

Chapter 1

Introduction

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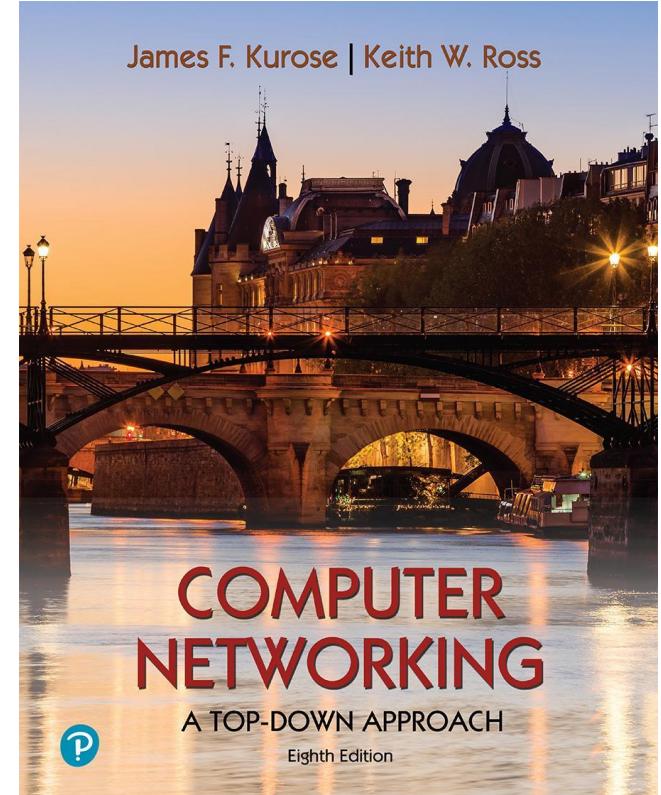
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*Computer Networking: A
Top-Down Approach*
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

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)

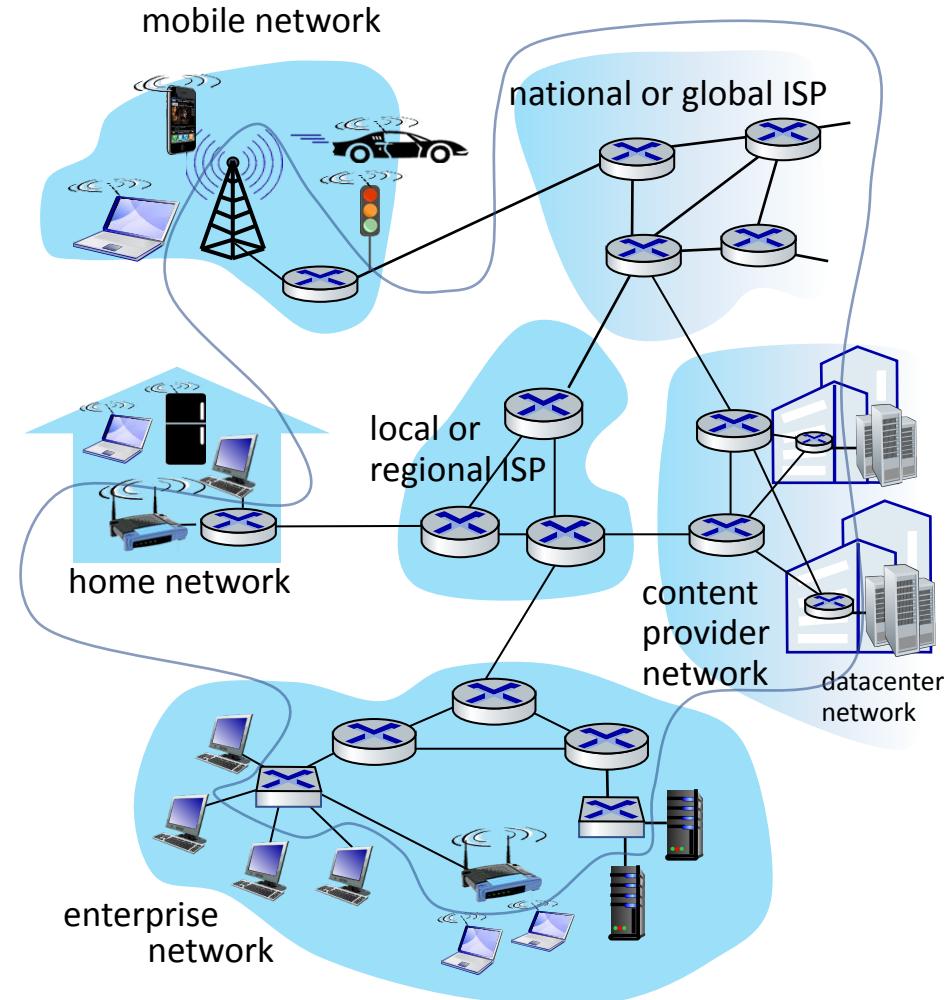
- routers, switches

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



Pacemaker & Monitor



Web-enabled toaster + weather forecaster



sensorized, bed mattress



Fitbit



Tweet-a-watt:
monitor energy use

bikes



cars

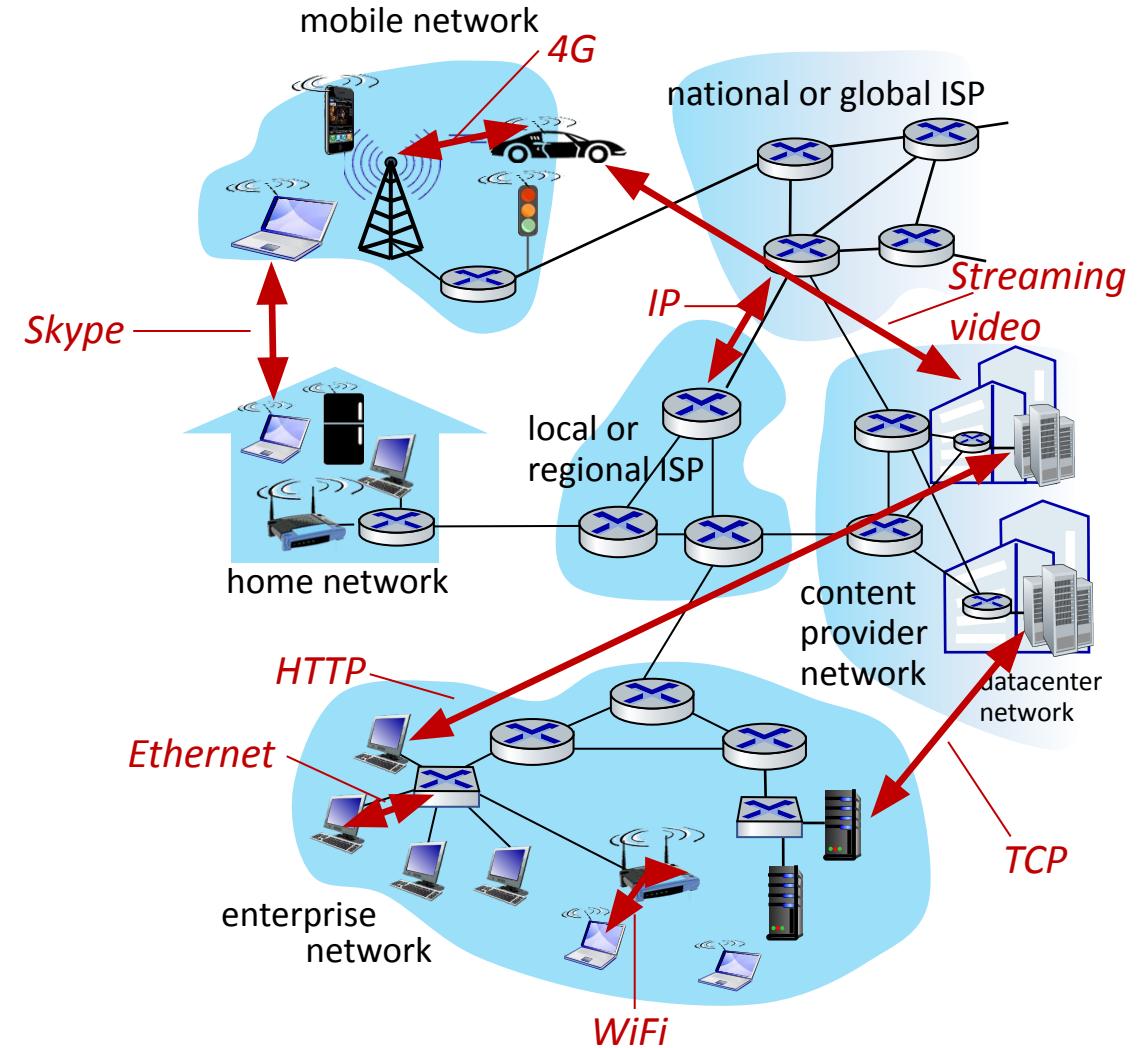


scooters

Others?

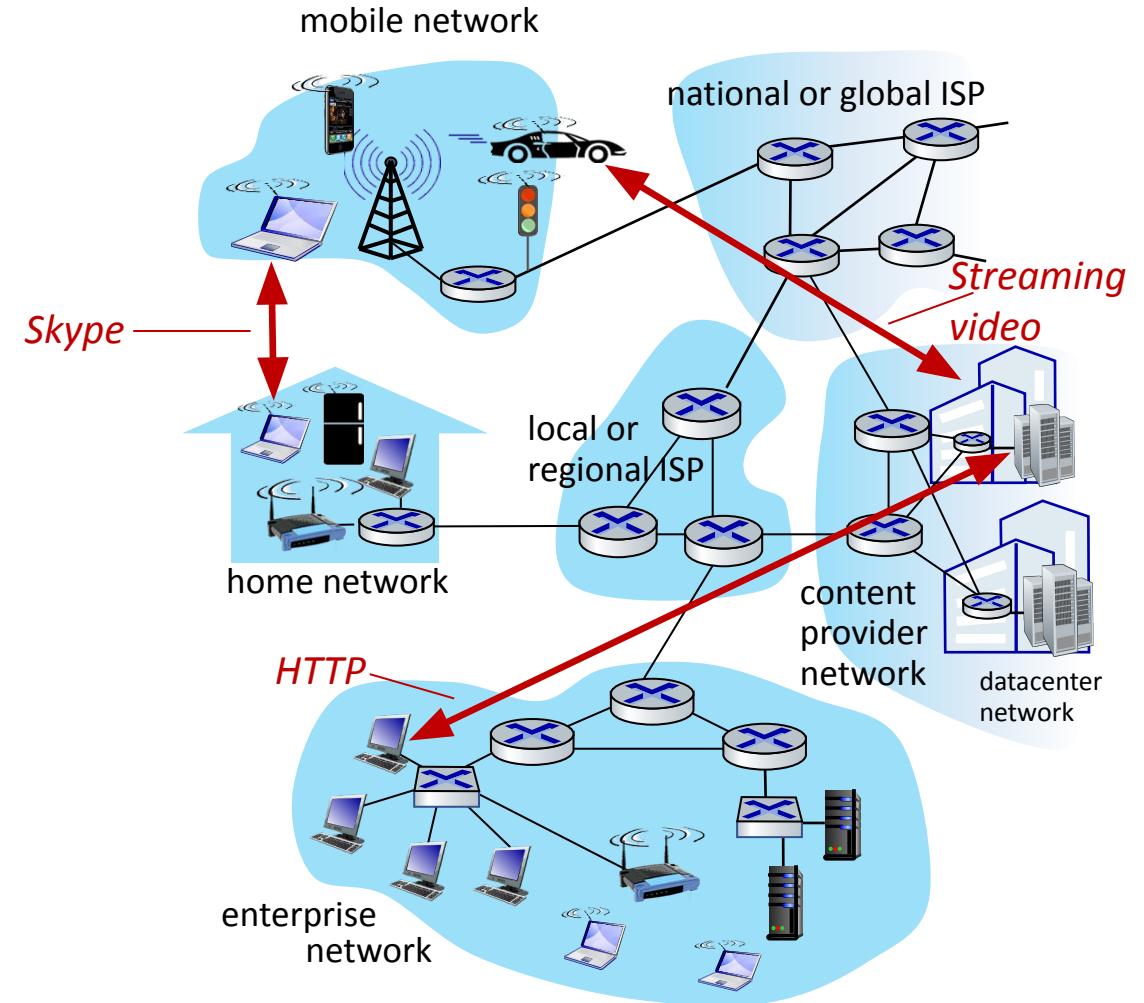
The Internet: a “nuts and bolts” view

- *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, inter-connected 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

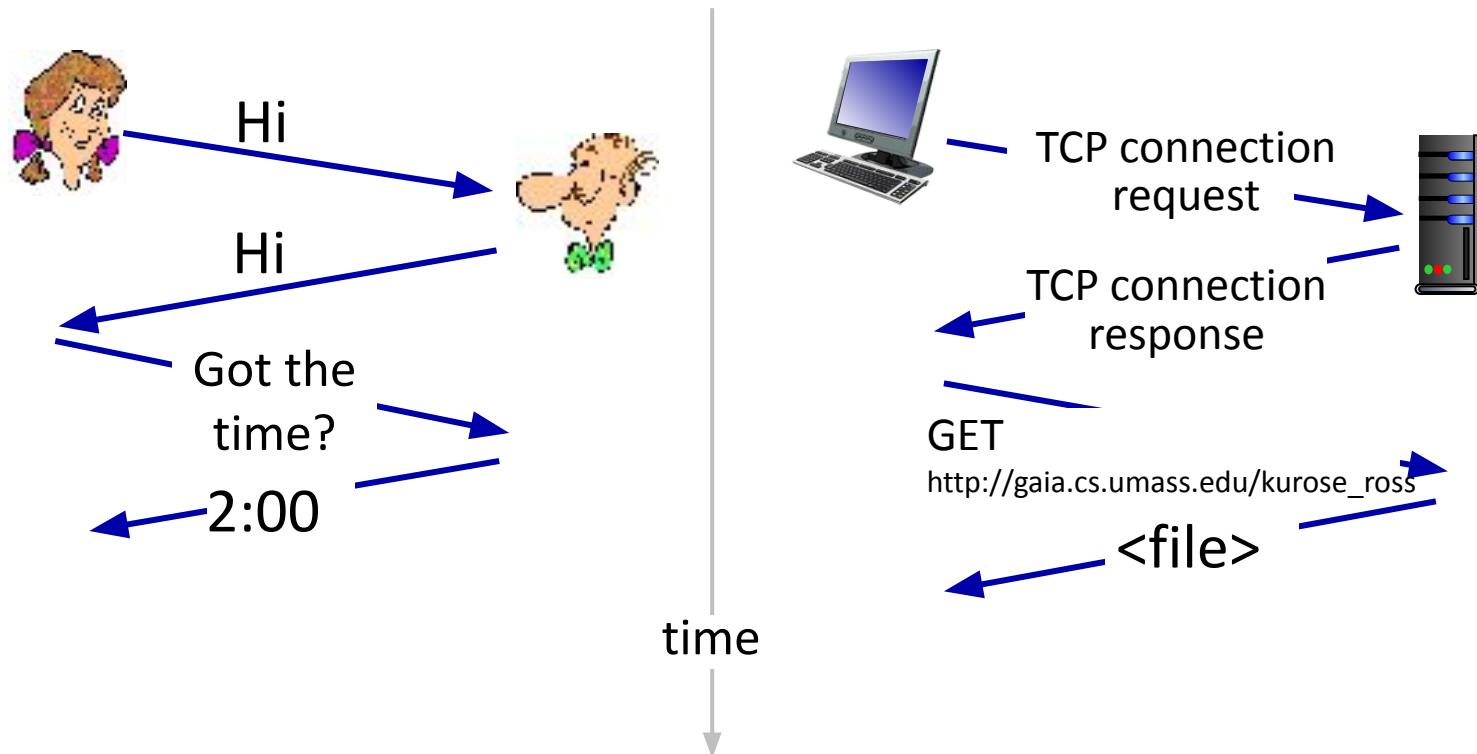
Network protocols:

- 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

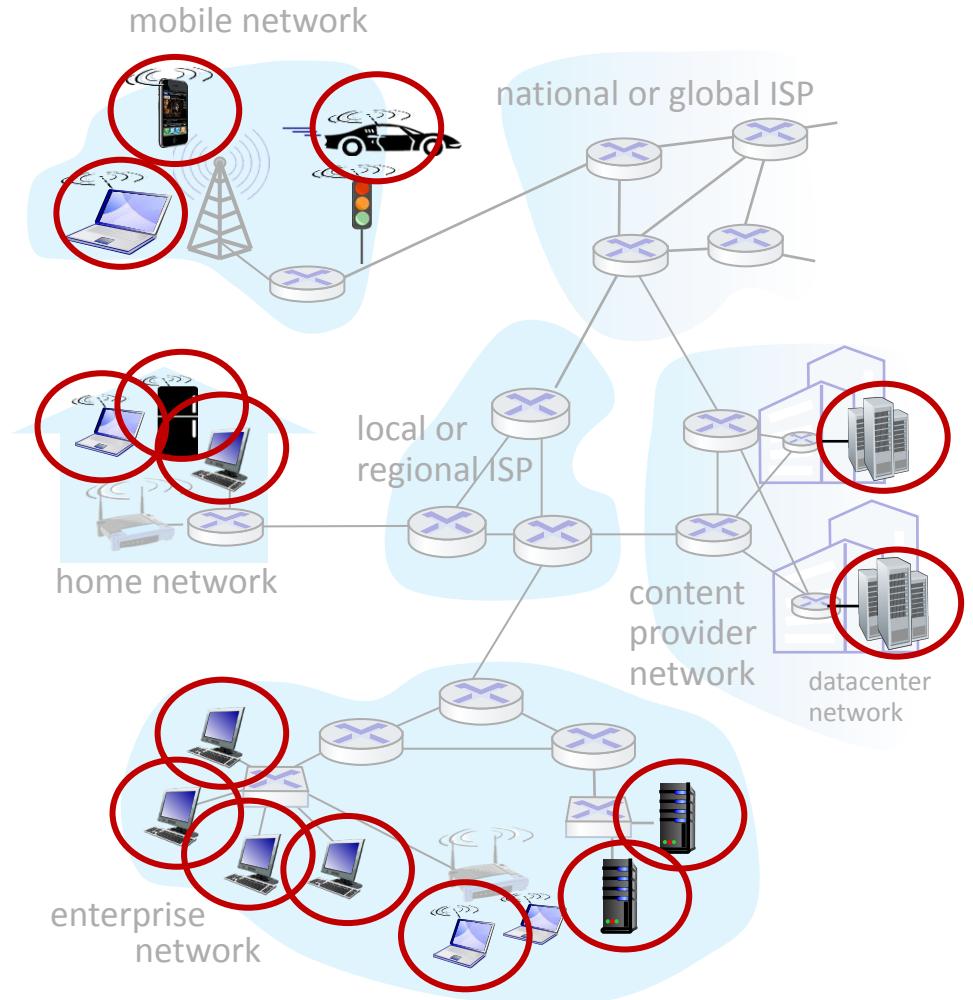
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- What *is* a protocol?
- **Network edge:** hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
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A closer look at Internet structure

Network edge:

