

# BİLGİSAYAR AĞLARI

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Bursa Uludağ Üniversitesi

Bilgisayar Mühendisliği Bölümü

# Ders Bilgileri

- Ofis: 111
- Gün ve Saati: Salı 09:40 – 12:00
- Sınıf: D101
- İletişim: [murtazacicioglu@uludag.edu.tr](mailto:murtazacicioglu@uludag.edu.tr)
- Ofis saatleri : Perşembe 10:00 – 11:00
- Dersin web sayfası : UKEY - Microsoft Teams
- Dersin Asistanı: Arş. Gör. Rabia KIRAN

# Ders Bilgileri

## ■ Değerlendirme:

- Quiz (UKEY), Ödevler → : %10
  - Proje → %15
  - Ara Sınav (Vize) → %15
  - Final Sınavı: %60
  - Derse Katılım (BONUS)
- 
- Geç Teslimler: Her geç gün için %10
  - En fazla iki gün geç göndermeler kabul edilir.

# Ders Bilgileri

## ■ Kaynaklar:

- Kurose j.F. – Ross K.W - Computer Networking: A Top-Down Approach – Pearson - [https://gaia.cs.umass.edu/kurose\\_ross/ppt.php](https://gaia.cs.umass.edu/kurose_ross/ppt.php)
- Andrew S. Tanenbaum, Nick Feamster, David Wetherall - Computer Networks\_ Global Edition-Pearson Education (2020)
- Bruce S. Davie, Larry L. Peterson, Computer Networks: A Systems Approach - <https://book.systemsapproach.org>

## ■ Yardımcı Kaynaklar

- William Stallings - Data and Computer Communications - Pearson
- Behrouz A. Forouzan - Data.Communications.and.Network.5e
- CISCO : Introduction to Networks – CCNA
- HUAWEI : Data Communication and Network Technology

# **SORULAR???**

# Dersin amacı

- Bilgisayar ağları ile ilgili temel kavramlar
- Ağların tarihçesini, ağ türlerini, fiziksel veri iletişim ortamında kullanılan medyayı, iletişim protokollerini, protokollerin sınıflandırılmasını, katmanlı mimari, ağ mimarisi ve Open System Interconnection (OSI) referans modelini açıklayabilme,
- TCP/IP referans modelini, TCP/IP referans modelindeki fonksiyonları ve protokoller, IP adres sistemini çözümleyebilme ve TCP/IP referans modelindeki diğer protokoller

# İçerik

## ■ Konular

- Computer Networks and The Internet
- The Application Layer
- The Transport Layer
- The Network Layer: the Data Plane
- The Network Layer: the Control Plane
- The Link Layer

## ■ Araçlar

- Wireshark
- Packet tracer
- Mininet

# 2024 CrowdStrike – 19/07/2024



# Pager – Call Device 17/09/2024



# Chapter 1: introduction

## *Chapter goal:*

- Get “feel,” “big picture,” introduction to terminology
  - more depth, detail *later* in course
- Approach:
  - use Internet as example



## *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
- Security
- Protocol layers, service models
- 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)

