

Chapter 5

Link Layer

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Link layer, LANs: Outline of Lecture 21

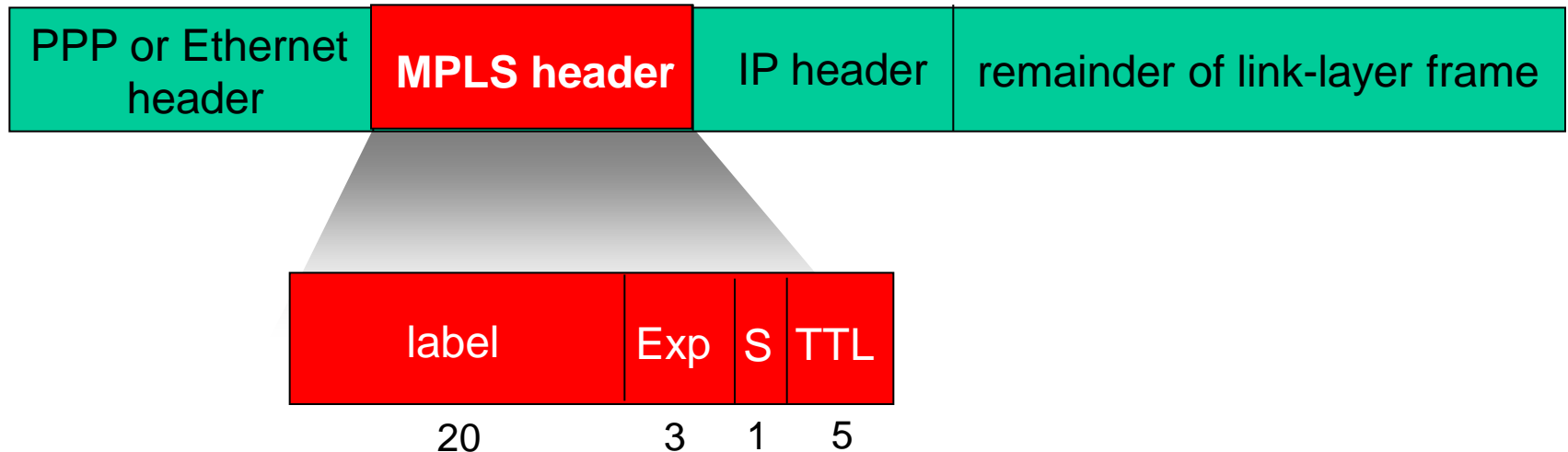
5.5 link virtualization: MPLS

5.6 data center networking

5.7 a day in the life of a web request

Multiprotocol label switching (MPLS)

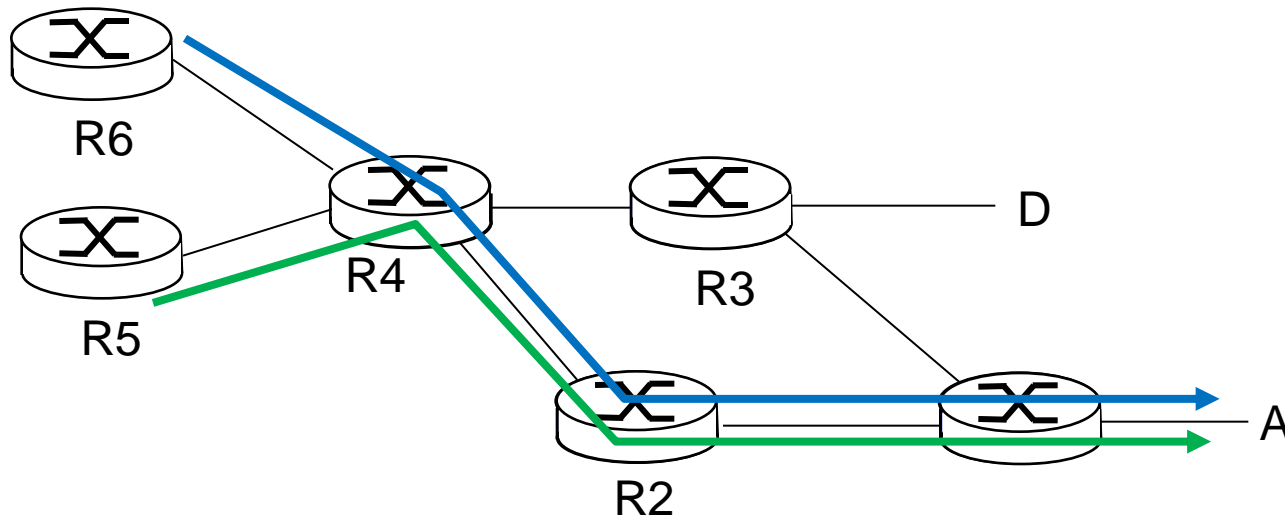
- ❖ initial goal: high-speed IP forwarding using fixed length label (instead of IP address)
 - fast lookup using fixed length identifier (rather than shortest prefix matching)
 - borrowing ideas from Virtual Circuit (VC) approach
 - but IP datagram still keeps IP address!