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



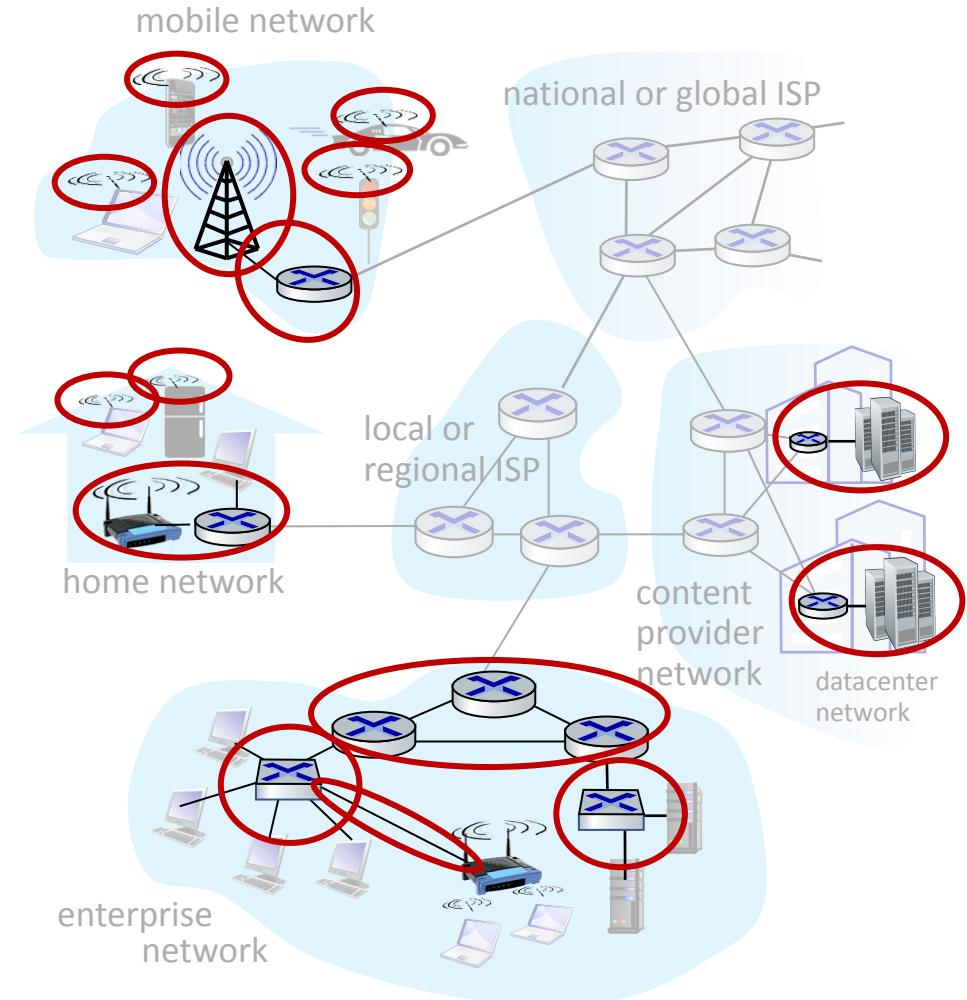
A closer look at Internet structure

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:

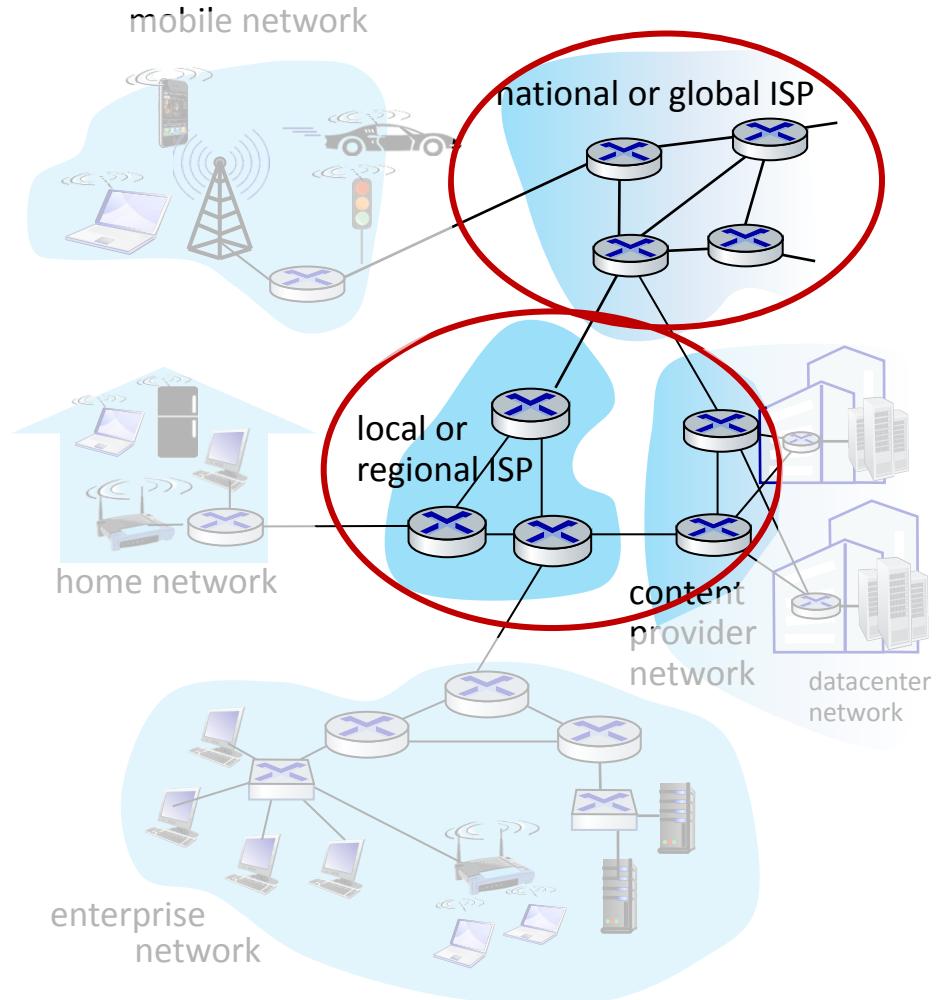
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- servers often in data centers

Access networks, physical media:

- wired, wireless communication links

Network core:

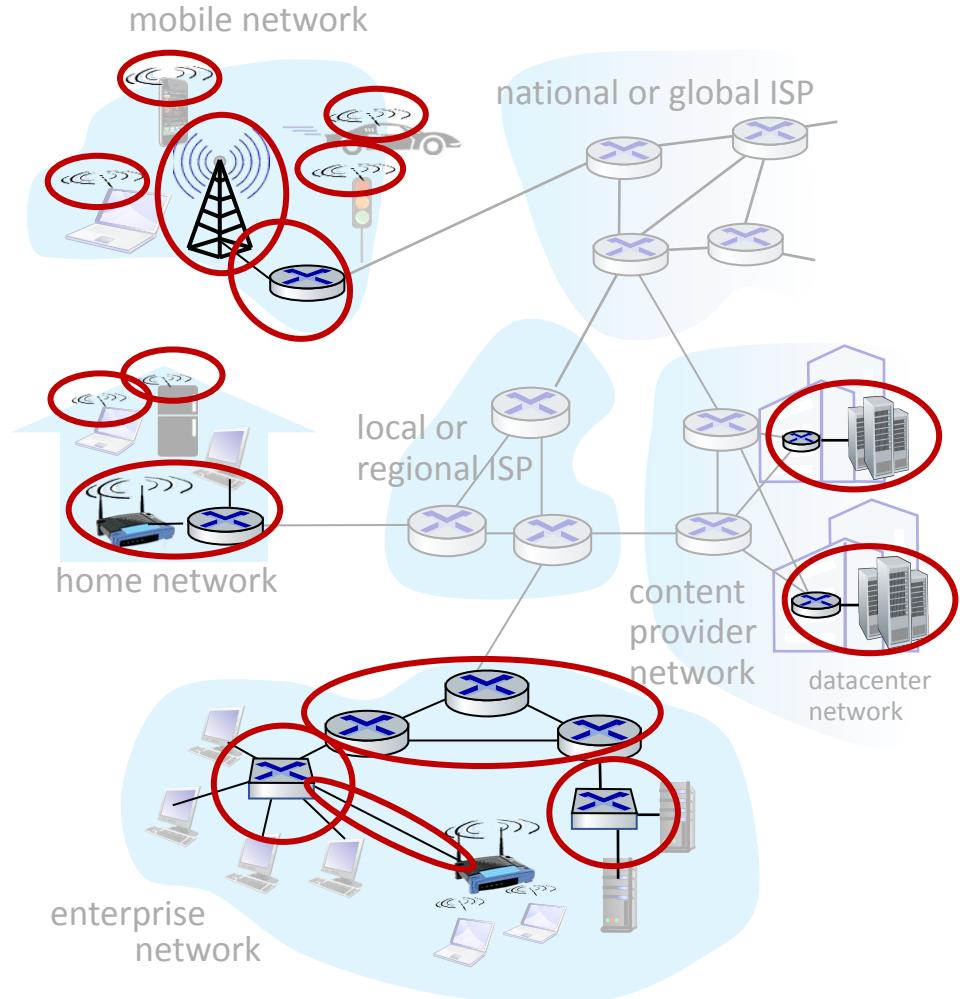
- interconnected routers
- network of networks



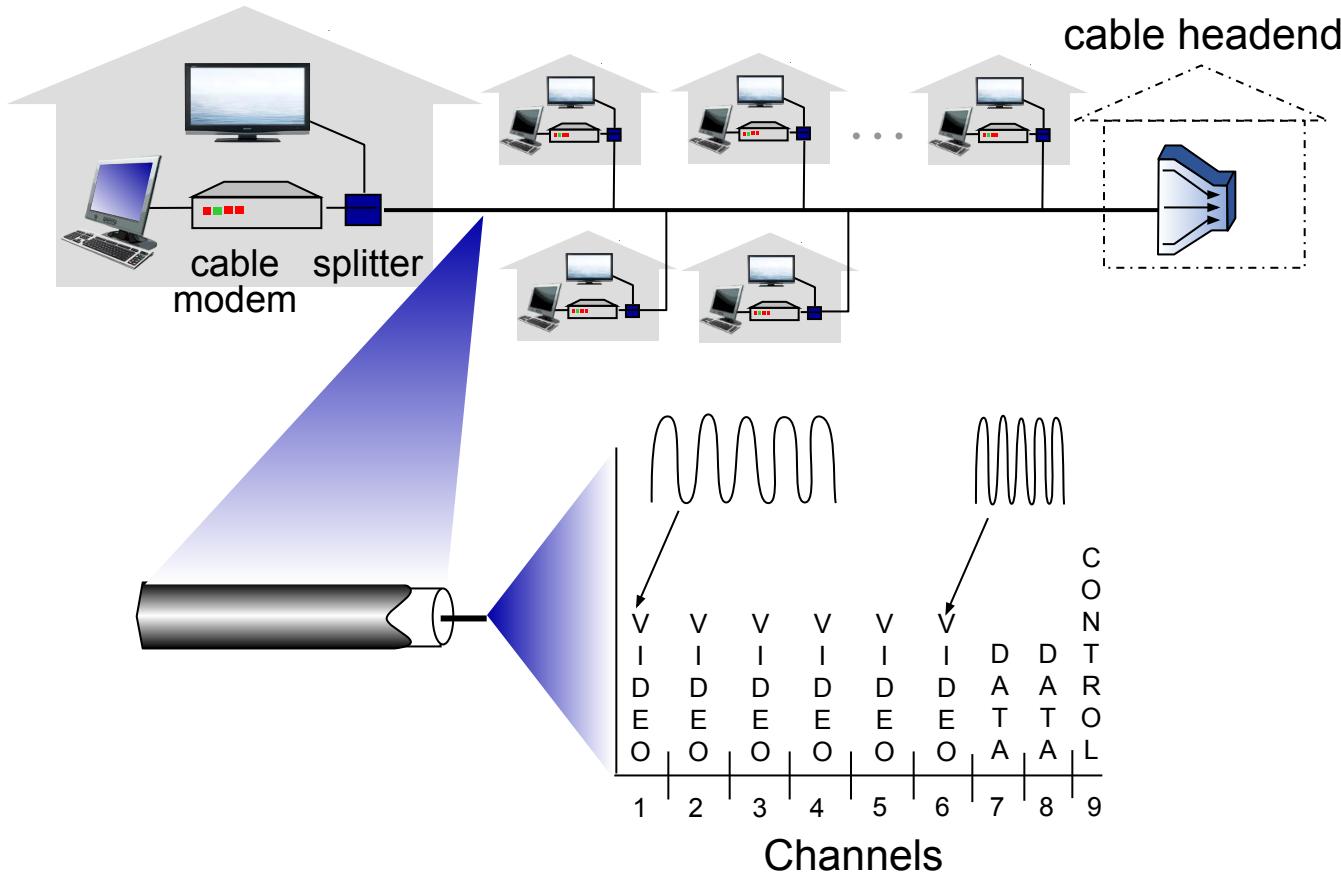
Access networks and physical media

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

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

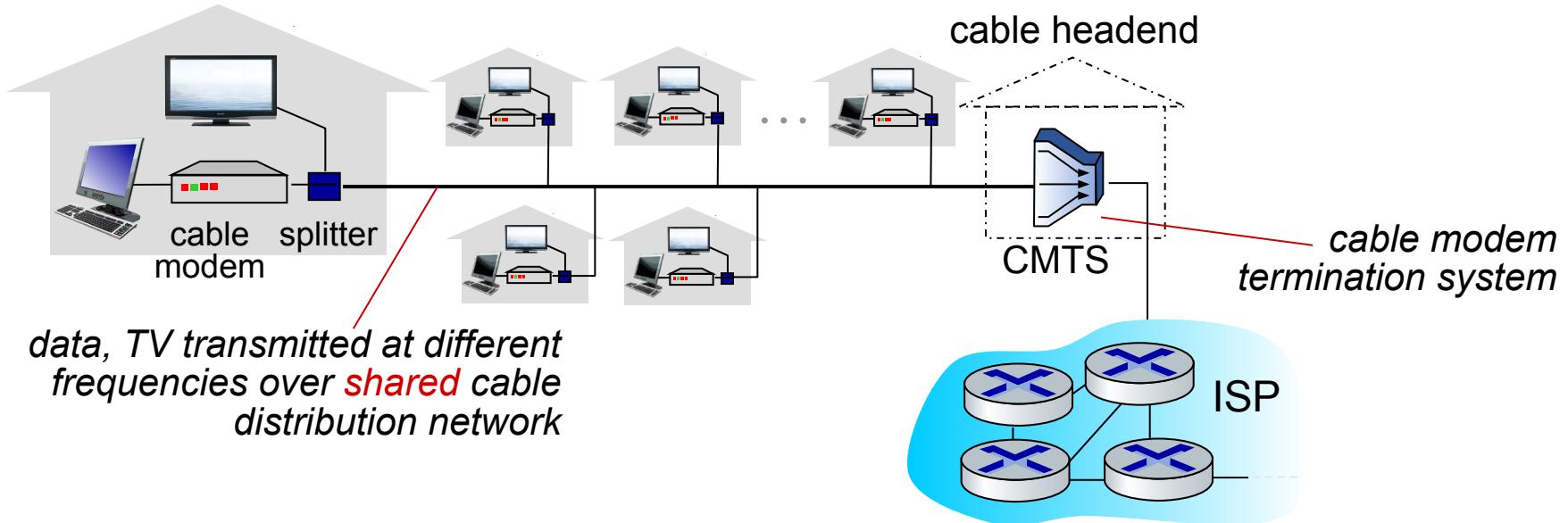


Access networks: cable-based access



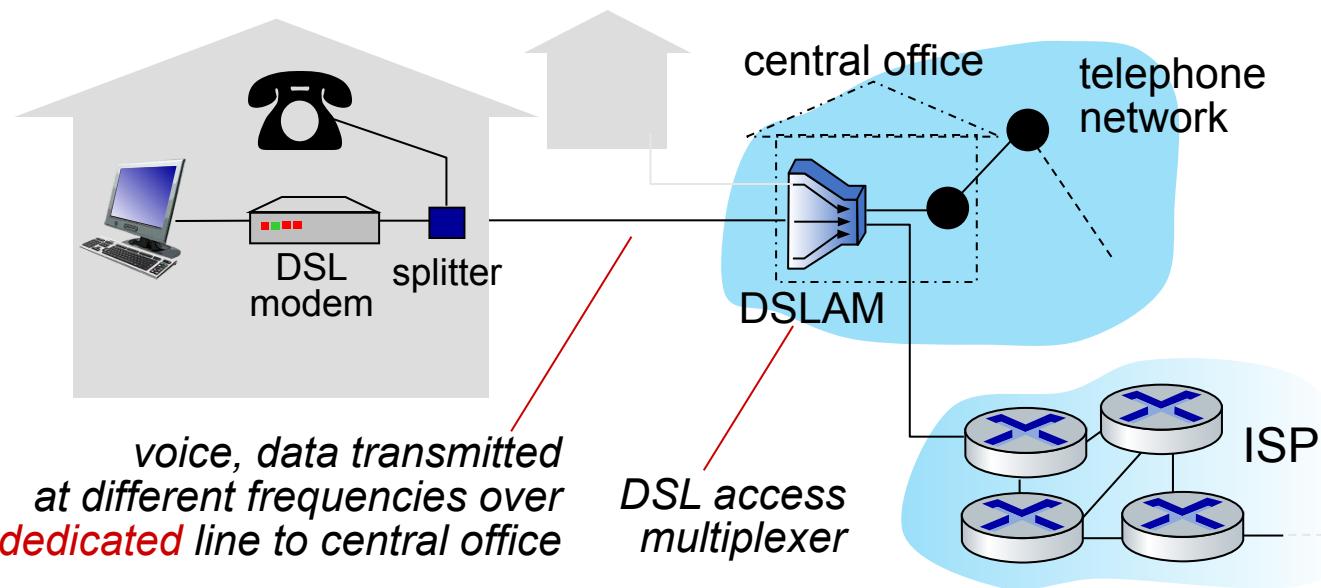
frequency division multiplexing (FDM): different channels transmitted in different frequency bands

Access networks: cable-based access



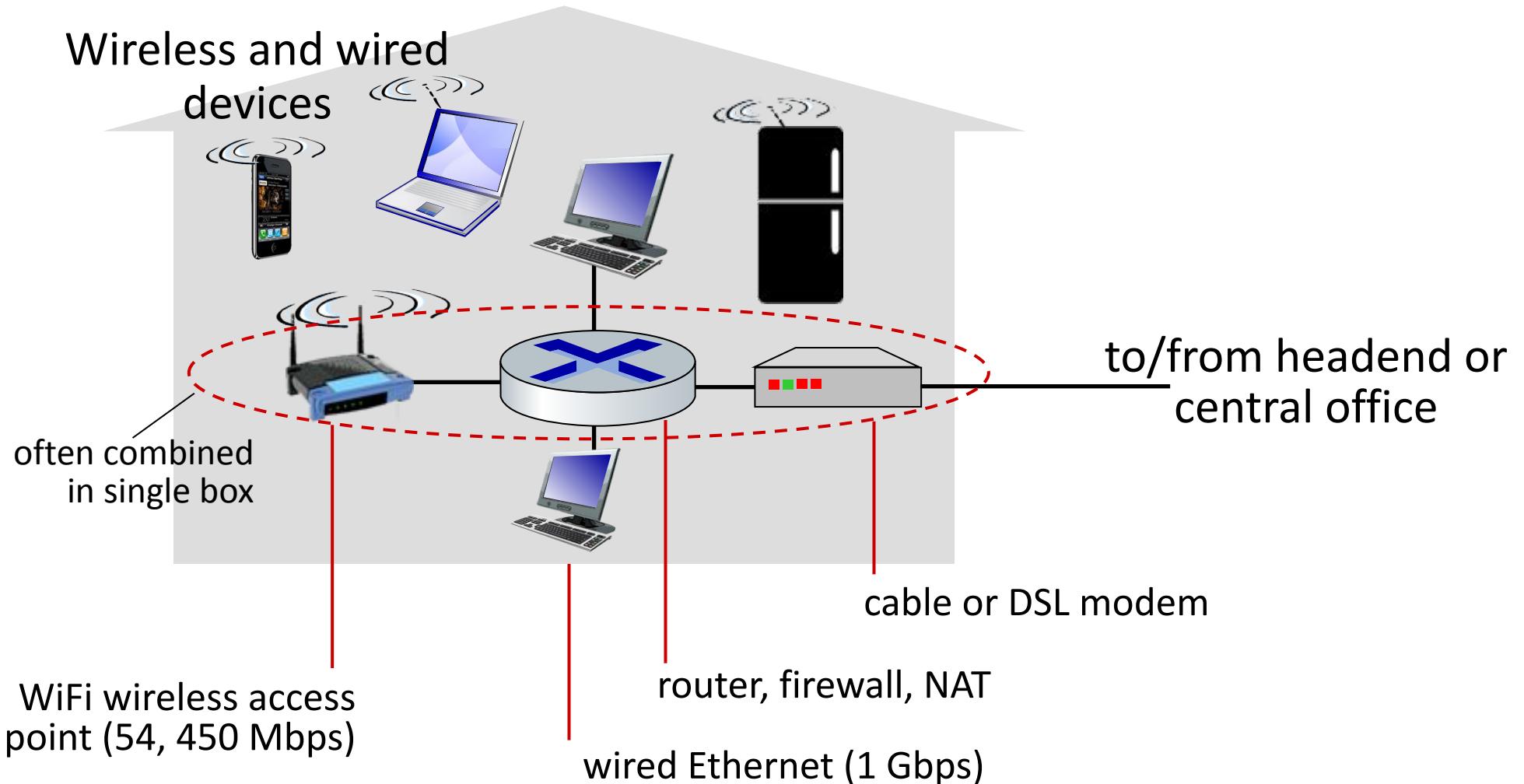
- HFC: hybrid fiber coax
 - asymmetric: up to 40 Mbps – 1.2 Gbps downstream transmission rate, 30-100 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
 - homes *share access network* to cable headend