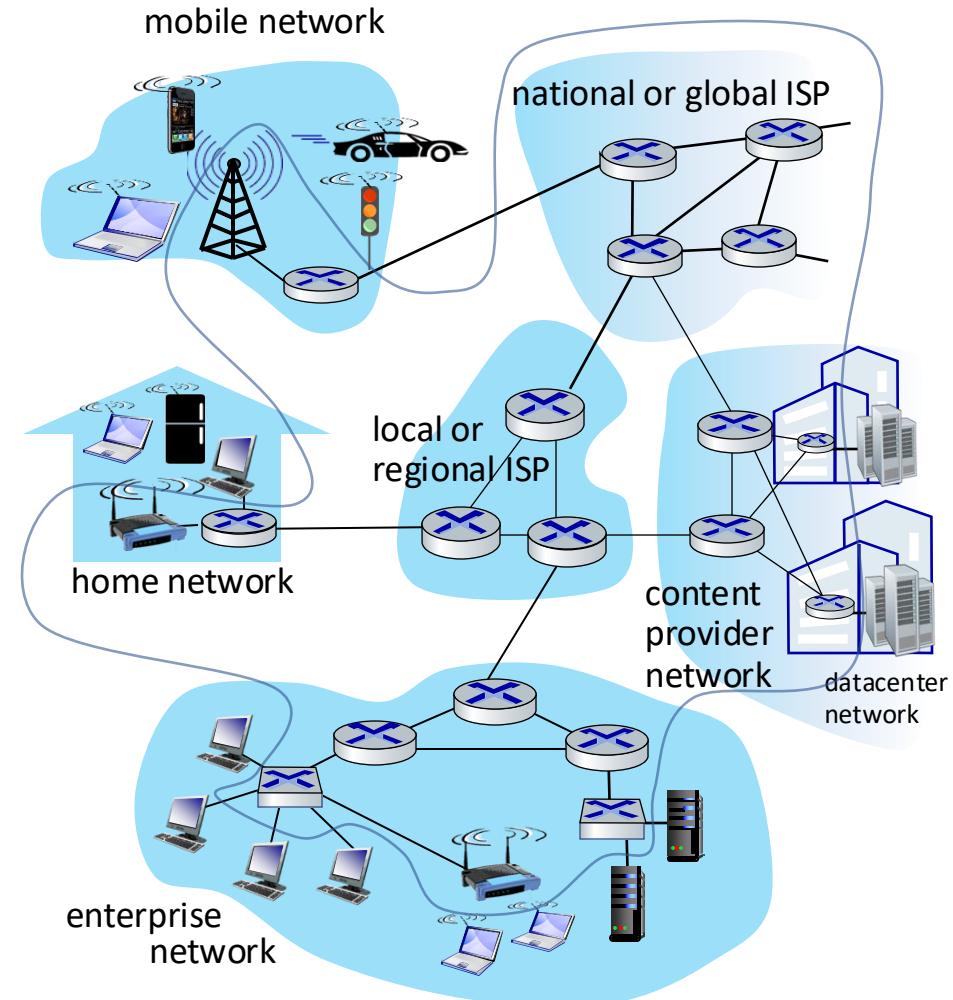
- routers, switches

*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



IP picture frame



Slingbox: remote control cable TV



Pacemaker & Monitor



