

# Chapter 1

# Introduction

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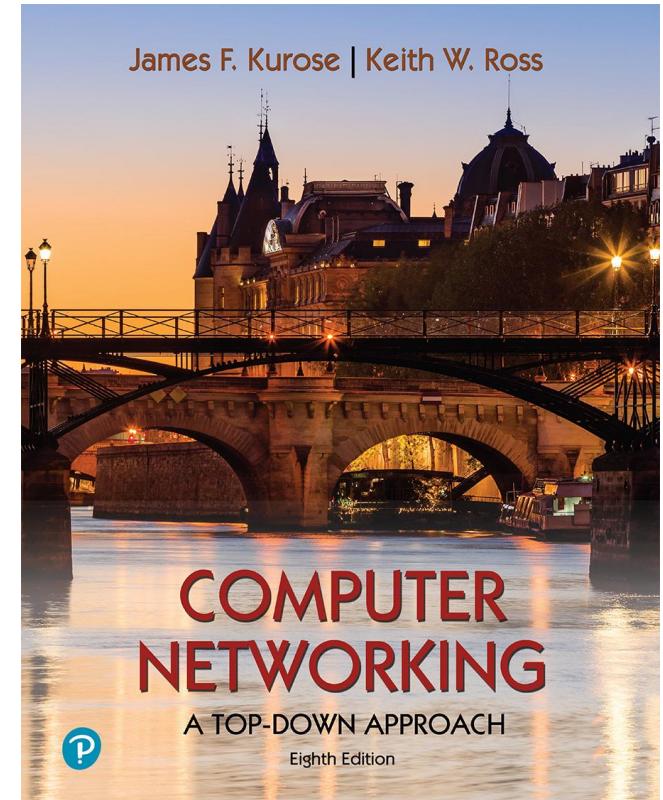
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*Computer Networking: A  
Top-Down Approach*  
8<sup>th</sup> edition  
Jim Kurose, Keith Ross  
Pearson, 2020

# Chapter 1: introduction

## *Chapter goal:*

- Get “feel,” “big picture,” introduction to terminology
  - more depth, detail *later* in course



## *Overview/roadmap:*

- What *is* the Internet? What *is* a protocol?
- **Network edge:** hosts, access network, physical media
- **Network core:** packet/circuit switching, internet structure
- **Performance:** loss, delay, throughput
- Protocol layers, service models
- Security
- History

# The Internet: a “nuts and bolts” view



Billions of connected computing *devices*:

- *hosts* = *end systems*
- running *network apps* at Internet's “edge”

*Packet switches*: forward packets (chunks of data)

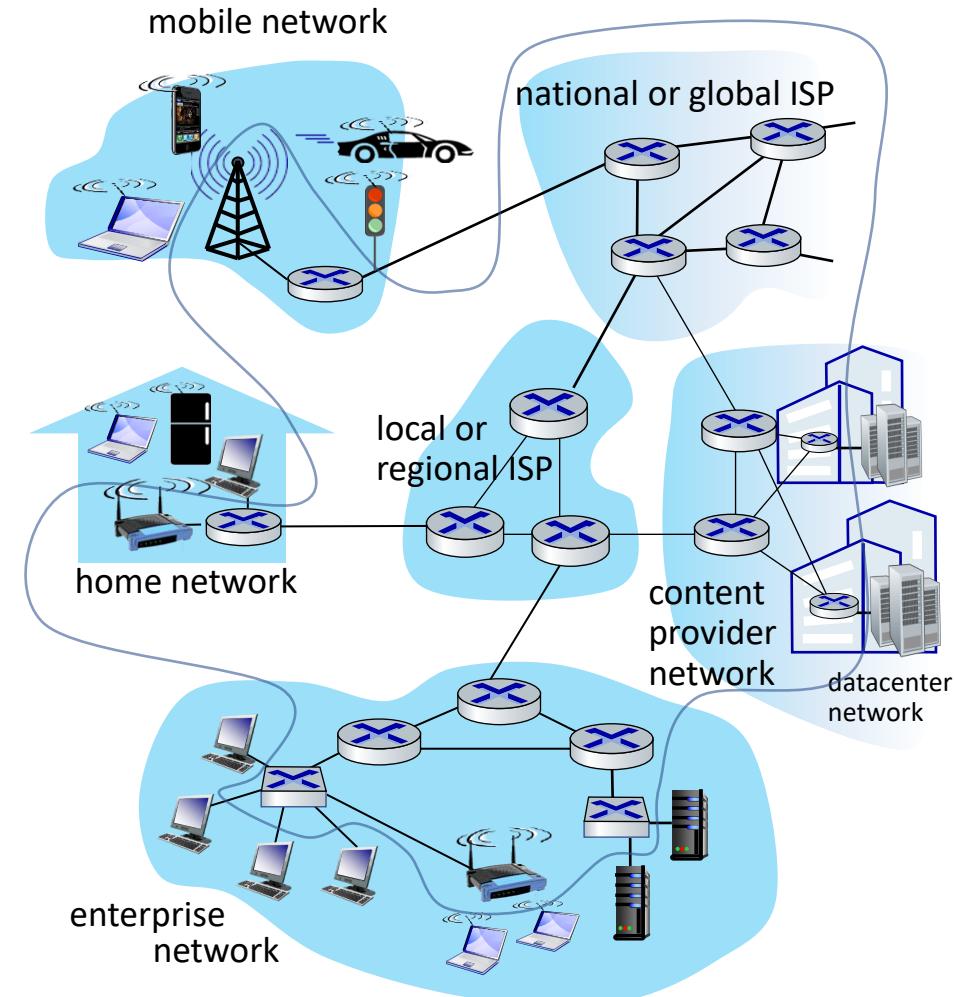
- *routers, switches*

*Communication links*

- fiber, copper, radio, satellite
- transmission rate: *bandwidth*

*Networks*

- collection of devices, routers, links: managed by an organization



# “Fun” Internet-connected devices



Amazon Echo



Internet refrigerator



Security Camera



Internet phones



IP picture frame



Slingbox: remote control cable TV



Gaming devices



Pacemaker & Monitor



Web-enabled toaster + weather forecaster



sensorized, bed mattress



Fitbit



Tweet-a-watt:  
monitor energy use

bikes



cars

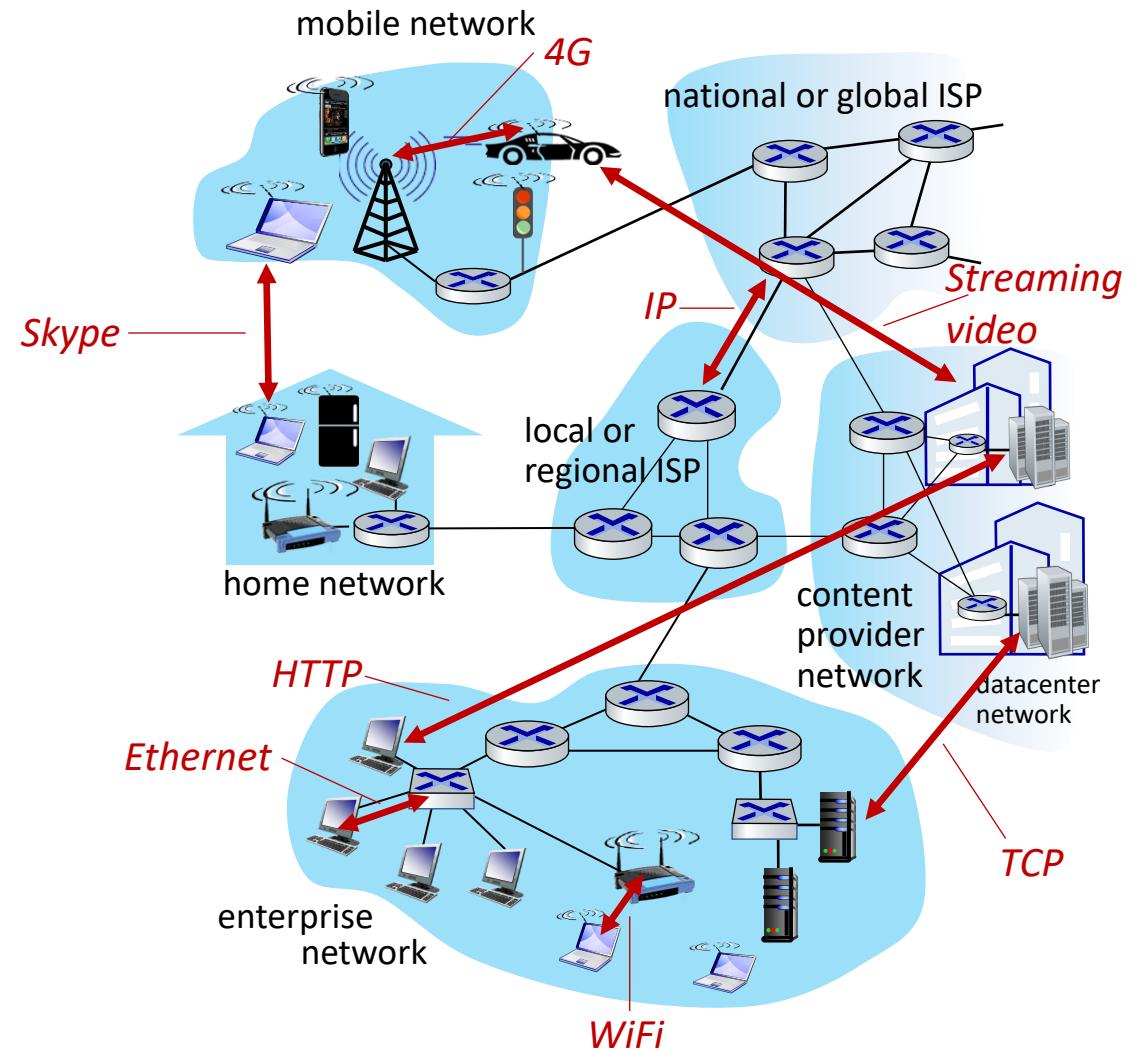


scooters

*Others?*

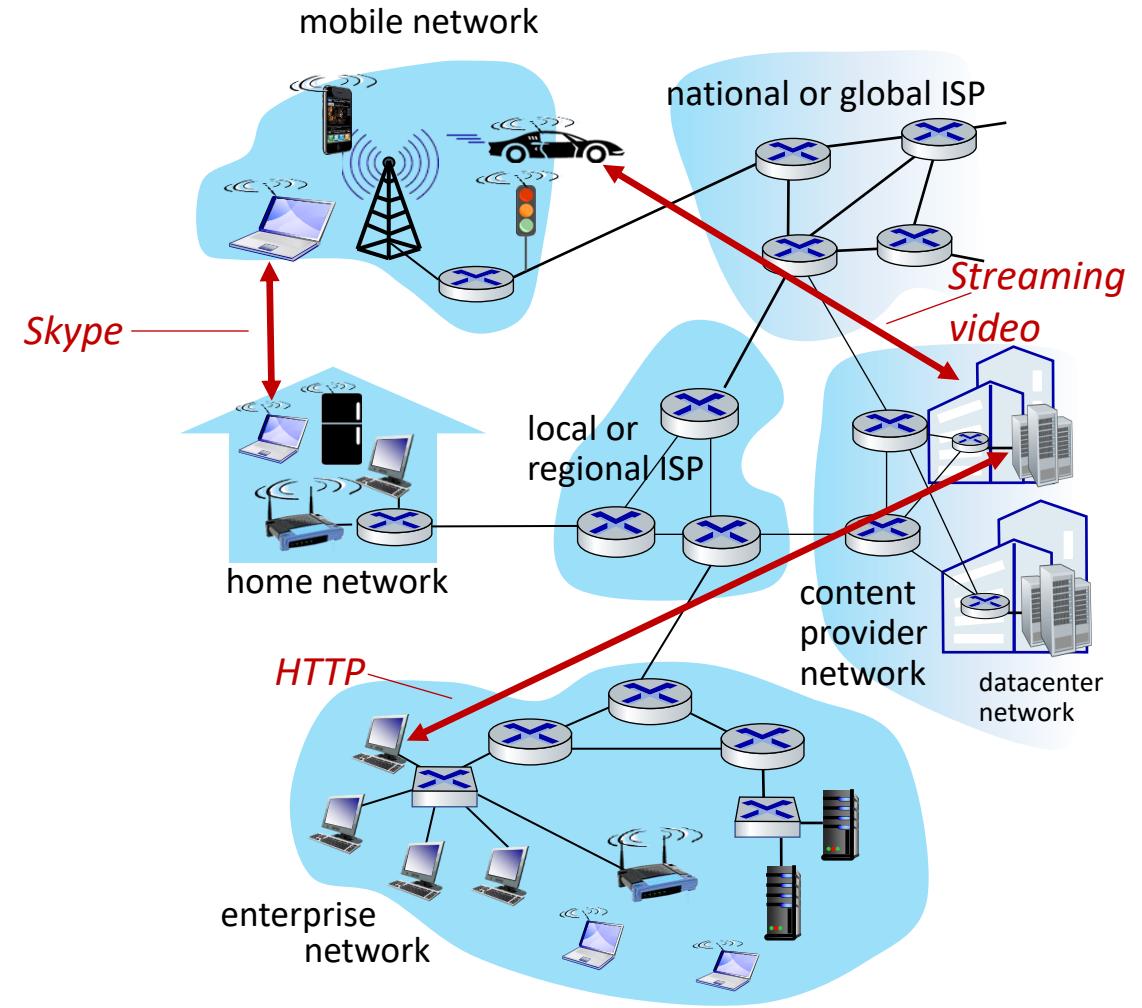
# The Internet: a “nuts and bolts” view

- *Internet: “network of networks”*
  - Interconnected ISPs
- *protocols are everywhere*
  - control sending, receiving of messages
  - e.g., HTTP (Web), streaming video, Skype, TCP, IP, WiFi, 4G, Ethernet
- *Internet standards*
  - RFC: Request for Comments
  - IETF: Internet Engineering Task Force



# The Internet: a “services” view

- *Infrastructure* that provides services to applications:
  - Web, streaming video, multimedia teleconferencing, email, games, e-commerce, social media, interconnected appliances, ...
- provides *programming interface* to distributed applications:
  - “hooks” allowing sending/receiving apps to “connect” to, use Internet transport service
  - provides service options, analogous to postal service



# What's a protocol?

## *Human protocols:*

- “what’s the time?”
- “I have a question”
- introductions

Rules for:

- ... specific messages sent
- ... specific actions taken when message received, or other events

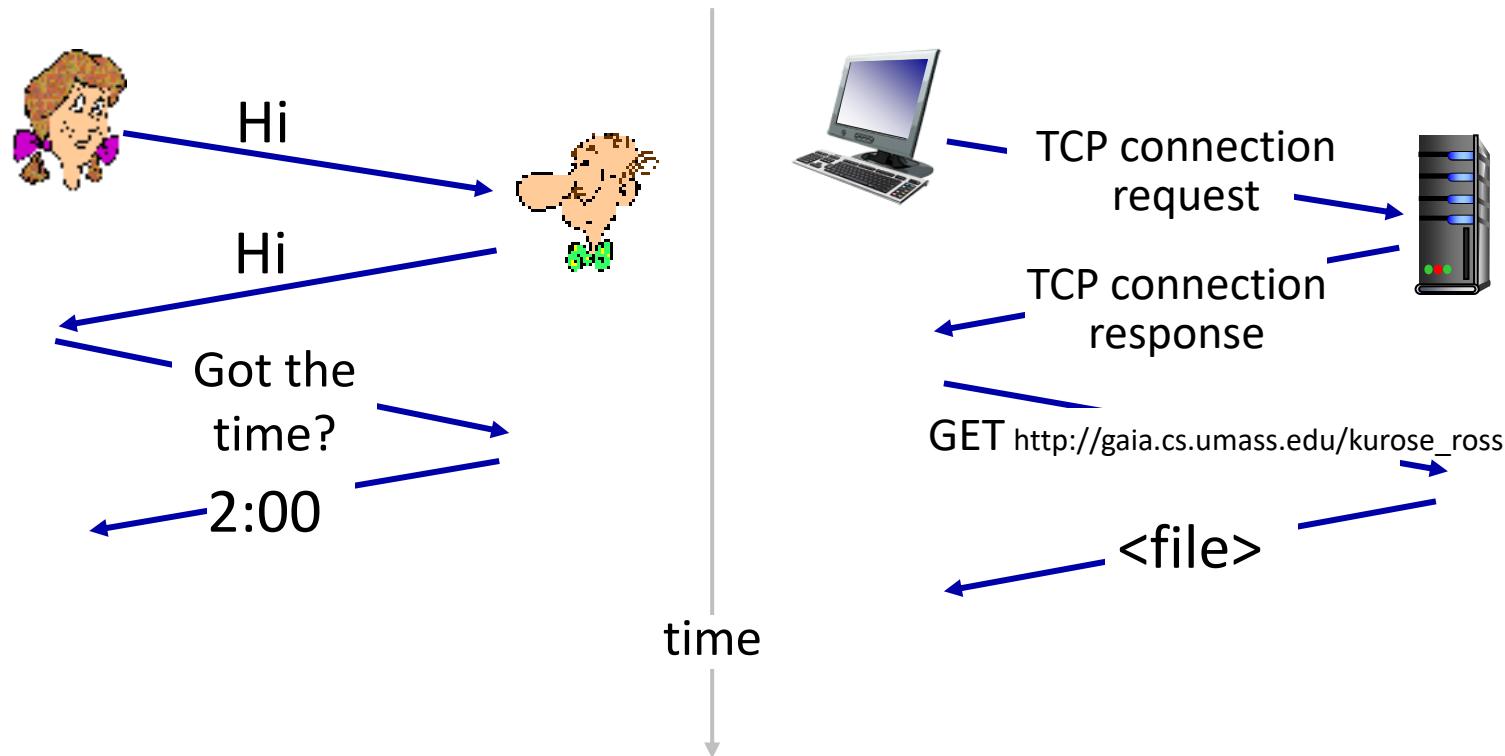
## *Network protocols:*

- computers (devices) rather than humans
- all communication activity in Internet governed by protocols

*Protocols define the **format, order** of messages sent and received among network entities, and **actions taken** on message transmission, receipt*

# What's a protocol?

A human protocol and a computer network protocol:



*Q:* other human protocols?