MPLS capable routers

- ❖ a.k.a. label-switched router
- ❖ forward packets to outgoing interface based only on label value (*don't inspect IP address*)
 - MPLS forwarding table distinct from IP forwarding tables
- ❖ *flexibility*: MPLS forwarding decisions can *differ* from those of IP
 - use destination *and* source addresses to route flows to same destination differently (traffic engineering)
 - re-route flows quickly if link fails: pre-computed backup paths (useful for VoIP)

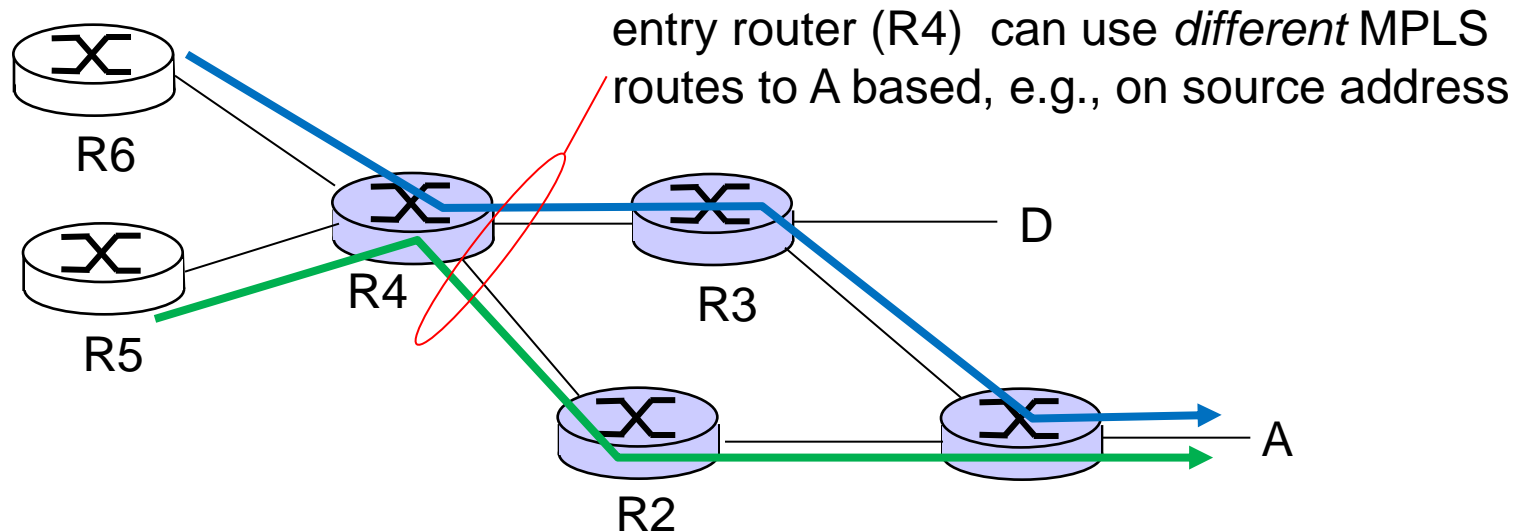
MPLS versus IP paths



- ❖ *IP routing: path to destination determined by destination address alone*



MPLS versus IP paths



❖ **IP routing:** path to destination determined by destination address alone



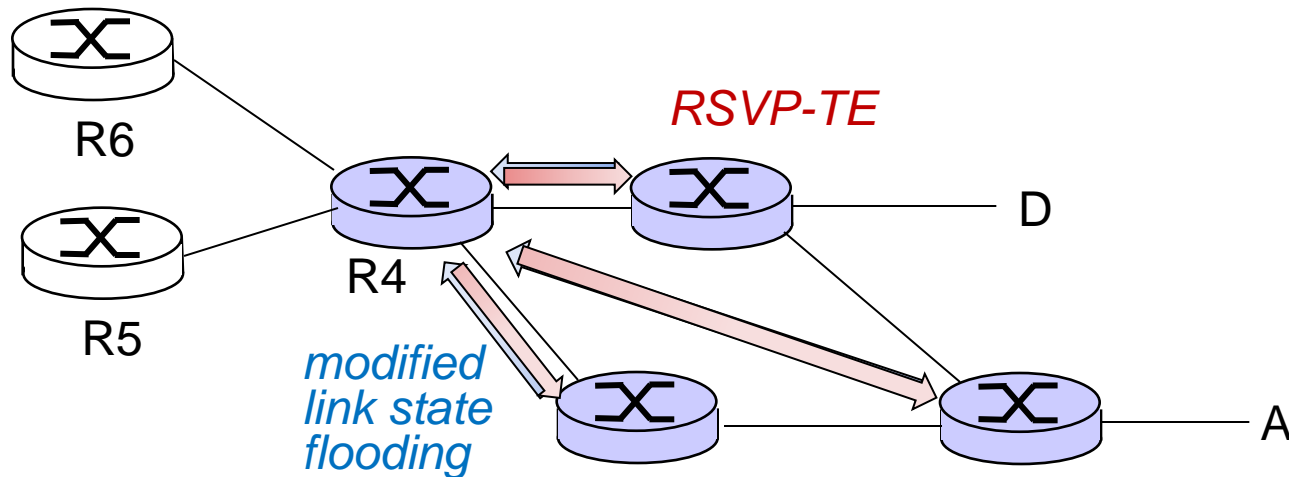
❖ **MPLS routing:** path to destination can be based on source *and* dest. address