Tweet-a-watt:  
monitor energy use



Web-enabled toaster +  
weather forecaster



AR devices

Internet phones



sensorized,  
bed  
mattress

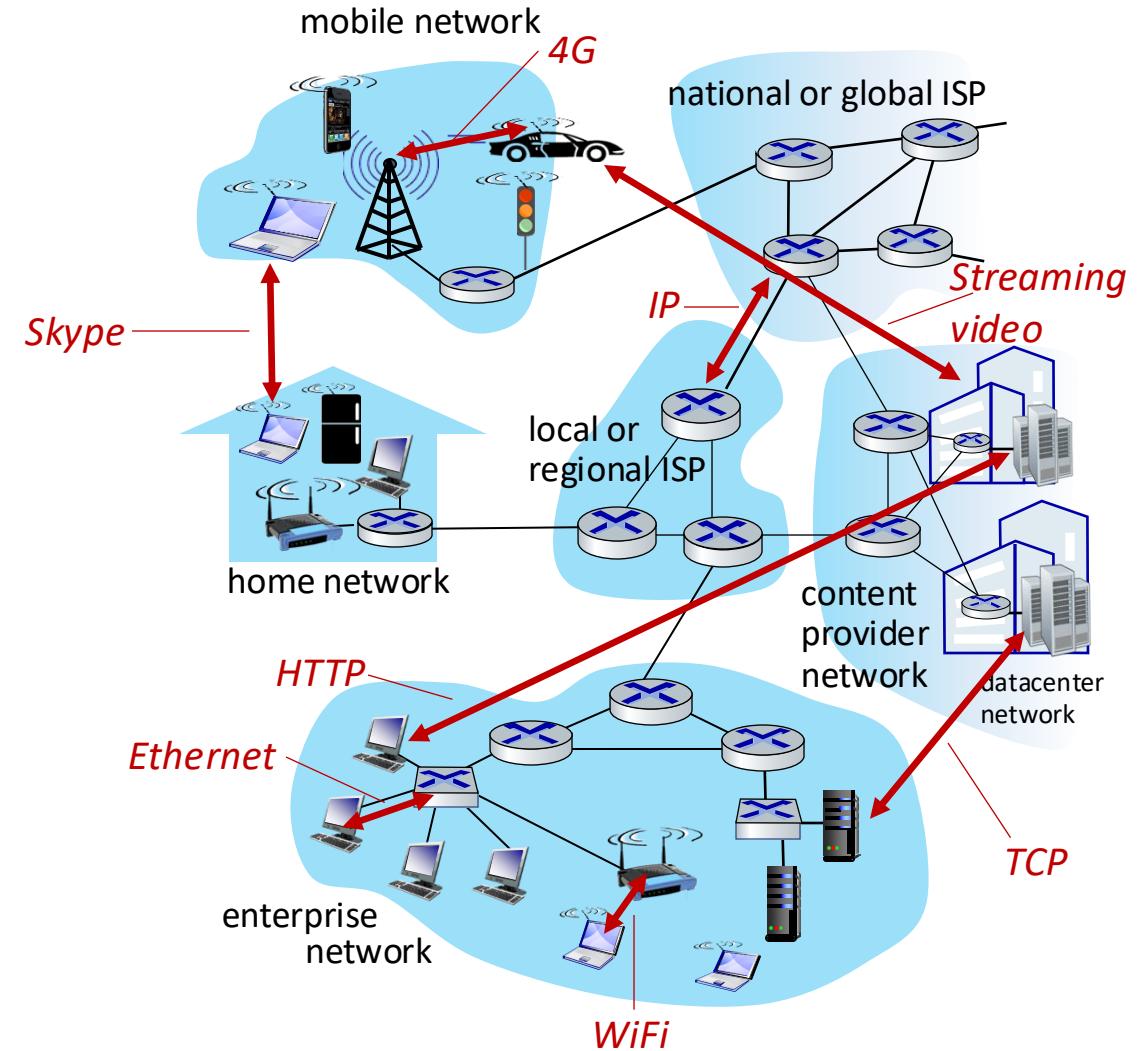


Fitbit

*Others?*