# Chapter 1: roadmap

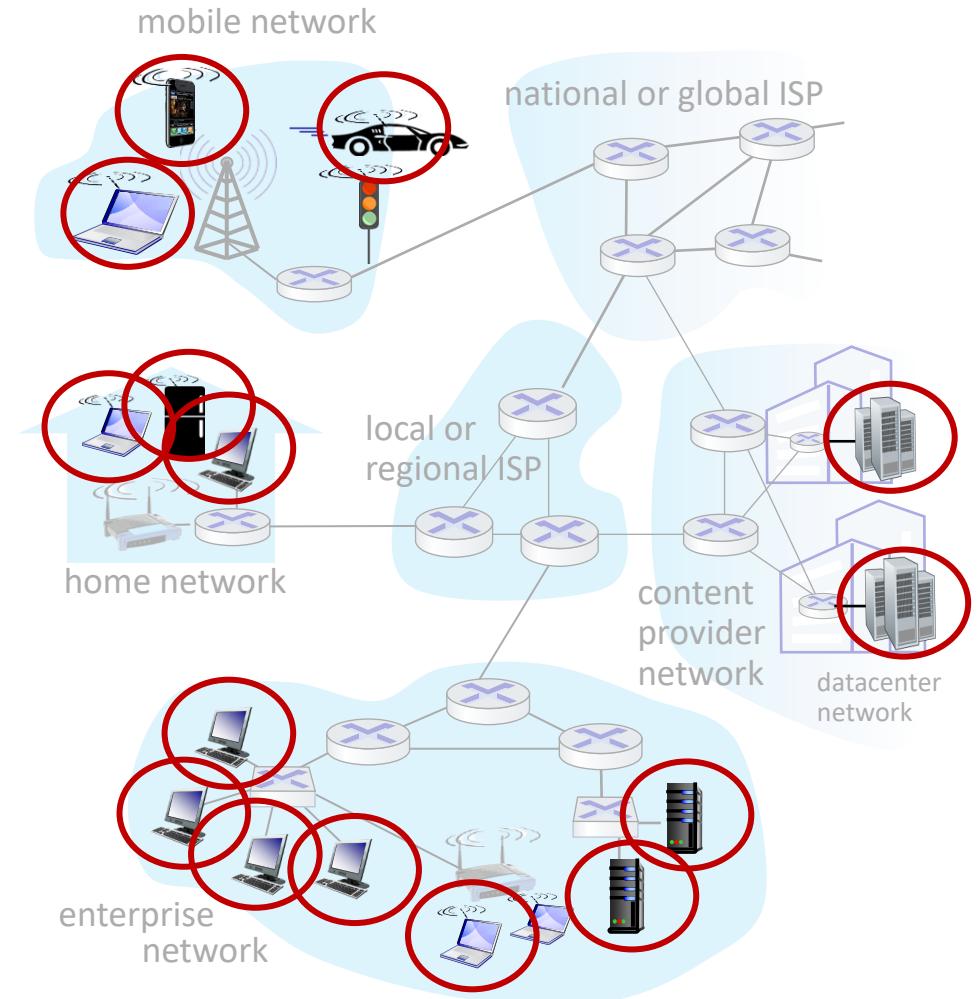
- What *is* the Internet?
- What *is* a protocol?
- **Network edge:** hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
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# A closer look at Internet structure

## Network edge:

- hosts: clients and servers
- servers often in data centers



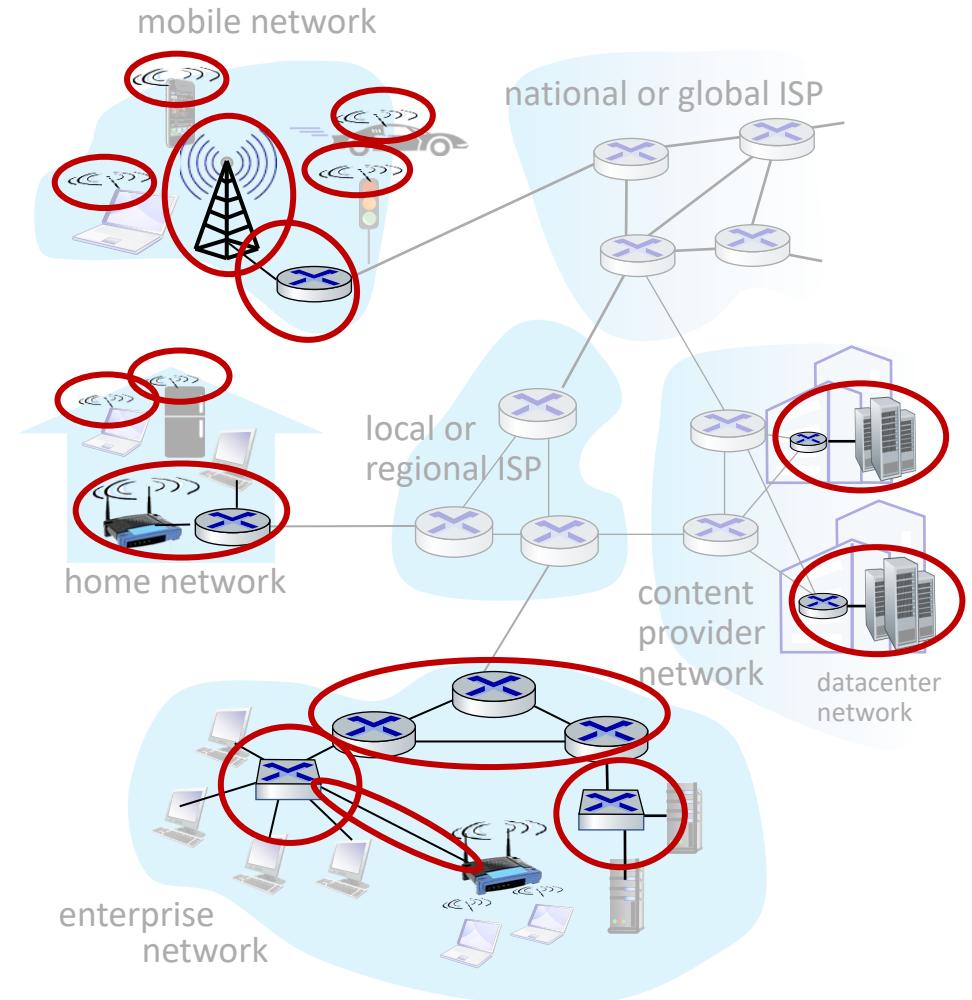
# A closer look at Internet structure

## Network edge:

- hosts: clients and servers
- servers often in data centers

## Access networks, physical media:

- wired, wireless communication links



# A closer look at Internet structure

## Network edge:

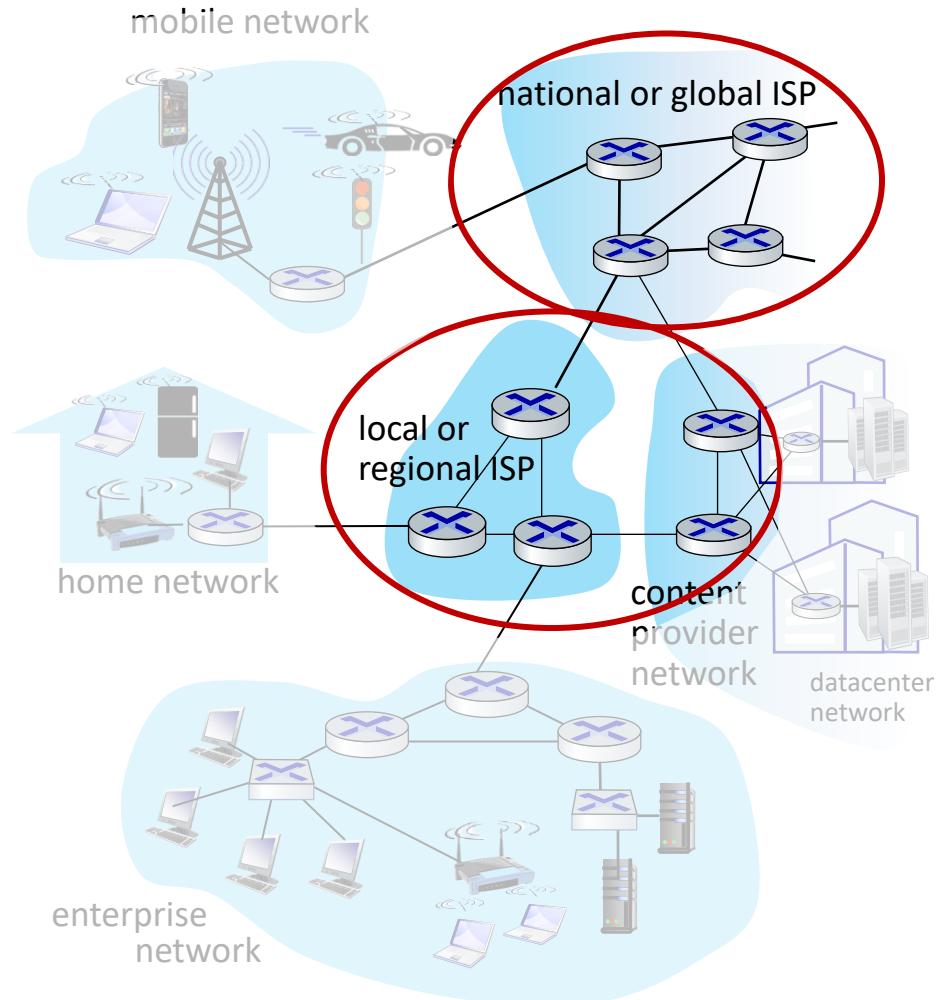
- hosts: clients and servers
- servers often in data centers

## Access networks, physical media:

- wired, wireless communication links

## Network core:

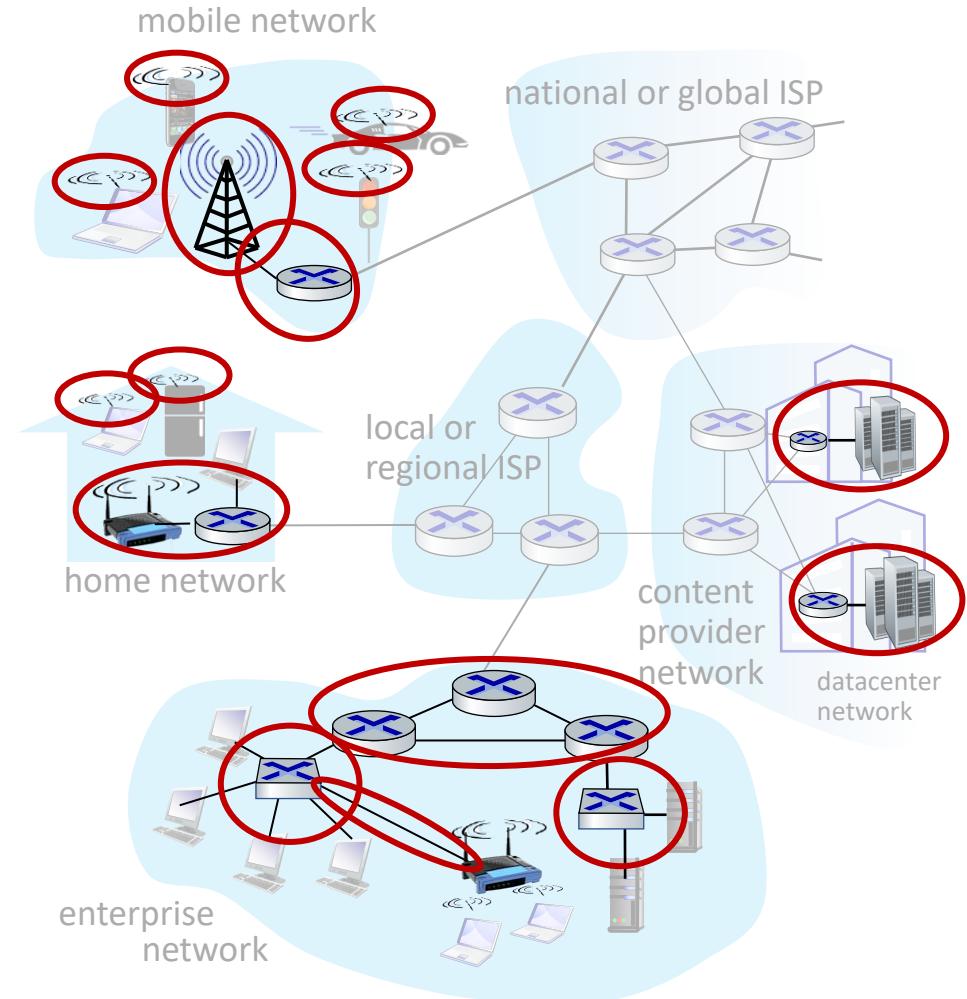
- interconnected routers
- network of networks



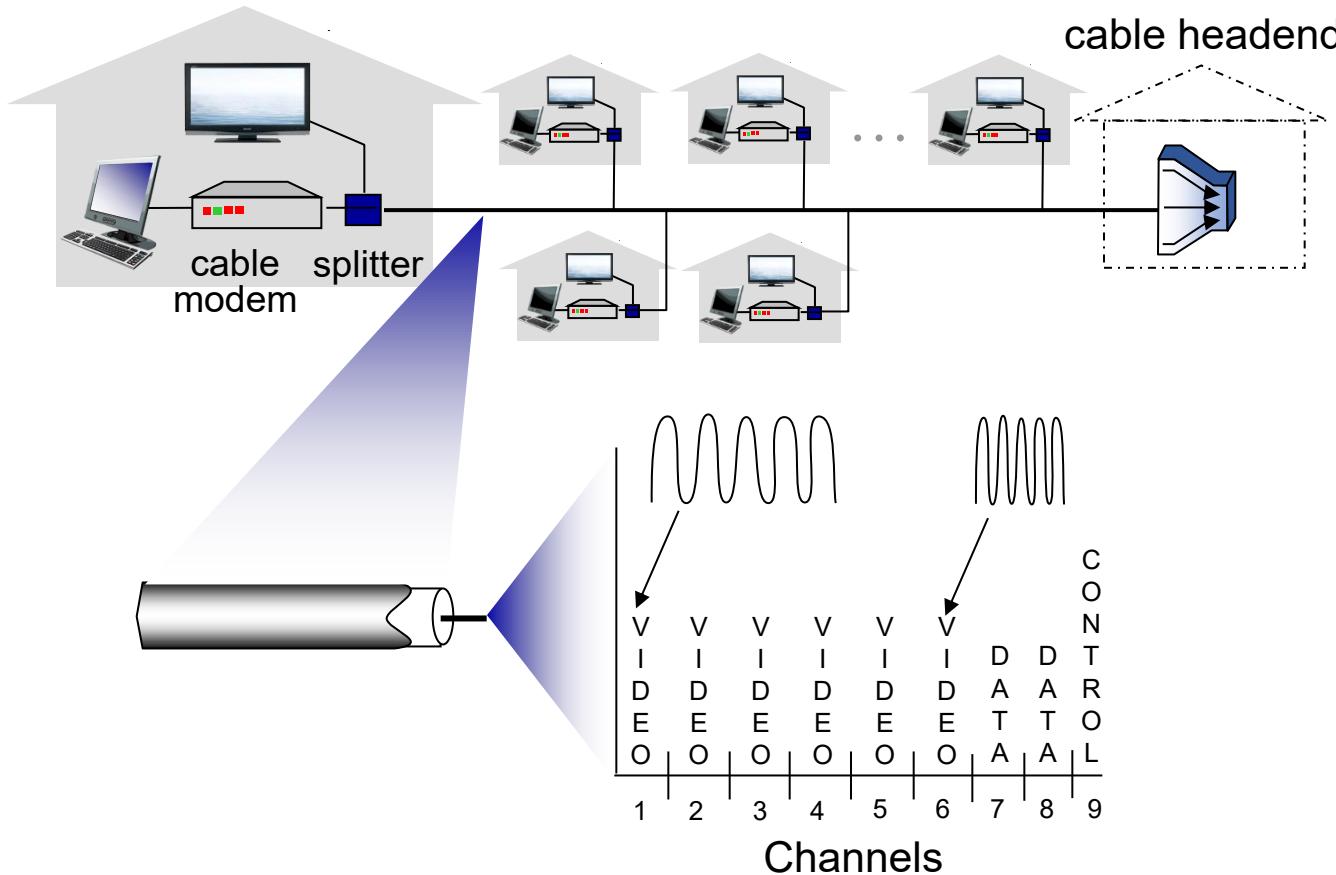
# Access networks and physical media

*Q: How to connect end systems  
to edge router?*

- residential access nets
- institutional access networks (school, company)
- mobile access networks (WiFi, 4G/5G)

