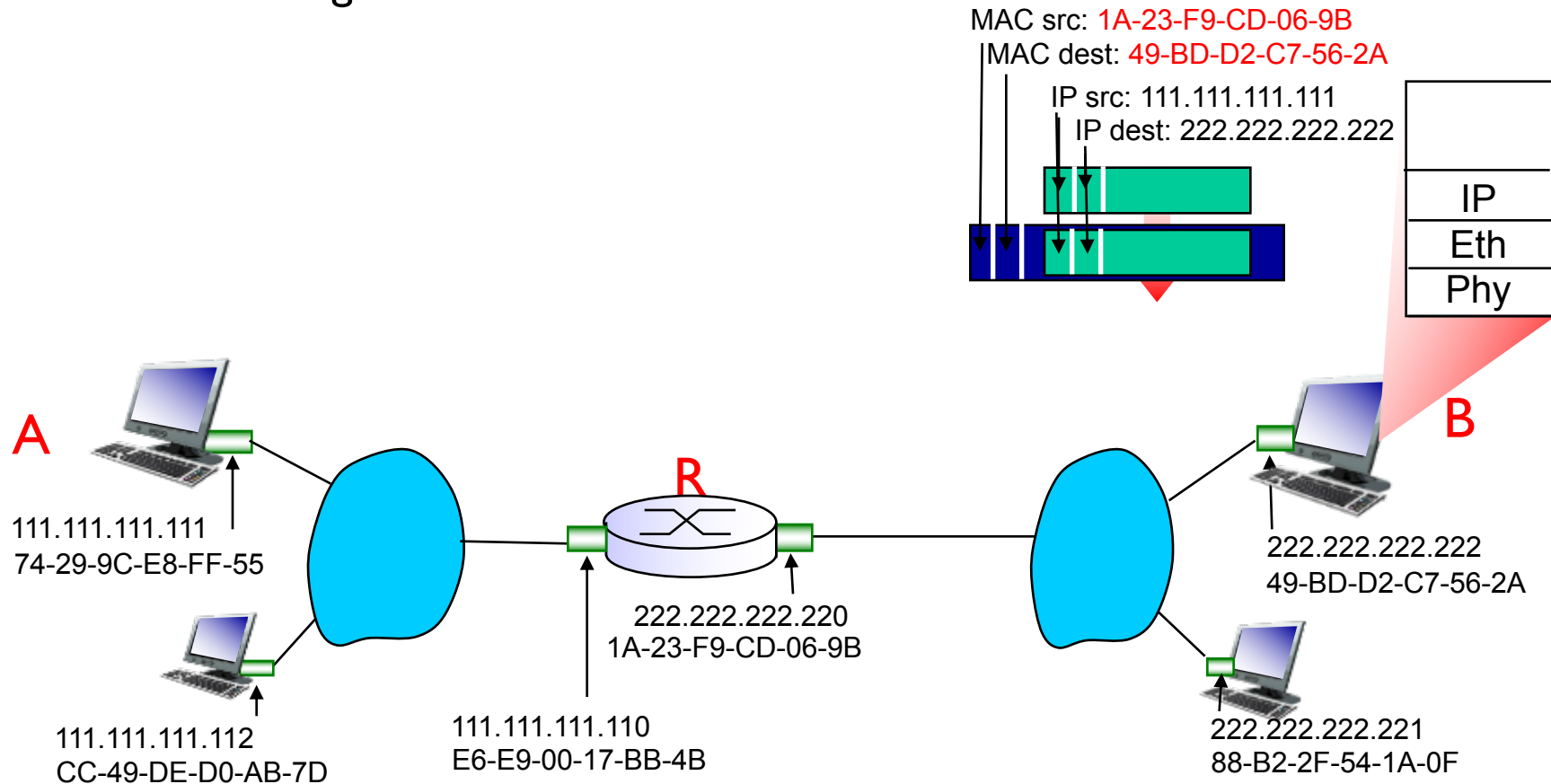
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Addressing: routing to another LAN

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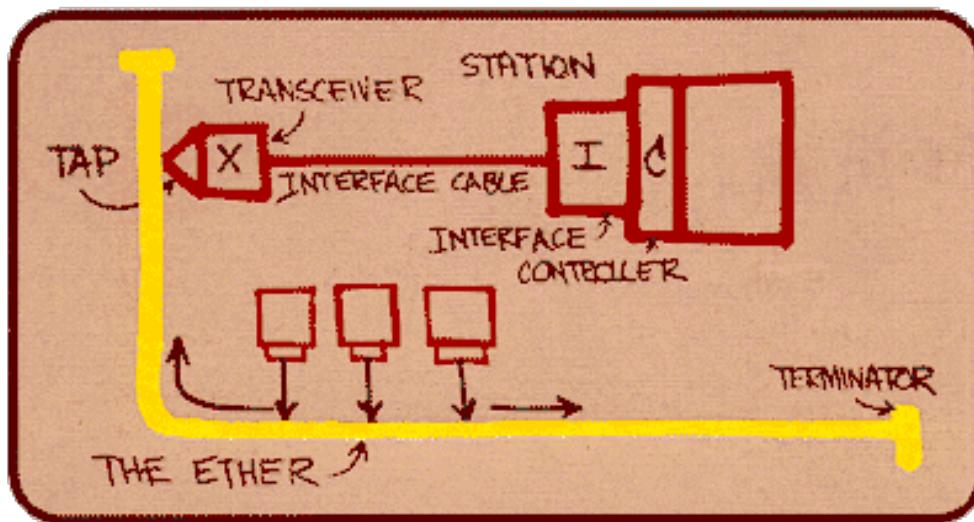
6.6 data center
networking