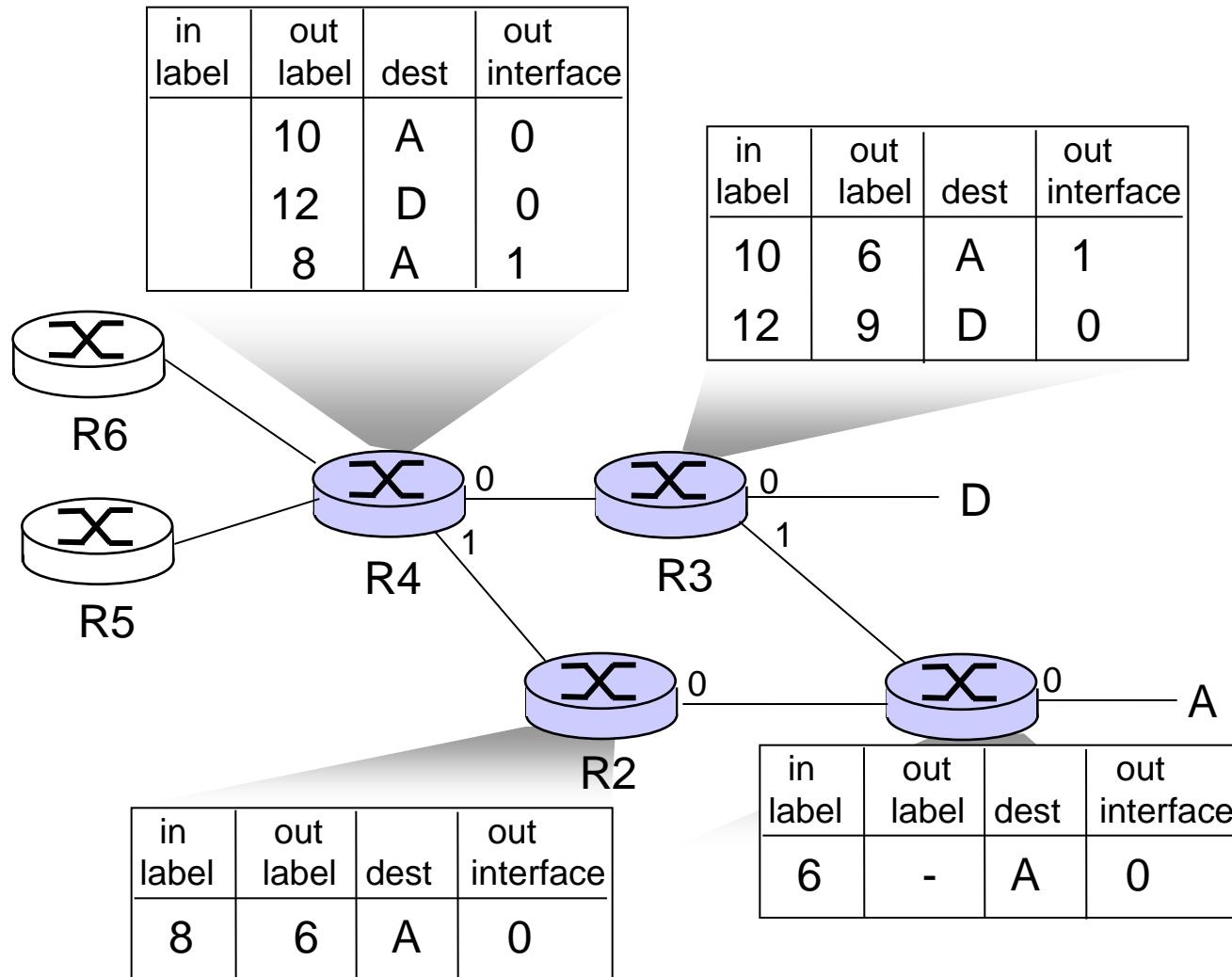
- **fast reroute:** precompute backup routes in case of link failure

MPLS signaling

- ❖ modify OSPF, IS-IS link-state flooding protocols to carry info used by MPLS routing,
 - e.g., link bandwidth, amount of “reserved” link bandwidth
- ❖ entry *MPLS router uses RSVP-TE signaling protocol to set up MPLS forwarding at downstream routers*