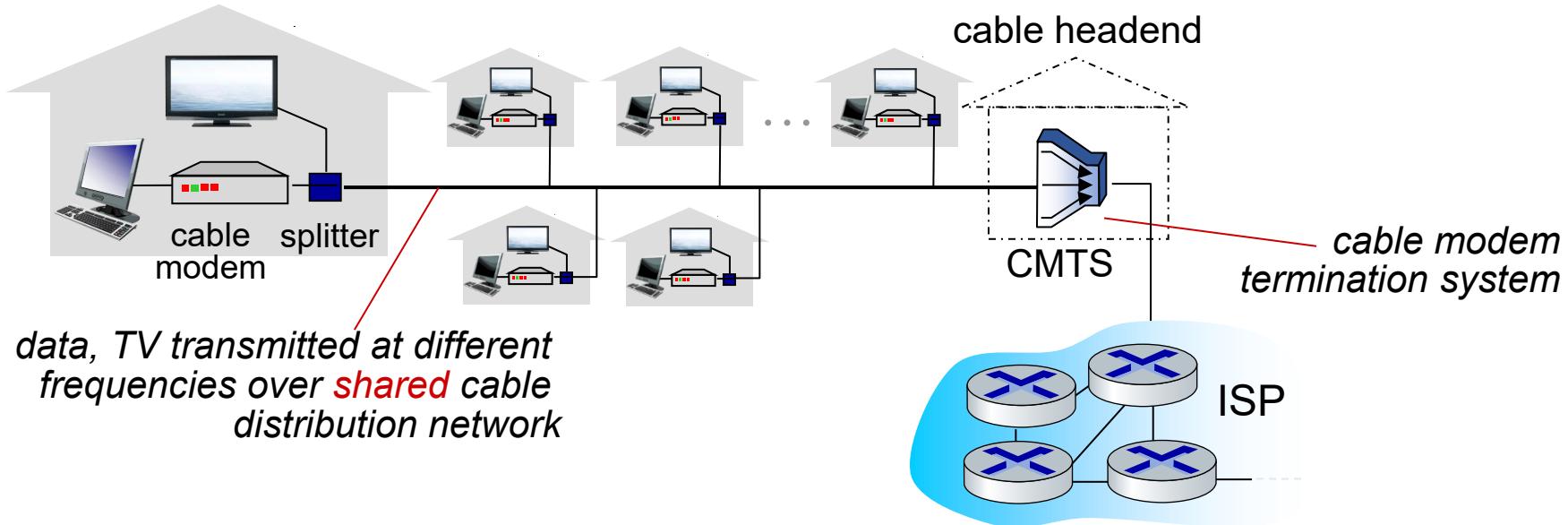


# Access networks: cable-based access



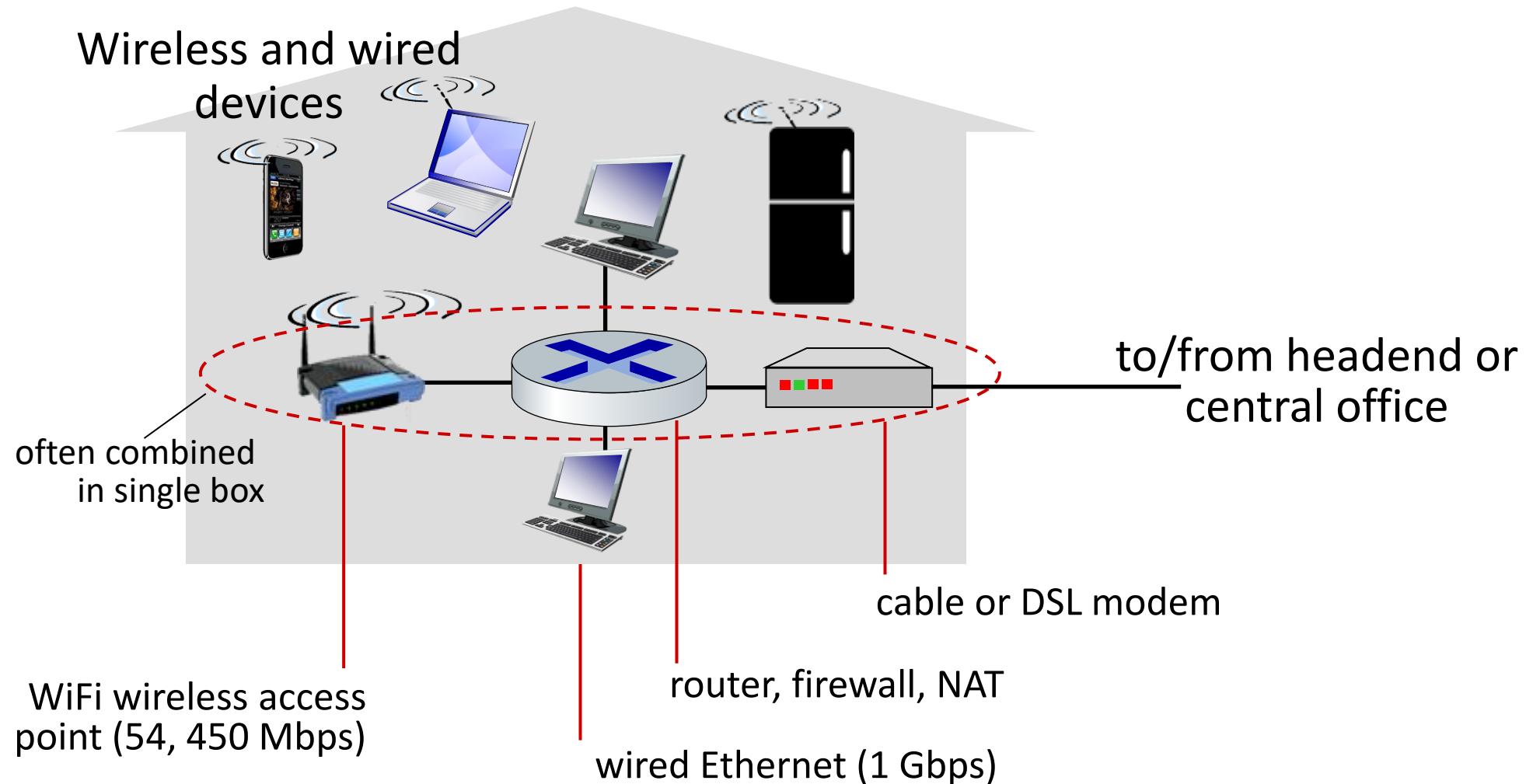
*frequency division multiplexing (FDM):* different channels transmitted in different frequency bands

# Access networks: cable-based access



- HFC: hybrid fiber coax
  - asymmetric: up to 40 Mbps – 1.2 Gbps downstream transmission rate, 30-100 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes **share access network** to cable headend

# Access networks: home networks



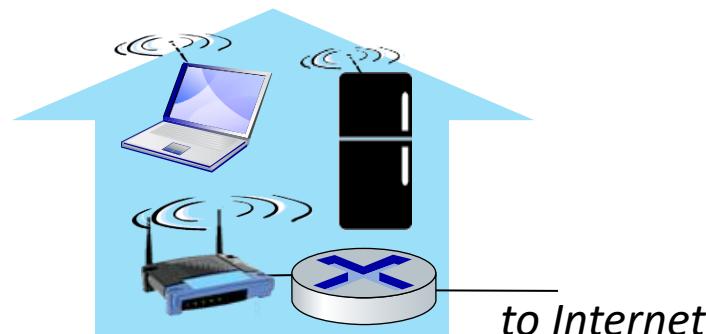
# Wireless access networks

Shared *wireless* access network connects end system to router

- via base station aka “access point”

## Wireless local area networks (WLANs)

- typically within or around building (~100 ft)
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate

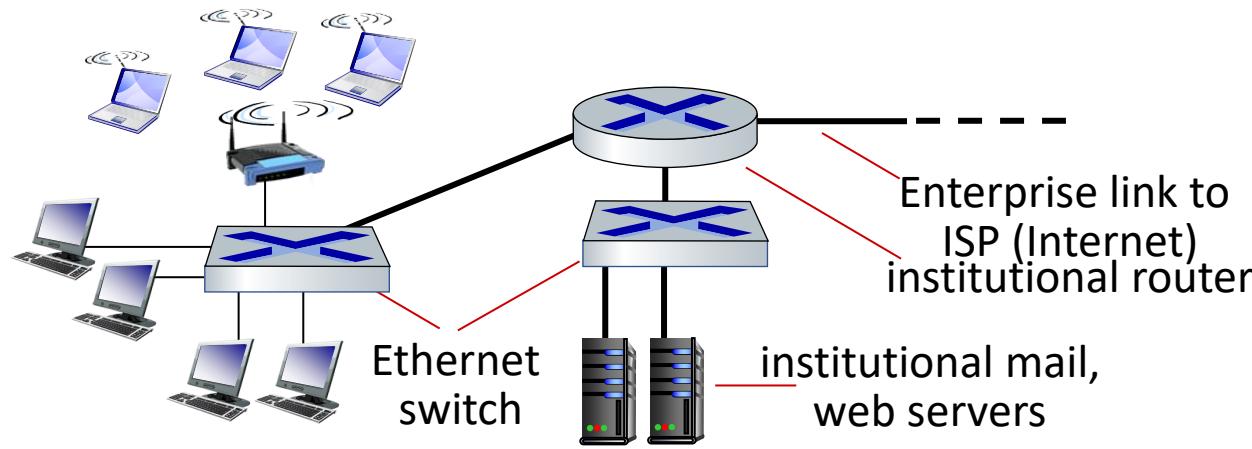


## Wide-area cellular access networks

- provided by mobile, cellular network operator (10's km)
- 10's Mbps
- 4G cellular networks (5G coming)



# Access networks: enterprise networks



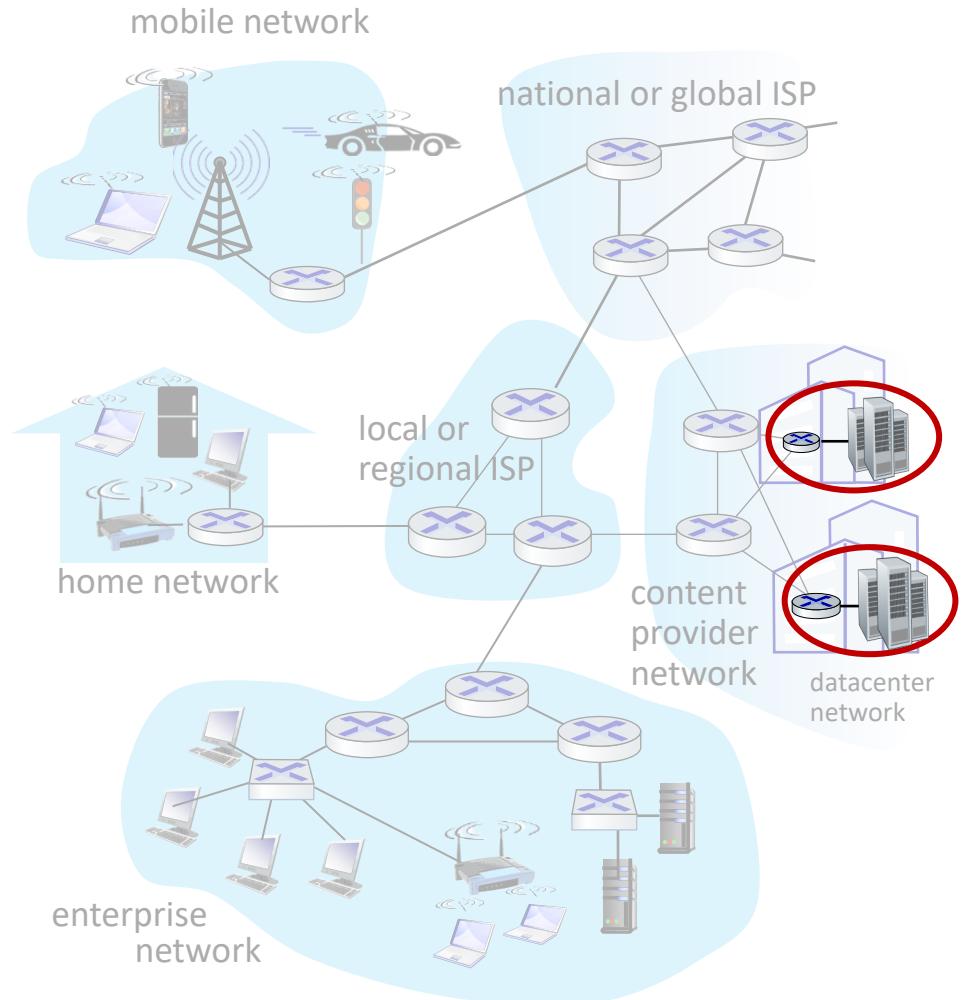
- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
  - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
  - WiFi: wireless access points at 11, 54, 450 Mbps

# Access networks: data center networks

- high-bandwidth links (10s to 100s Gbps) connect hundreds to thousands of servers together, and to Internet



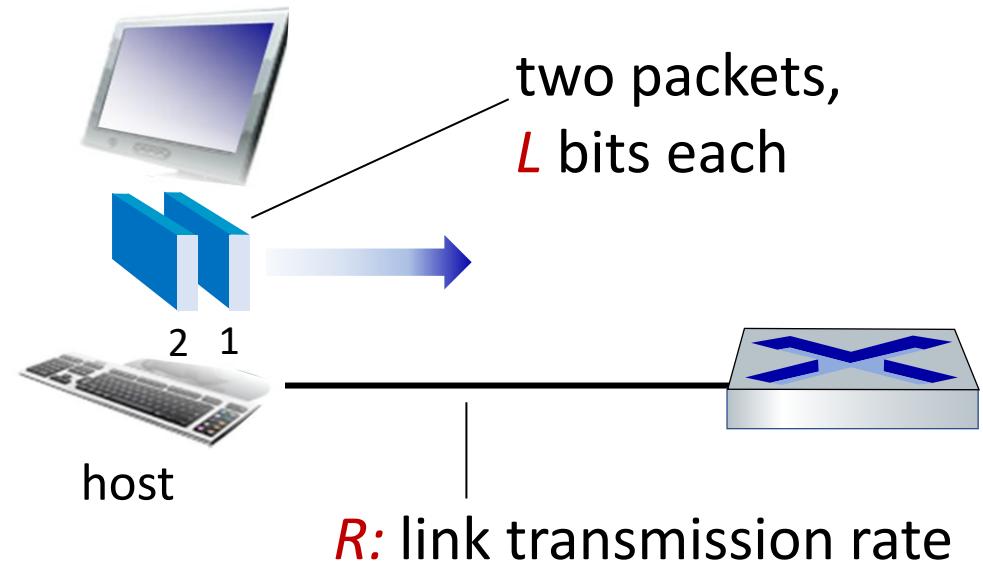
Courtesy: Massachusetts Green High Performance Computing Center (mghpcc.org)



# Host: sends *packets* of data

host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length  $L$  bits
- transmits packet into access network at *transmission rate R*
  - link transmission rate, aka link *capacity, aka link bandwidth*

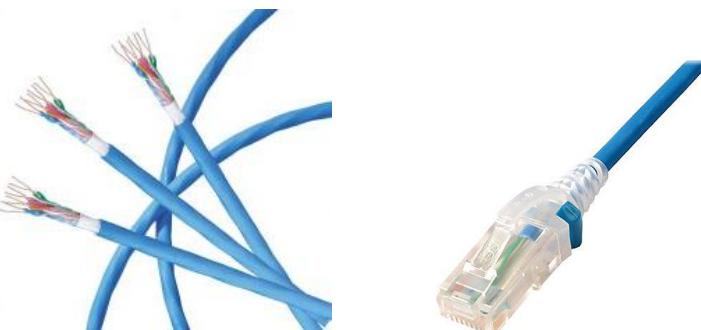


$$\text{packet transmission delay} = \frac{\text{time needed to transmit } L\text{-bit packet into link}}{R \text{ (bits/sec)}}$$

# Links: physical media

## Twisted pair (TP)

- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6: 10Gbps Ethernet



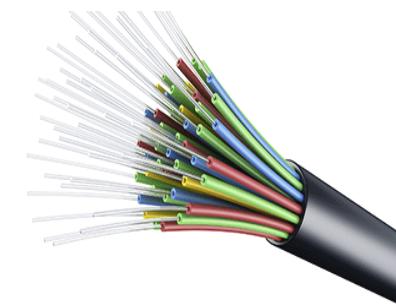
## Coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple frequency channels on cable
  - 100's Mbps per channel



## Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
  - high-speed point-to-point transmission (10's-100's Gbps)
- low error rate: repeaters spaced far apart + immune to electromagnetic noise



# Links: physical media

## Radio link types:

- **Wireless LAN (WiFi)**
  - 10-100's Mbps; 10's of meters
- **wide-area** (e.g., 4G/5G cellular)
  - 10's Mbps over ~10 Km
- **Bluetooth:** cable replacement
  - short distances, limited rates
- **terrestrial microwave**
  - point-to-point; 45 Mbps channels
- **satellite**
  - up to 45 Mbps per channel
  - 270 msec end-end delay

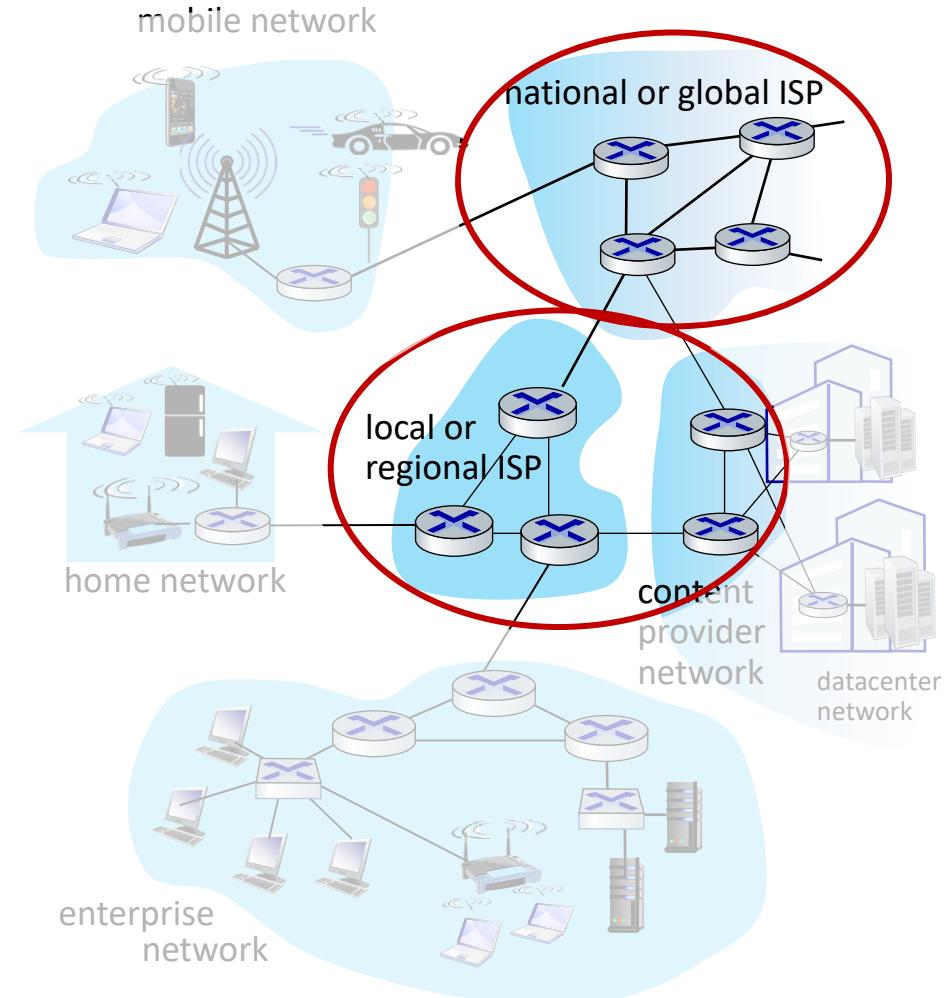
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# The network core