6.7 a day in the life of a
web request

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 – 10 Gbps



Metcalfe's Ethernet sketch

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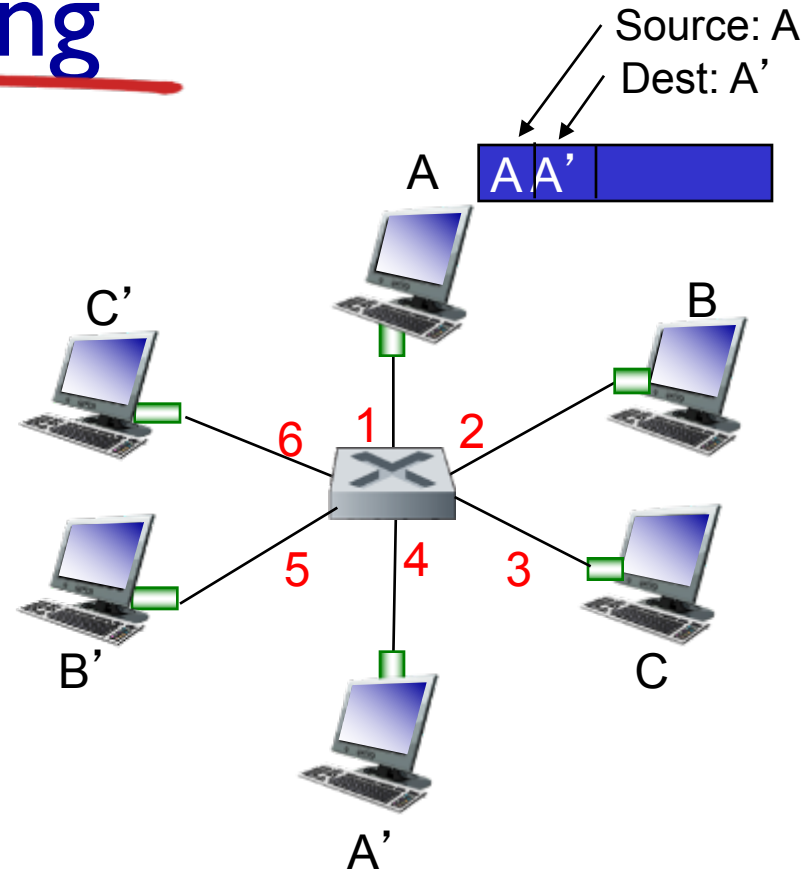
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Switch: self-learning

- 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)*

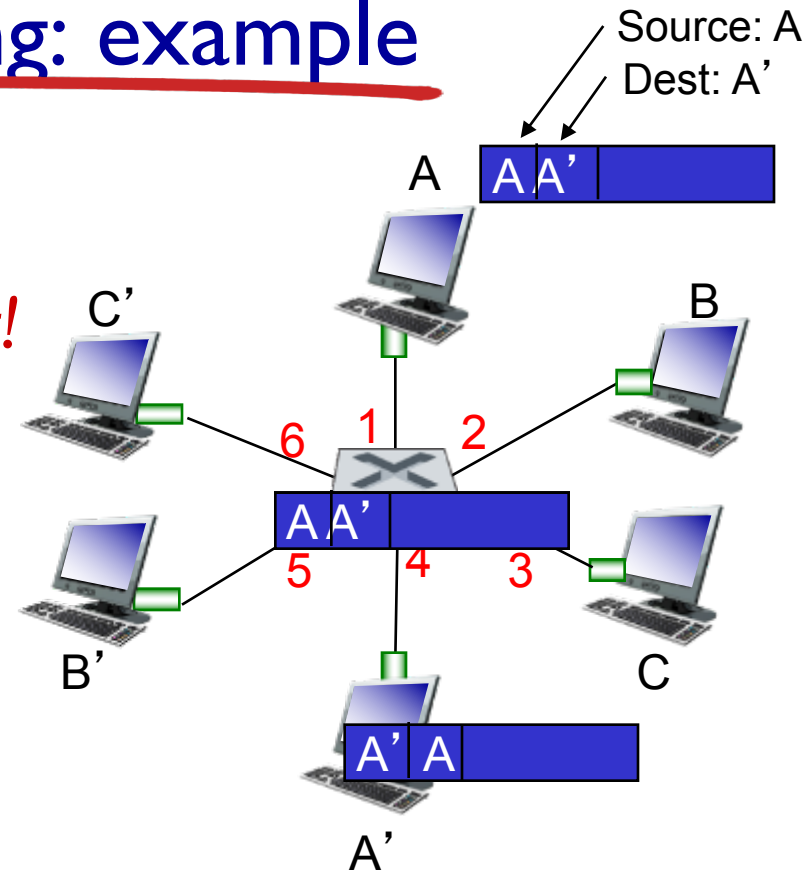
Switch: frame filtering/forwarding

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



MAC addr	interface	TTL
A	1	60
A'	4	60

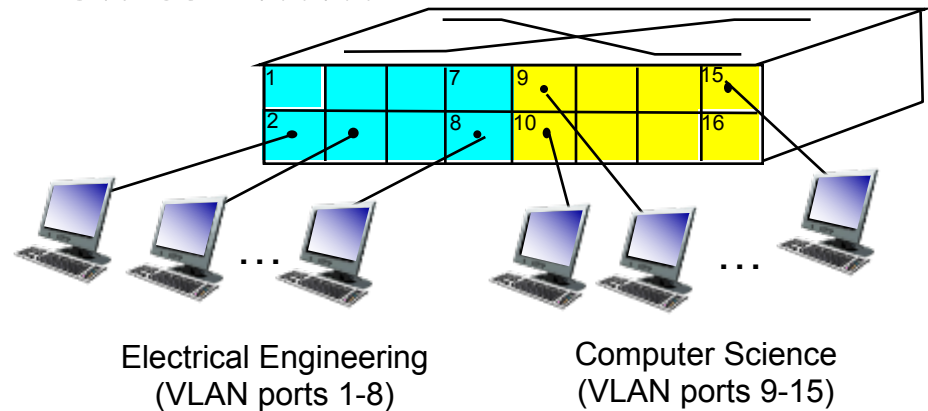
*switch table
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VLANs