Access networks: digital subscriber line (DSL)



- use *existing* telephone line to central office DSLAM
 - data over DSL phone line goes to Internet
 - voice over DSL phone line goes to telephone net
- 24-52 Mbps dedicated downstream transmission rate
- 3.5-16 Mbps dedicated upstream transmission rate

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

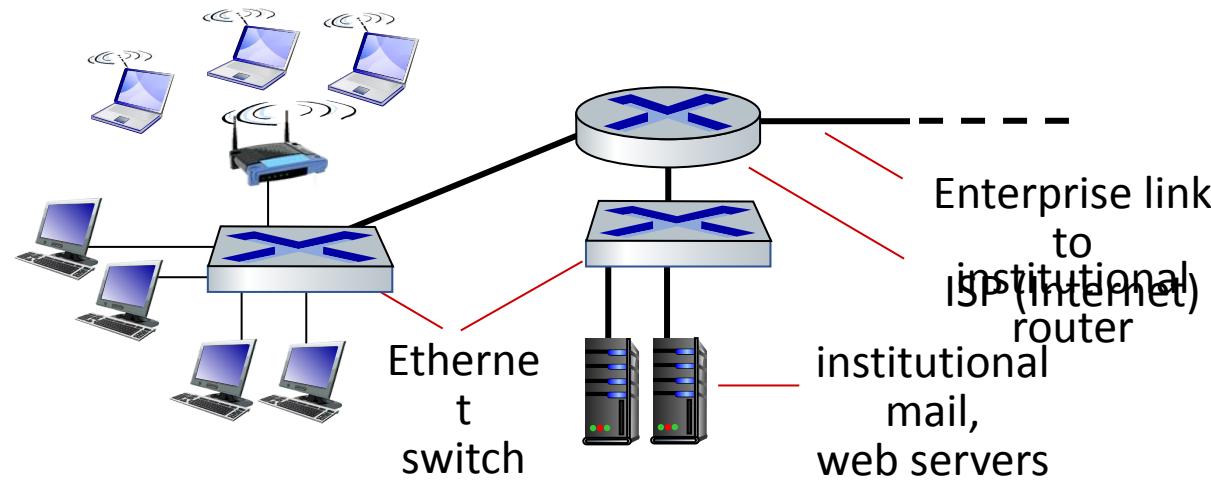


Wide-area cellular access networks

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



Access networks: enterprise networks



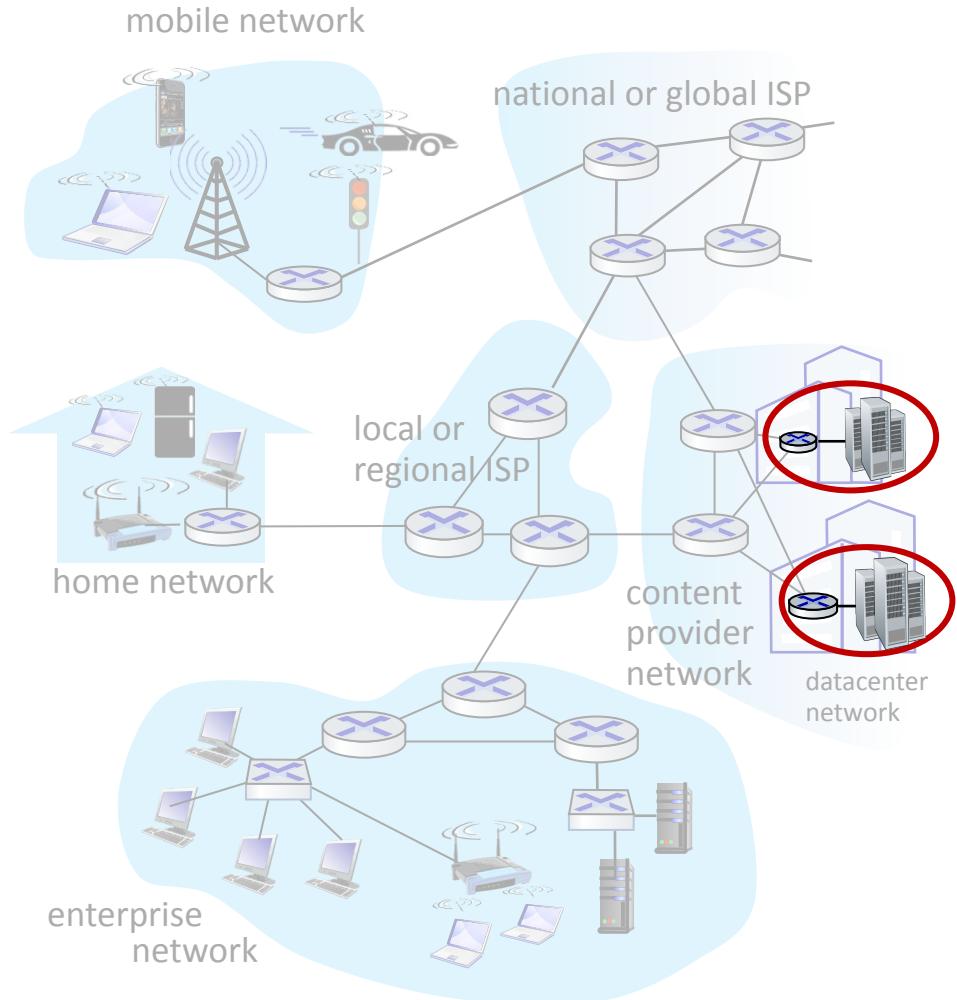
- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
 - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
 - WiFi: wireless access points at 11, 54, 450 Mbps

Access networks: data center networks

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



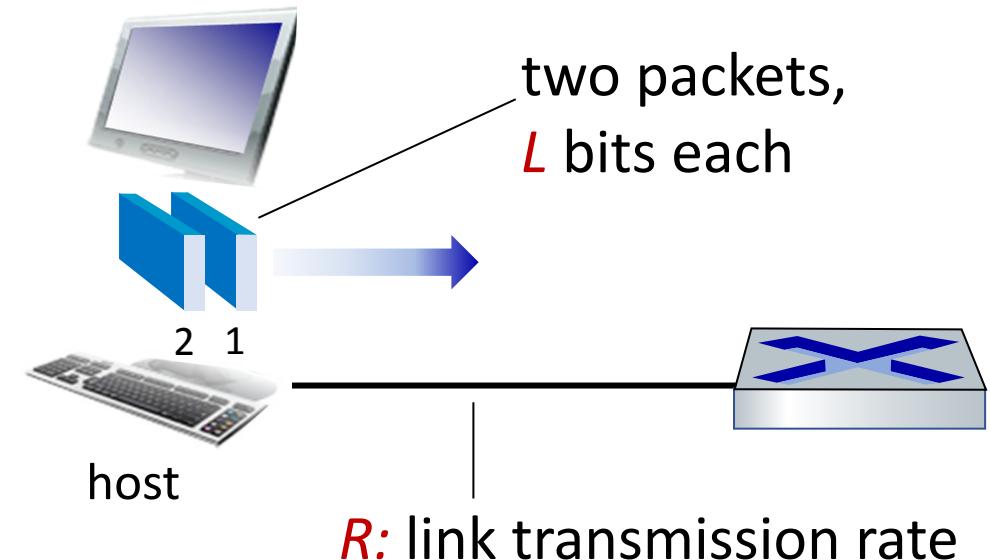
Courtesy: Massachusetts Green High Performance Computing Center (mghpcc.org)



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*



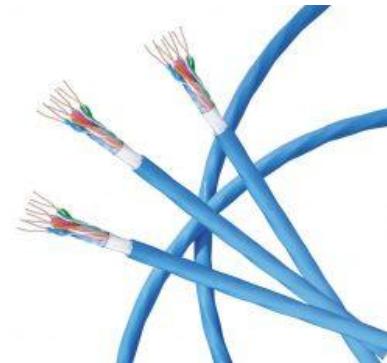
$$\text{packet transmission delay} = \frac{\text{time needed to transmit } L\text{-bit packet into link}}{R \text{ (bits/sec)}} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Links: physical media

- **bit**: propagates between transmitter/receiver pairs
- **physical link**: what lies between transmitter & receiver
- **guided media**:
 - signals propagate in solid media: copper, fiber, coax
- **unguided media**:
 - signals propagate freely, e.g., radio

Twisted pair (TP)

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



Links: physical media

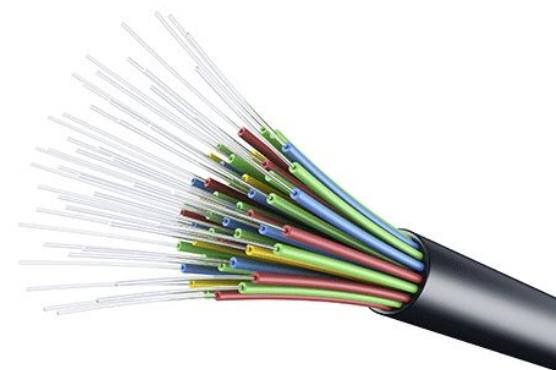
Coaxial cable:

- 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 operation:
 - 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

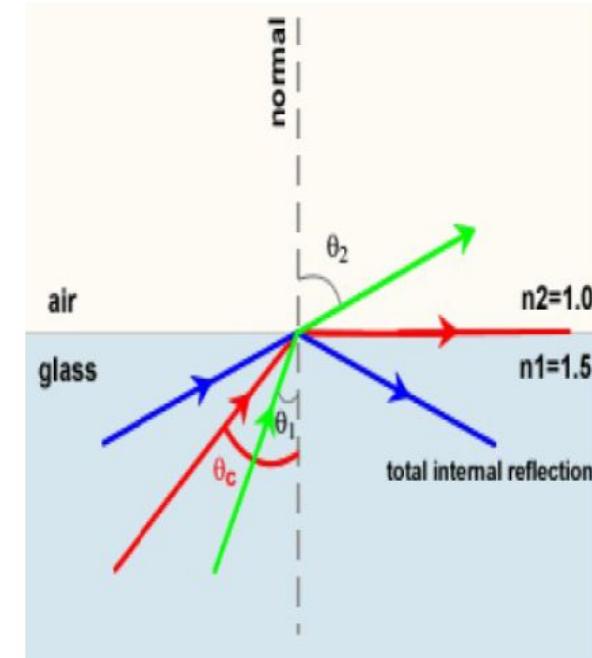
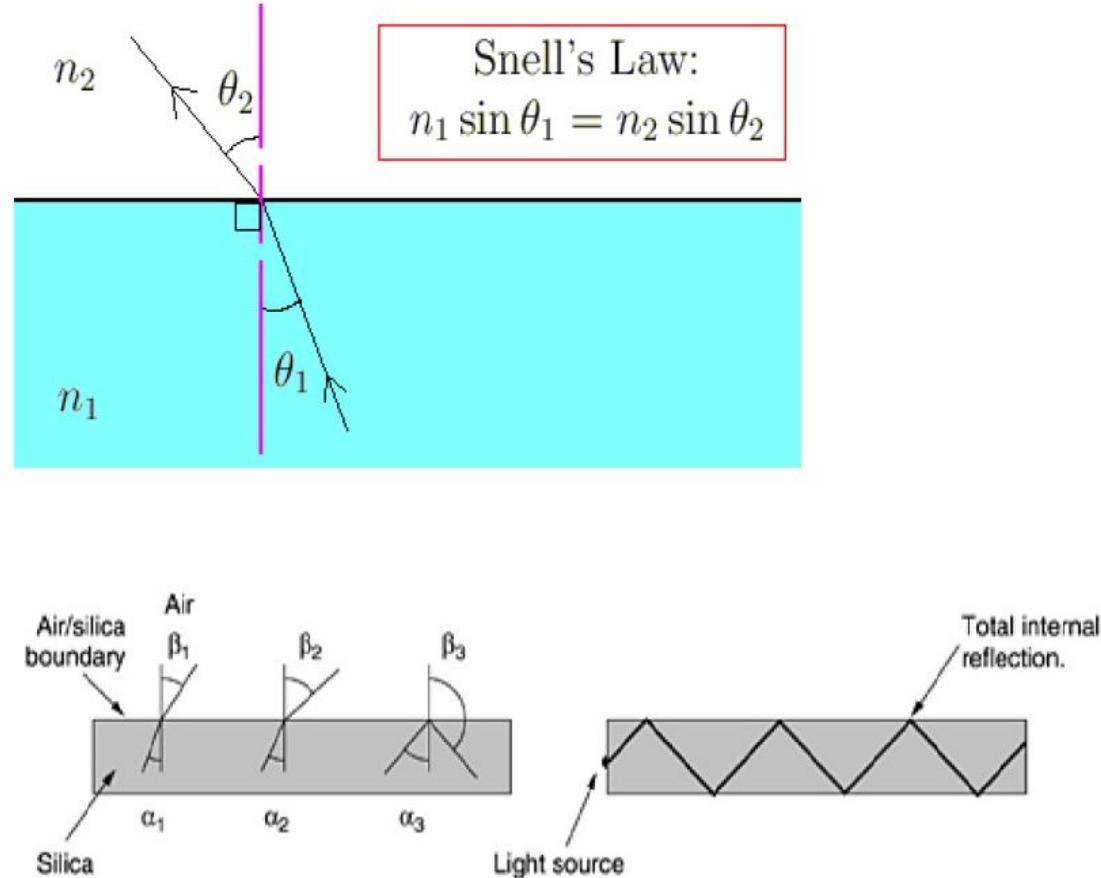
Wireless radio

- signal carried in various “bands” in electromagnetic spectrum
- no physical “wire”
- broadcast, “half-duplex” (sender to receiver)
- propagation environment effects:
 - reflection
 - obstruction by objects
 - Interference/noise

Radio link types:

- **Wireless LAN (WiFi)**
 - 10-100's Mbps; 10's of meters
- **wide-area** (e.g., 4G 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

Snell's Law: Refraction, Critical Angle, TIR



Snell's Law (numerical example)

A beam of light going through a medium with an index of refraction of 1.14 has an angle of incidence of 48° with another medium. If the light wave is at a new angle of 39° , what is the index of refraction for the second medium?

Use Snell's Law. Answer: 1.346

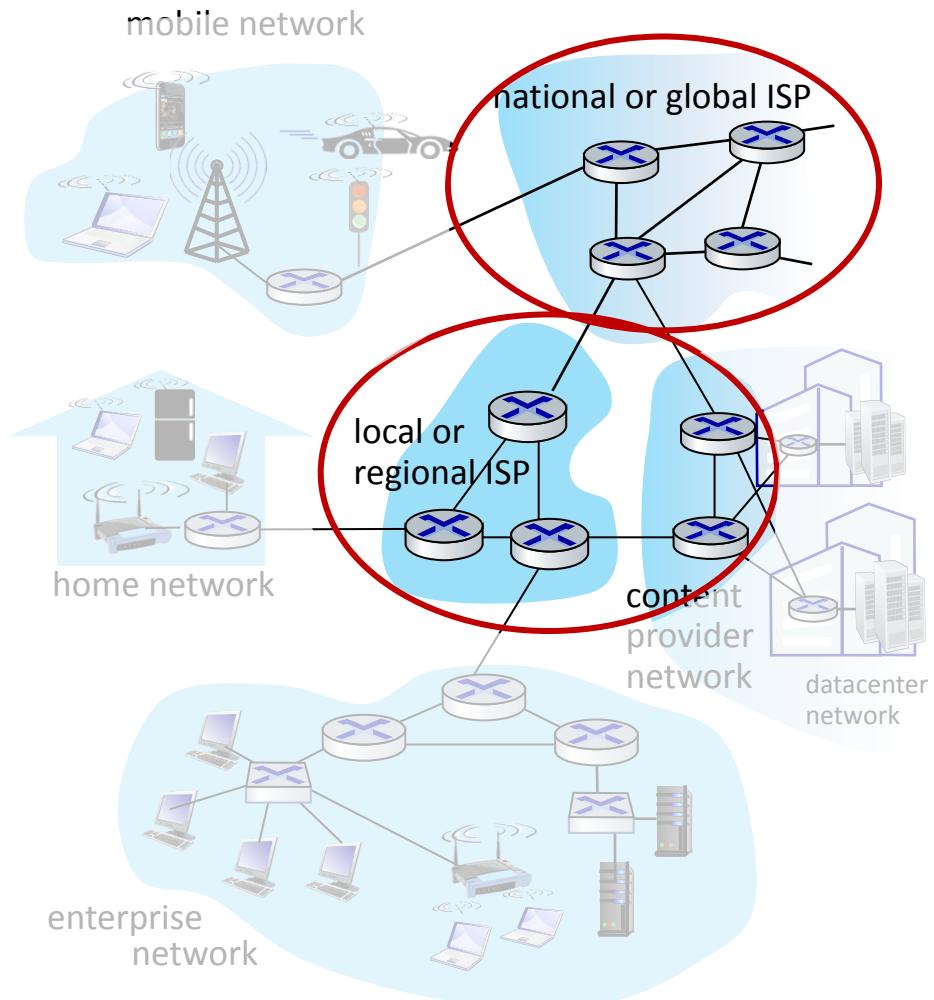
Chapter 1: roadmap

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The network core

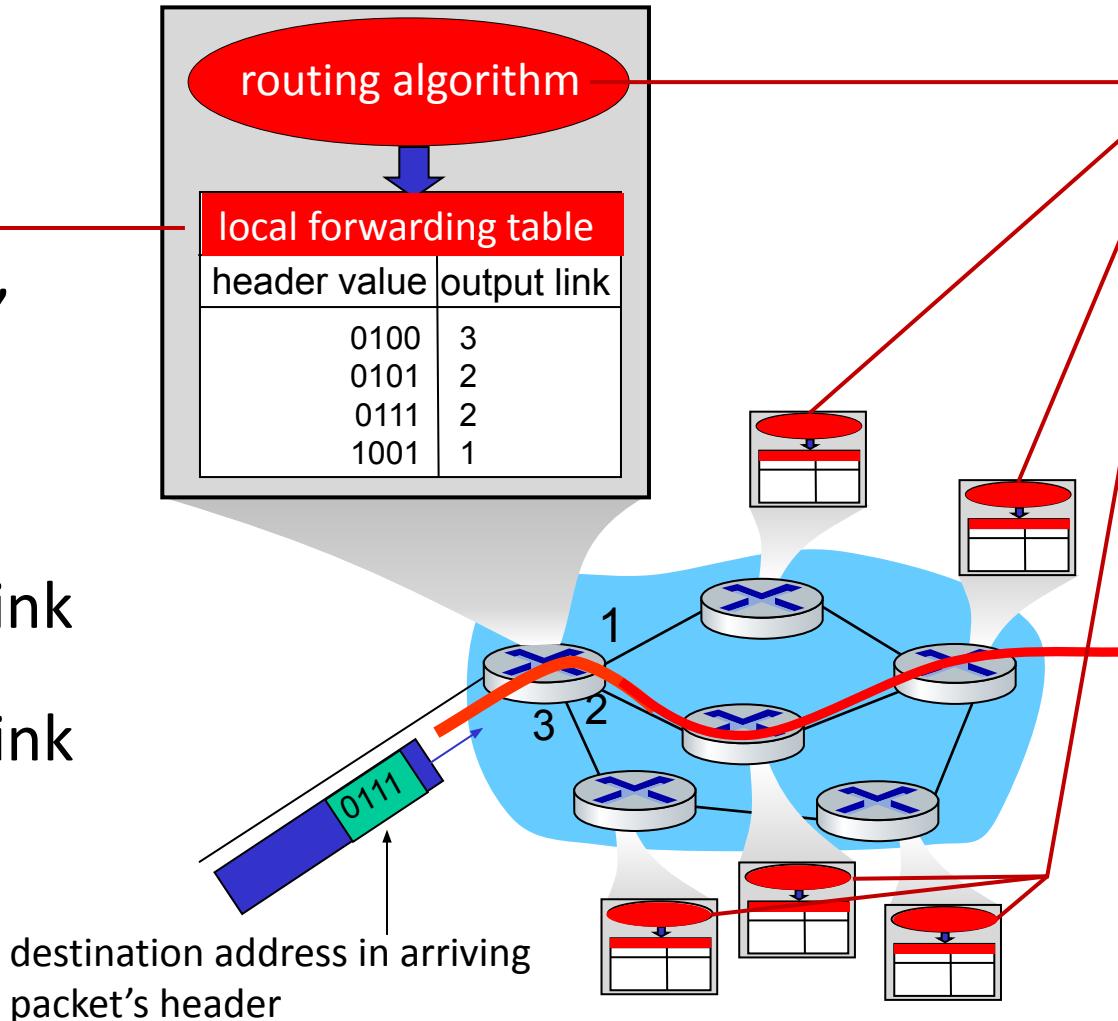
- mesh of interconnected routers
- **packet-switching**: hosts break application-layer messages into *packets*
 - network **forwards** packets from one router to the next, across links on path from **source to destination**