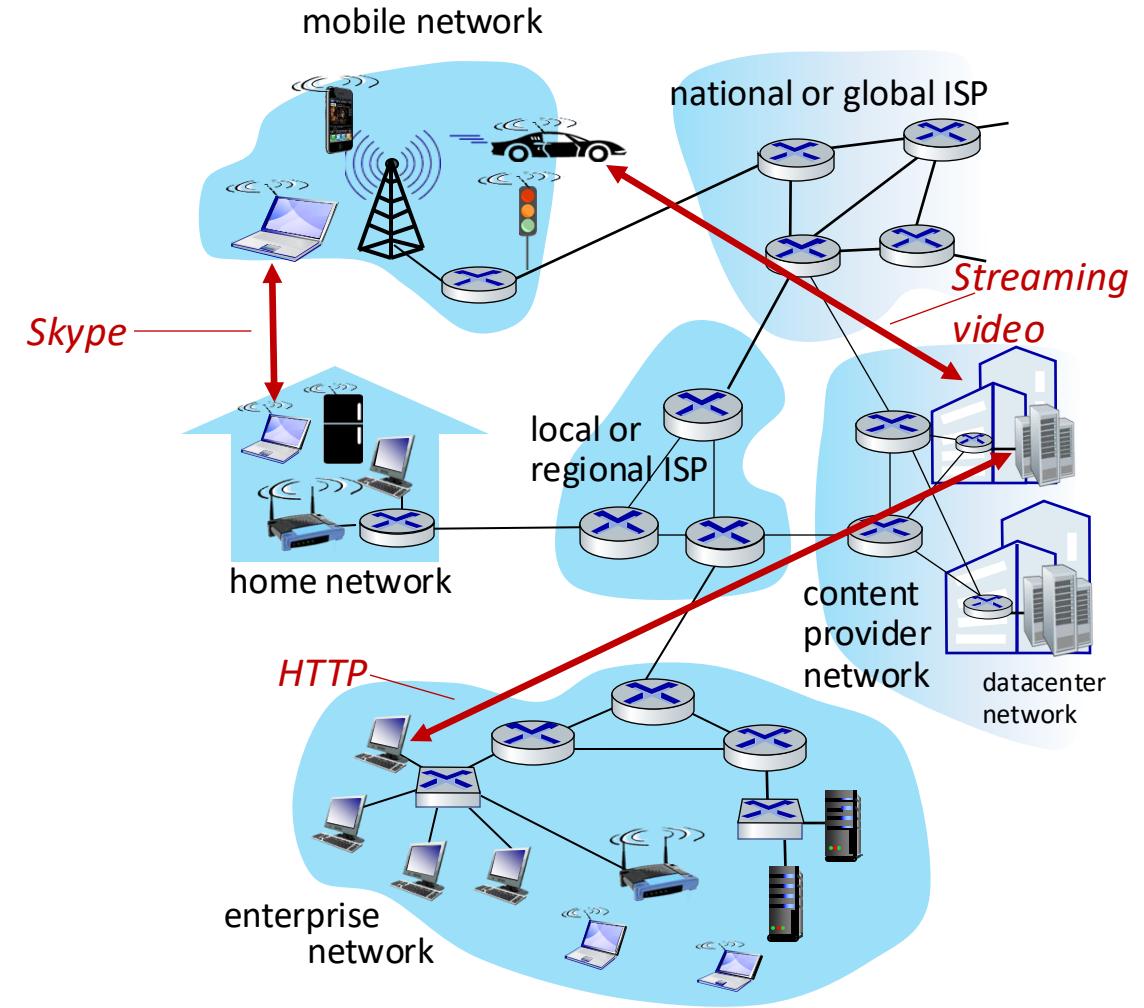
# The Internet: a “nuts and bolts” view

- *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 “service” 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