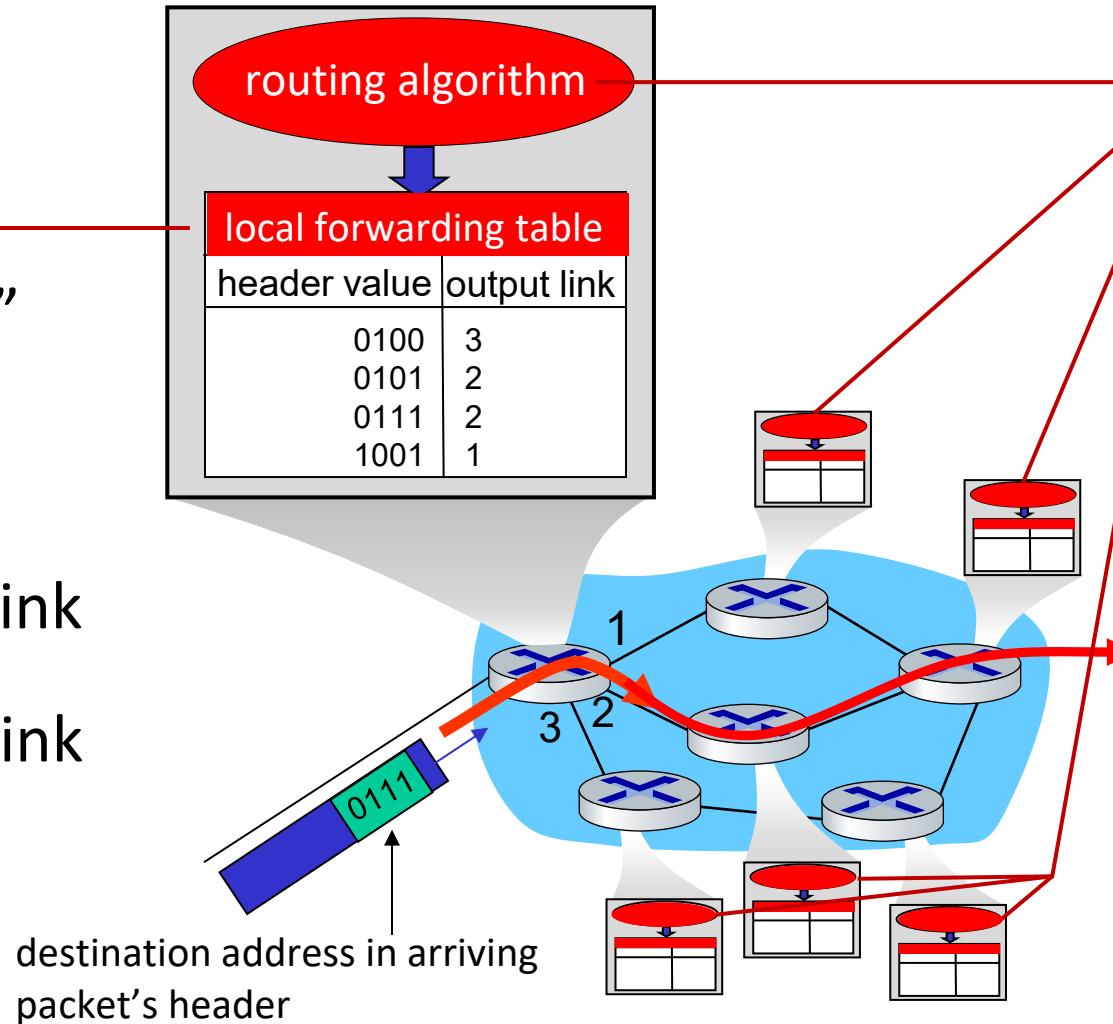
- mesh of interconnected routers
- **packet-switching**: hosts break application-layer messages into *packets*
  - network **forwards** packets from one router to the next, across links on path from source to destination



# Two key network-core functions

## Forwarding:

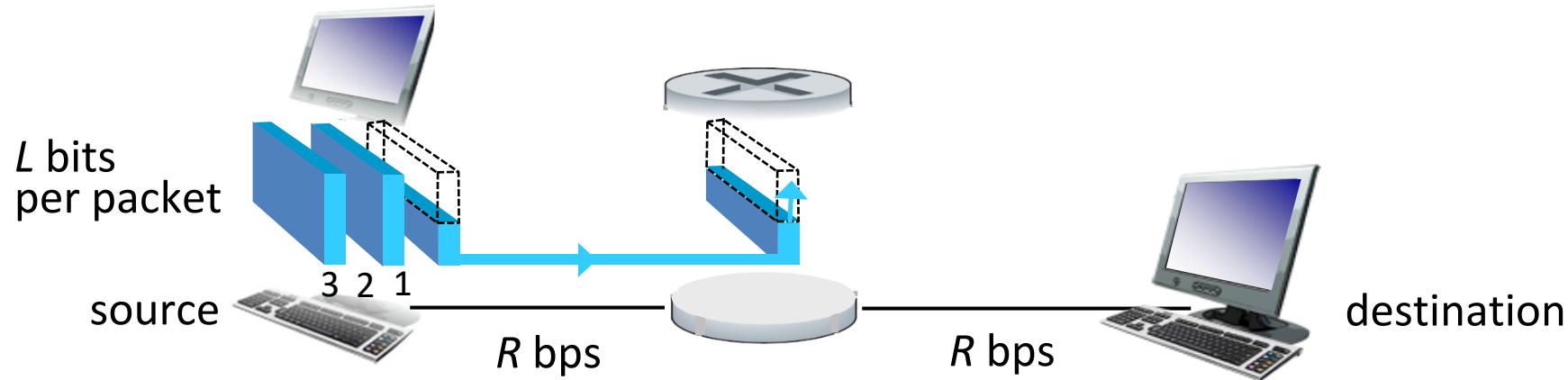
- aka “switching”
- *local* action:  
move arriving  
packets from  
router’s input link  
to appropriate  
router output link



## Routing:

- *global* action:  
determine source-destination paths taken by packets
- routing algorithms

# Packet-switching: store-and-forward

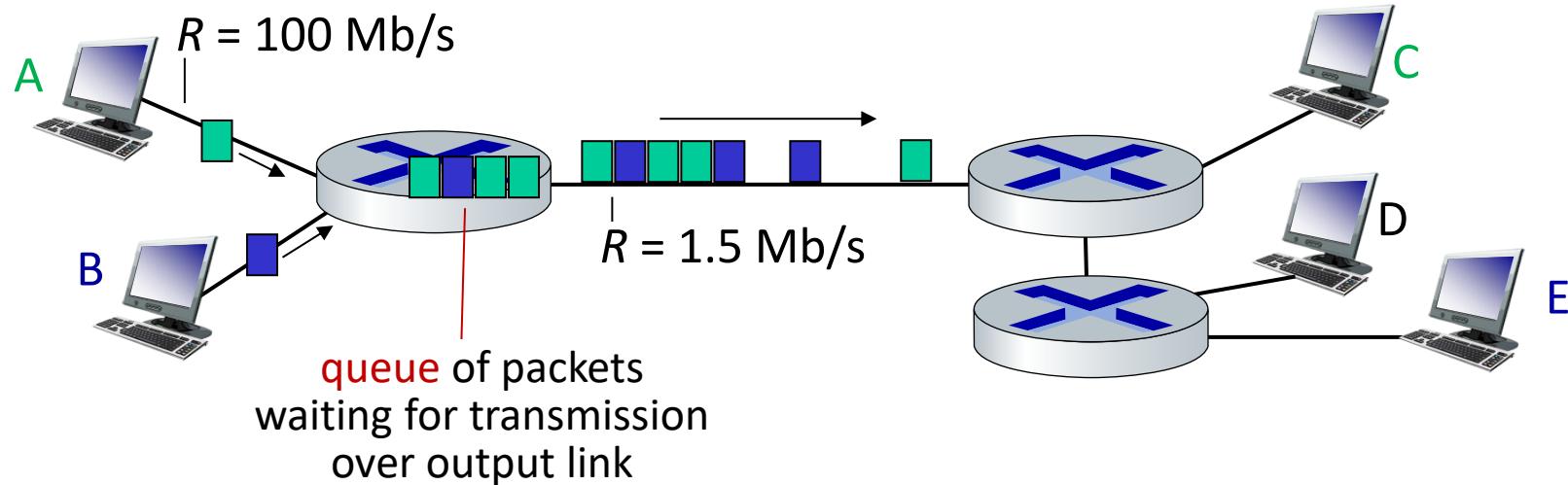


- **packet transmission delay:** takes  $L/R$  seconds to transmit (push out)  $L$ -bit packet into link at  $R$  bps
- ***store and forward:*** entire packet must arrive at router before it can be transmitted on next link

*One-hop numerical example:*

- $L = 10$  Kbits
- $R = 100$  Mbps
- one-hop transmission delay = 0.1 msec

# Packet-switching: queueing



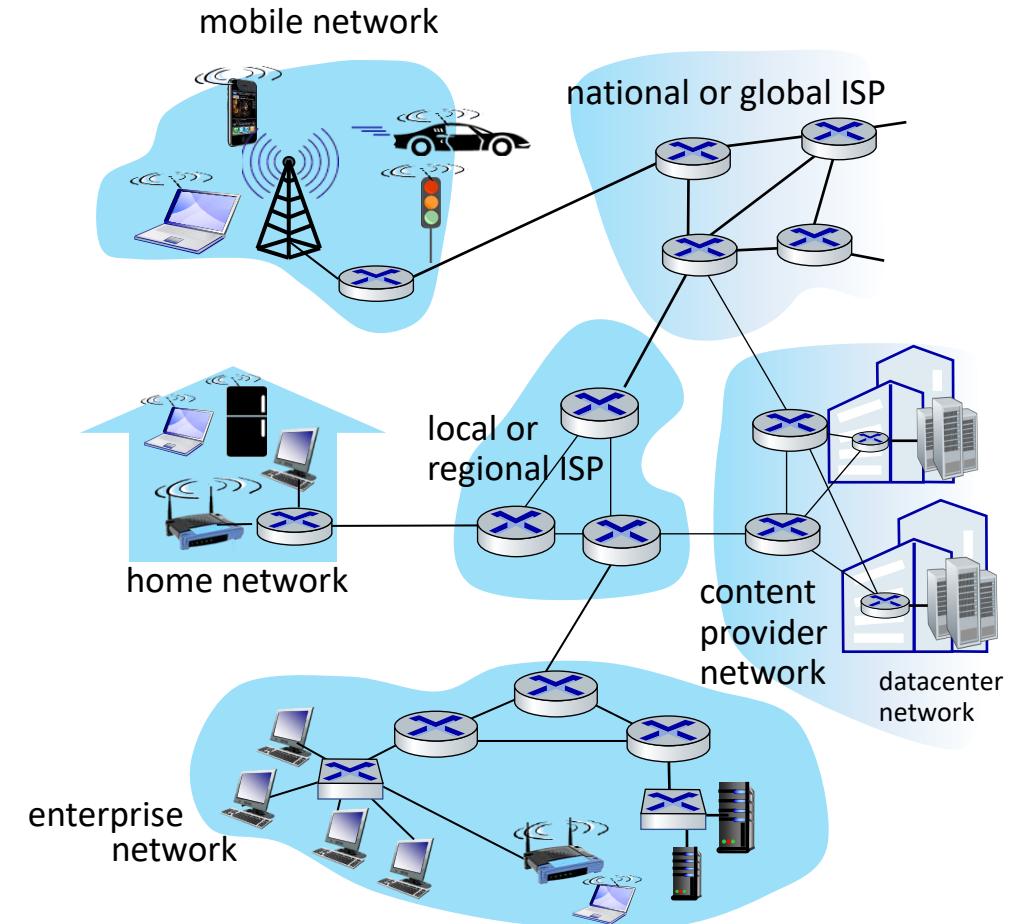
**Queueing** occurs when work arrives faster than it can be serviced:





# Internet structure: a “network of networks”

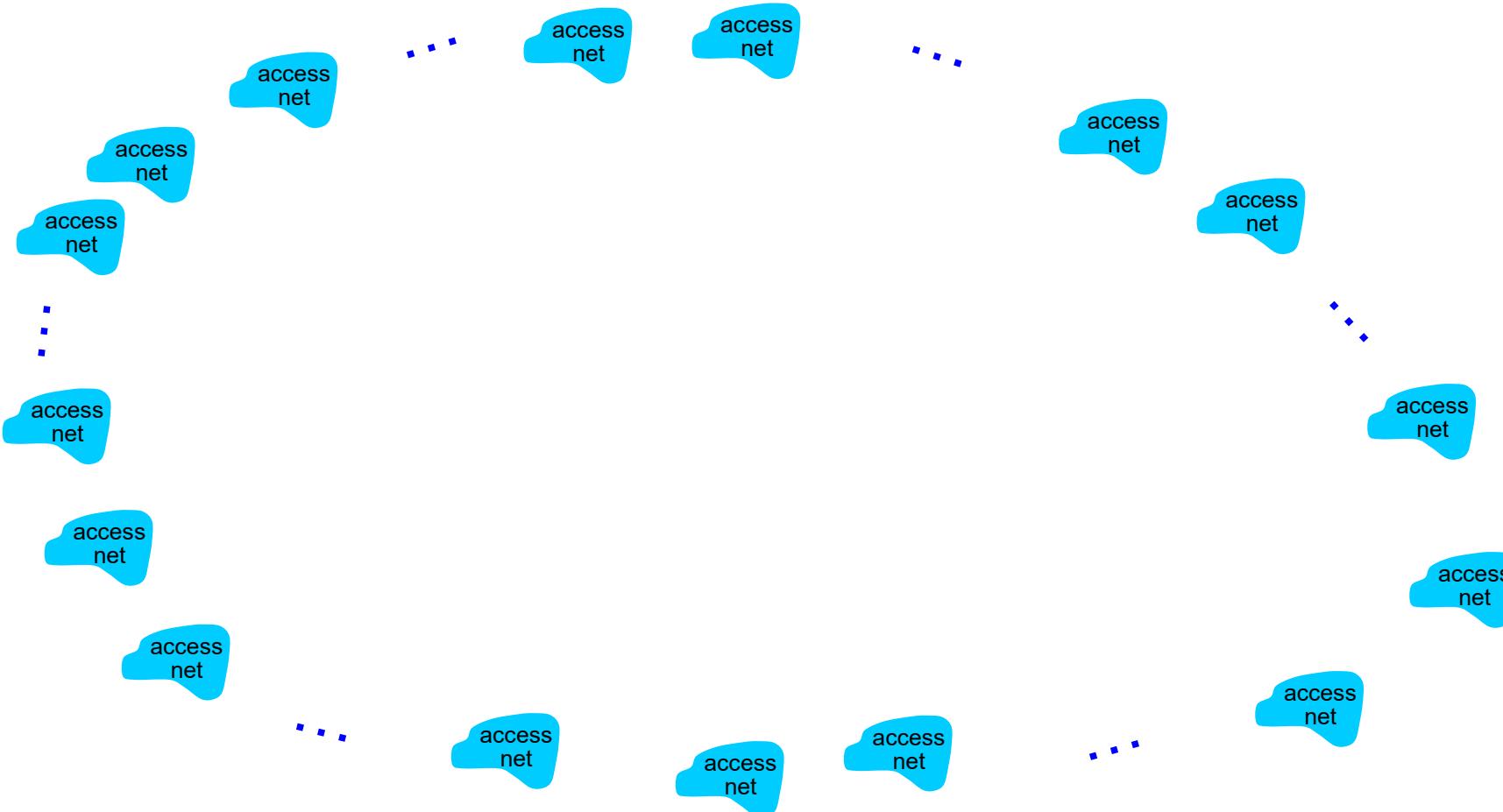
- hosts connect to Internet via **access** Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
  - so that *any* two hosts (*anywhere!*) can send packets to each other
- resulting network of networks is very complex
  - evolution driven by **economics, national policies**



*Let's take a stepwise approach to describe current Internet structure*

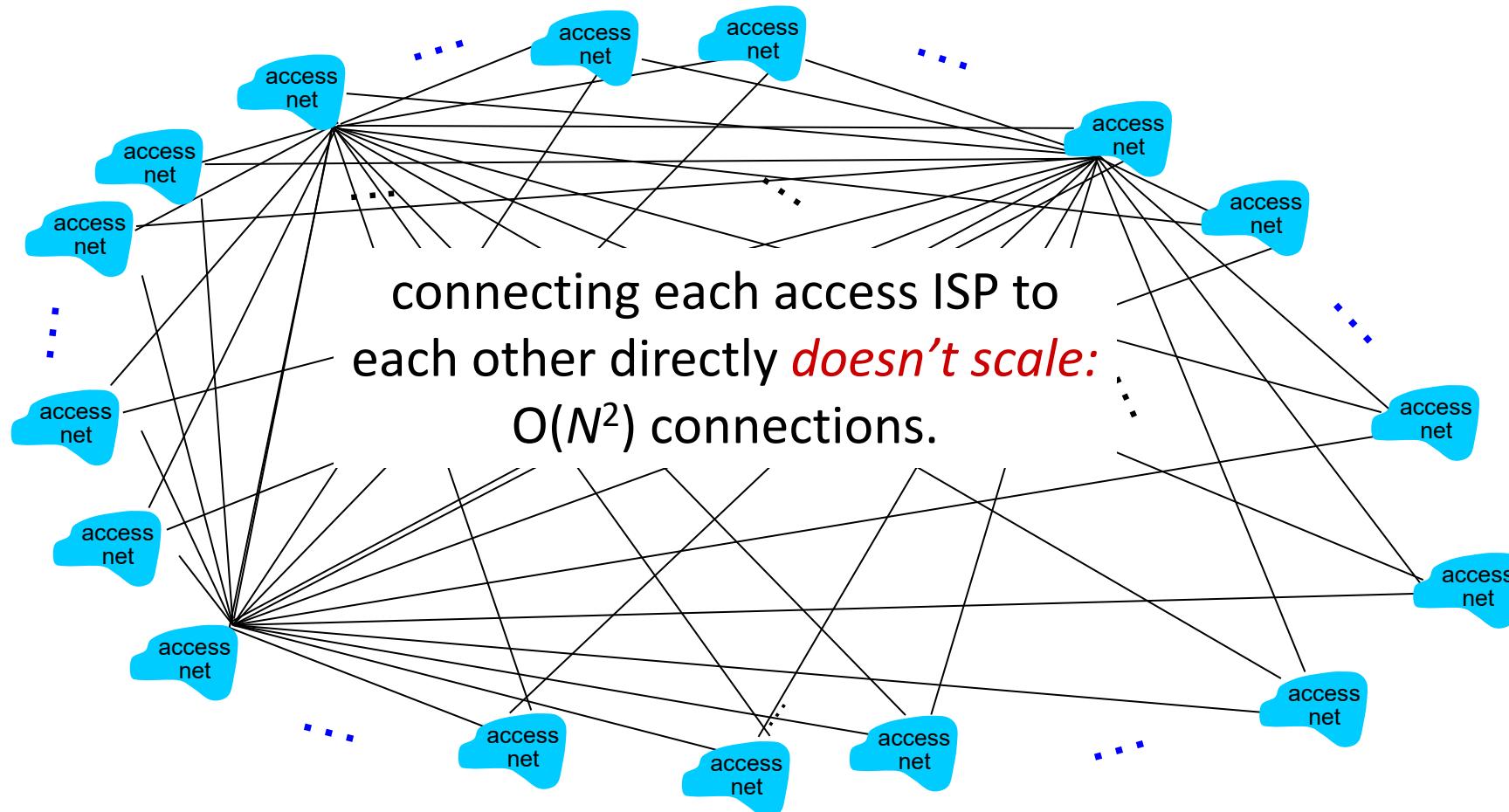
# Internet structure: a “network of networks”

*Question:* given *millions* of access ISPs, how to connect them together?