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

Sample routing table

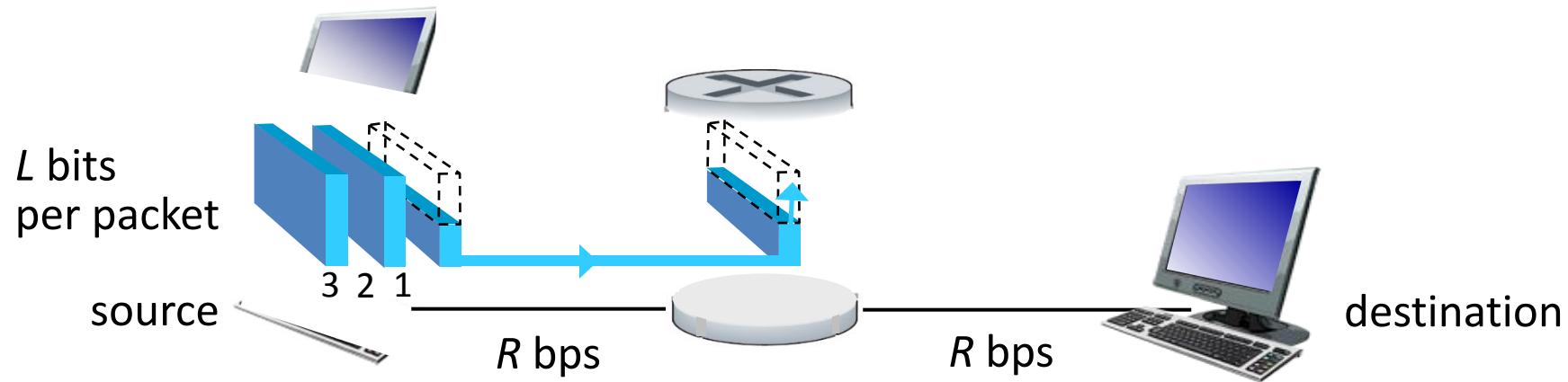
- Gateway & interface column refers to the forwarding table
- All columns combined are known as the routing table

Network Destination	Netmask	Gateway	Interface	Metric
101.25.67.0	255.255.255.0	10.0.0.2	eth3	1
default	0.0.0.0	10.0.0.1	eth0	0
192.25.67.0	255.255.255.0	10.0.0.3	eth5	10





Packet-switching: store-and-forward

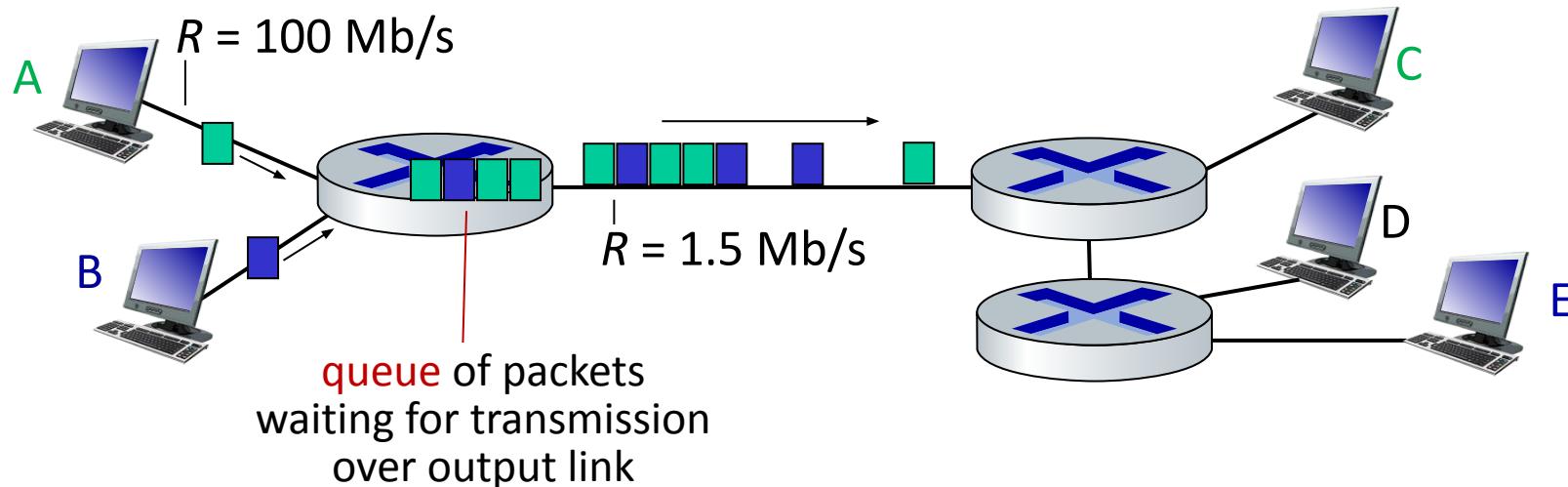


- **packet transmission delay:** takes L/R seconds to transmit (push out) L -bit packet into link at R bps
- ***store and forward:*** entire packet must arrive at router before it can be transmitted on next link
- No resources are reserved. On demand switching.
- Connectionless: No connection state is maintained by the routers in the path
- Best effort delivery and individual packets may follow any path. E.g., Internet

One-hop numerical example:

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

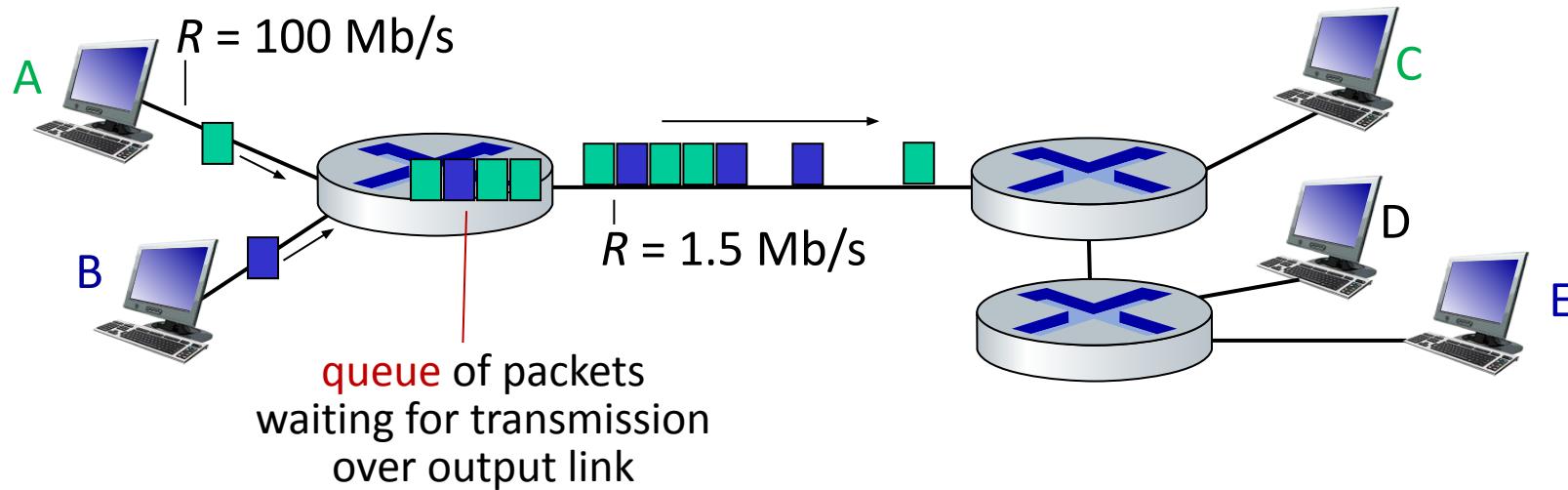
Packet-switching: queueing



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



Packet-switching: queueing



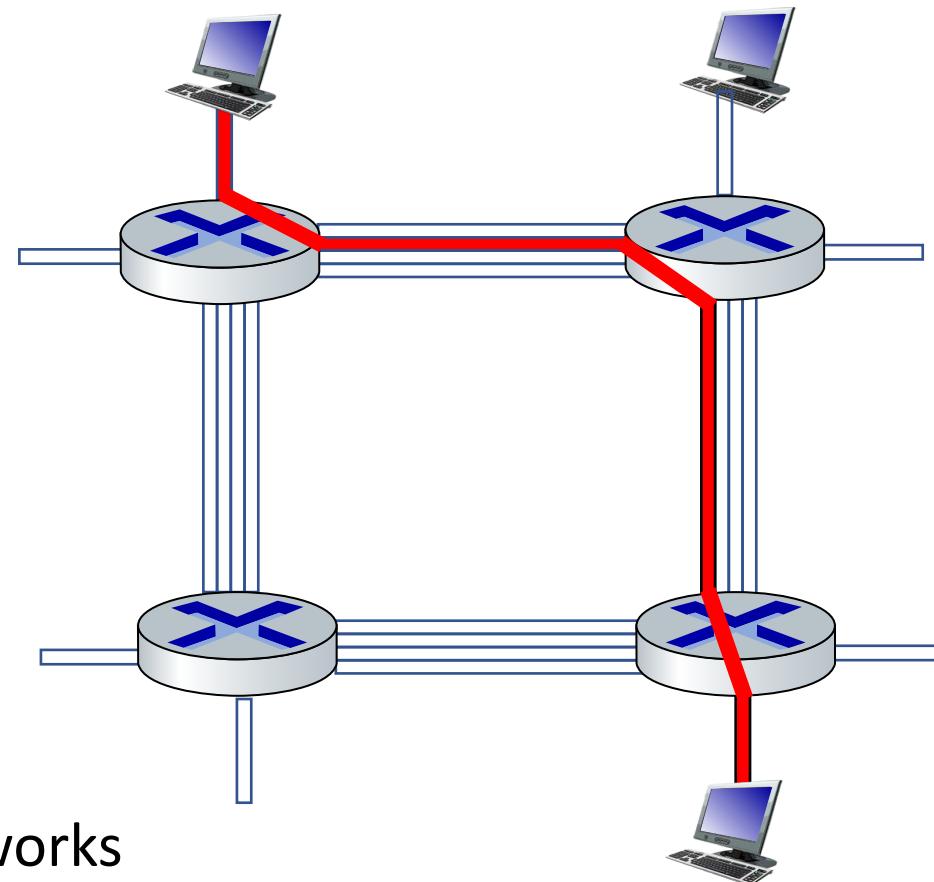
Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

Alternative to packet switching: circuit switching

end-end resources (buffers, link trans. rate) allocated to, reserved for “call” between source and destination

- in diagram, each link has four circuits.
 - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
 - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (**no sharing**)
- commonly used in traditional telephone networks
- Cafeteria example



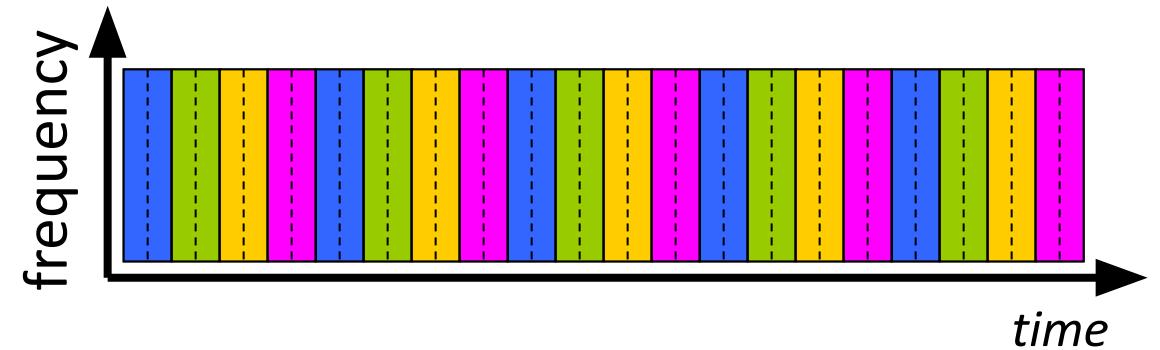
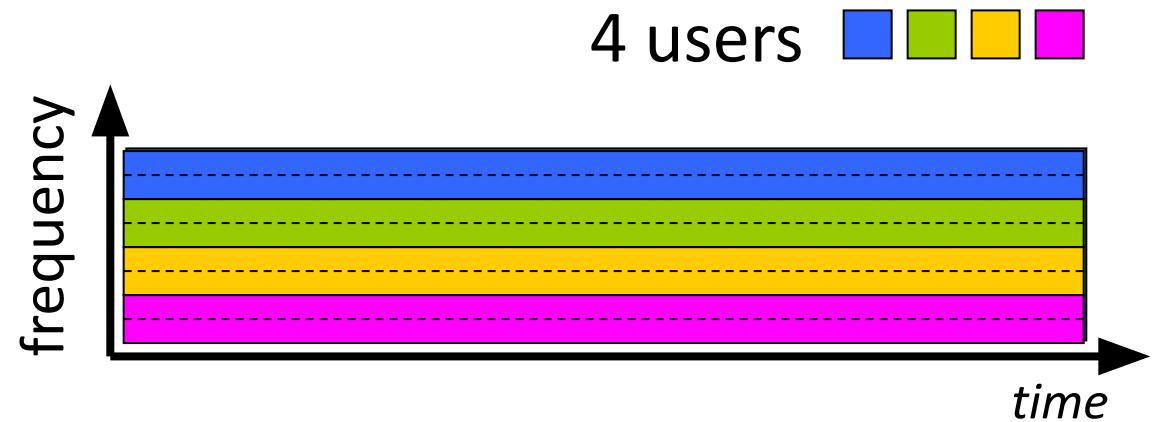
Circuit switching: FDM and TDM

Frequency Division Multiplexing (FDM)

- optical, electromagnetic frequencies divided into (narrow) frequency bands
- each call allocated its own band, can transmit at max rate of that narrow band

Time Division Multiplexing (TDM)

- time divided into slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band (only) during its time slot(s)



Circuit switching (a numerical example)

- For TDM: If the link can transmit/generate ‘f’ frames per second and each slot consists of ‘b’ bits, the transmission rate of each circuit is ‘ $f \cdot b$ ’ bits per second.
- How long it takes to send a file of 640,000 bits from Host A to Host B over a circuit-switched network. Suppose that all links in the network use TDM with 24 slots and have a bit rate of 1.536 Mbps. Also suppose that it takes 500 msec to establish an end-to-end circuit before Host A can begin to transmit the file.
 - Each circuit has a transmission rate of $(1.536 \text{ Mbps})/24 = 64 \text{ kbps}$,
 - so it takes $(640,000 \text{ bits})/(64 \text{ kbps}) = 10 \text{ seconds}$ to transmit the file.
 - To this 10 seconds we add the circuit establishment time, giving 10.5 seconds to send the file

Packet switching versus circuit switching

- Advantages of packet switching:
 - Great for ‘bursty’ data – sometimes data to send, but sometimes not.
 - Resource can be shared.
 - Simpler, no call setup.
- Disadvantages:
 - Excessive congestion possible: packet delay and loss due to buffer overflow
 - protocols needed for reliable data transfer (TCP – Unit-3)
 - congestion control (using TCP – Unit-3)
 - No guaranteed service (does not mean its unreliable, it means you may or may not get bandwidth)
 - Out-of-order delivery (reassembly at network layer – Unit-4)
- **Q: How to provide circuit-like behavior with packet-switching?**
 - “It’s complicated.” We’ll study various techniques that try to make packet switching as “circuit-like” as possible.

Packet switching versus circuit switching

- Advantages of circuit switching:
 - Great for constant traffic
 - Minimal delay and loss
 - Guaranteed service
- Disadvantages:
 - Sharing not possible so limited number of users can have access to link
 - Call setup required which takes some time
 - Resource idle if no data to send. (e.g. caller and callee are not talking and put the phone on hold)

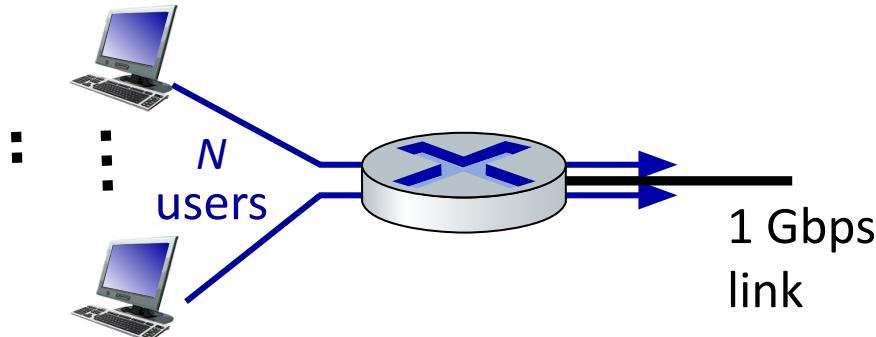
Packet switching versus circuit switching

- Suppose a link capacity is 1Mbps and 10 users are there but only one user generates one thousand 1,000 bits packets, while other users are totally inactive. Under TDM circuit switching, how much time will the active user need to send its data (i.e., one thousand 1,000 bits packets)?
 - Each user will get only 100 Kbps (i.e., the circuit transmission rate).
 - It needs to send 1,000,000 bits so time required = $1,000,000/100,000 = 10$ seconds.
- What about packet switching?
 - Just 1 second

Packet switching versus circuit switching

example:

- 1 Gb/s link
- each user:
 - 100 Mb/s when “active”
 - active 10% of time



Q: how many users can use this network under circuit-switching and packet switching?