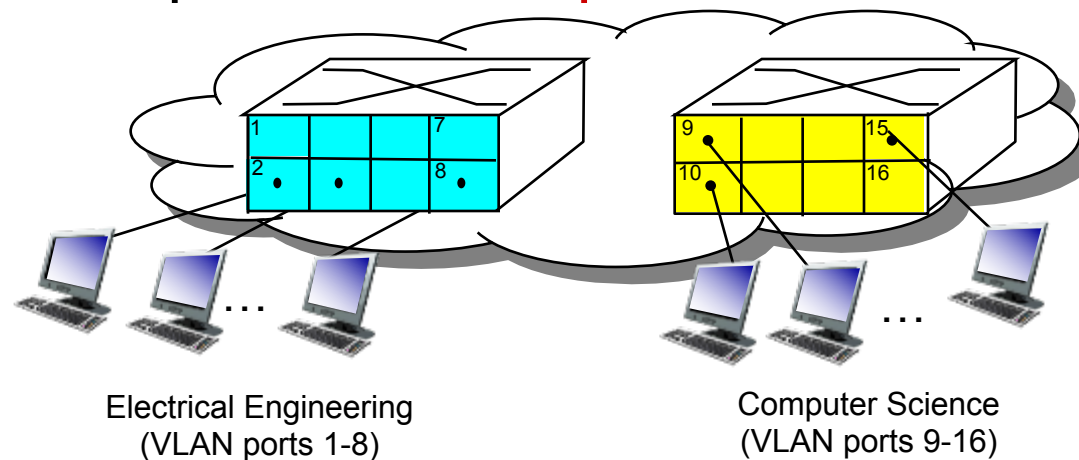
Virtual Local Area Network

switch(es) supporting VLAN capabilities can be configured to define multiple *virtual* LANS over single physical LAN infrastructure.

port-based VLAN: switch ports grouped (by switch management software) so that *single* physical switch

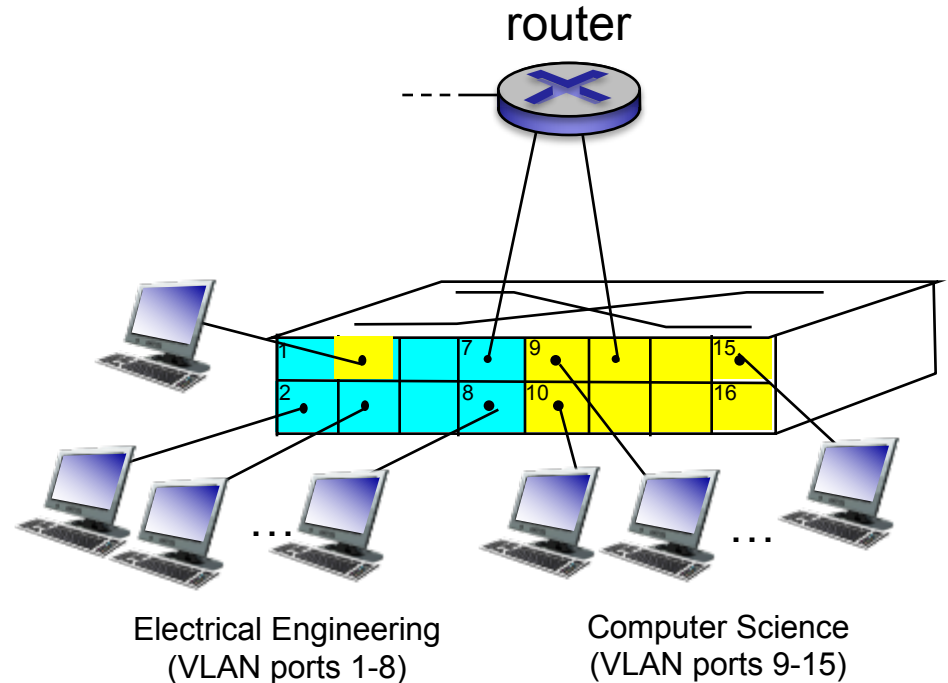


... operates as **multiple** virtual switches



Port-based VLAN

- **traffic isolation:** frames to/from ports 1-8 can *only* reach ports 1-8
 - can also define VLAN based on MAC addresses of endpoints, rather than switch port
- **dynamic membership:** ports can be dynamically assigned among VLANs
- **forwarding between VLANs:** done via routing (just as with separate switches)
 - in practice vendors sell combined switches plus routers



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MPLS

6.6 data center
networking

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Data center networks

- 10's to 100's of thousands of hosts, often closely coupled, in close proximity:
 - e-business (e.g. Amazon)
 - content-servers (e.g., YouTube, Akamai, Apple, Microsoft)
 - search engines, data mining (e.g., Google)
- challenges:
 - multiple applications, each serving massive numbers of clients
 - managing/balancing load, avoiding processing, networking, data bottlenecks