MPLS forwarding tables



Link layer, LANs: outline

5.1 introduction, services

5.2 error detection,
correction

5.3 multiple access
protocols

5.4 LANs

- addressing, ARP
- Ethernet
- switches
- VLANs

5.5 link virtualization:
MPLS

5.6 data center
networking

5.7 a day in the life of a
web request

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

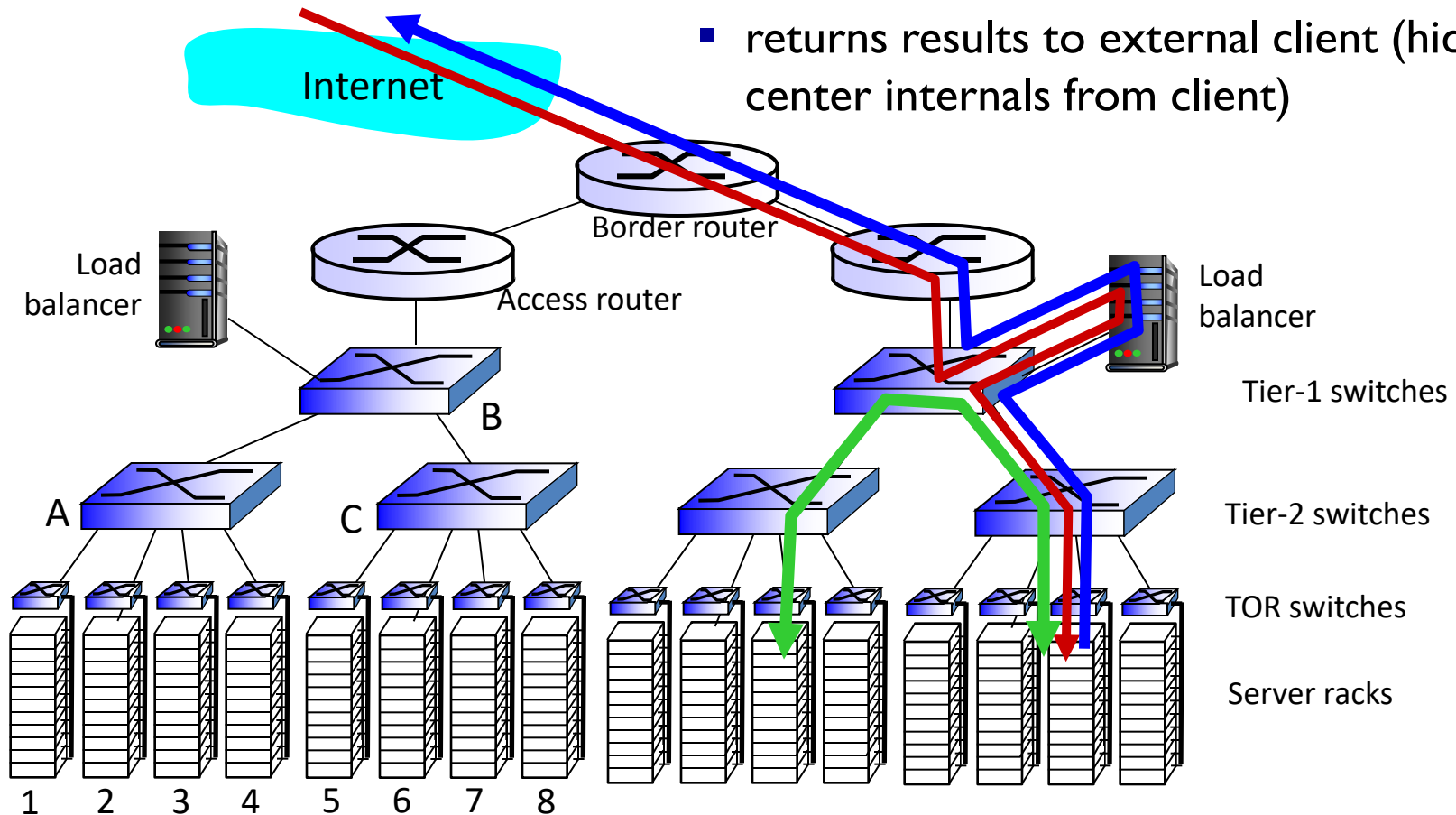


Inside a 40-ft Microsoft container,
Chicago data center

Data center networks

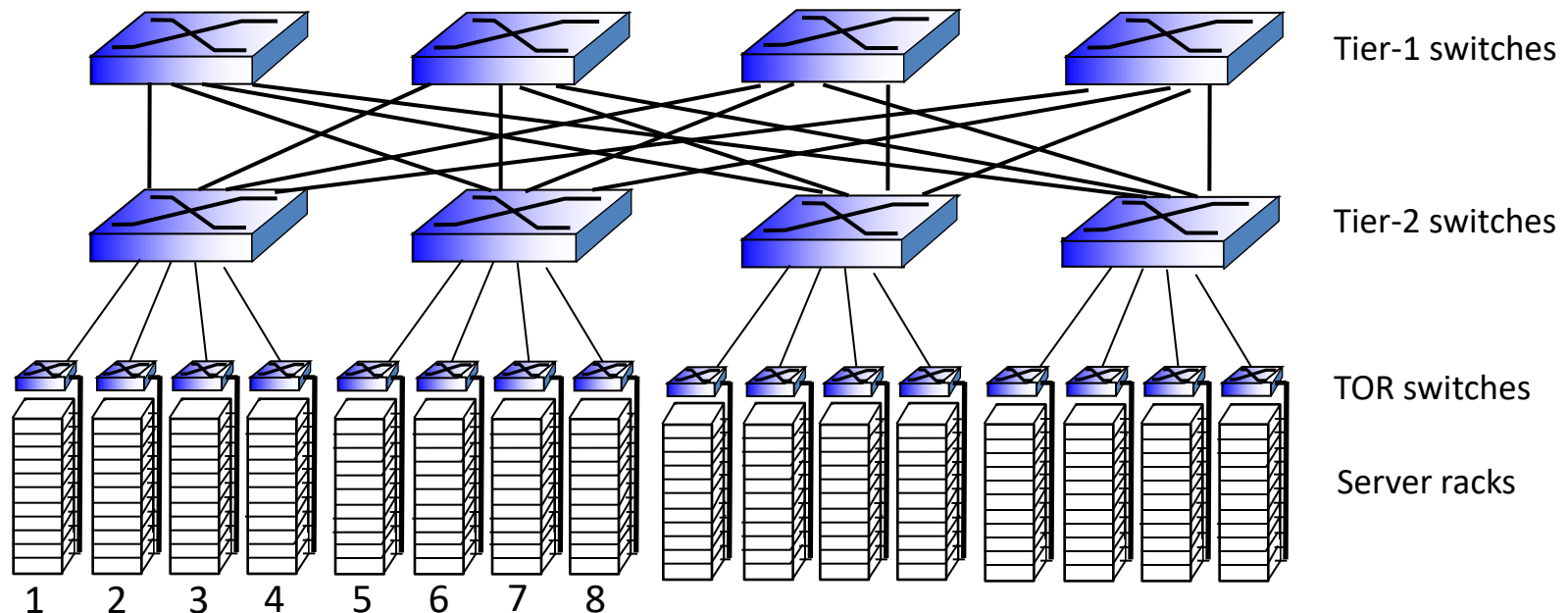
load balancer: application-layer routing