# Internet structure: a “network of networks”

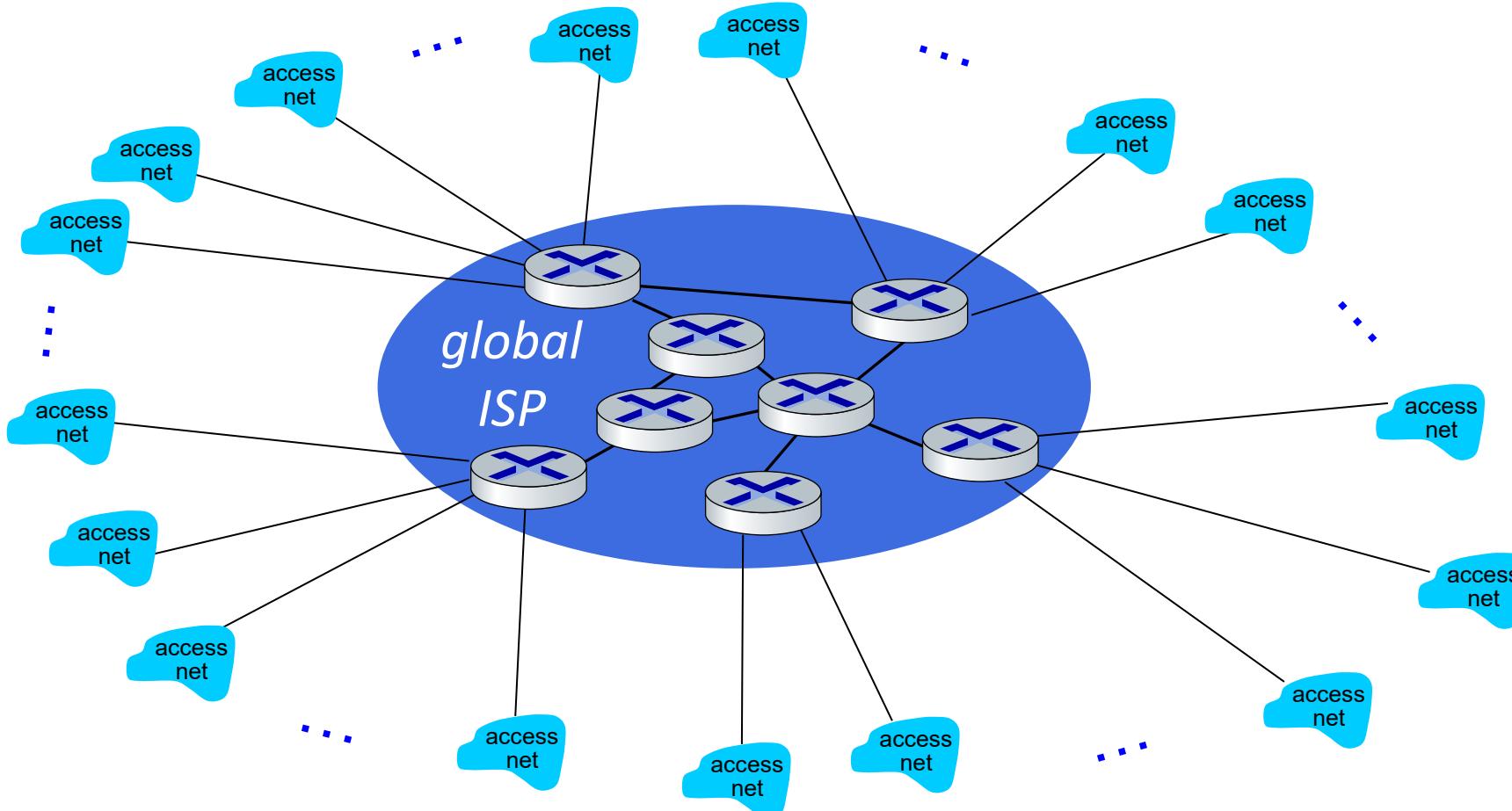
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# Internet structure: a “network of networks”

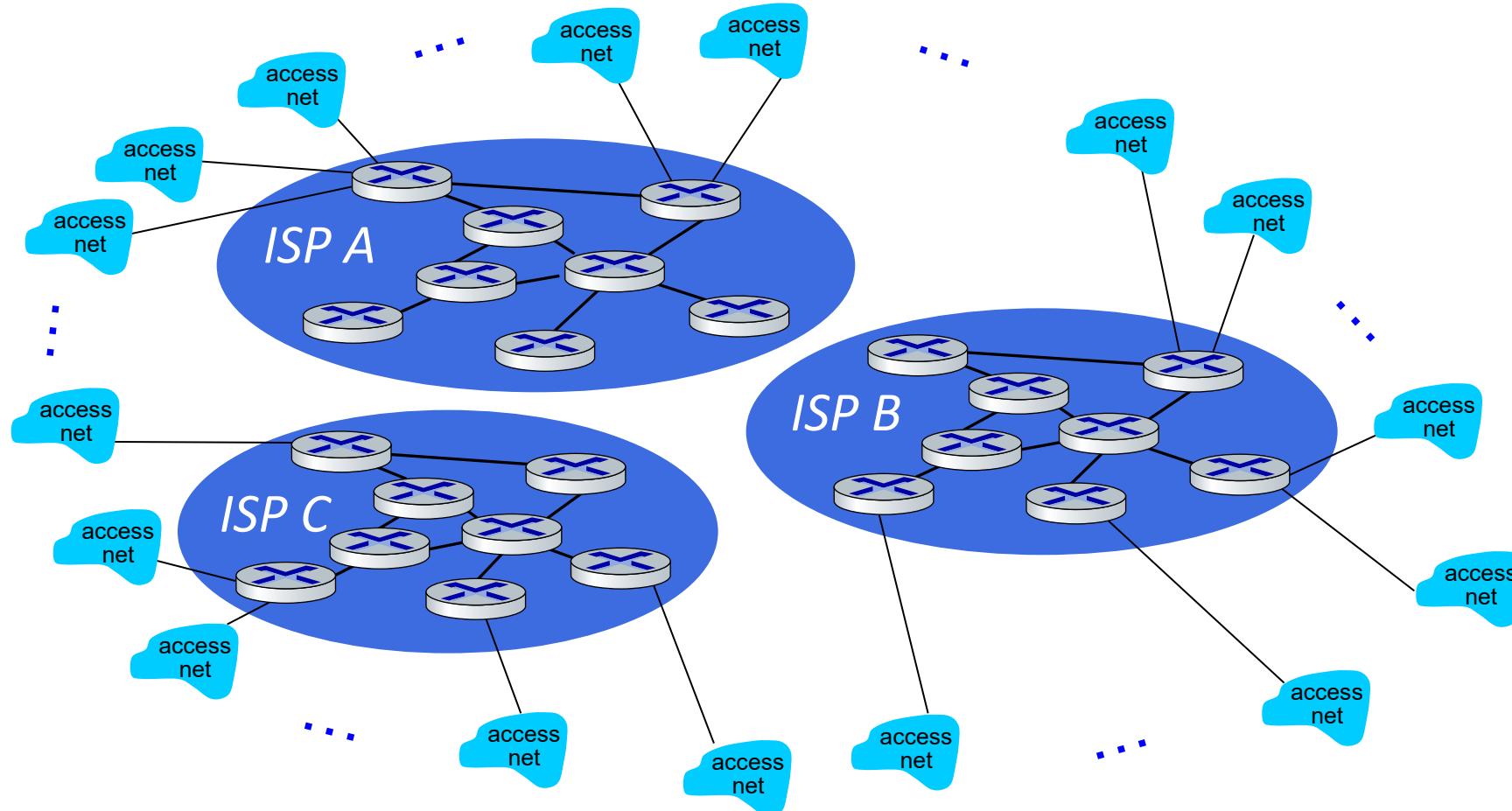
*Option: connect each access ISP to one global transit ISP?*

*Customer and provider ISPs have economic agreement.*



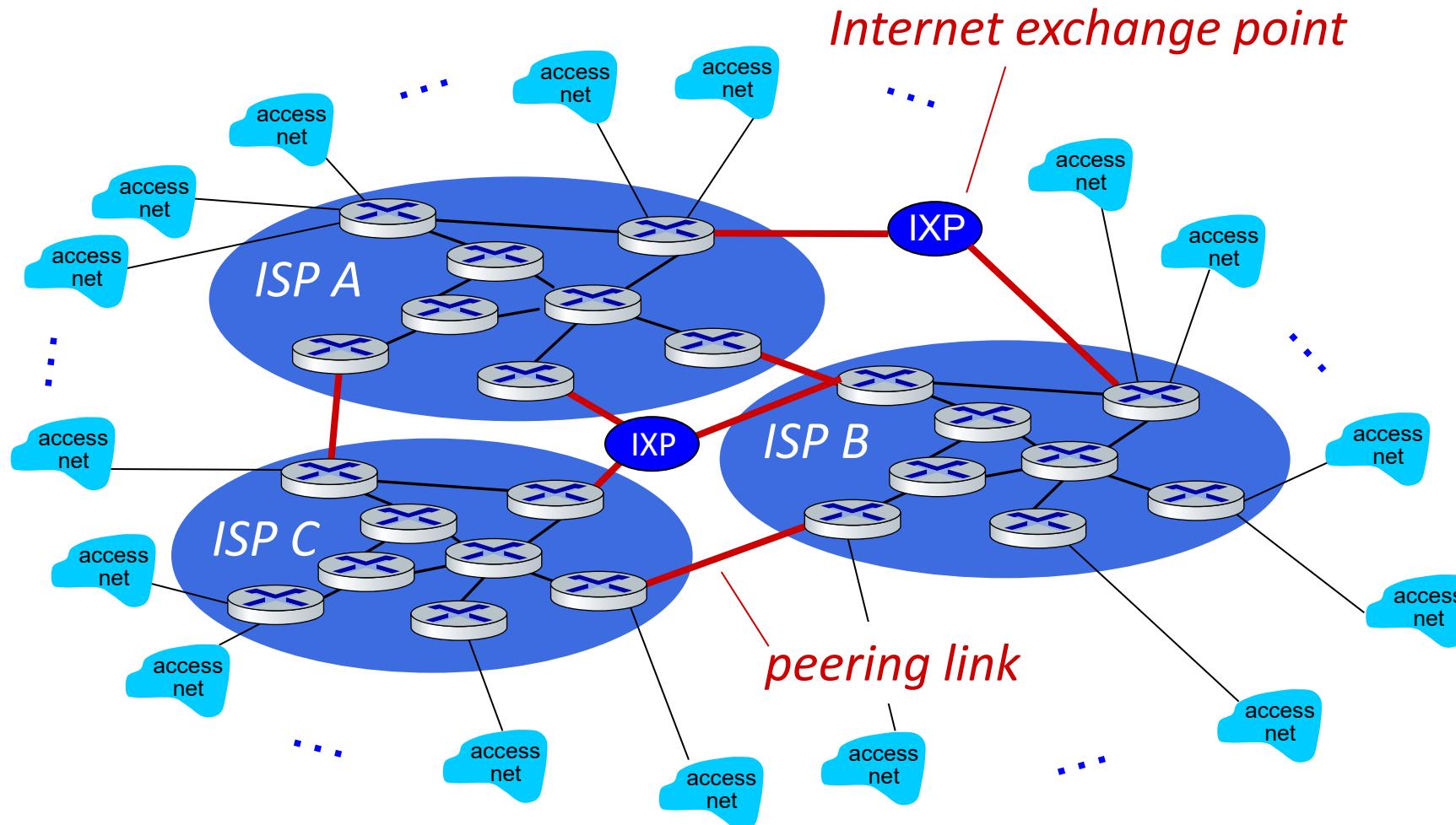
# Internet structure: a “network of networks”

But if one global ISP is viable business, there will be competitors ....



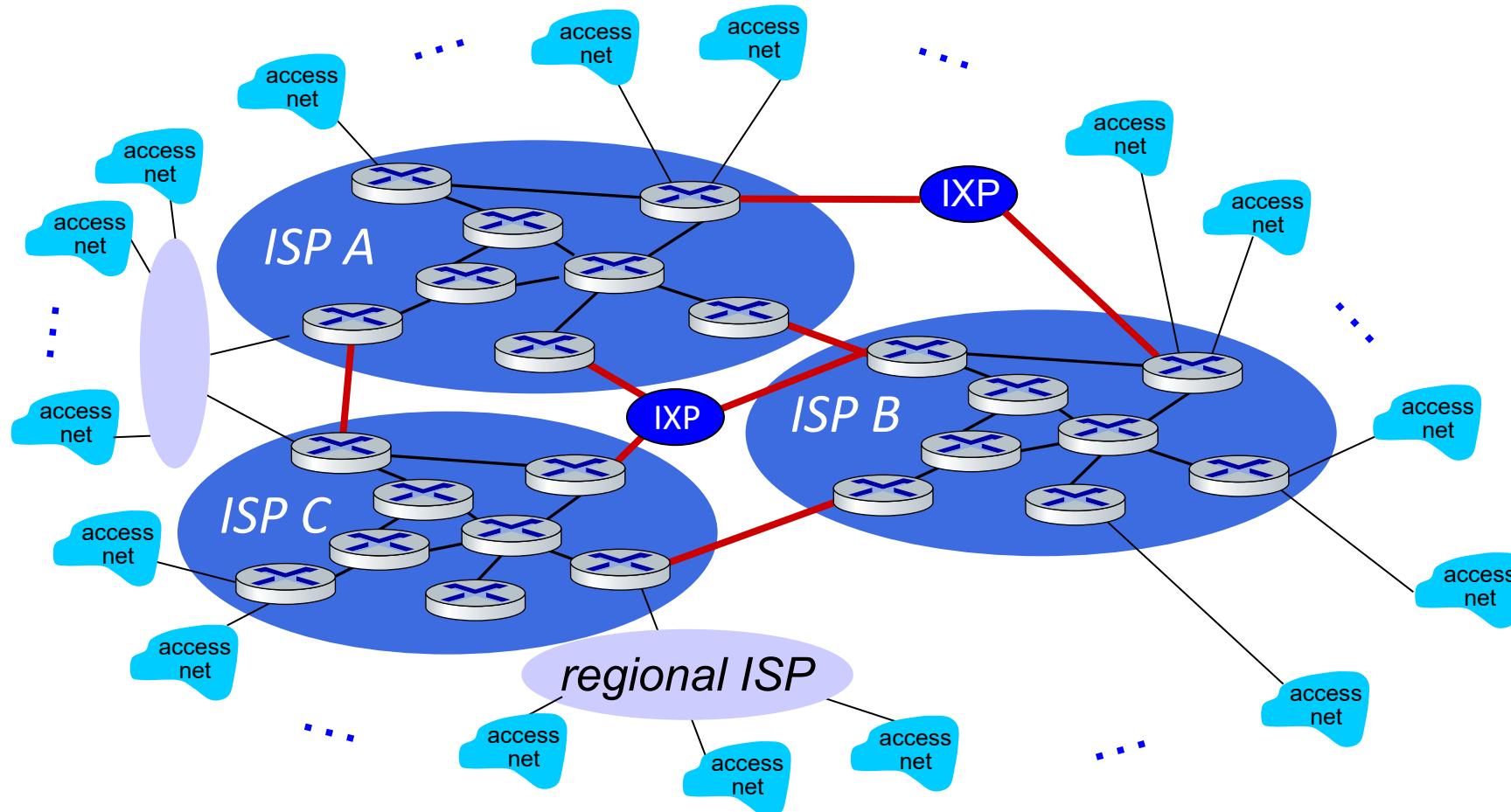
# Internet structure: a “network of networks”

But if one global ISP is viable business, there will be competitors ... who will want to be connected



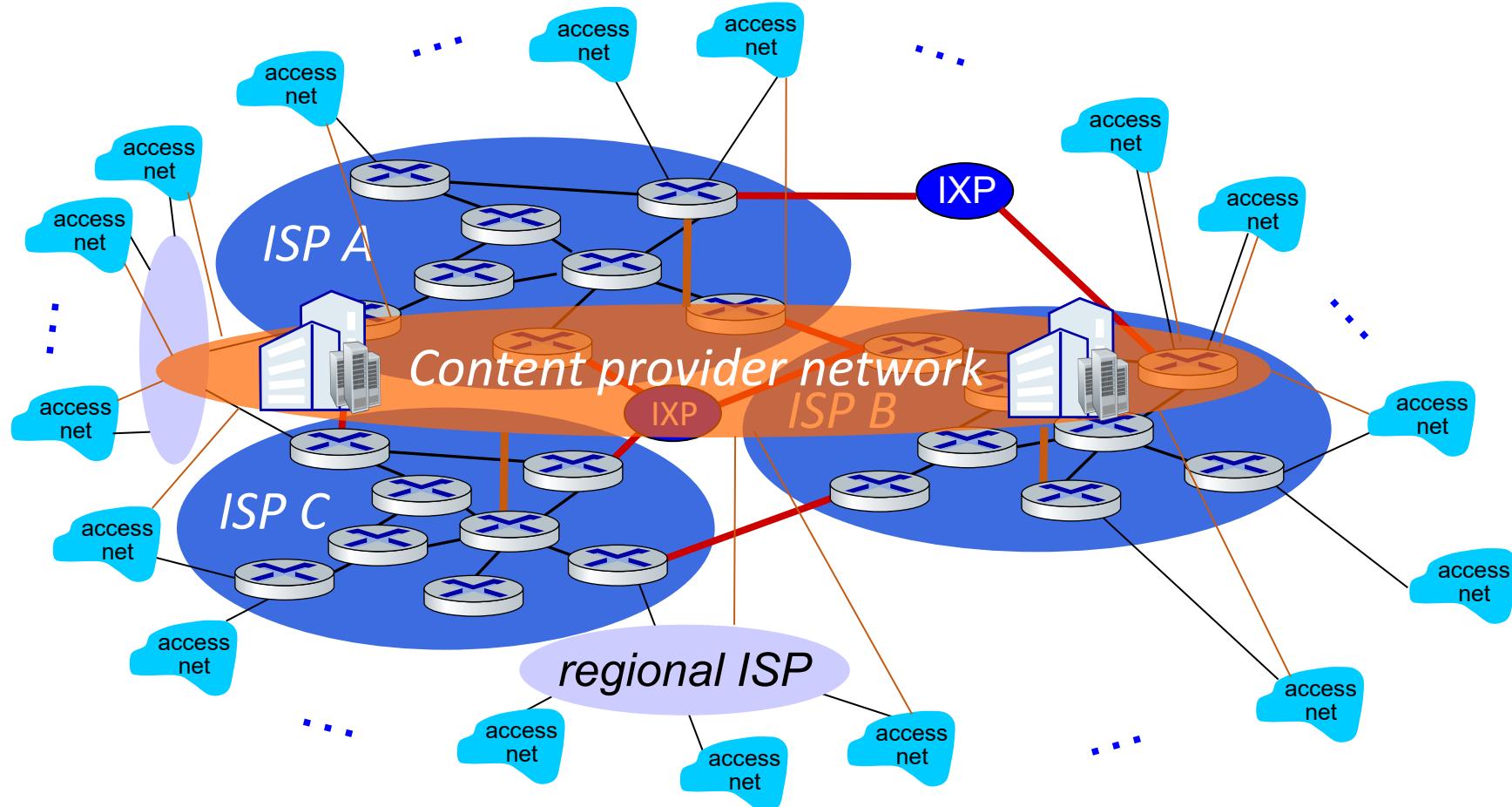
# Internet structure: a “network of networks”