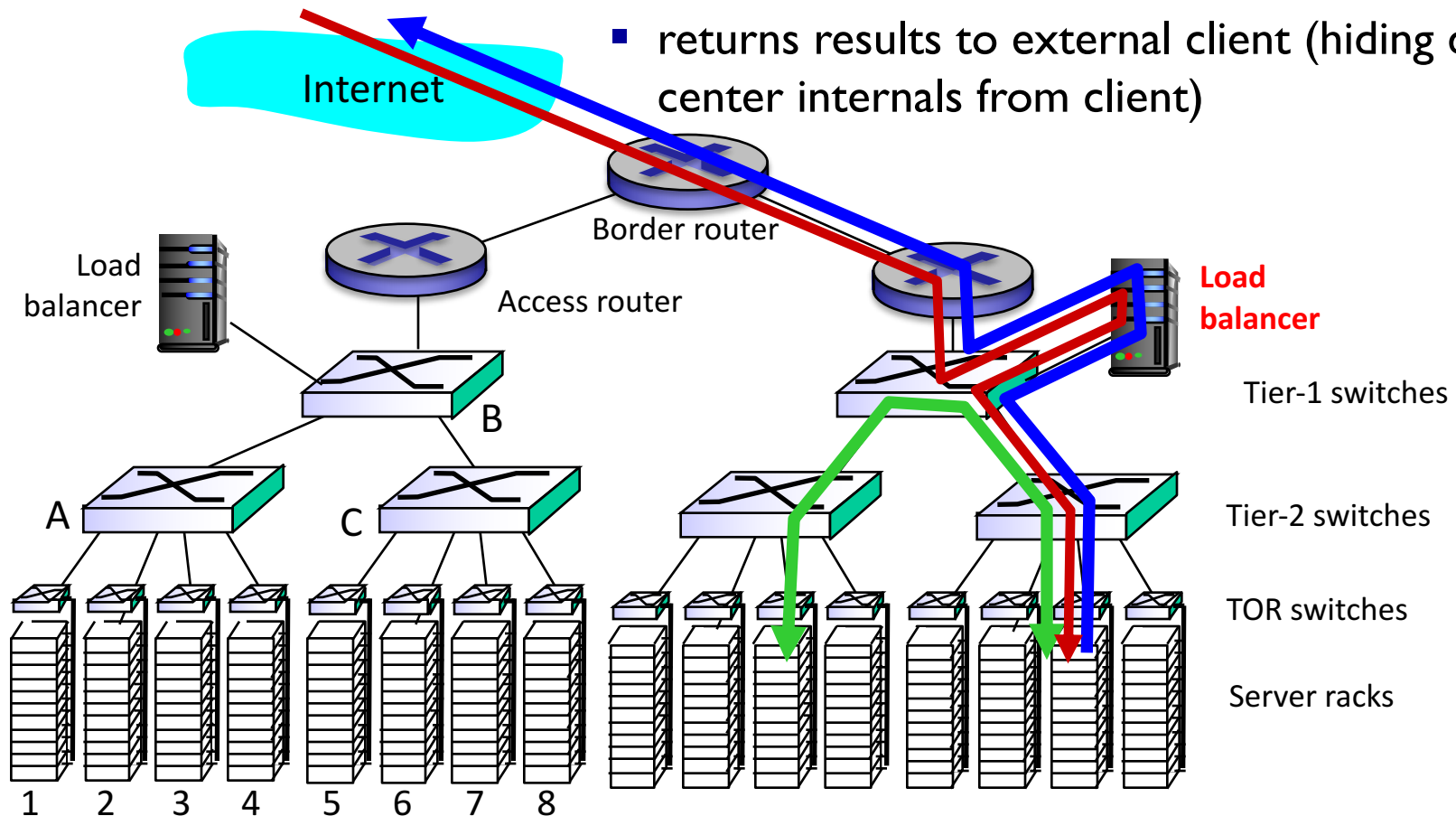


Inside a 40-ft Microsoft container,
Chicago data center

Data center networks

load balancer: application-layer routing

- receives external client requests
- directs workload within data center
- returns results to external client (hiding data center internals from client)