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



Data center networks

- ❖ rich interconnection among switches, racks:
 - increased throughput between racks (multiple routing paths possible)
 - increased reliability via redundancy



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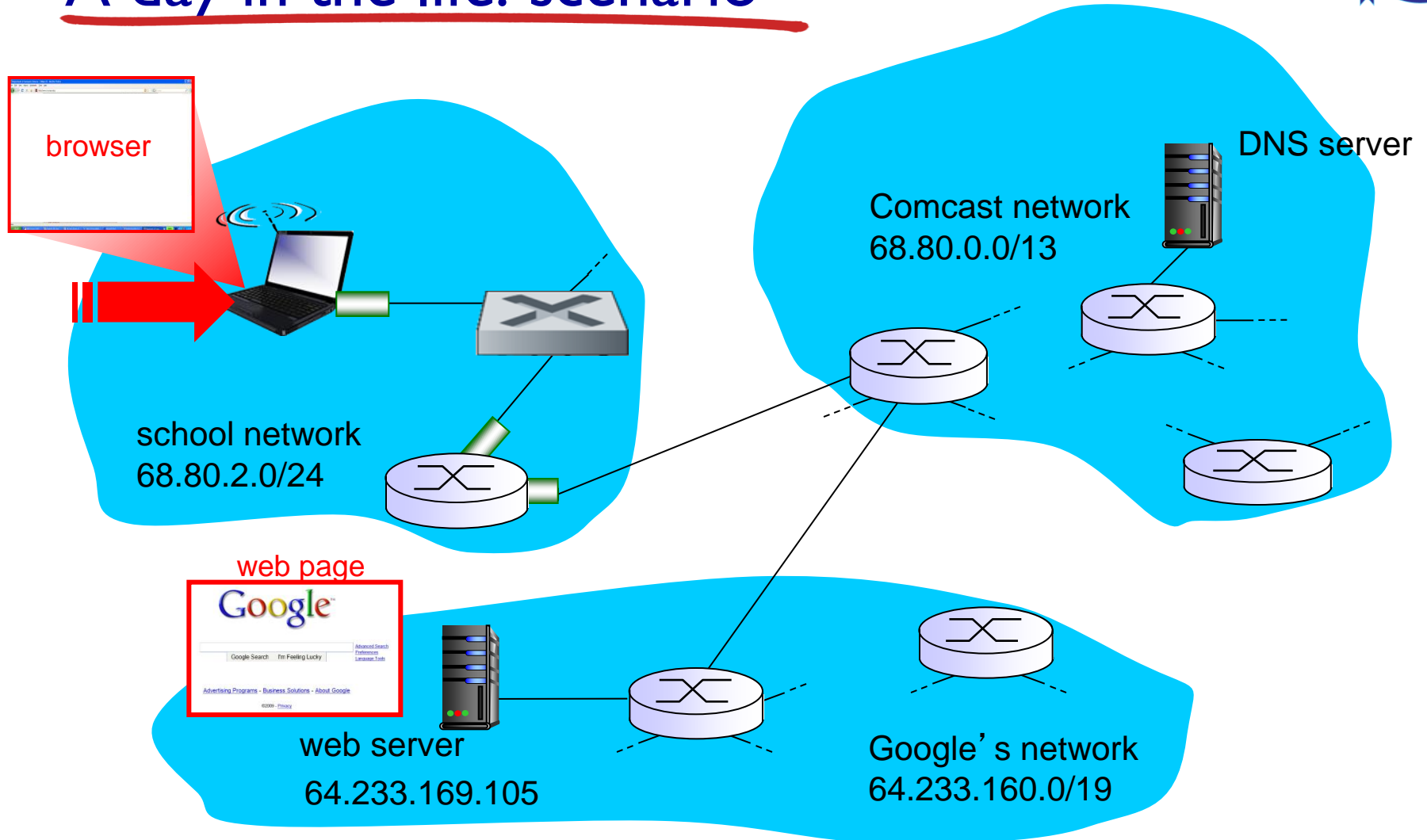
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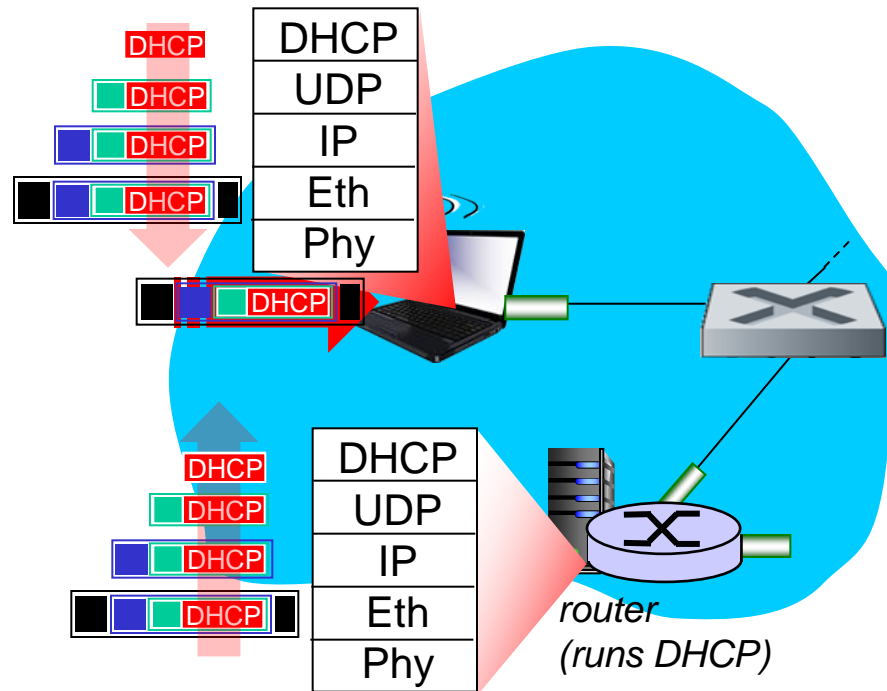
Synthesis: a day in the life of a web request