▪ *circuit-switching:* 10 users

▪ *packet switching:* with 35 users,
probability > 10 active at same time
is less than .0004 *

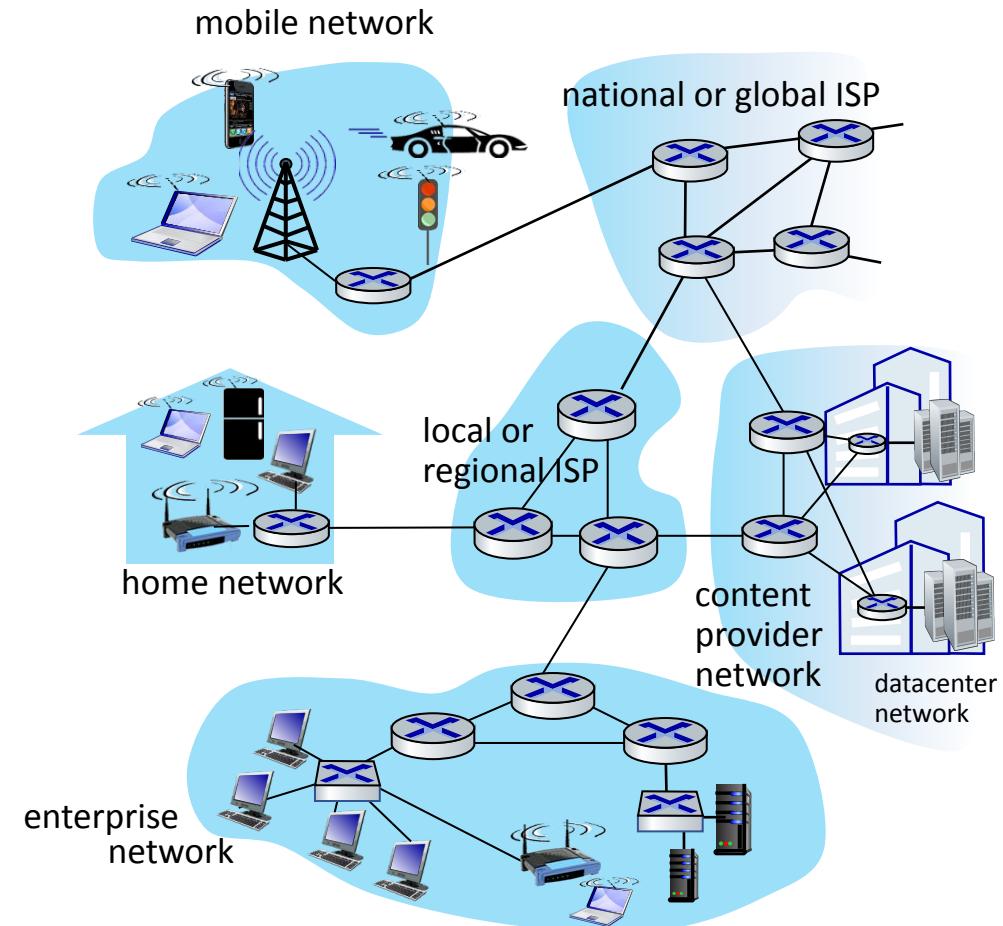
Q: how did we get value 0.0004?

A: HW problem (for those with
course in probability only)

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

Internet structure: a “network of networks”

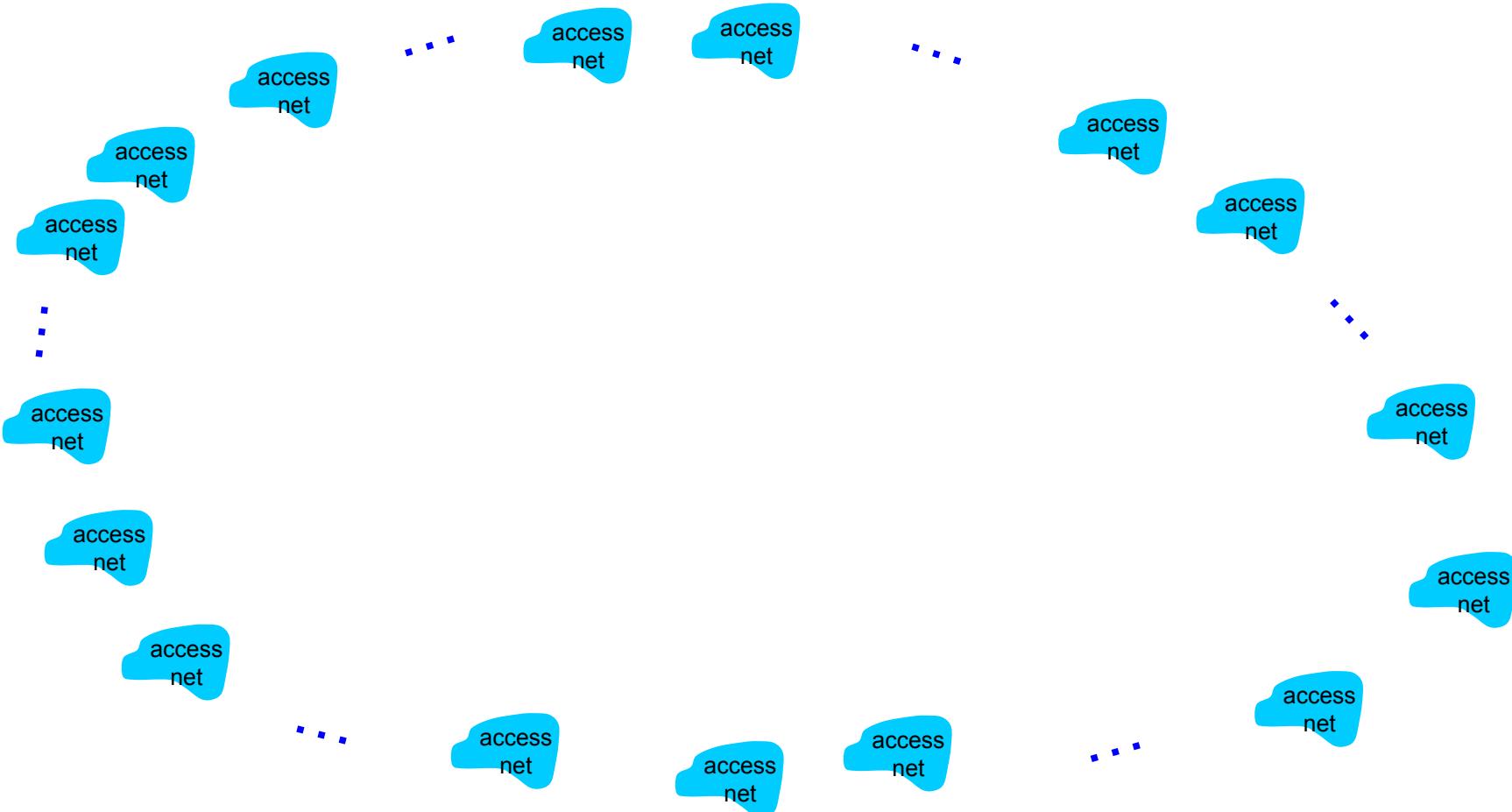
- hosts connect to Internet via **access** Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
 - so that *any two hosts (anywhere!)* can send packets to each other
- resulting network of networks is very complex
 - evolution driven by **economics, national policies**



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

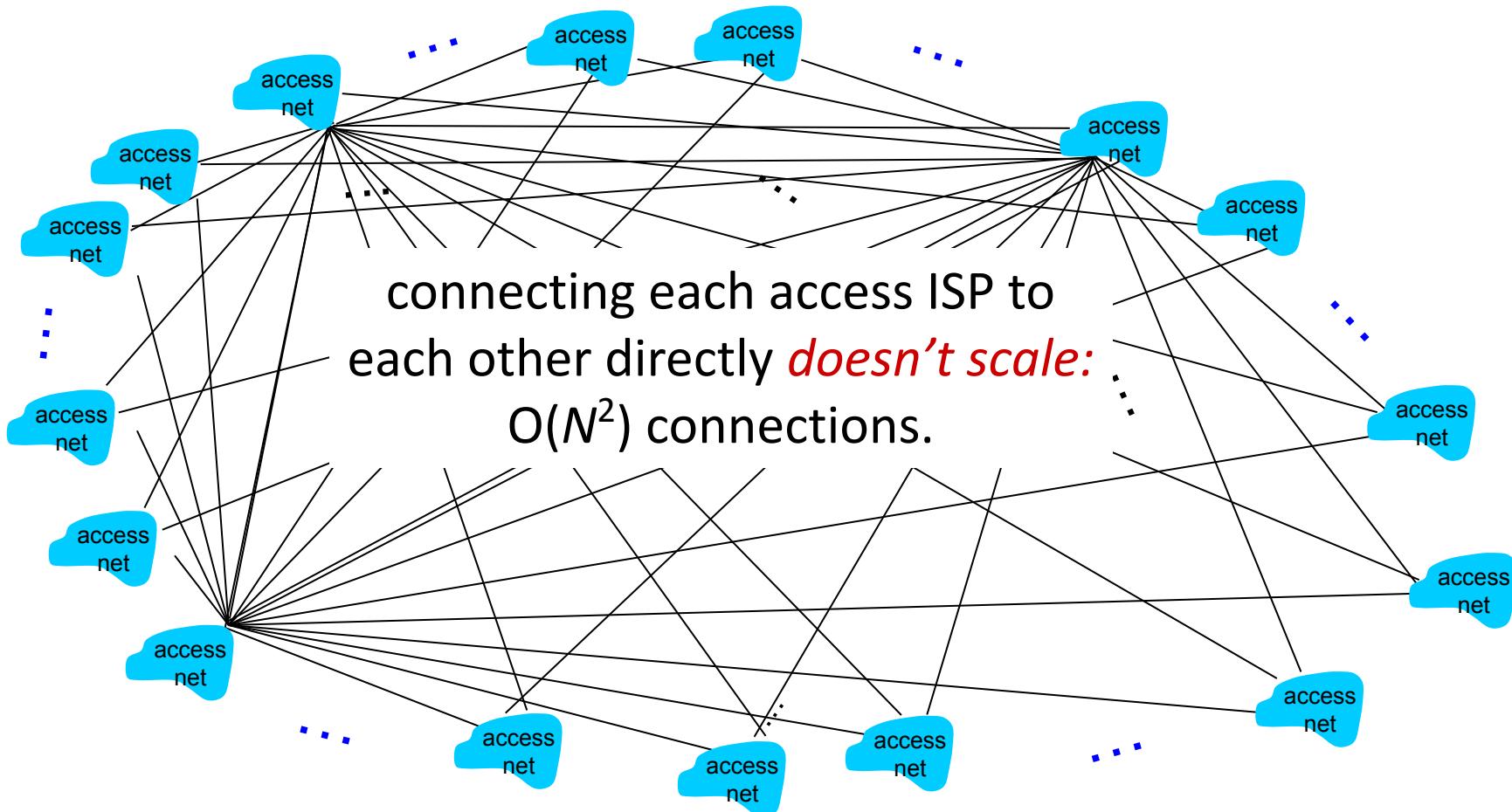
Internet structure: a “network of networks”

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



Internet structure: a “network of networks”

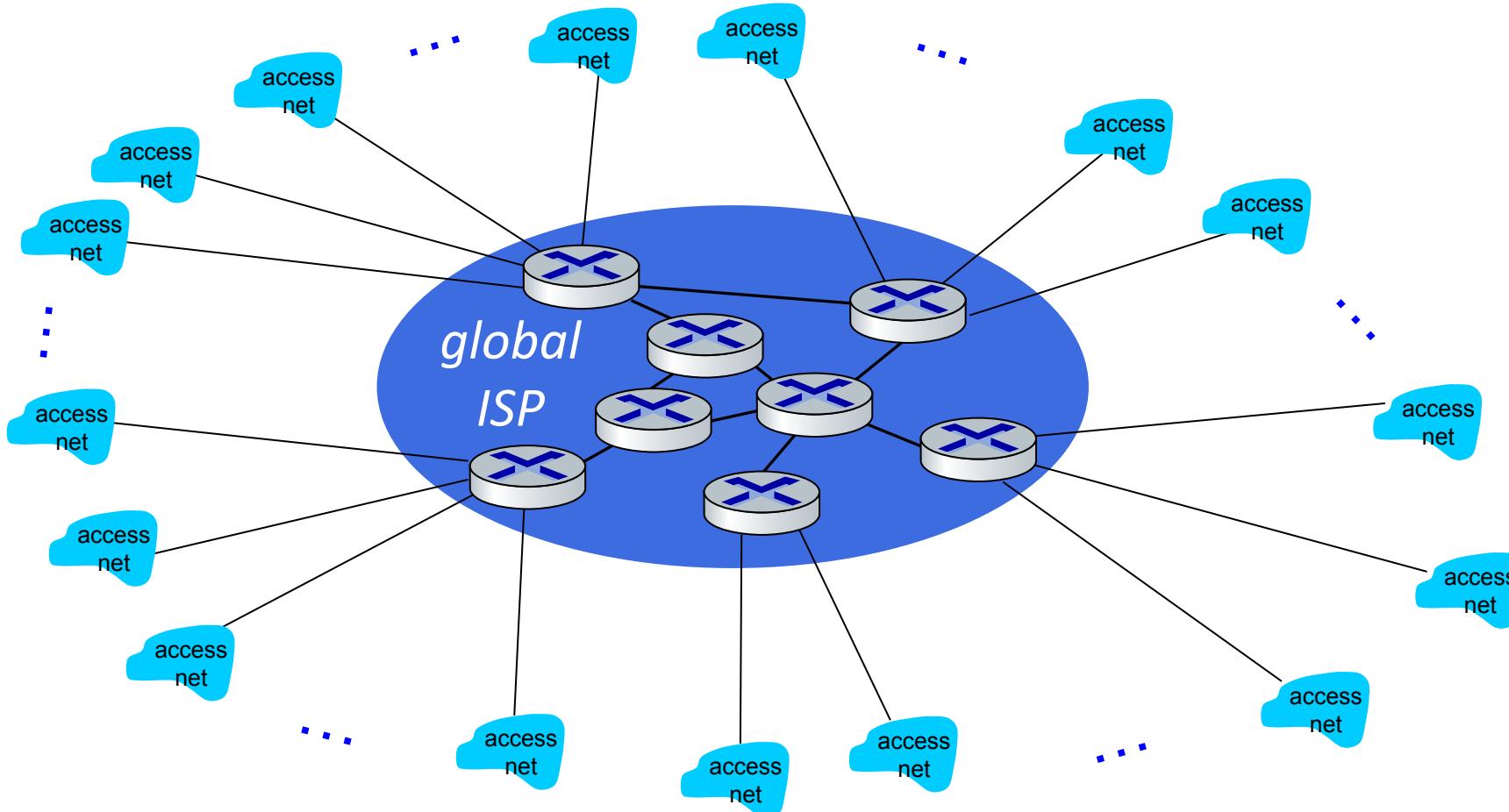
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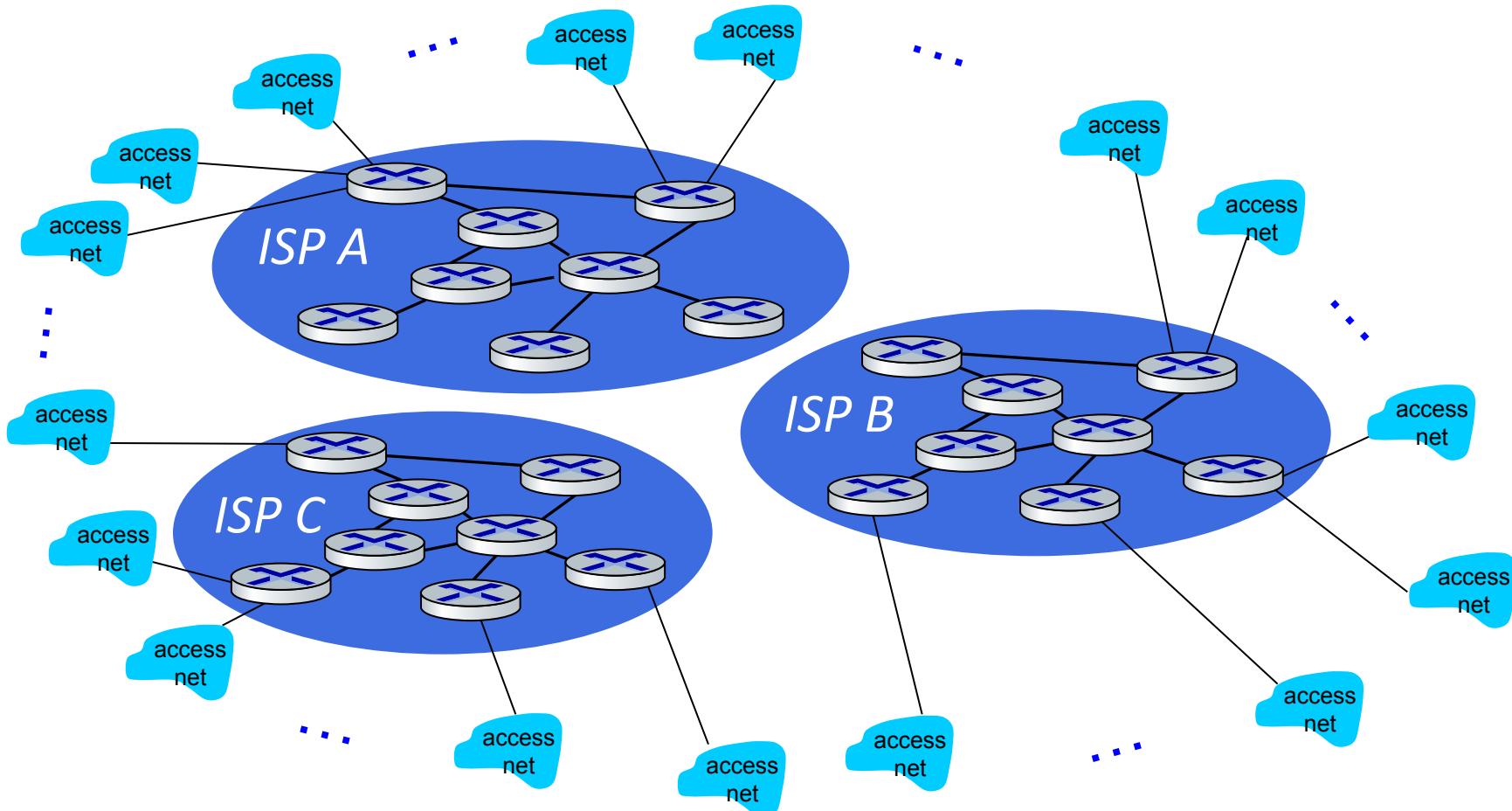
Option: connect each access ISP to one global transit ISP?

Customer and provider ISPs have economic agreement.