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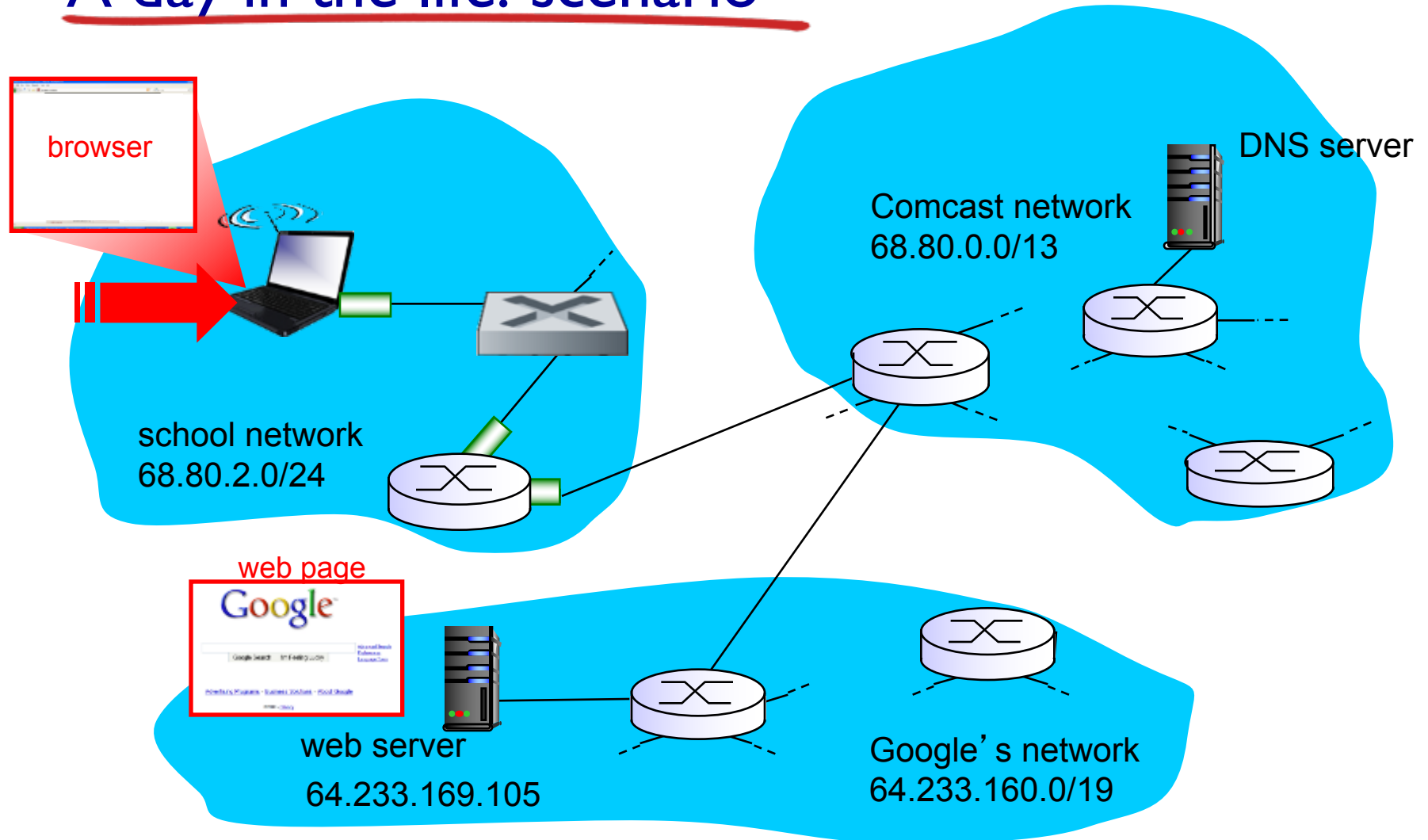
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networking

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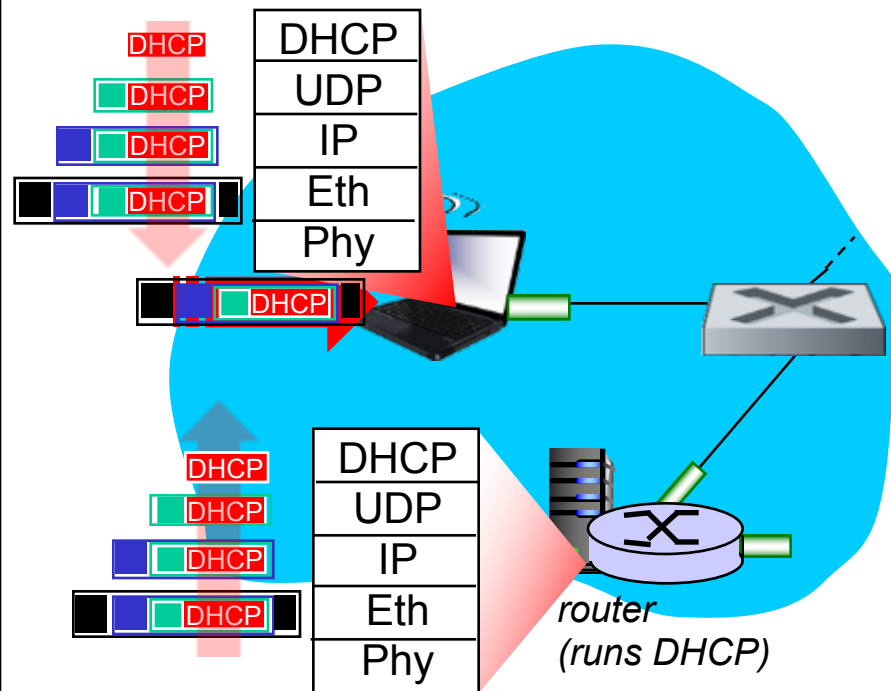
Synthesis: a day in the life of a web request

- journey down protocol stack complete!
 - application, transport, network, link
- putting-it-all-together: synthesis!
 - *goal*: identify, review, understand protocols (at all layers) involved in seemingly simple scenario: requesting www page
 - *scenario*: student attaches laptop to campus network, requests/receives www.google.com