- ❖ 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

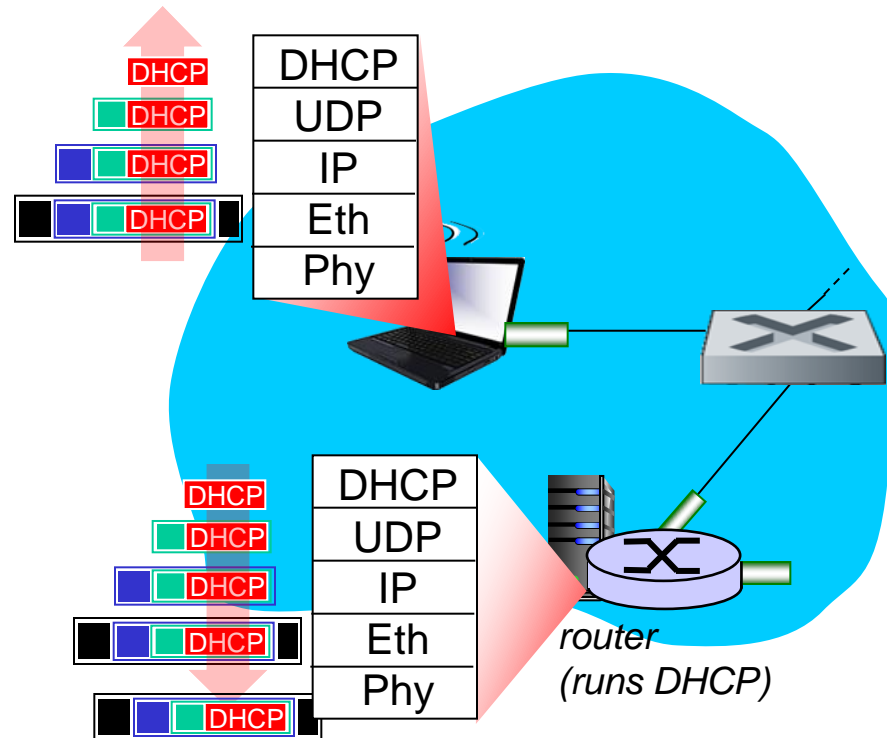


A day in the life... connecting to the Internet



- ❖ 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

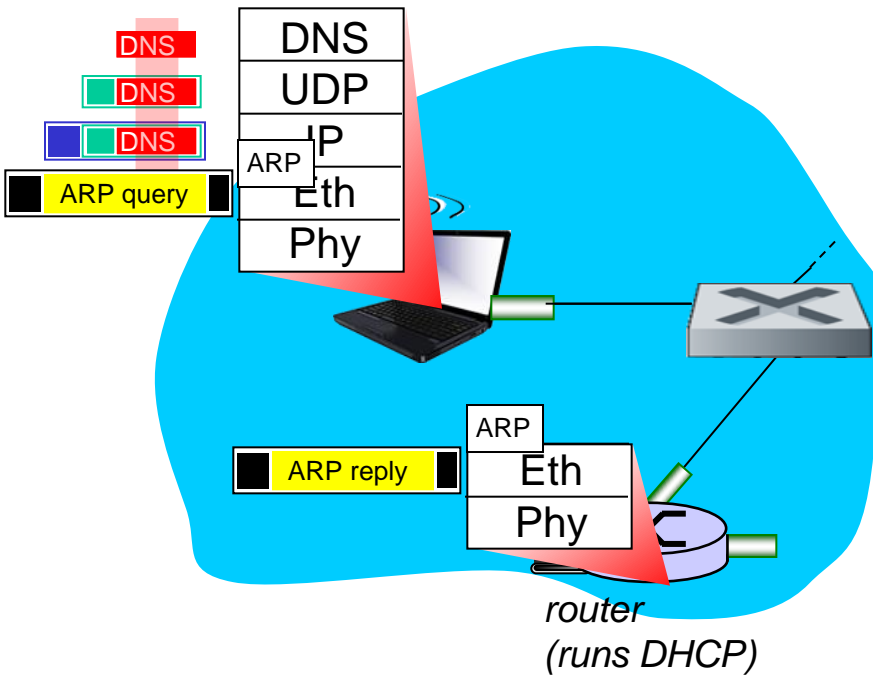
A day in the life... connecting to the Internet