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

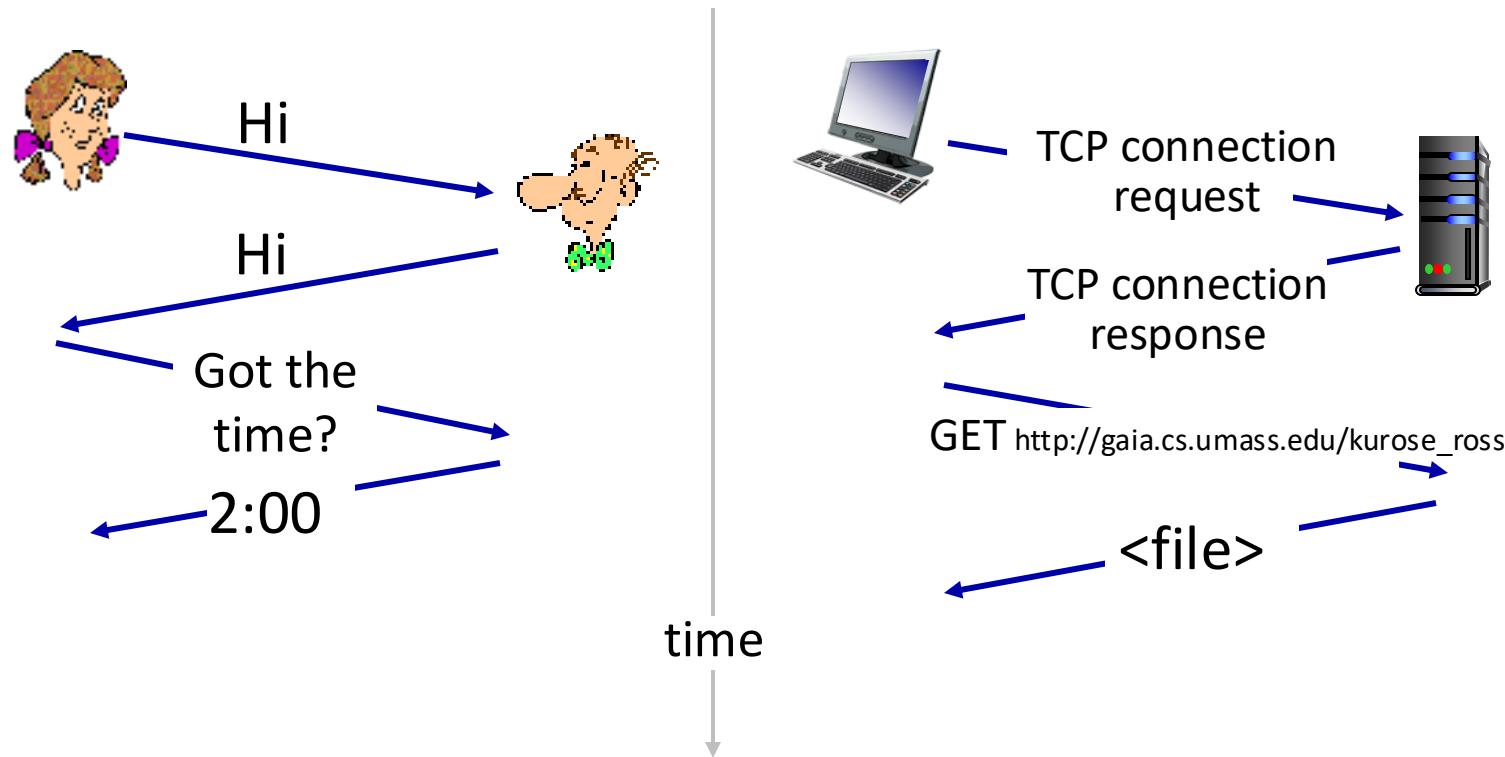
## *Network protocols:*

- 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 msg transmission, receipt*

# What's a protocol?

A human protocol and a computer network protocol:



*Q:* other human protocols?