A day in the life: scenario

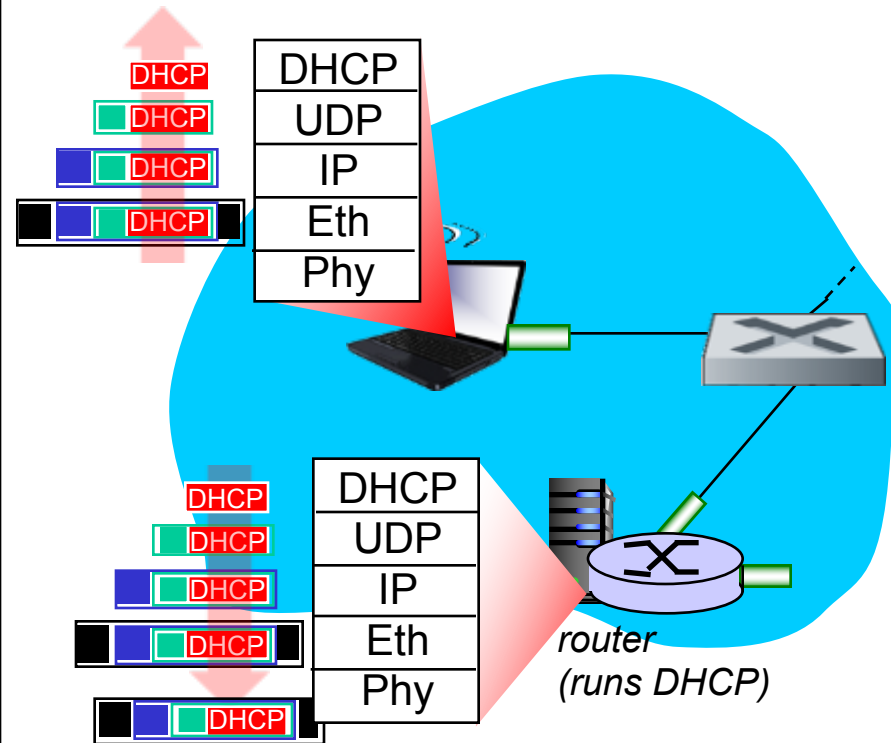


A day in the life... connecting to the Internet



- connecting laptop needs to get its own IP address, addr of first-hop router, addr of DNS server: use **DHCP**
- DHCP request **encapsulated** in **UDP**, encapsulated in **IP**, encapsulated in **802.3** Ethernet
- Ethernet frame **broadcast** (dest: FFFFFFFFFFFFFFFF) on LAN, received at router running **DHCP** server
- Ethernet **demuxed** to IP demuxed, UDP demuxed to DHCP

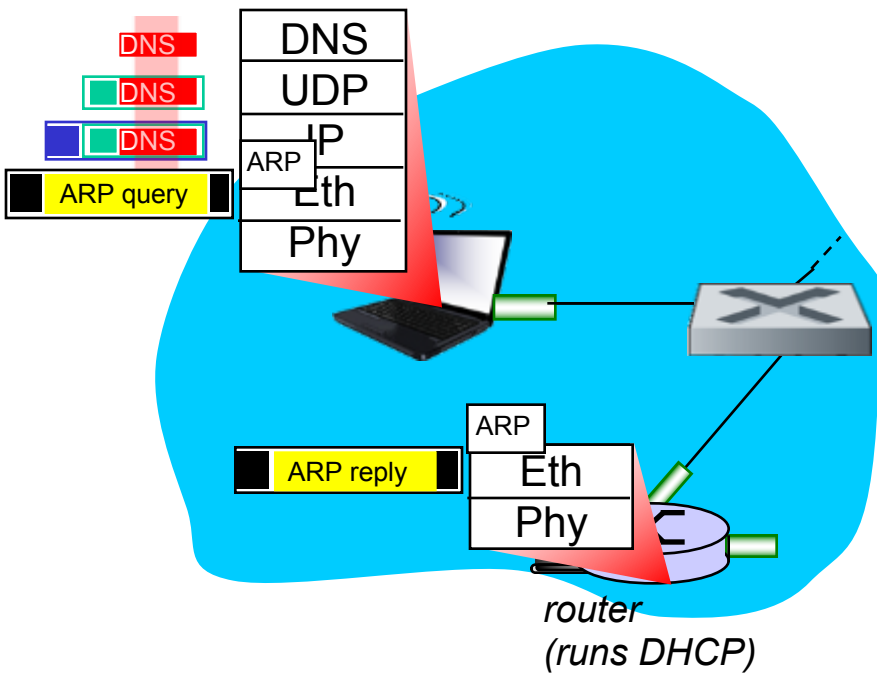
A day in the life... connecting to the Internet



- DHCP server formulates **DHCP ACK** containing client's IP address, IP address of first-hop router for client, name & IP address of DNS server
- encapsulation at DHCP server, frame forwarded (**switch learning**) through LAN, demultiplexing at client
- DHCP client receives DHCP ACK reply