... and regional networks may arise to connect access nets to ISPs

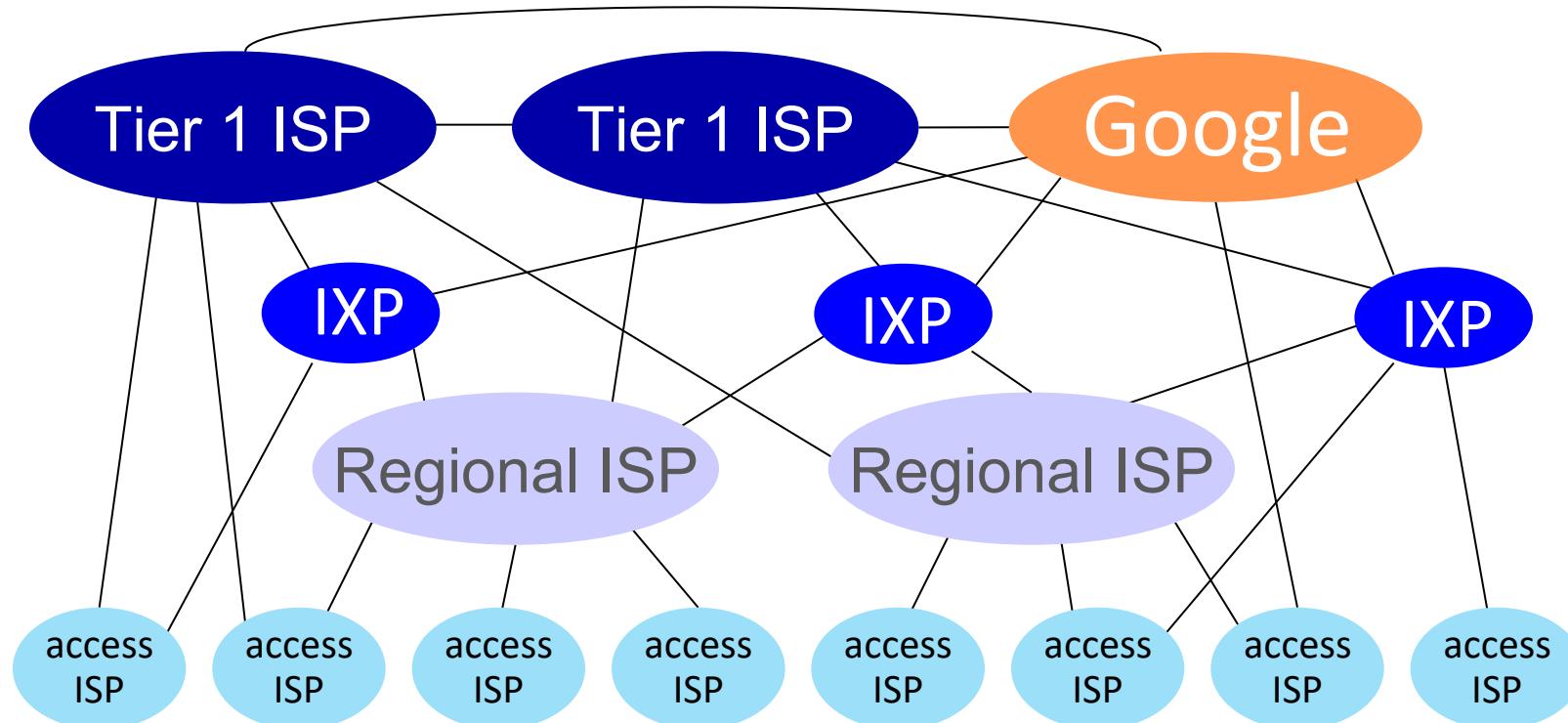


# Internet structure: a “network of networks”

... and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users



# Internet structure: a “network of networks”



At “center”: small # of well-connected large networks

- “tier-1” commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
- content provider networks (e.g., Google, Facebook): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs

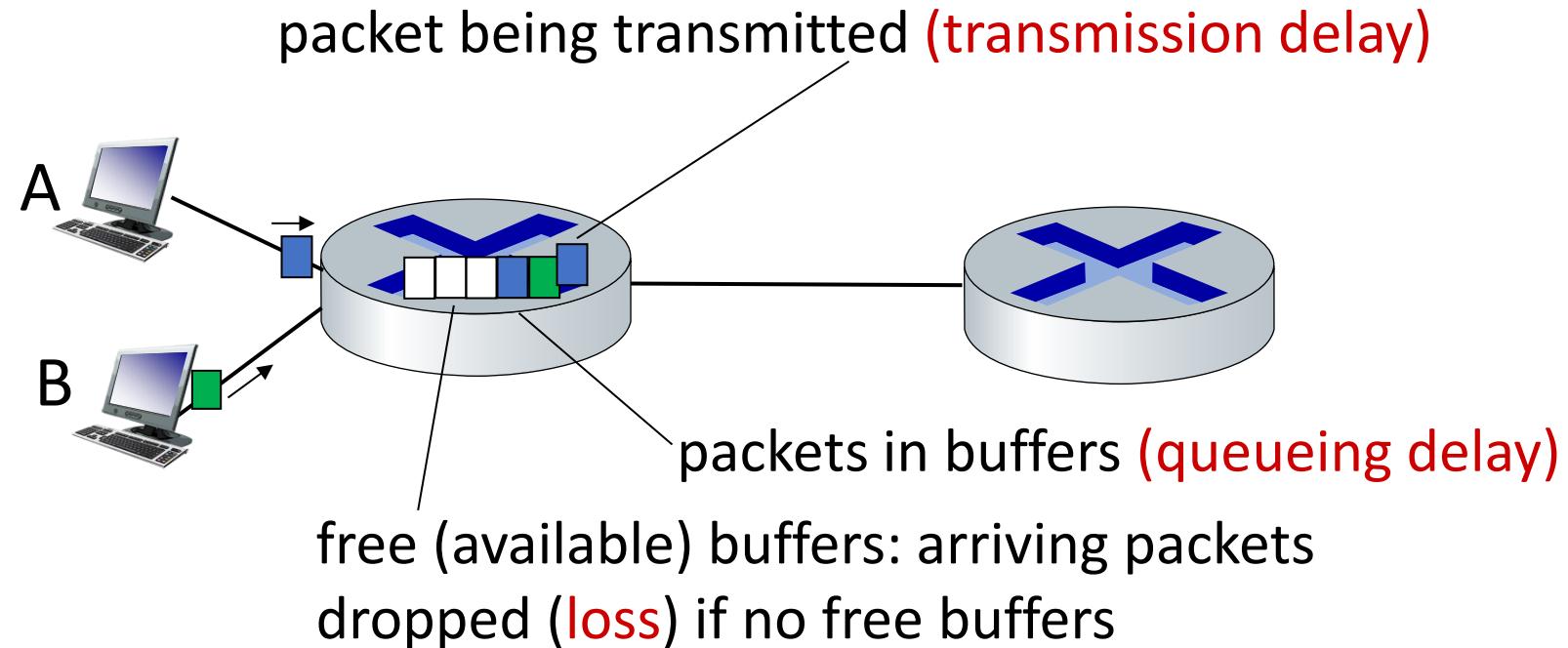
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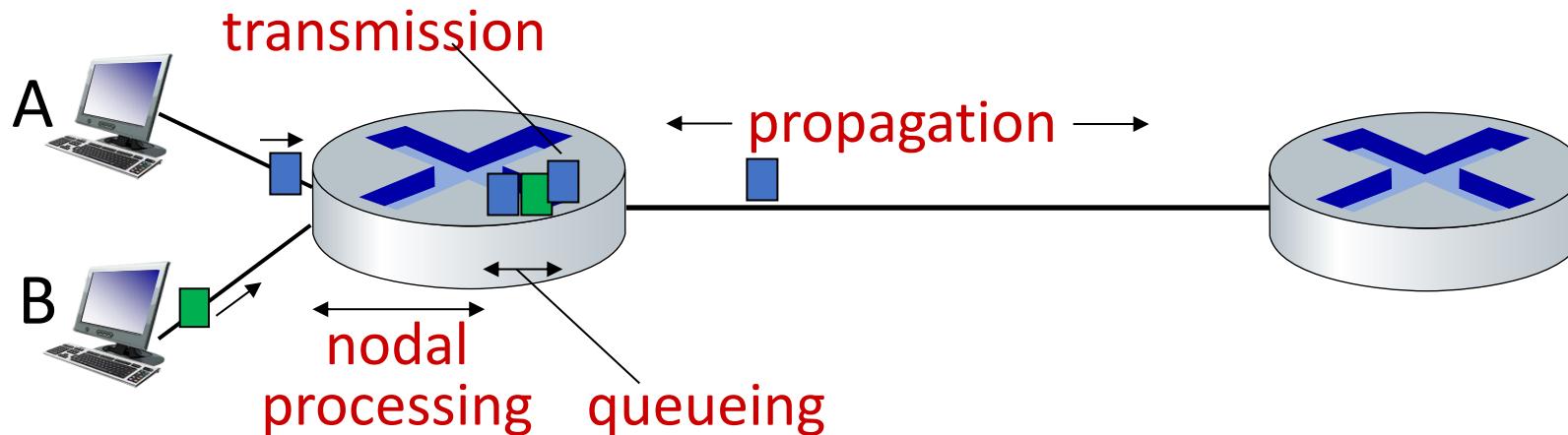


# How do packet delay and loss occur?

- packets *queue* in router buffers, waiting for turn for transmission
  - queue length grows when arrival rate to link (temporarily) exceeds output link capacity
- packet *loss* occurs when memory to hold queued packets fills up



# Packet delay: four sources



$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

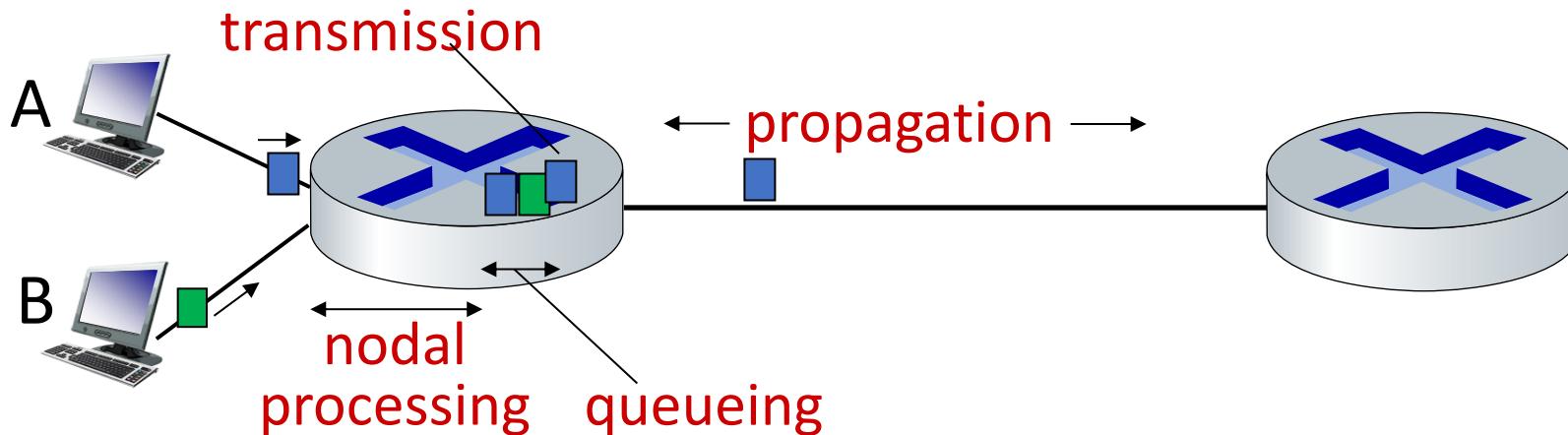
$d_{\text{proc}}$ : nodal processing

- check bit errors
- determine output link
- typically < microsecs

$d_{\text{queue}}$ : queueing delay

- time waiting at output link for transmission
- depends on congestion level of router

# Packet delay: four sources



$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

$d_{\text{trans}}$ : transmission delay:

- $L$ : packet length (bits)
- $R$ : link *transmission rate (bps)*
- $d_{\text{trans}} = L/R$

$d_{\text{trans}}$  and  $d_{\text{prop}}$   
very different

$d_{\text{prop}}$ : propagation delay:

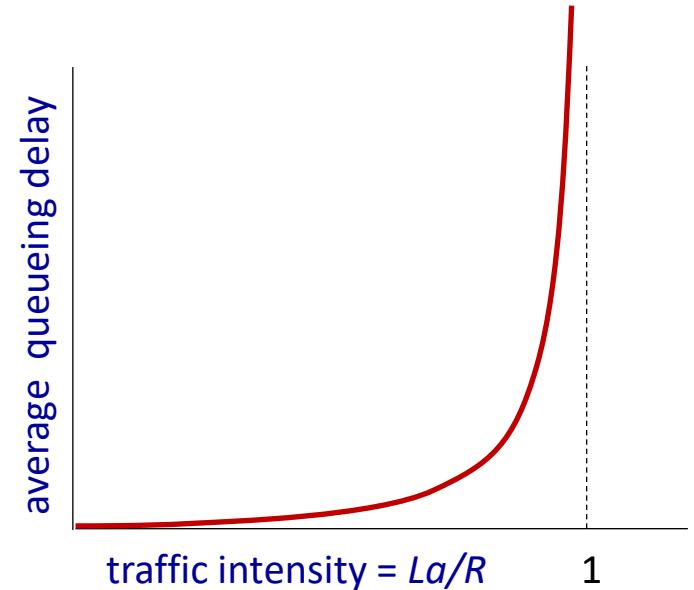
- $d$ : length of physical link
- $s$ : propagation speed ( $\sim 2 \times 10^8$  m/sec)
- $d_{\text{prop}} = d/s$

# Packet queueing delay (revisited)

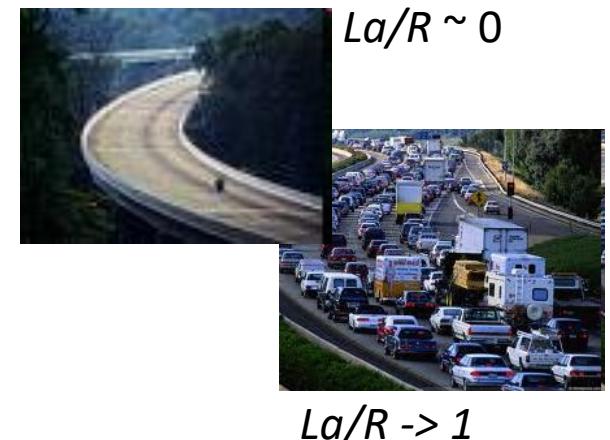
- $a$ : average packet arrival rate
- $L$ : packet length (bits)
- $R$ : link bandwidth (bit transmission rate)

$$\frac{L \cdot a}{R} : \frac{\text{arrival rate of bits}}{\text{service rate of bits}}$$

*“traffic intensity”*

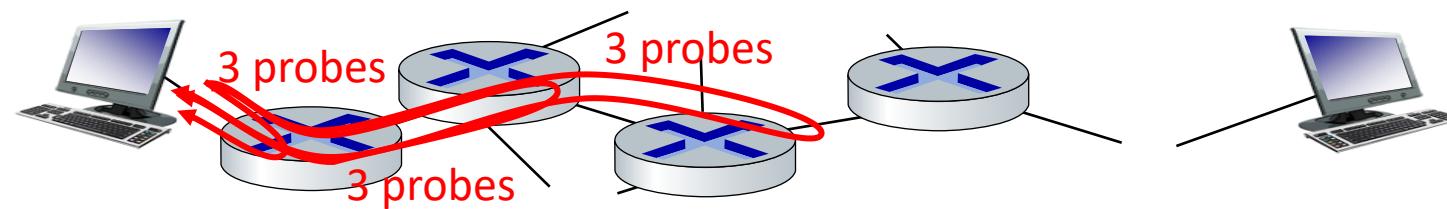


- $La/R \sim 0$ : avg. queueing delay small
- $La/R \rightarrow 1$ : avg. queueing delay large
- $La/R > 1$ : more “work” arriving is more than can be serviced - average delay infinite!



# “Real” Internet delays and routes

- what do “real” Internet delay & loss look like?
- **traceroute** program: provides delay measurement from source to router along end-end Internet path towards destination. For all  $i$ :
  - sends three packets that will reach router  $i$  on path towards destination (with time-to-live field value of  $i$ )
  - router  $i$  will return packets to sender
  - sender measures time interval between transmission and reply



# Real Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

3 delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

3 delay measurements to border1-rt-fa5-1-0.gw.umass.edu

trans-oceanic link

looks like delays decrease! Why?