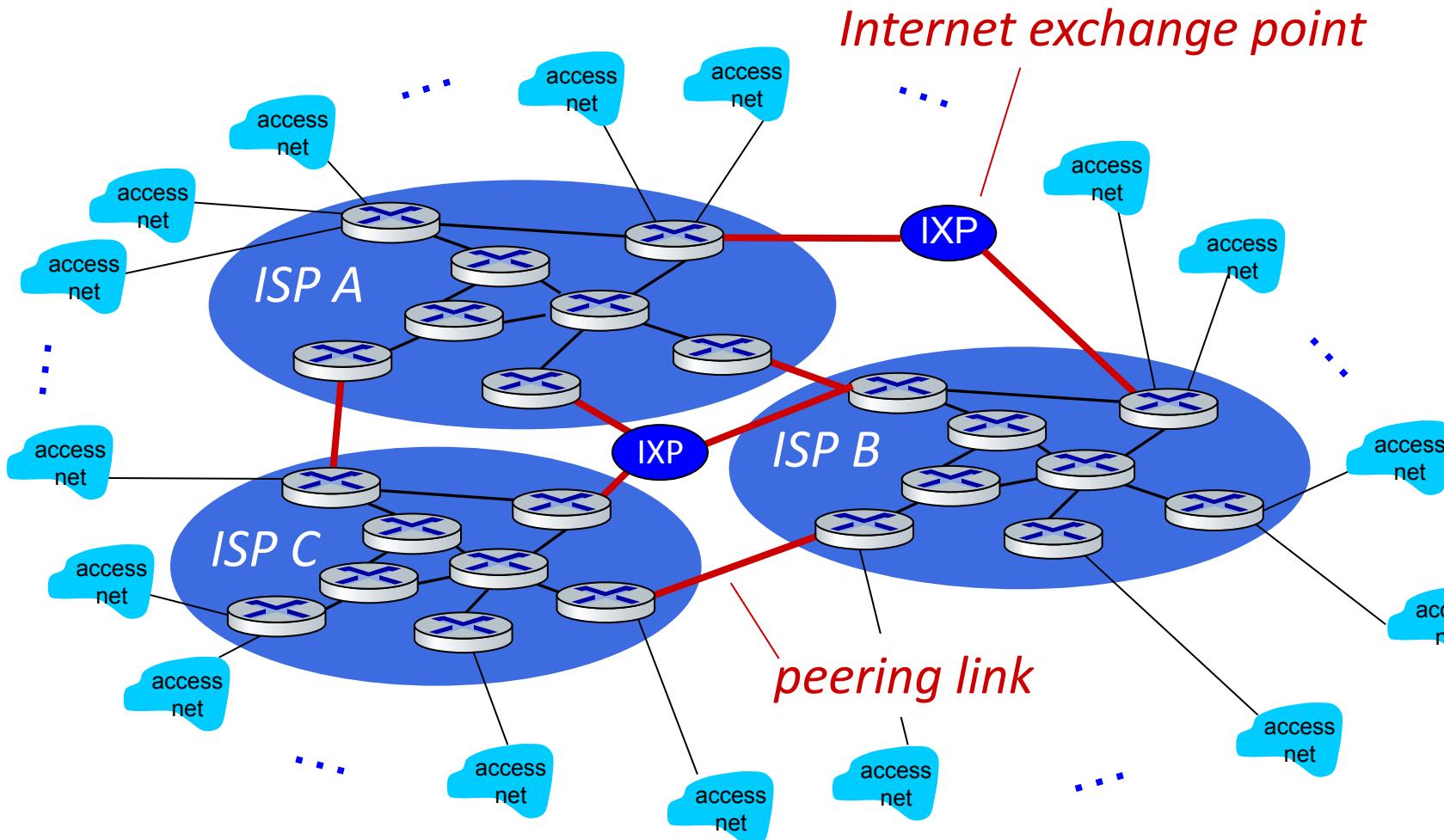
Internet structure: a “network of networks”

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



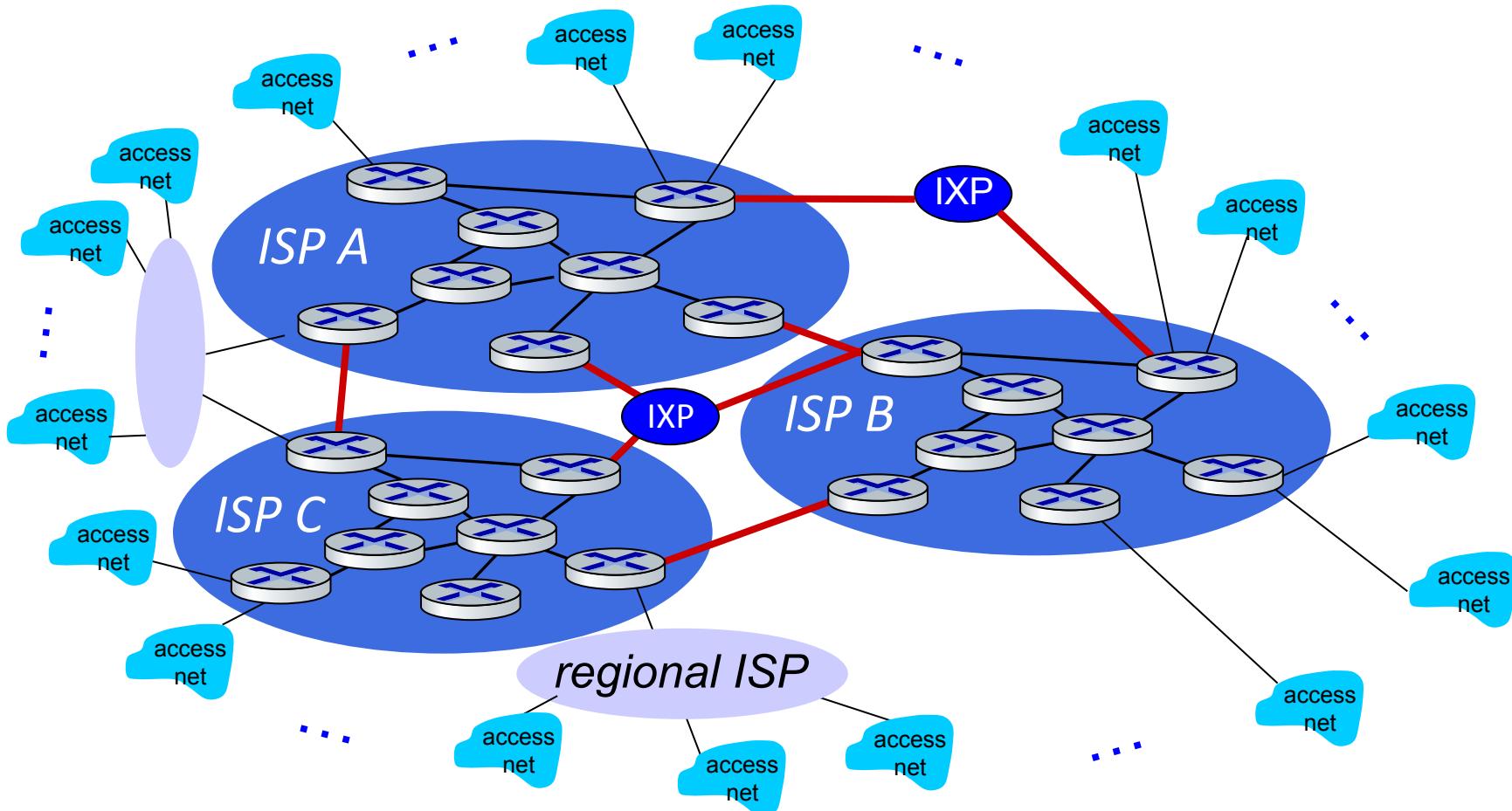
Internet structure: a “network of networks”

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



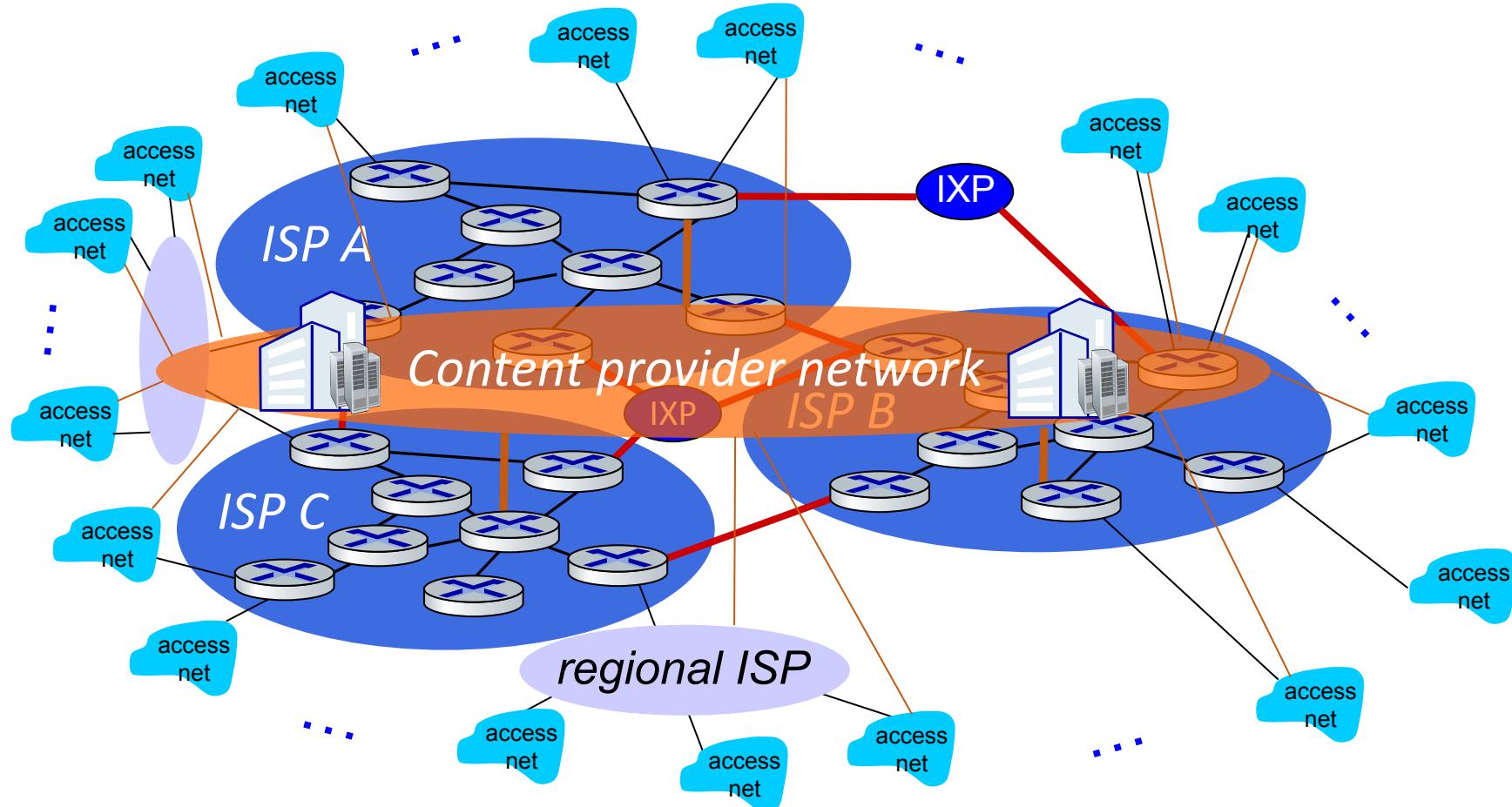
Internet structure: a “network of networks”

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

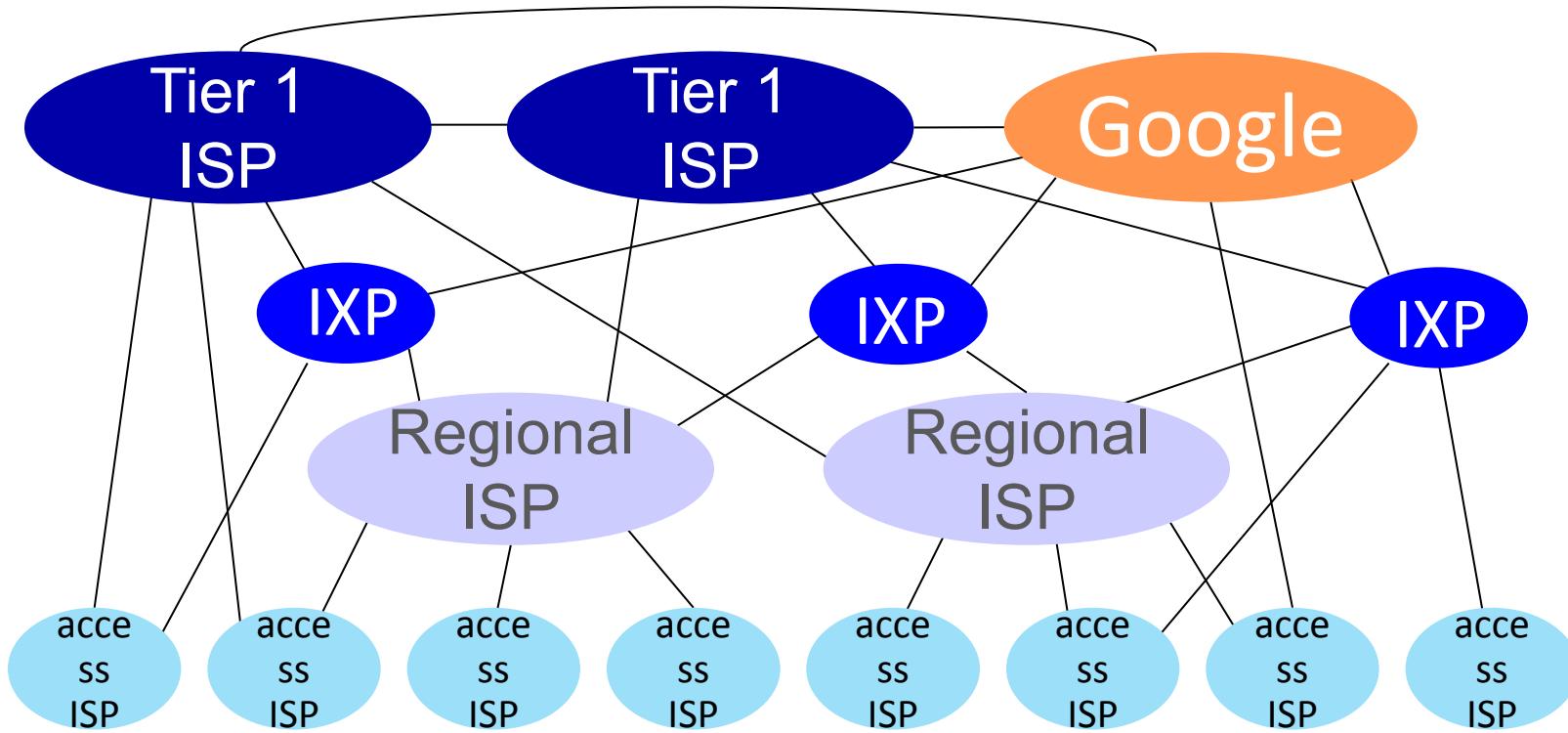


Internet structure: a “network of networks”

... 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

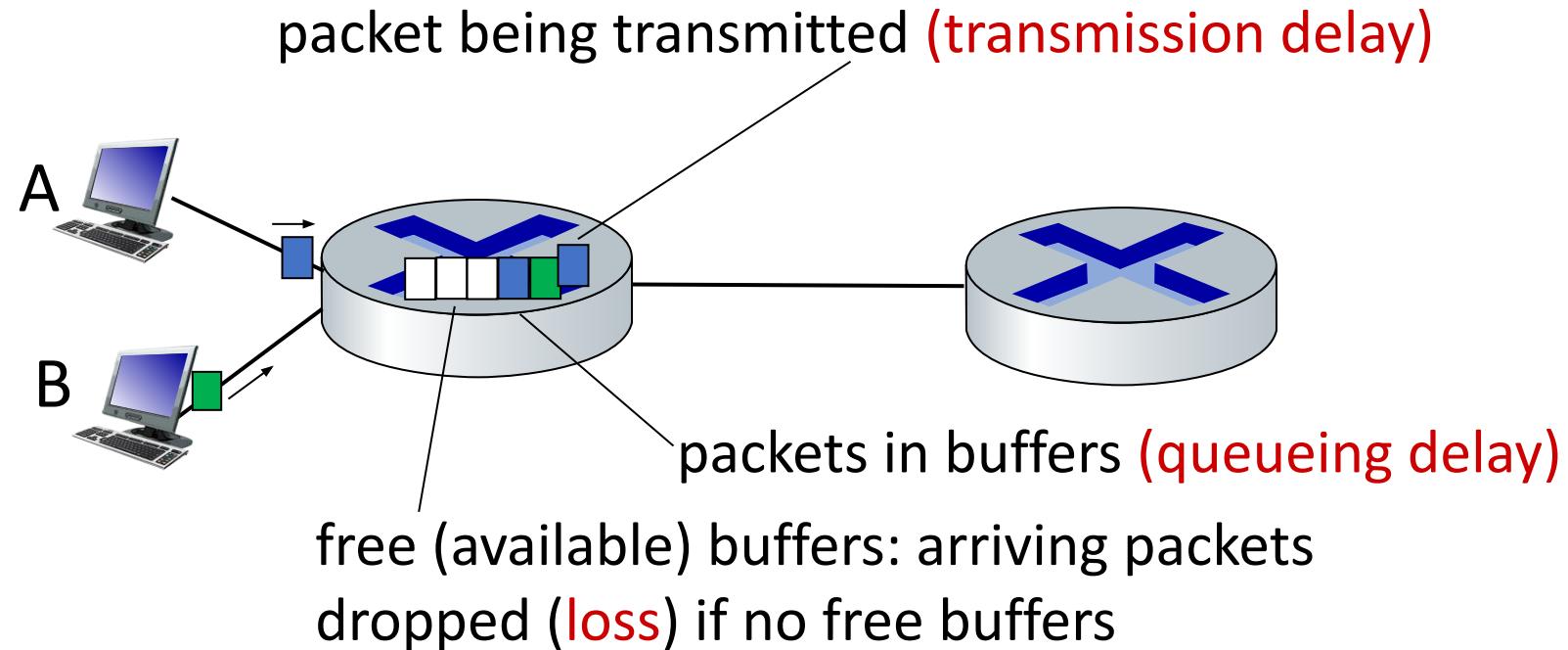
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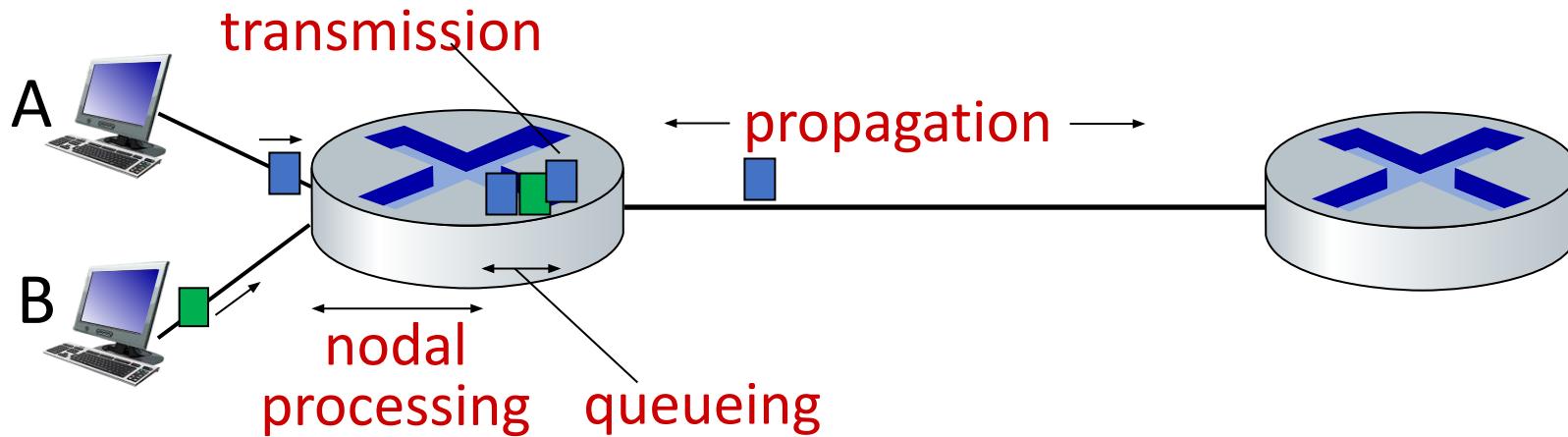


How do packet delay and loss occur?