# Chapter 1: roadmap

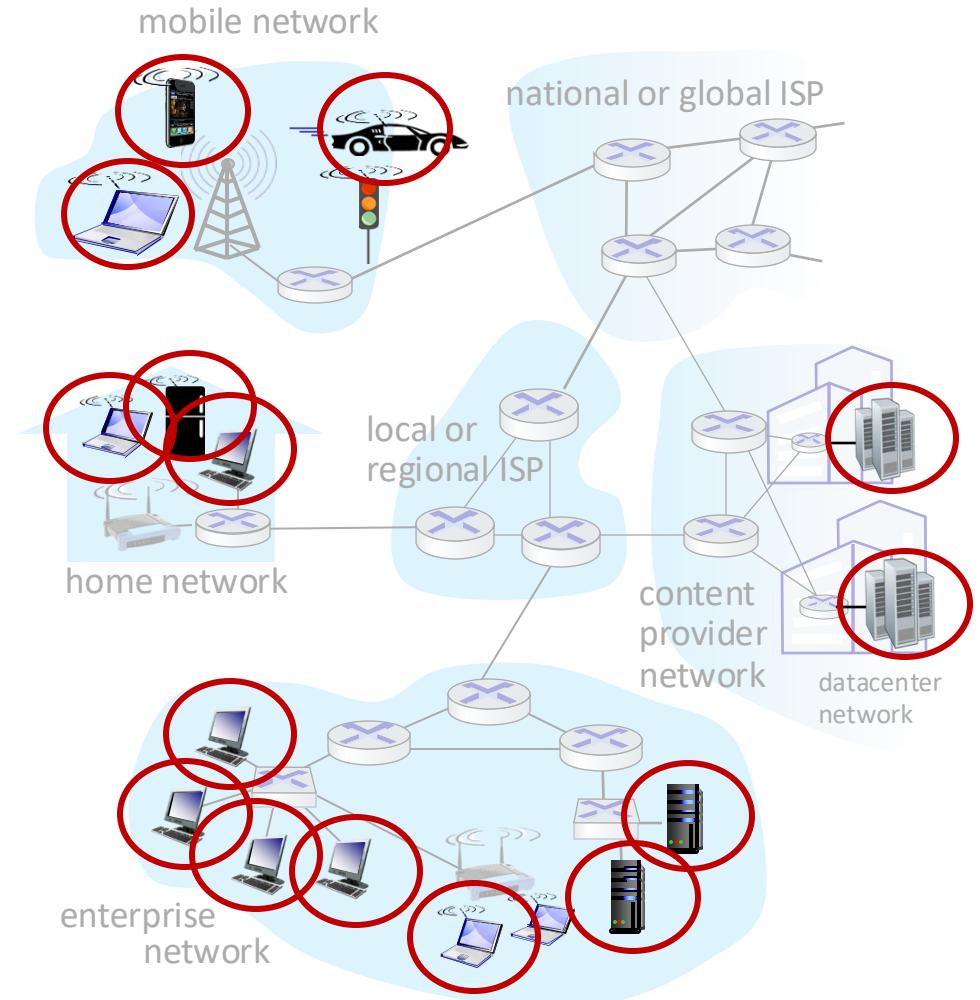
- What *is* the Internet?
- What *is* a protocol?
- **Network edge:** hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
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# A closer look at Internet structure