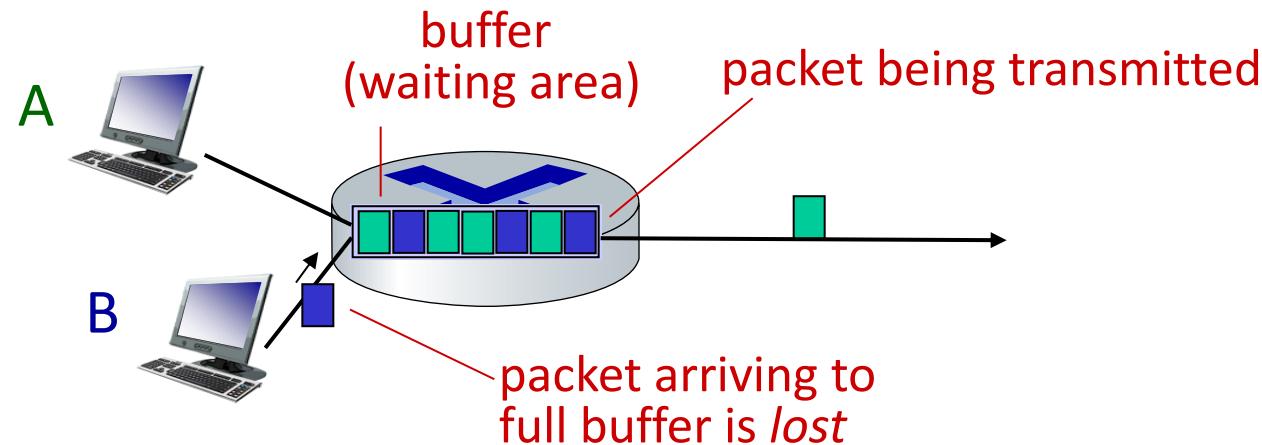
\* means no response (probe lost, router not replying)

1	cs-gw (128.119.240.254)	1 ms	1 ms	2 ms
2	border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)	1 ms	1 ms	2 ms
3	cht-vbns.gw.umass.edu (128.119.3.130)	6 ms	5 ms	5 ms
4	jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)	16 ms	11 ms	13 ms
5	jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)	21 ms	18 ms	18 ms
6	abilene-vbns.abilene.ucaid.edu (198.32.11.9)	22 ms	18 ms	22 ms
7	nycm-wash.abilene.ucaid.edu (198.32.8.46)	22 ms	22 ms	22 ms
8	62.40.103.253 (62.40.103.253)	104 ms	109 ms	106 ms
9	de2-1.de1.de.geant.net (62.40.96.129)	109 ms	102 ms	104 ms
10	de.fr1.fr.geant.net (62.40.96.50)	113 ms	121 ms	114 ms
11	renater-gw.fr1.fr.geant.net (62.40.103.54)	112 ms	114 ms	112 ms
12	nio-n2.cssi.renater.fr (193.51.206.13)	111 ms	114 ms	116 ms
13	nice.cssi.renater.fr (195.220.98.102)	123 ms	125 ms	124 ms
14	r3t2-nice.cssi.renater.fr (195.220.98.110)	126 ms	126 ms	124 ms
15	eurecom-valbonne.r3t2.ft.net (193.48.50.54)	135 ms	128 ms	133 ms
16	194.214.211.25 (194.214.211.25)	126 ms	128 ms	126 ms
17	***			
18	***			
19	fantasia.eurecom.fr (193.55.113.142)	132 ms	128 ms	136 ms

\* Do some traceroutes from exotic countries at [www.traceroute.org](http://www.traceroute.org)

# Packet loss

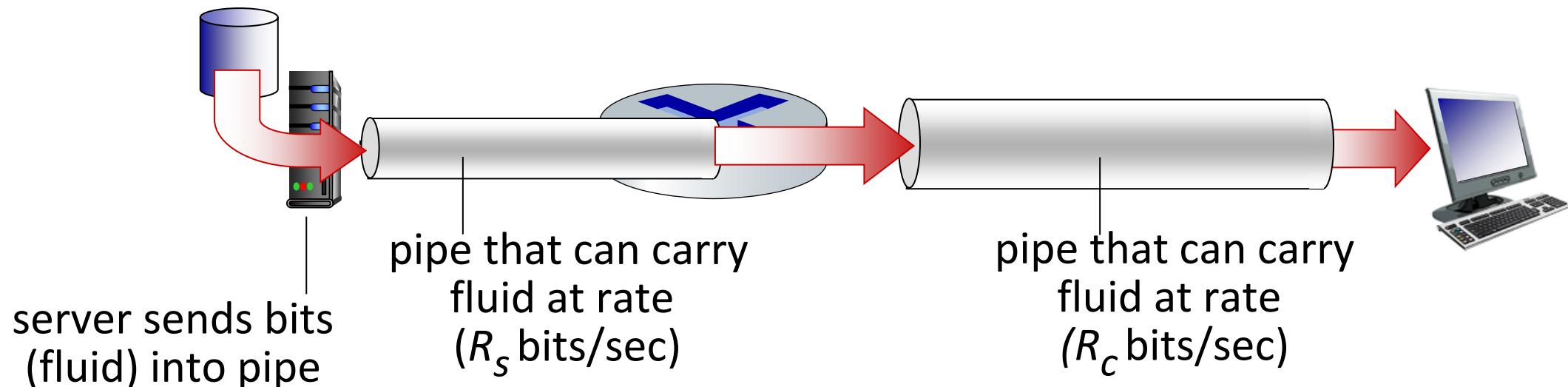
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



\* Check out the Java applet for an interactive animation (on publisher's website) of queuing and loss

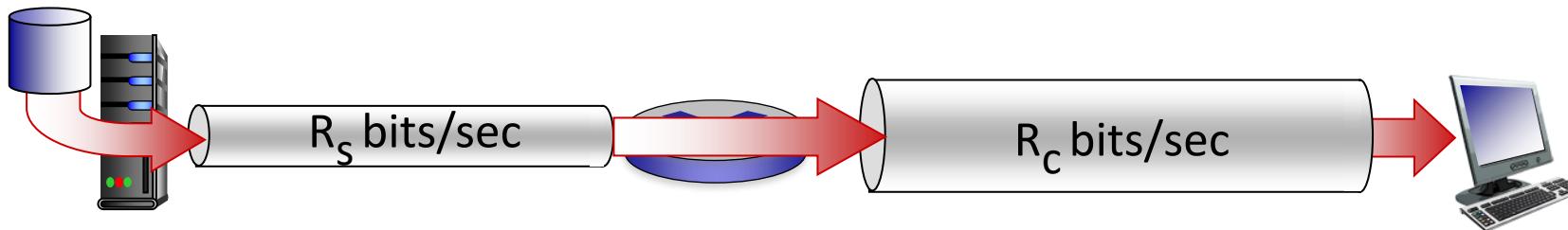
# Throughput

- *throughput*: rate (bits/time unit) at which bits are being sent from sender to receiver
  - *instantaneous*: rate at given point in time
  - *average*: rate over longer period of time

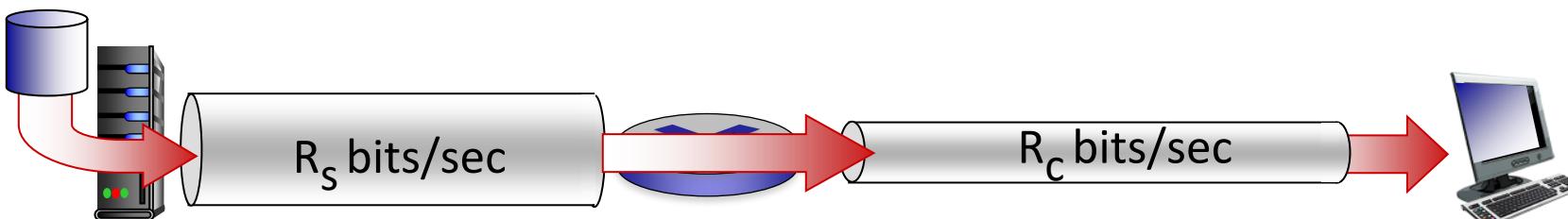


# Throughput

$R_s < R_c$  What is average end-end throughput?



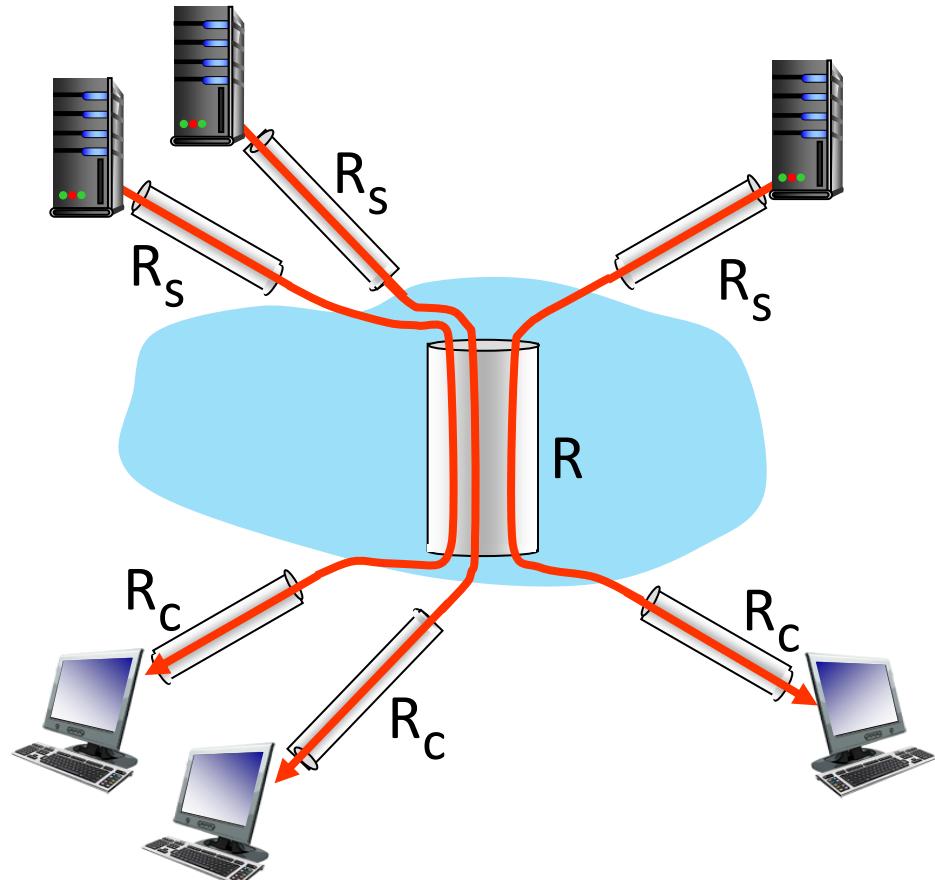
$R_s > R_c$  What is average end-end throughput?



*bottleneck link*

link on end-end path that constrains end-end throughput

# Throughput: network scenario



10 connections (fairly) share  
backbone bottleneck link  $R$  bits/sec

- per-connection end-end throughput:  $\min(R_c, R_s, R/10)$
- in practice:  $R_c$  or  $R_s$  is often bottleneck

\* Check out the online interactive exercises for more examples: [http://gaia.cs.umass.edu/kurose\\_ross/](http://gaia.cs.umass.edu/kurose_ross/)

# Chapter 1: roadmap

- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- **Security**
- Protocol layers, service models
- History



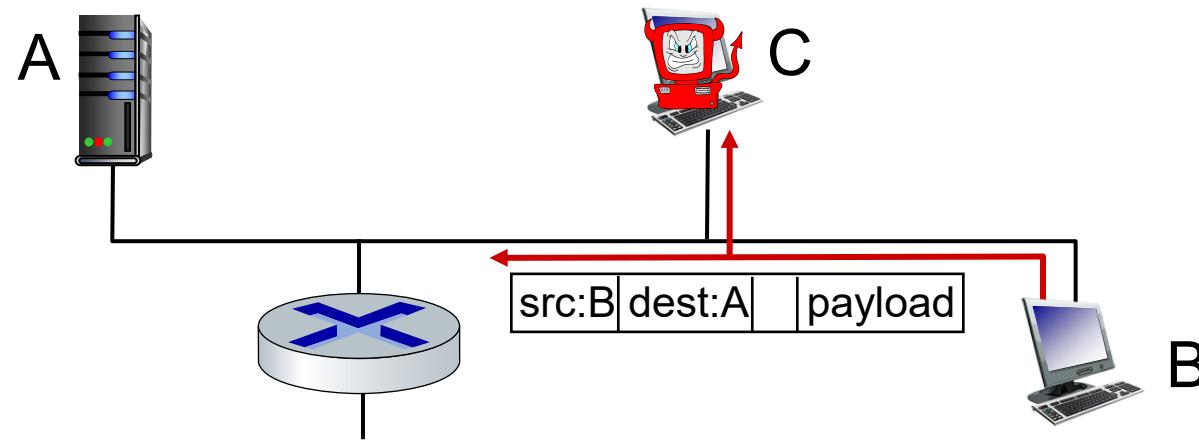
# Network security

- Internet not originally designed with (much) security in mind
  - *original vision*: “a group of mutually trusting users attached to a transparent network” ☺
  - Internet protocol designers playing “catch-up”
  - security considerations in all layers!
- We now need to think about:
  - how bad entities can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks

# Bad entities: packet interception

*packet “sniffing”:*

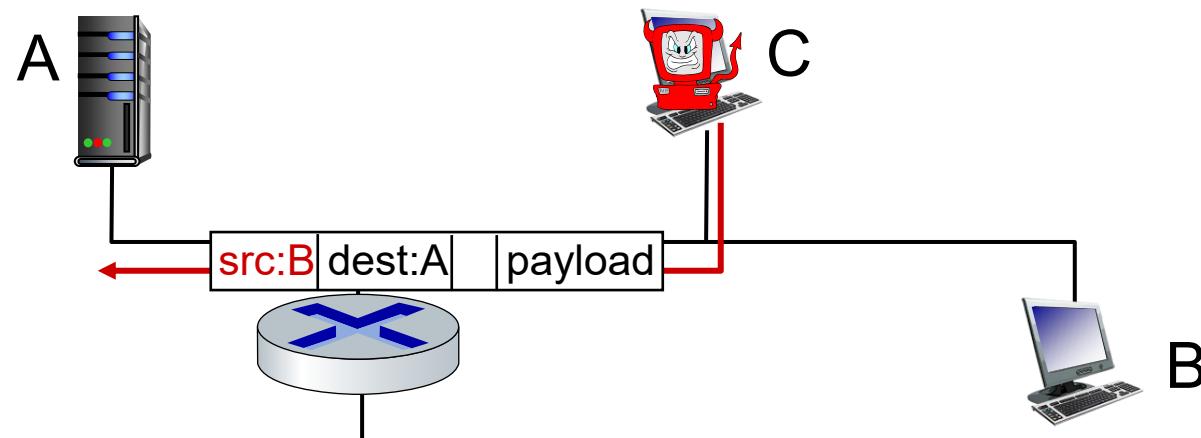
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



Wireshark software used for our end-of-chapter labs is a (free) packet-sniffer

# Bad entities: fake identity

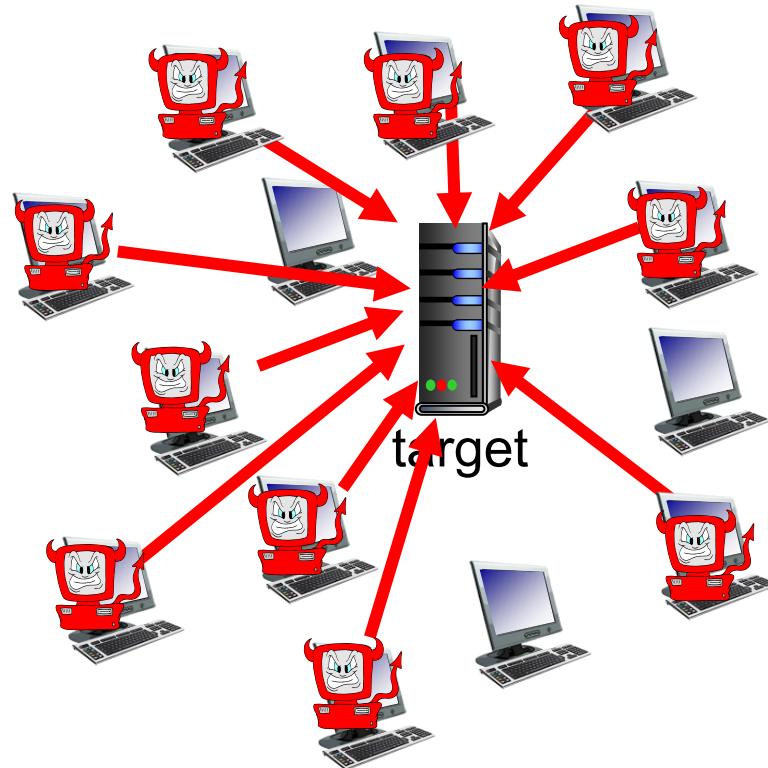
*IP spoofing*: injection of packet with false source address



# Bad entities: denial of service

*Denial of Service (DoS):* attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

1. select target
2. break into hosts  
around the network  
(see botnet)
3. send packets to target  
from compromised  
hosts



# Lines of defense:

- **authentication:** proving you are who you say you are
  - cellular networks provides hardware identity via SIM card; no such hardware assist in traditional Internet
- **confidentiality:** via encryption
- **integrity checks:** digital signatures prevent/detect tampering
- **access restrictions:** password-protected VPNs
- **firewalls:** specialized “middleboxes” in access and core networks:
  - off-by-default: filter incoming packets to restrict senders, receivers, applications
  - detecting/reacting to DOS attacks

*... lots more on security (throughout, Chapter 8)*

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# Protocol “layers” and reference models

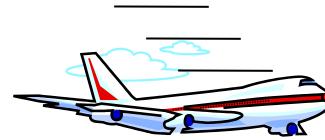
Networks are complex, with many “pieces”:

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

*Question:* is there any hope of *organizing* structure of network?

- and/or our *discussion* of networks?

# Example: organization of air travel



*end-to-end transfer of person plus baggage*

ticket (purchase)

baggage (check)

gates (load)

runway takeoff

airplane routing

ticket (complain)

baggage (claim)

gates (unload)

runway landing

airplane routing

airplane routing

How would you *define/discuss* the *system* of airline travel?