- ❖ 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

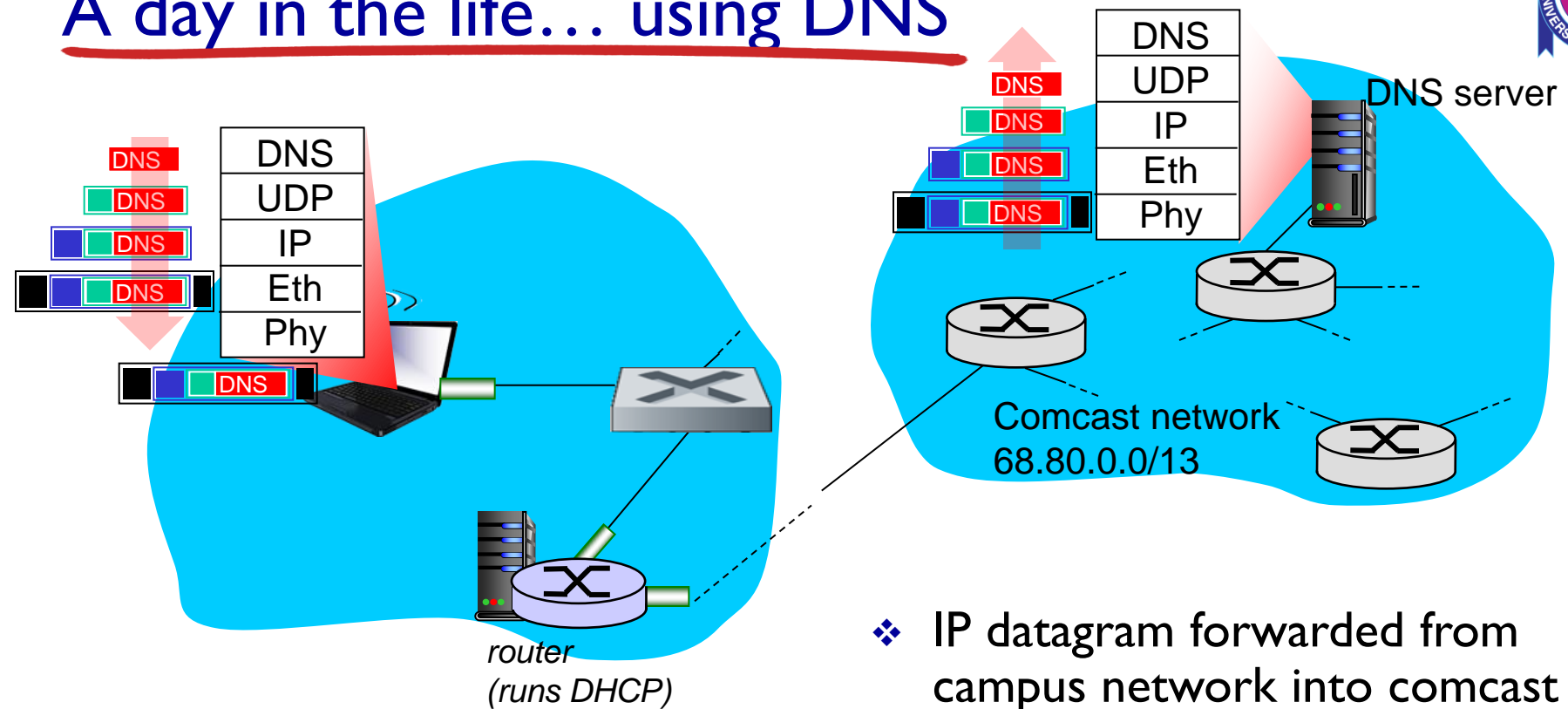
Client now has IP address, knows name & addr of DNS server, IP address of its first-hop router