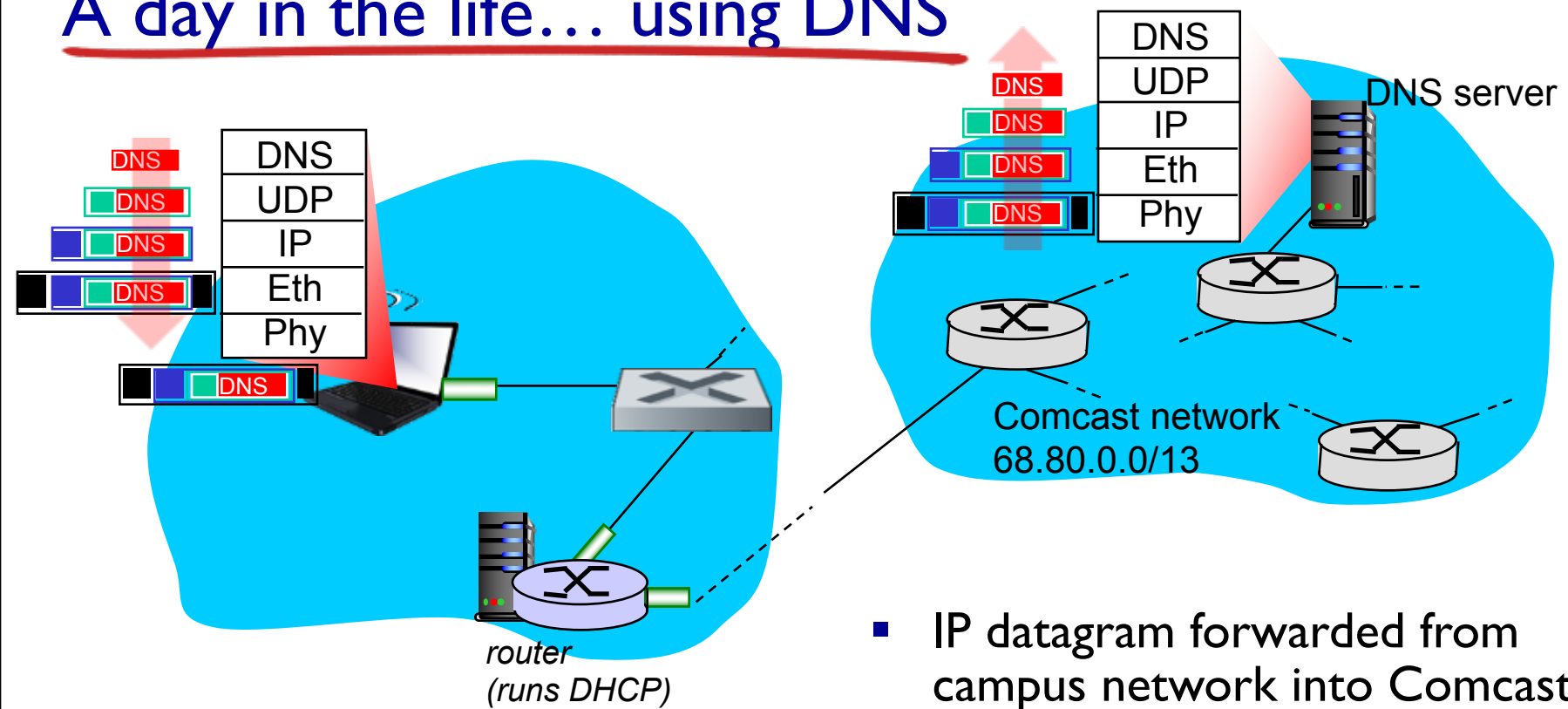
Client now has IP address, knows name & addr of DNS server, IP address of its first-hop router

A day in the life... ARP (before DNS, before HTTP)



- before sending **HTTP** request, need IP address of `www.google.com`:
DNS
- DNS query created, encapsulated in UDP, encapsulated in IP, encapsulated in Eth. To send frame to router, need MAC address of router interface: **ARP**
- **ARP query** broadcast, received by router, which replies with **ARP reply** giving MAC address of router interface
- client now knows MAC address of first hop router, so can now send frame containing DNS query