- a series of steps, involving many services

# Example: organization of air travel



*layers:* each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below

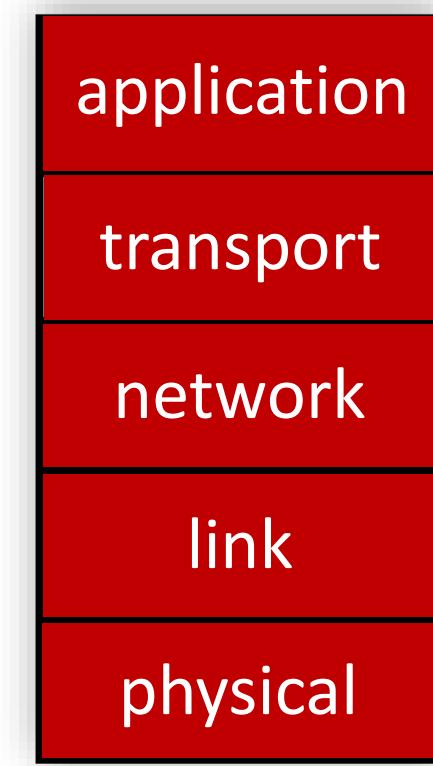
# Why layering?

Approach to designing/discussing complex systems:

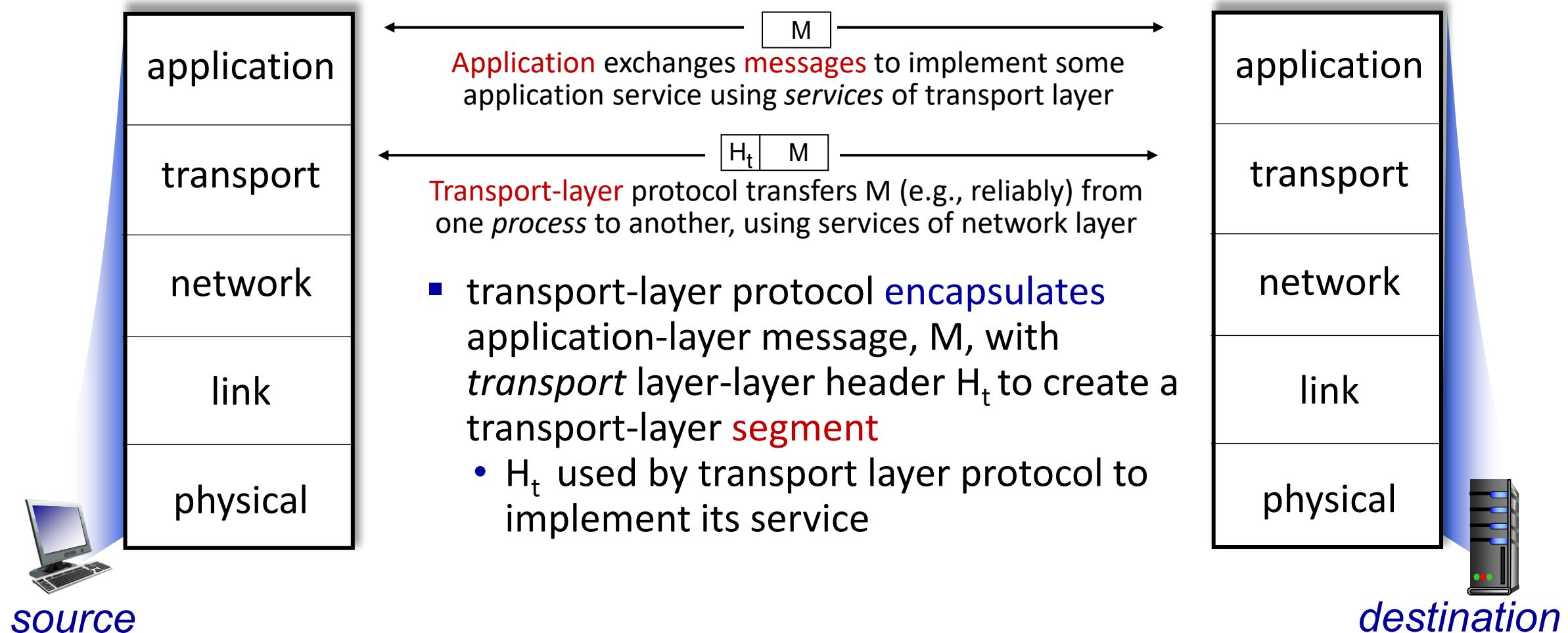
- explicit structure allows identification, relationship of system's pieces
  - layered *reference model* for discussion
- modularization eases maintenance, updating of system
  - change in layer's service *implementation*: transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system

# Layered Internet protocol stack

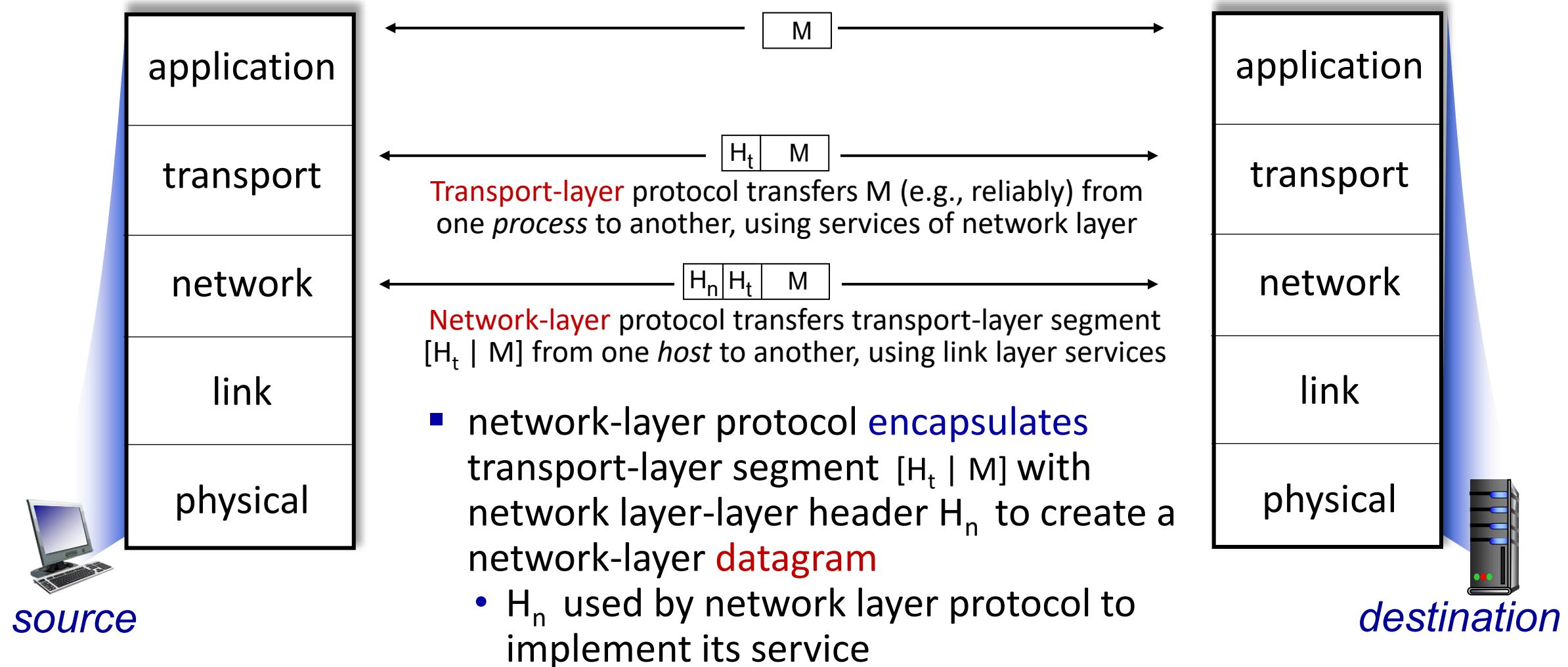
- *application*: supporting network applications
  - HTTP, IMAP, SMTP, DNS
- *transport*: process-process data transfer
  - TCP, UDP
- *network*: routing of datagrams from source to destination
  - IP, routing protocols
- *link*: data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP
- *physical*: bits “on the wire”



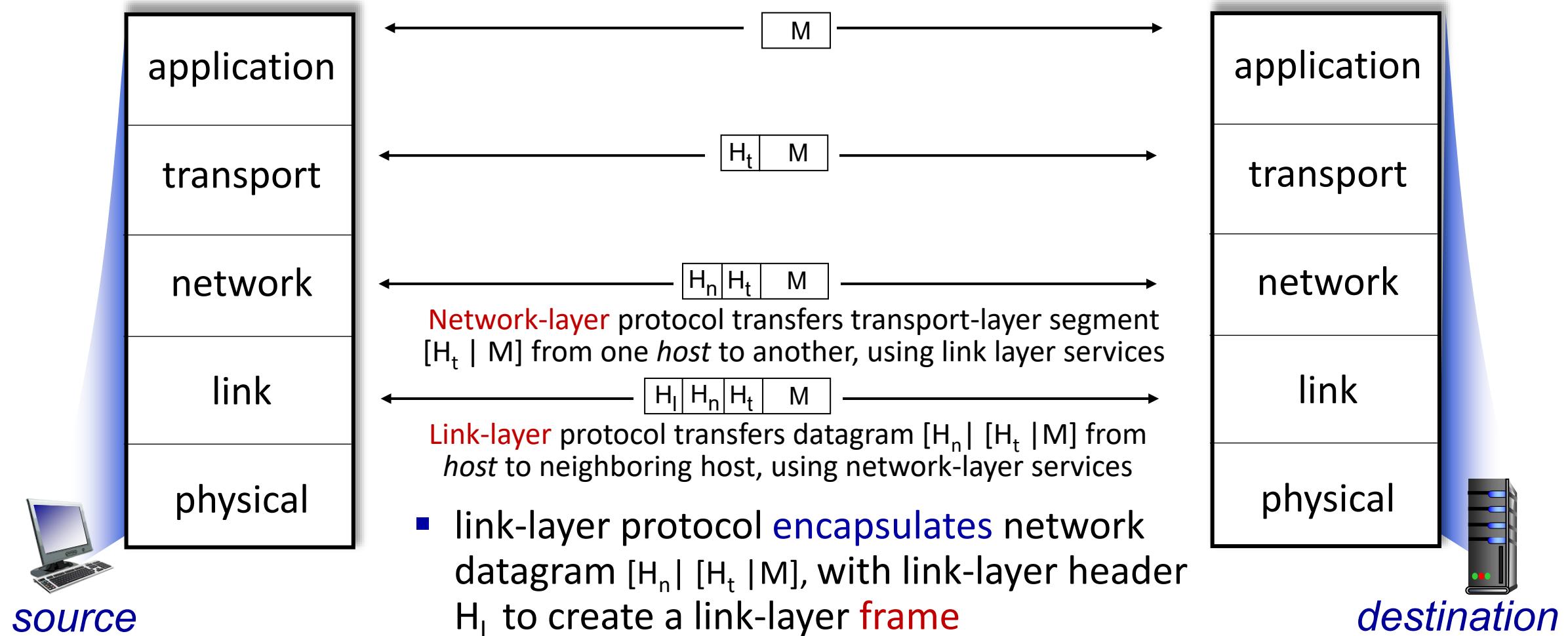
# Services, Layering and Encapsulation



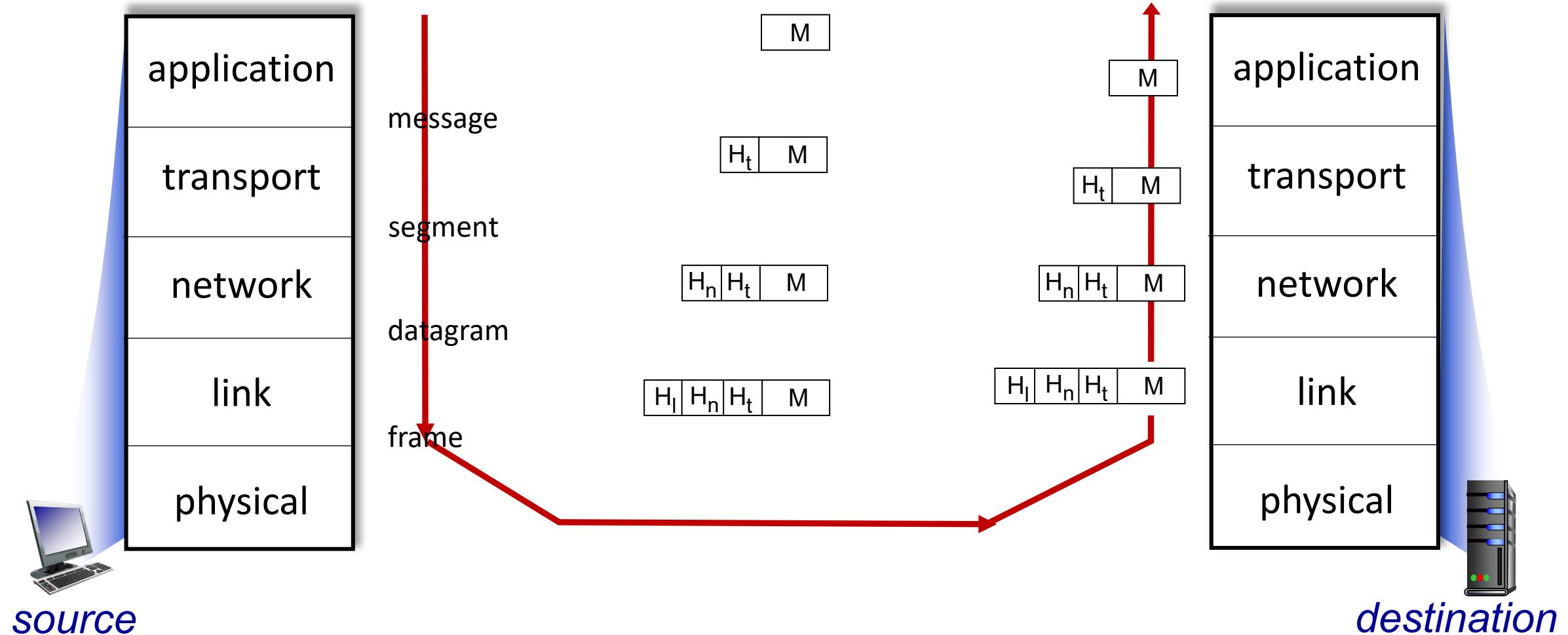
# Services, Layering and Encapsulation



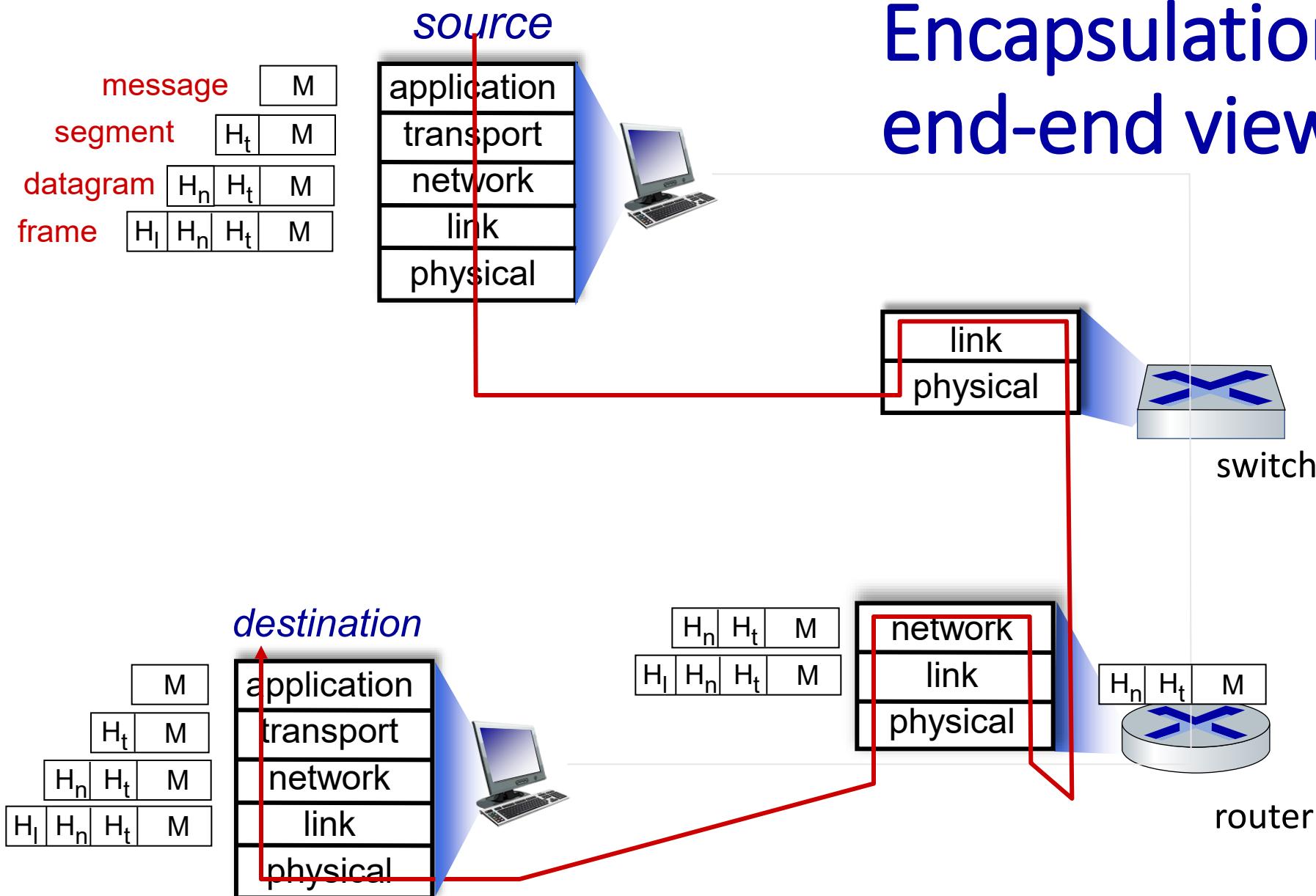
# Services, Layering and Encapsulation



# Services, Layering and Encapsulation



# Encapsulation: an end-end view



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# Chapter 1: summary

*We've covered a "ton" of material!*

- Internet overview
- what's a protocol?
- network edge, access network, core
  - packet-switching versus circuit-switching
  - Internet structure
- performance: loss, delay, throughput
- layering, service models
- security
- history

*You now have:*

- context, overview, vocabulary, "feel" of networking
- more depth, detail, *and fun* to follow!