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

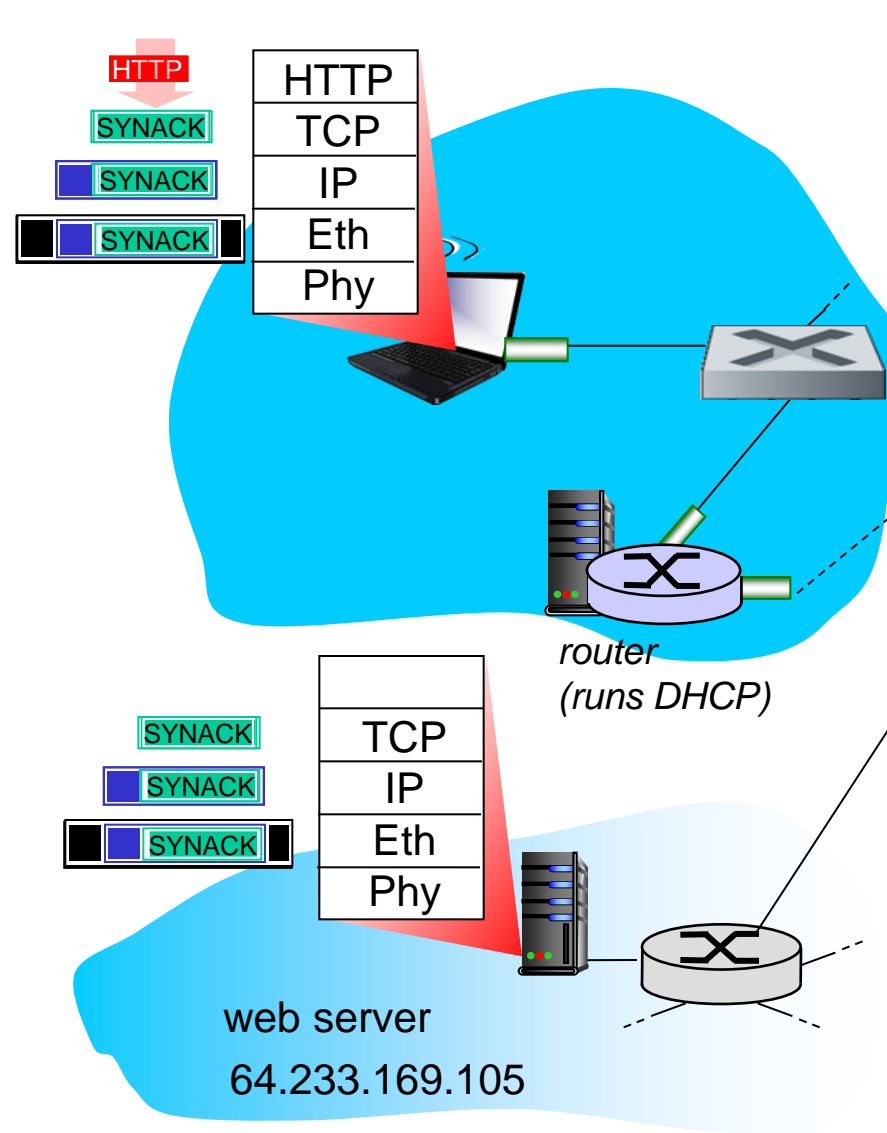
A day in the life... using DNS



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

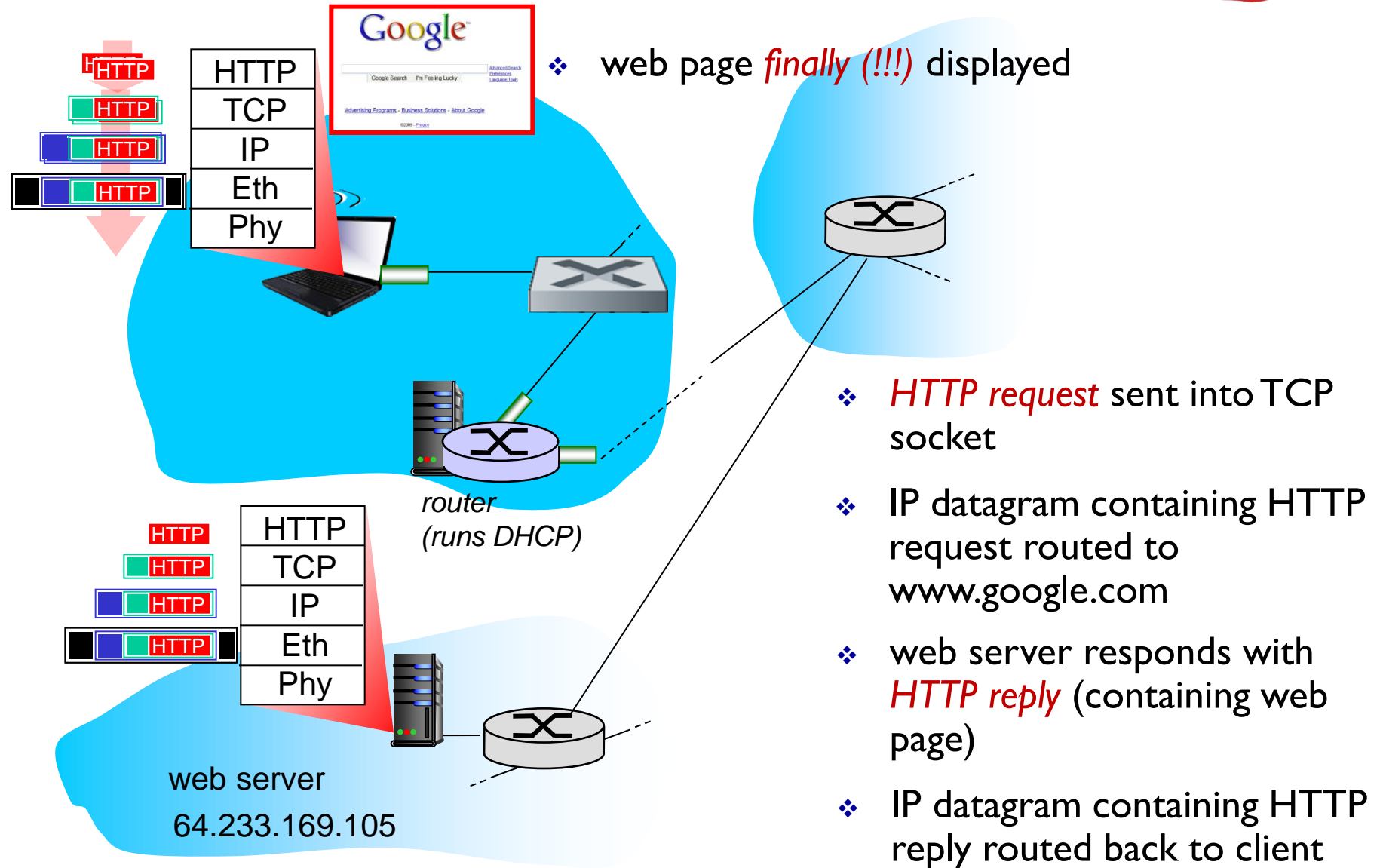
- ❖ IP datagram forwarded from campus network into comcast network, routed (tables created by *RIP, OSPF, IS-IS* and/or *BGP* routing protocols) to DNS server
- ❖ demux'ed to DNS server
- ❖ DNS server replies to client with IP address of **www.google.com**

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



- ❖ to send HTTP request, client first opens **TCP socket** to web server
- ❖ TCP **SYN segment** (step 1 in 3-way handshake) *inter-domain routed* to web server
- ❖ web server responds with **TCP SYNACK** (step 2 in 3-way handshake)
- ❖ **TCP connection established!**

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



Chapter 5: 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, VLANs
 - virtualized networks as a link layer: MPLS
- ❖ synthesis: a day in the life of a web request

Chapter 5: let's take a breath

- ❖ journey down protocol stack *complete* (except PHY)
- ❖ solid understanding of networking principles, practice
- ❖ could stop here but *lots* of interesting topics!
 - wireless
 - multimedia
 - security
 - network management