## Network edge:

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



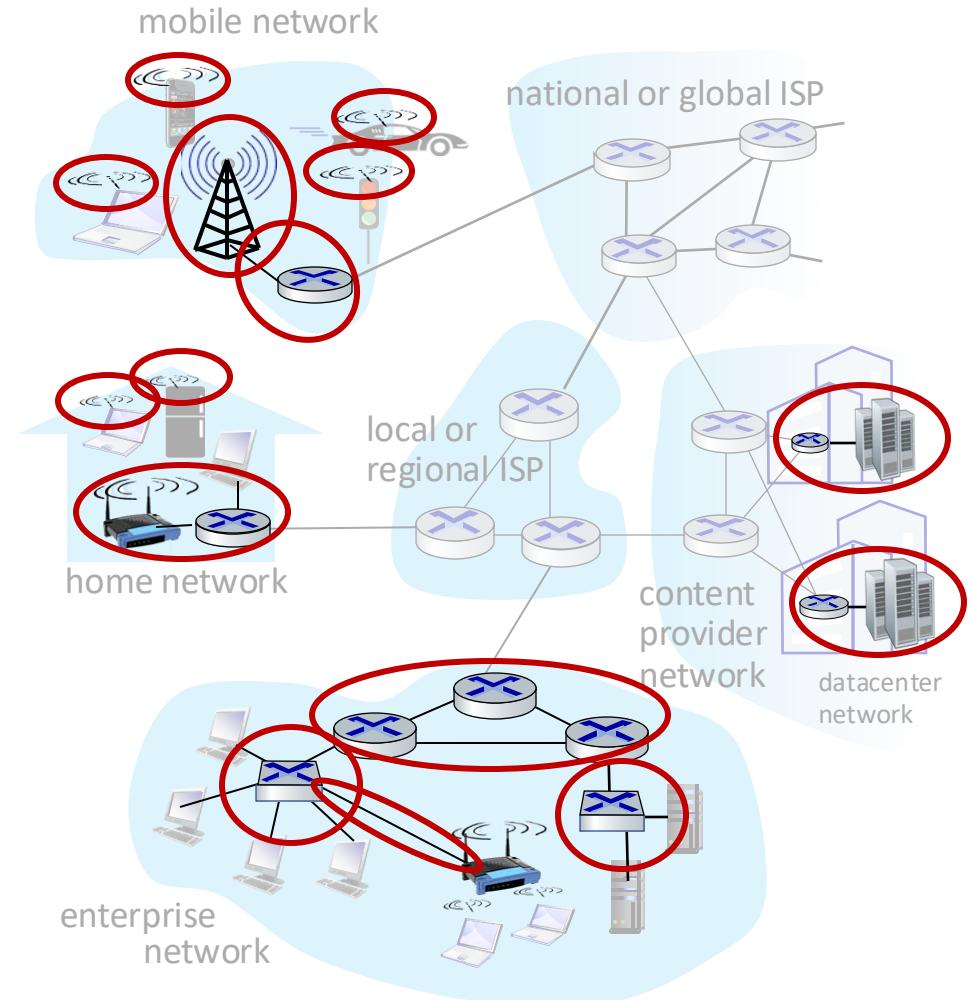
# A closer look at Internet structure

## Network edge:

- hosts: clients and servers
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## Access networks, physical media:

- wired, wireless communication links



# A closer look at Internet structure

## Network edge:

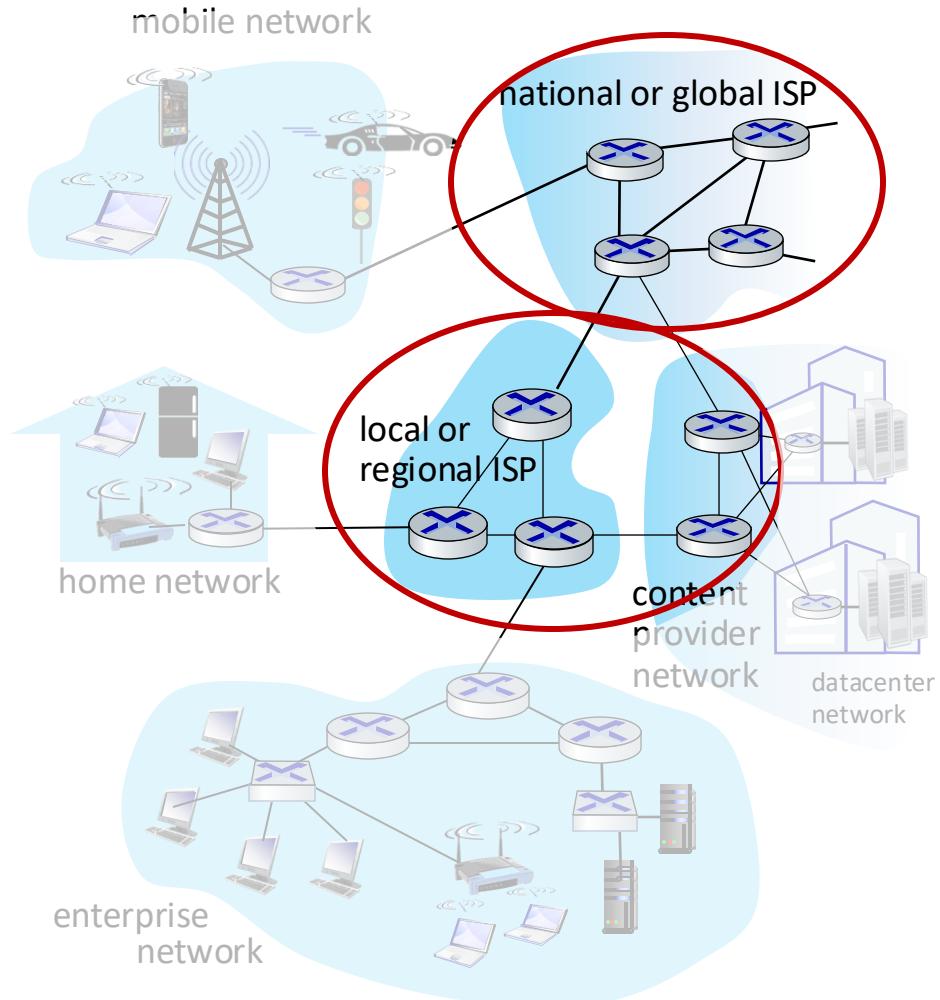
- hosts: clients and servers
- servers often in data centers