- 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



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

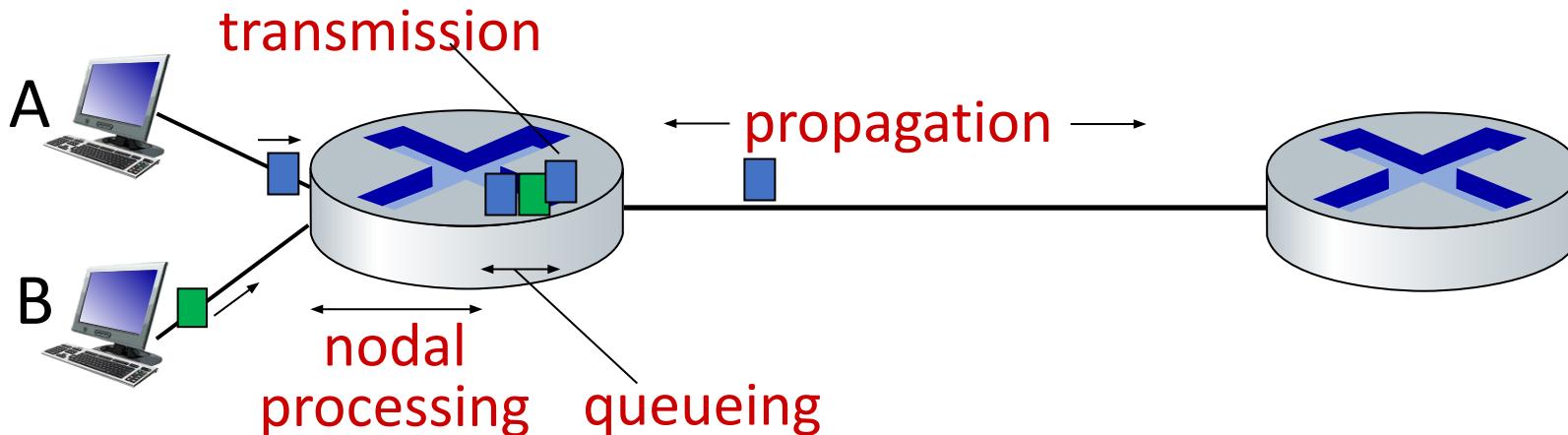
d_{proc} : nodal processing

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

d_{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_{trans} : transmission delay:

- L : packet length (bits)
- R : link *transmission rate (bps)*

$$\boxed{\mathbf{d_{trans} = L/R}}$$

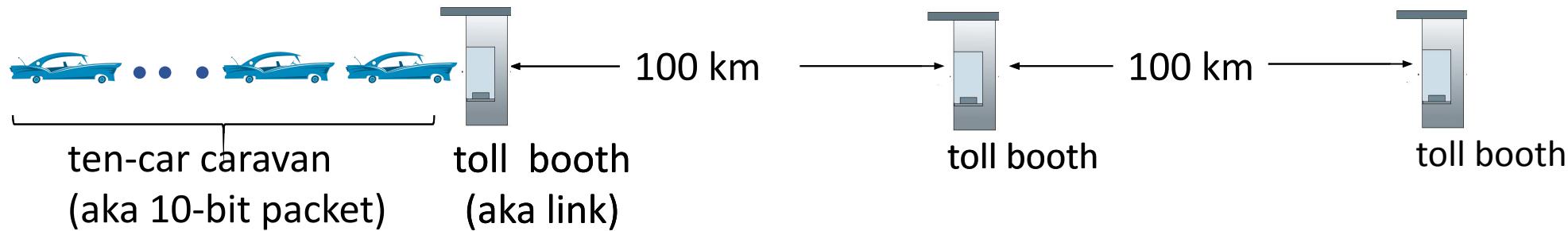
d_{trans} and d_{prop}
very different

d_{prop} : propagation delay:

- d : length of physical link
- s : propagation speed ($\sim 2 \times 10^8$ m/sec)

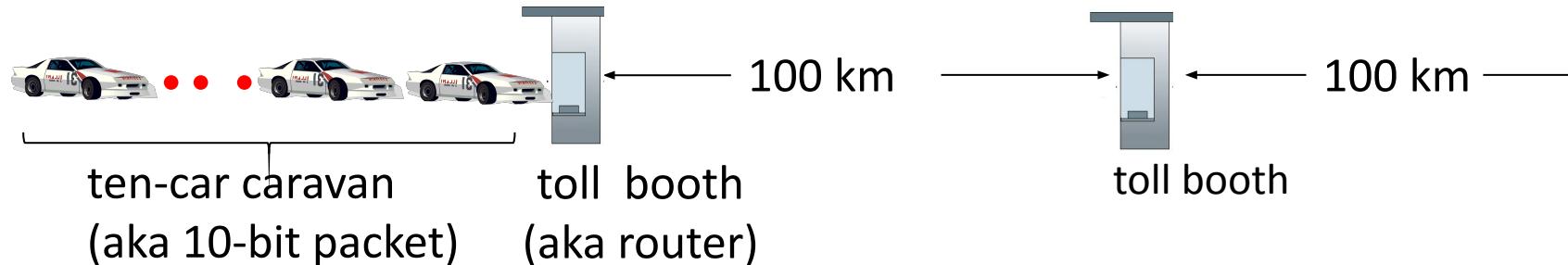
$$\boxed{\mathbf{d_{prop} = d/s}}$$

Caravan analogy



- car ~ bit; caravan ~ packet; toll service ~ link transmission
- toll booth takes 12 sec to service car (bit transmission time)
- “propagate” at 100 km/hr
- **Q: How long until caravan is lined up before 2nd toll booth?**
- time to “push” entire caravan through toll booth onto highway = $12 * 10 = 120$ sec
- time for last car to propagate from 1st to 2nd toll both: $100\text{km}/(100\text{km/hr}) = 1$ hr
- **A: 62 minutes**

Caravan analogy



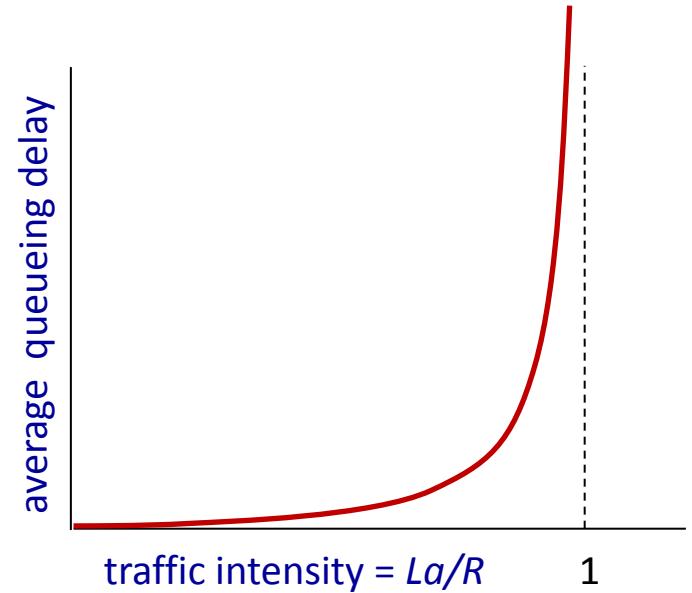
- suppose cars now “propagate” at 1000 km/hr
 - and suppose toll booth now takes one min to service a car
 - ***Q: Will cars arrive to 2nd booth before all cars serviced at first booth?***
- A: Yes!** after 7 min, first car arrives at second booth; three cars still at first booth

Packet queueing delay (revisited)

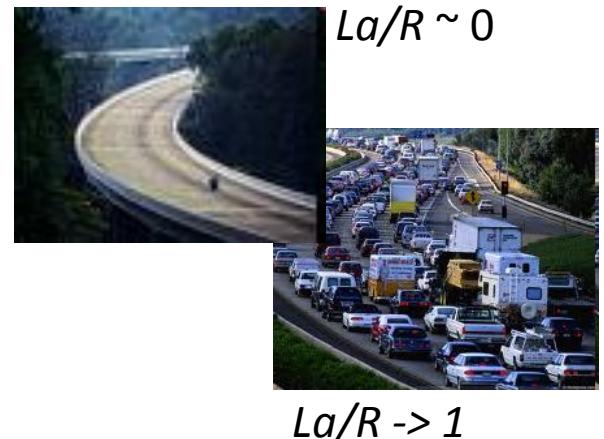
- a : average packet arrival rate
- L : packet length (bits)
- R : link bandwidth (bit transmission rate)

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

“traffic intensity”

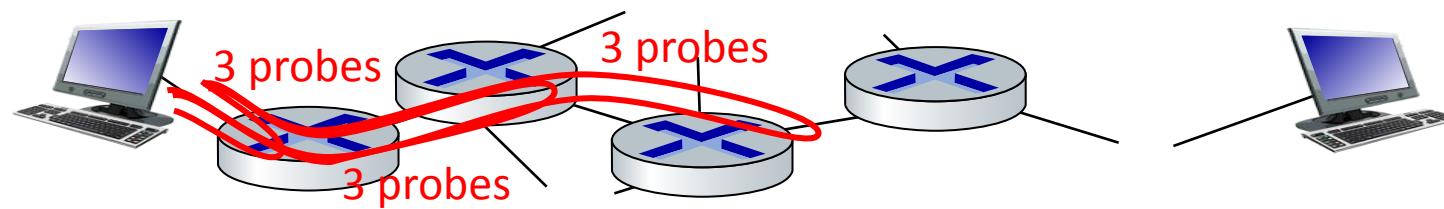


- $La/R \sim 0$: avg. queueing delay small
- $La/R \rightarrow 1$: avg. queueing delay large
- $La/R > 1$: more “work” arriving is more than can be serviced - average delay infinite!



“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

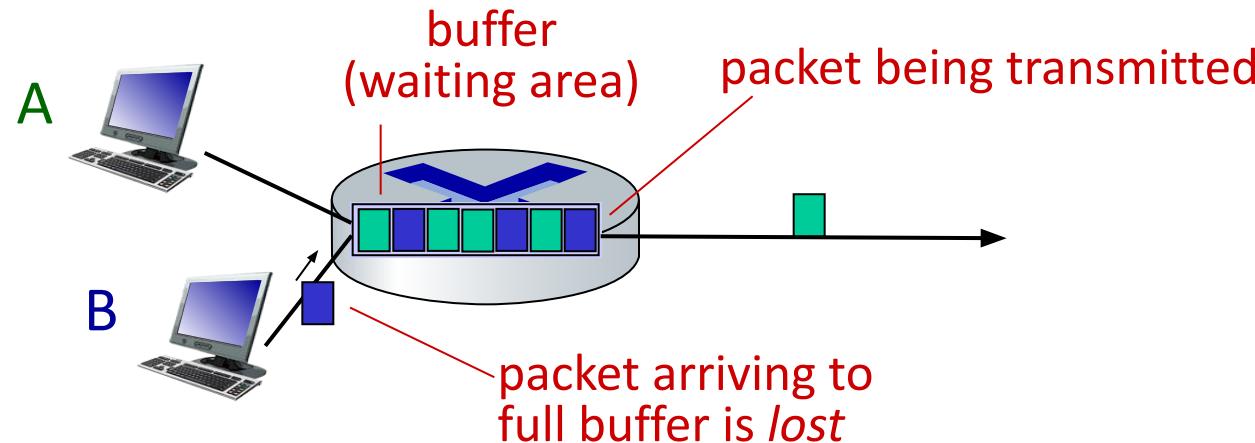
traceroute: gaia.cs.umass.edu to www.eurecom.fr

		3 delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu			
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 delay measurements to border1-rt-fa5-1-0.gw.umass.edu
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	trans-oceanic link
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	looks like delays decrease! Why?
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	***	* means no response (probe lost, router not replying)			
19	fantasia.eurecom.fr (193.55.113.142)	132 ms	128 ms	136 ms	

* Do some traceroutes from exotic countries at www.traceroute.org

Packet loss

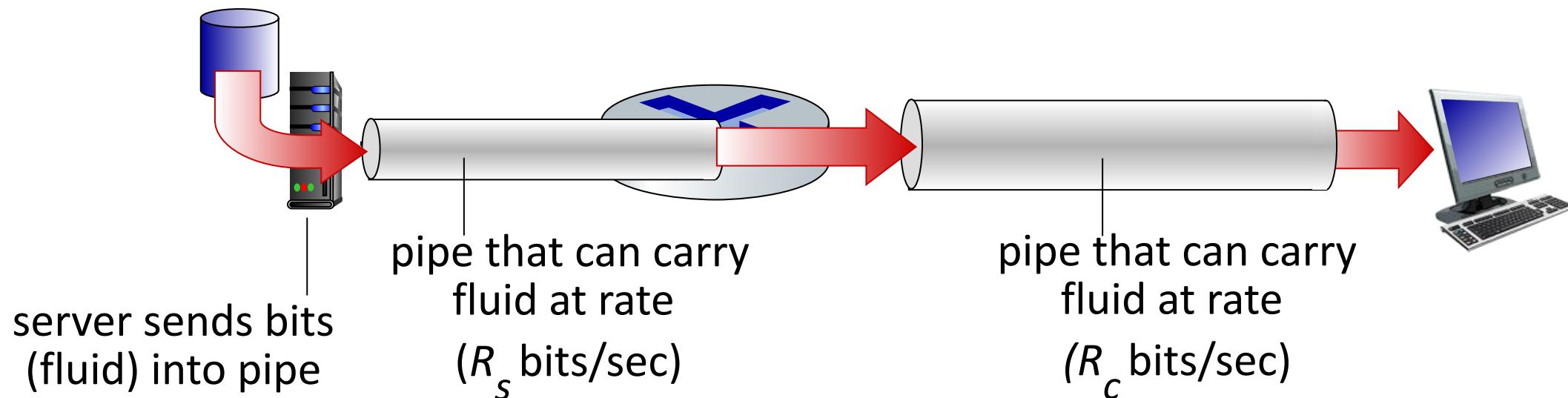
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



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

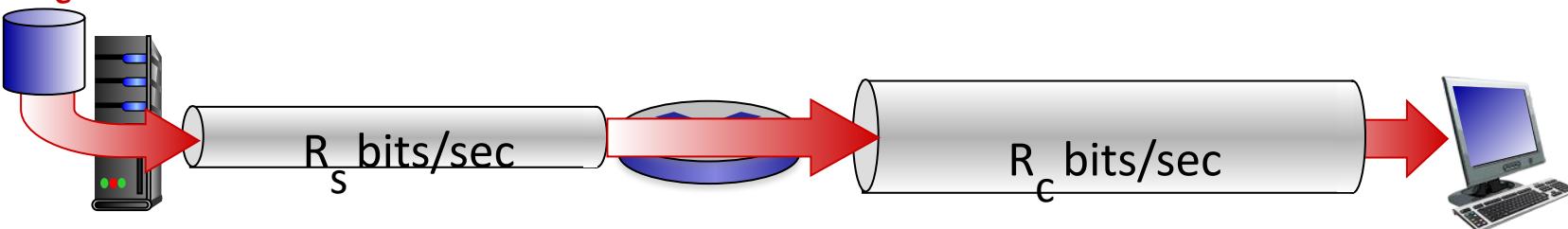
Throughput

- *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

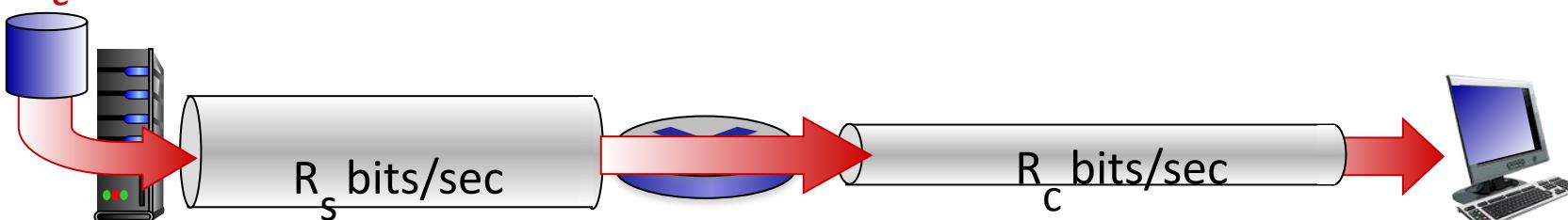


Throughput

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



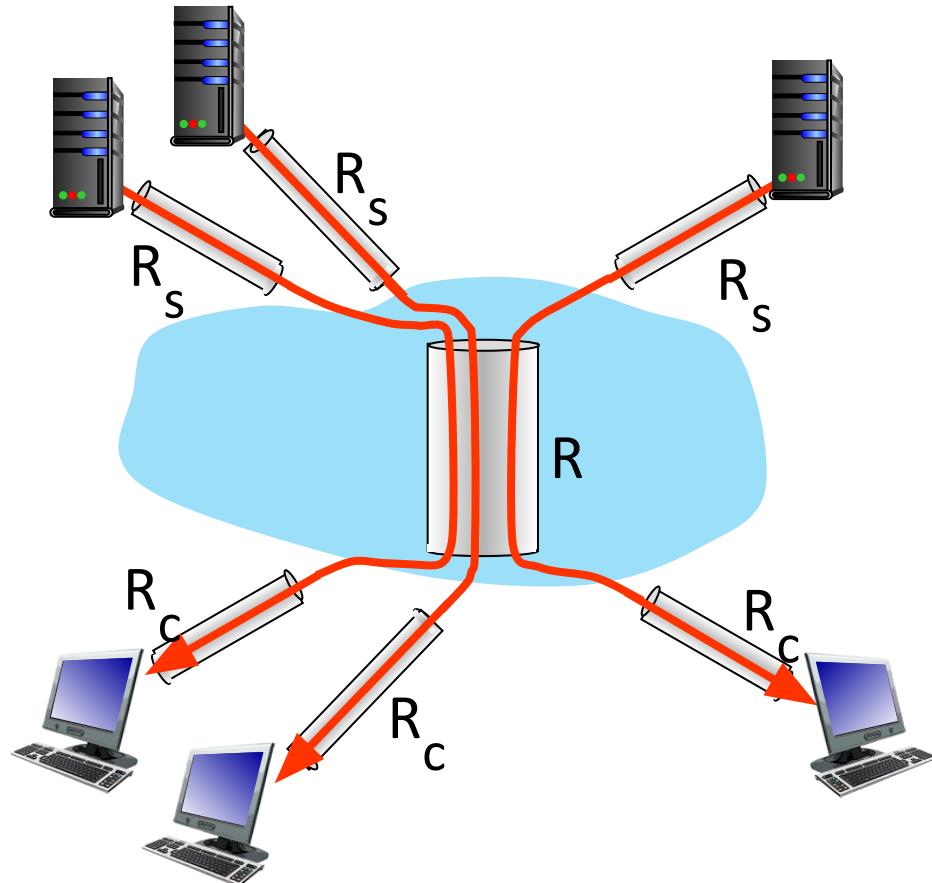
$R_s > R_c$ What is average end-end throughput?



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/

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



Protocol “layers” and reference models

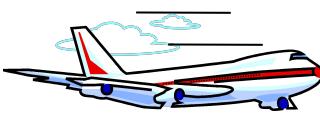
Networks are complex,
with many “pieces”:

- 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 (e.g., gate layer- loading and unloading)
- relying on services provided by layer below (e.g., takeoff/landing layer - runway-to-runway passenger transfer service)

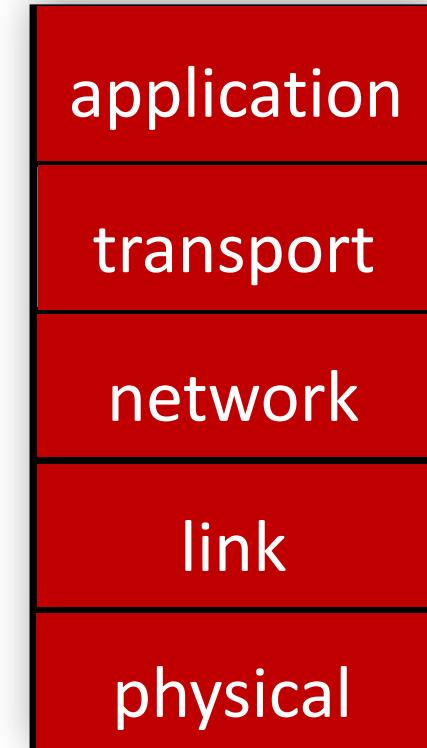
Why layering?