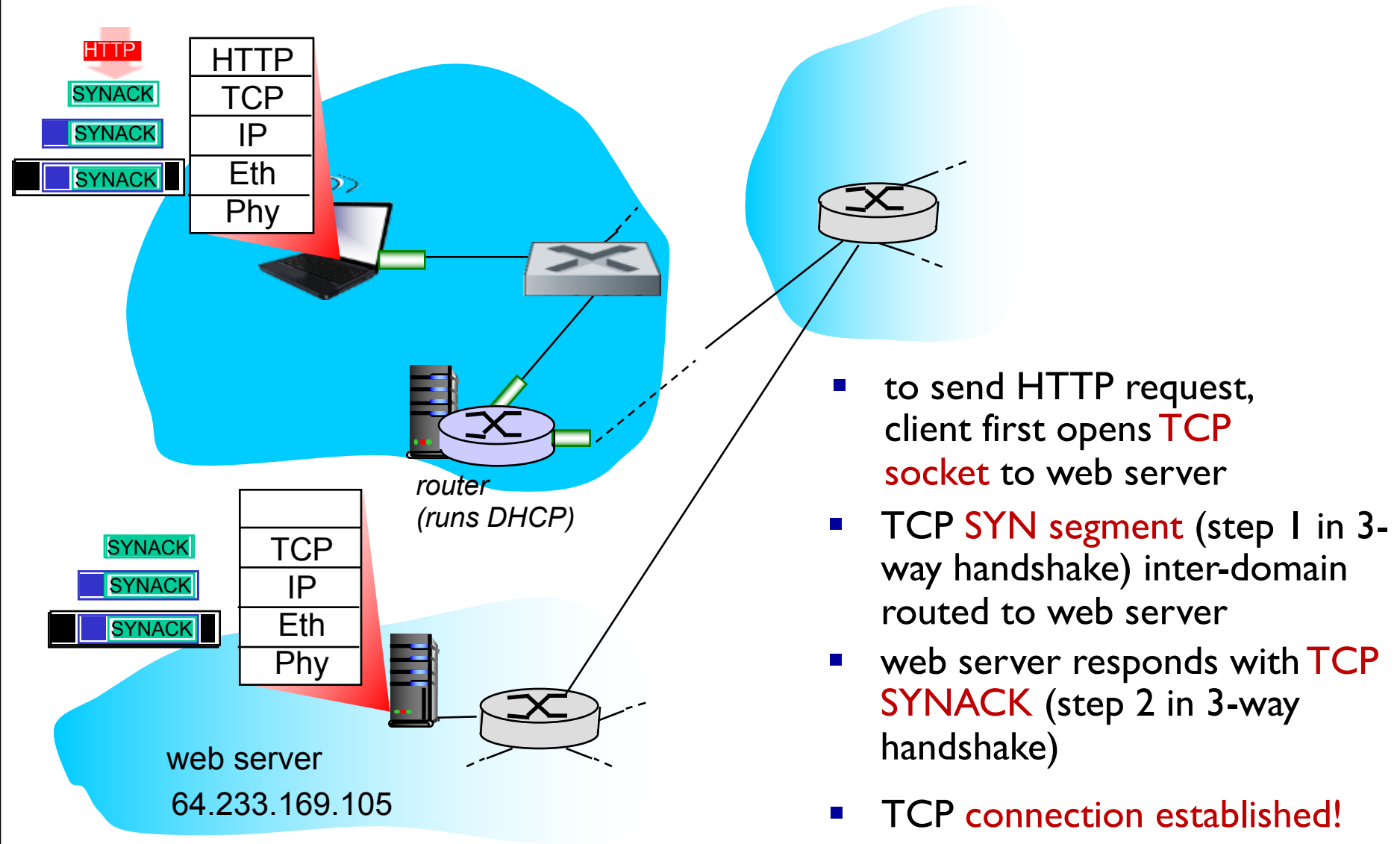
A day in the life... using DNS



- IP datagram containing DNS query forwarded via LAN switch from client to 1st hop router

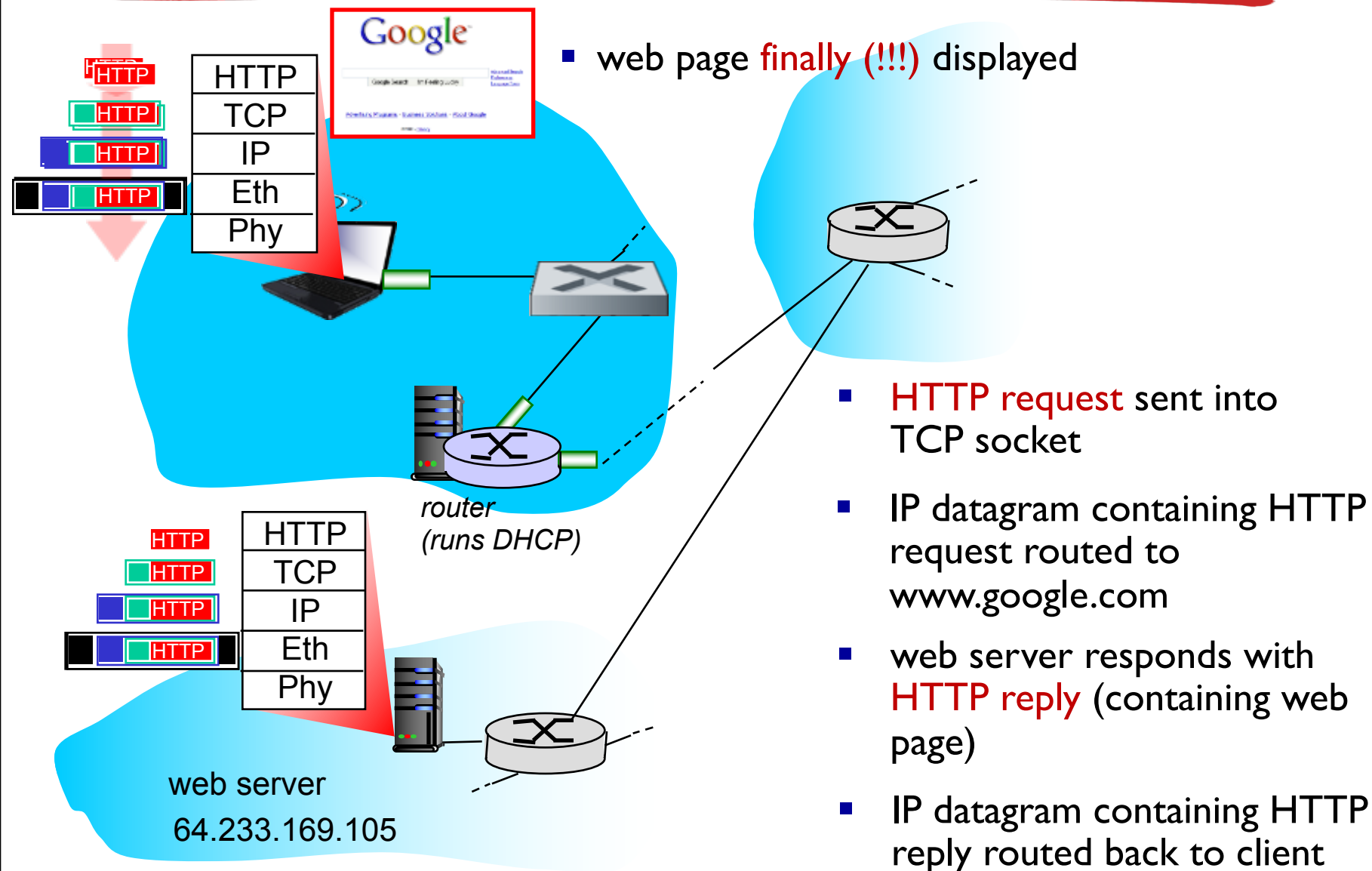
- IP datagram forwarded from campus network into Comcast network, routed (tables created by **RIP**, **OSPF**, **IS-IS** and/or **BGP** routing protocols) to DNS server
- demuxed to DNS server
- DNS server replies to client with IP address of **www.google.com**

A day in the life...TCP connection carrying HTTP



A day in the life... HTTP request/reply

- web page **finally (!!!)** displayed



Chapter 6
End

Wish you success!