Approach to designing/discussing complex systems:

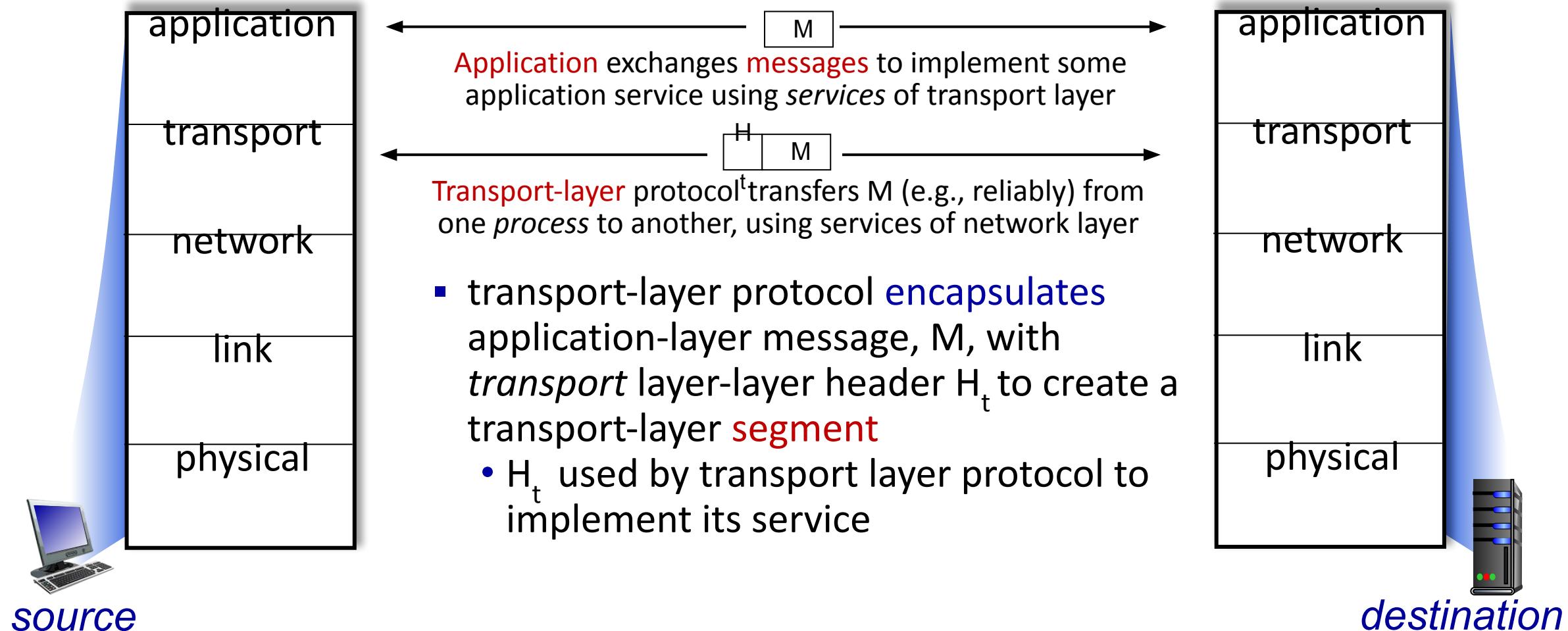
- explicit structure allows identification, relationship of system's pieces
 - layered *reference model* for discussion
- modularization eases maintenance, updating of system
 - change in layer's service *implementation*: transparent to rest of system
 - e.g., change in gate procedure doesn't affect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

Layered Internet protocol stack

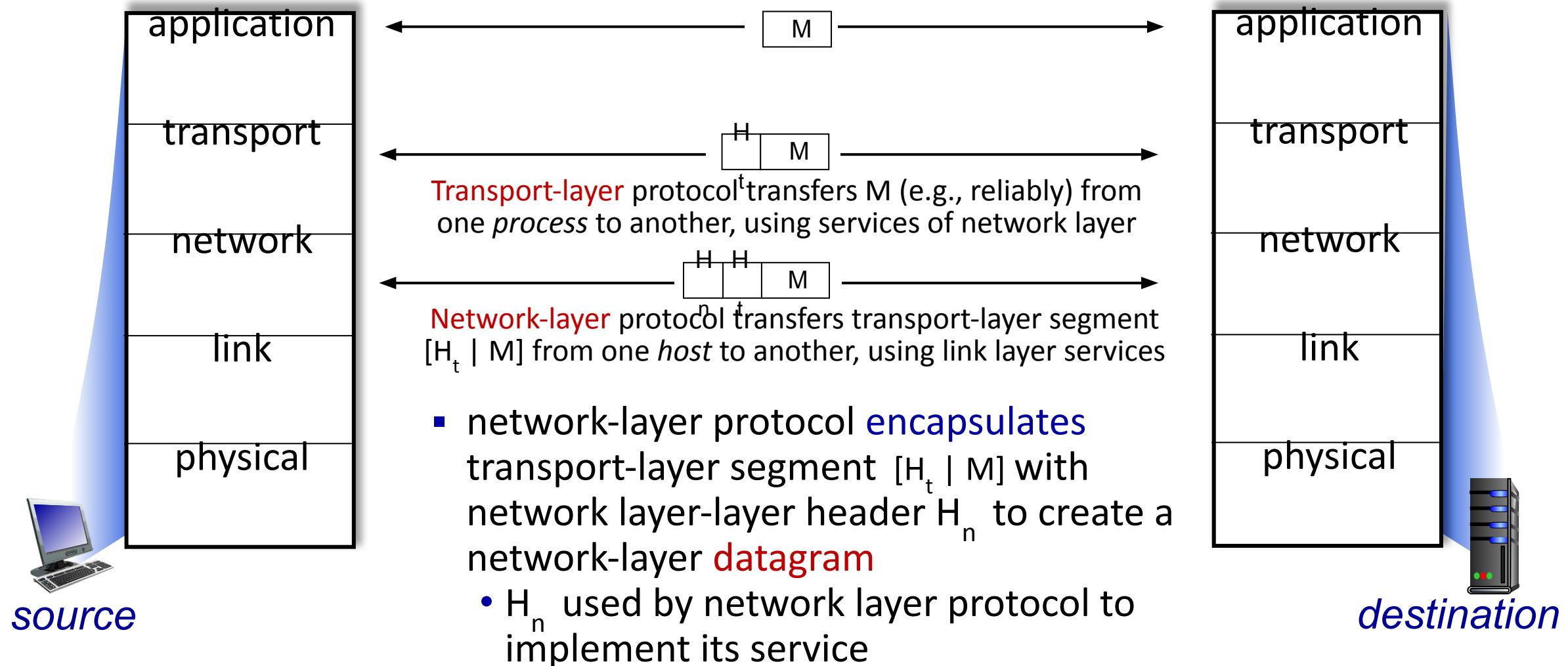
- ***application***: supporting network applications
 - HTTP, IMAP, SMTP, DNS
- ***transport***: process-process data transfer
 - TCP, UDP
- ***network***: routing of datagrams from source to destination
 - IP, routing protocols
- ***link***: data transfer between neighboring network elements
 - Ethernet,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



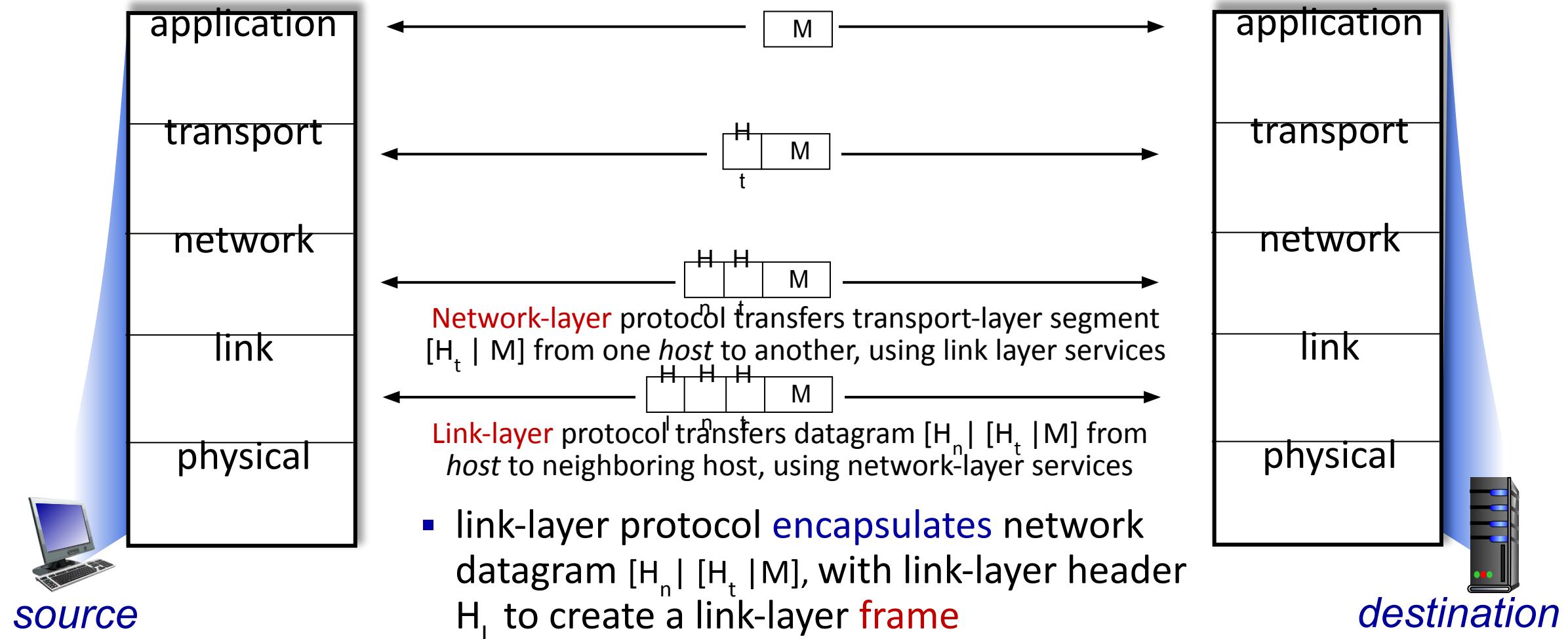
Services, Layering and Encapsulation



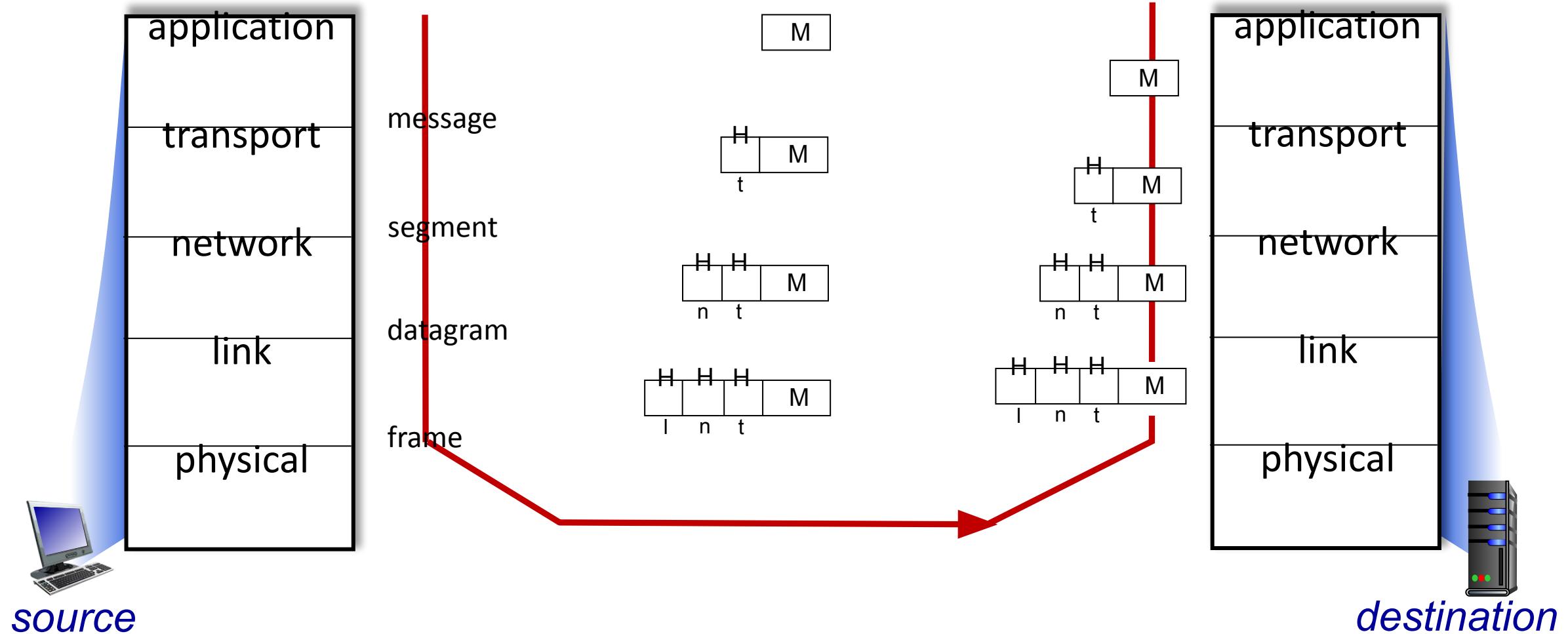
Services, Layering and Encapsulation



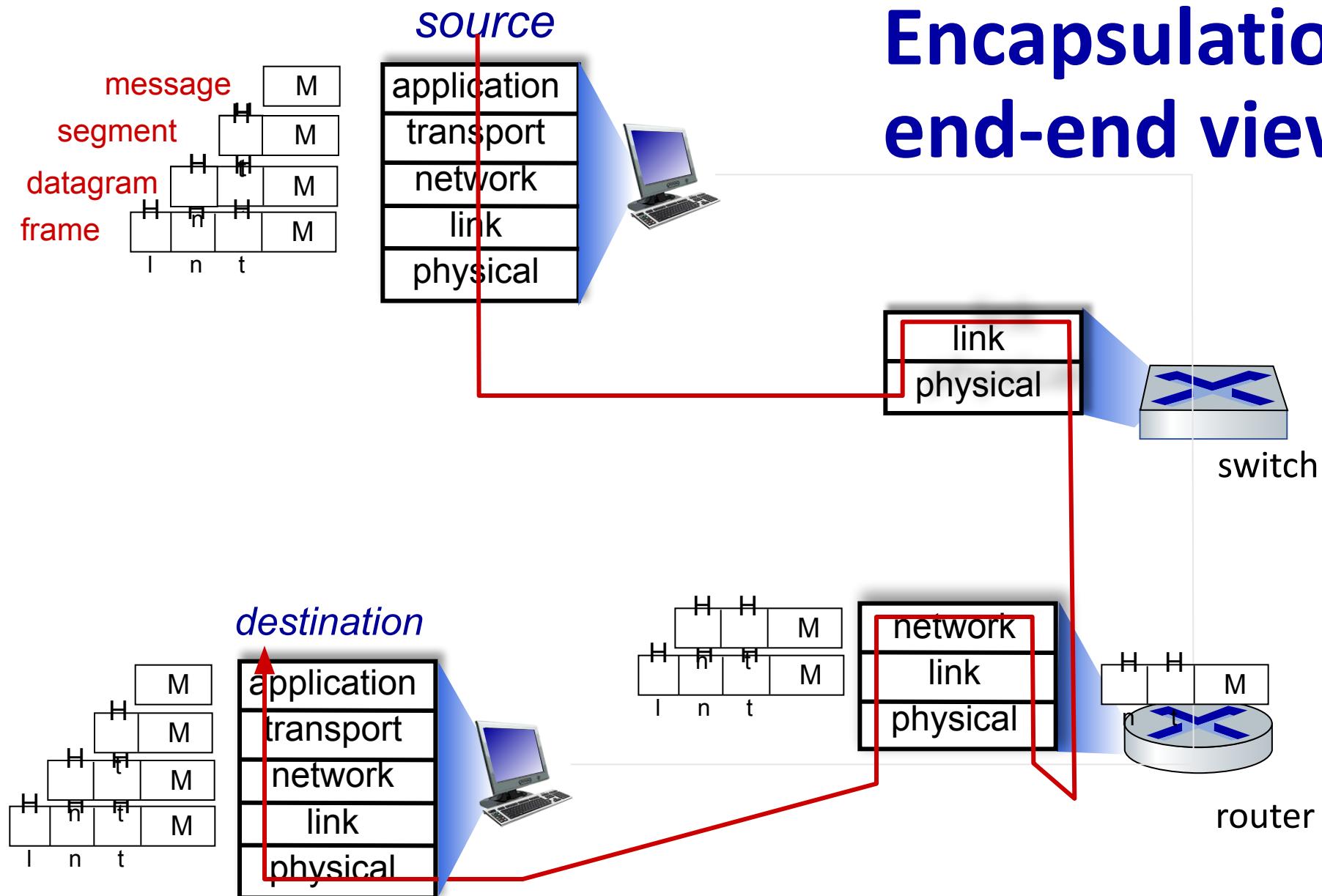
Services, Layering and Encapsulation



Services, Layering and Encapsulation



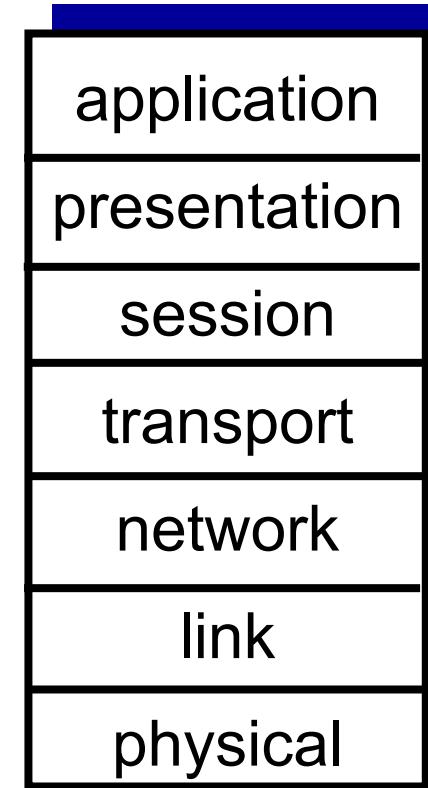
Encapsulation: an end-end view



ISO/OSI reference model

Two layers not found in Internet protocol stack!

- *presentation*: allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session*: synchronization, checkpointing, recovery of data exchange
- Internet stack “missing” these layers!
 - these services, *if needed*, must be implemented in application
 - needed?



The seven layer OSI/ISO reference model

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 (left for your specialization 😊)

You now have:

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

Some numerical Problems

1. Suppose that a user at a PC at one end of Canada sends a 1-Mbit file to a remote server on the other end over a data link operating at 64 kbps. Assume that we are using a fiber optic link with a propagation rate of the speed of light, approximately $3 * 10^8$ m/sec, and that the distance is 4800 km.
 - (a) What is the overall network delay, i.e. time to transmit the file?
(Ignore any processing or queueing delays.)

Some numerical Problems

$$d_{\text{total}} = d_{\text{propagation}} + d_{\text{transmission}}$$

$$d_{\text{propagation}} = \text{distance/speed} = 4800 * 10^3 / 3 * 10^8 = 0.016 \text{ seconds}$$

$$d_{\text{transmission}} = \text{length/rate} = 10^6 / 64 * 10^3 = 15.625 \text{ seconds}$$

Some numerical Problems

2. Suppose you are downloading an MP3 file of 64 MB, the server has a transmission rate of $R_s = 4 \text{ Mbps}$, and you have an access link of $R_c = 2 \text{ Mbps}$. What is the throughput ? What is the overall network delay, i.e. time to transmit the file? (Ignore any processing or queueing delays.)

$$\text{Throughput} = \min(R_s, R_c) = 2 \text{ Mbps}$$

$$\text{Time to transmit the file} = 64 * 8 / 2 = 256 \text{ seconds}$$

Some numerical Problems

3. What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4×10^8 m/s in cable.

$$\text{Propagation time} = 12000 * 1000 / 2.4 * 10^8 = 50 \text{ ms}$$

Some numerical Problems

4. What are the propagation time and the transmission time for a 2.5-kbyte message (an e-mail) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

$$\text{Propagation time} = 12000 * 1000 / 2.4 * 10^8 = 50 \text{ ms}$$

$$\text{Transmission time} = 2500 * 8 / 10^9 = 0.02 \text{ ms}$$

Message is short and the bandwidth is high, the dominant factor is the propagation time, not the transmission time. The transmission time can be ignored.

Some numerical Problems

5. What are the propagation time and the transmission time for a 5 MB image if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

$$\text{Propagation time} = 12000 * 1000 / 2.4 * 10^8 = 50 \text{ ms}$$

$$\text{Transmission time} = 5,000,000 * 8 / 10^6 = 40 \text{ s}$$

Message is long and the bandwidth is less, the dominant factor is the transmission time, not the propagation time. The propagation time can be ignored.