## Access networks, physical media:

- wired, wireless communication links

## Network core:

- interconnected routers
- network of networks



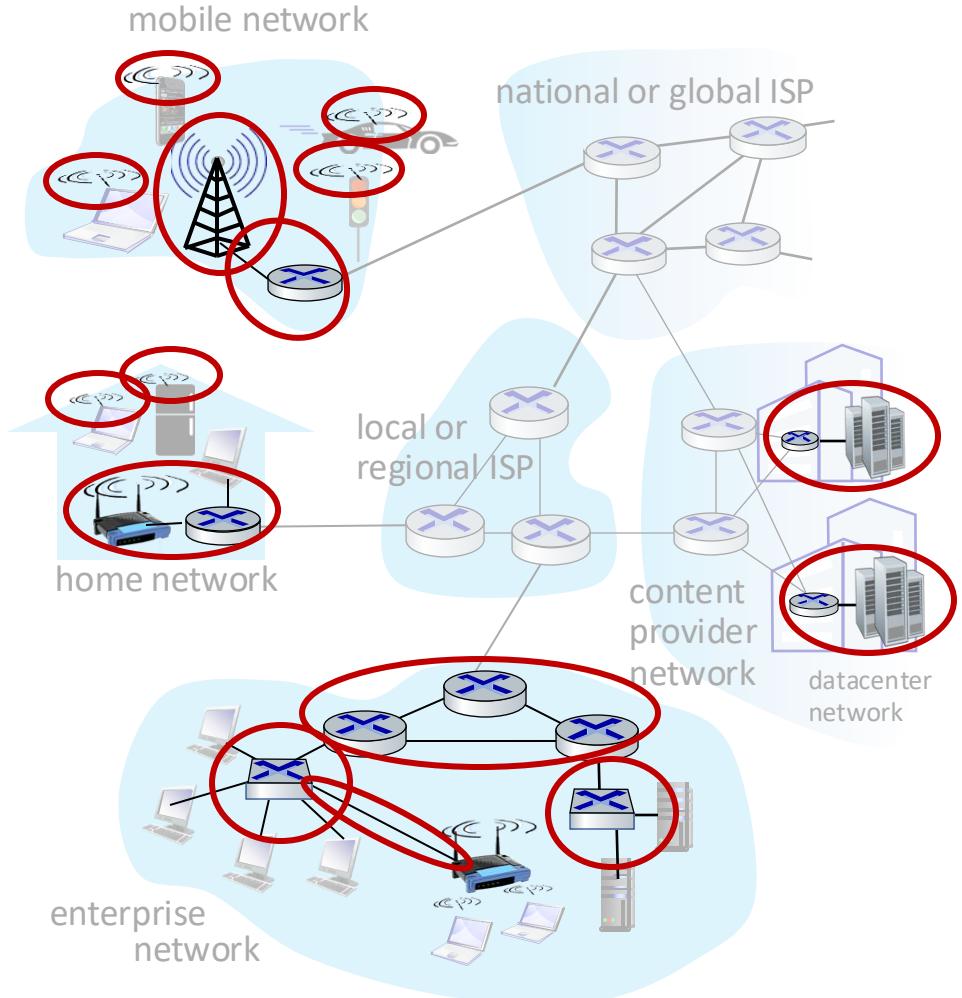
# Access networks and physical media

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

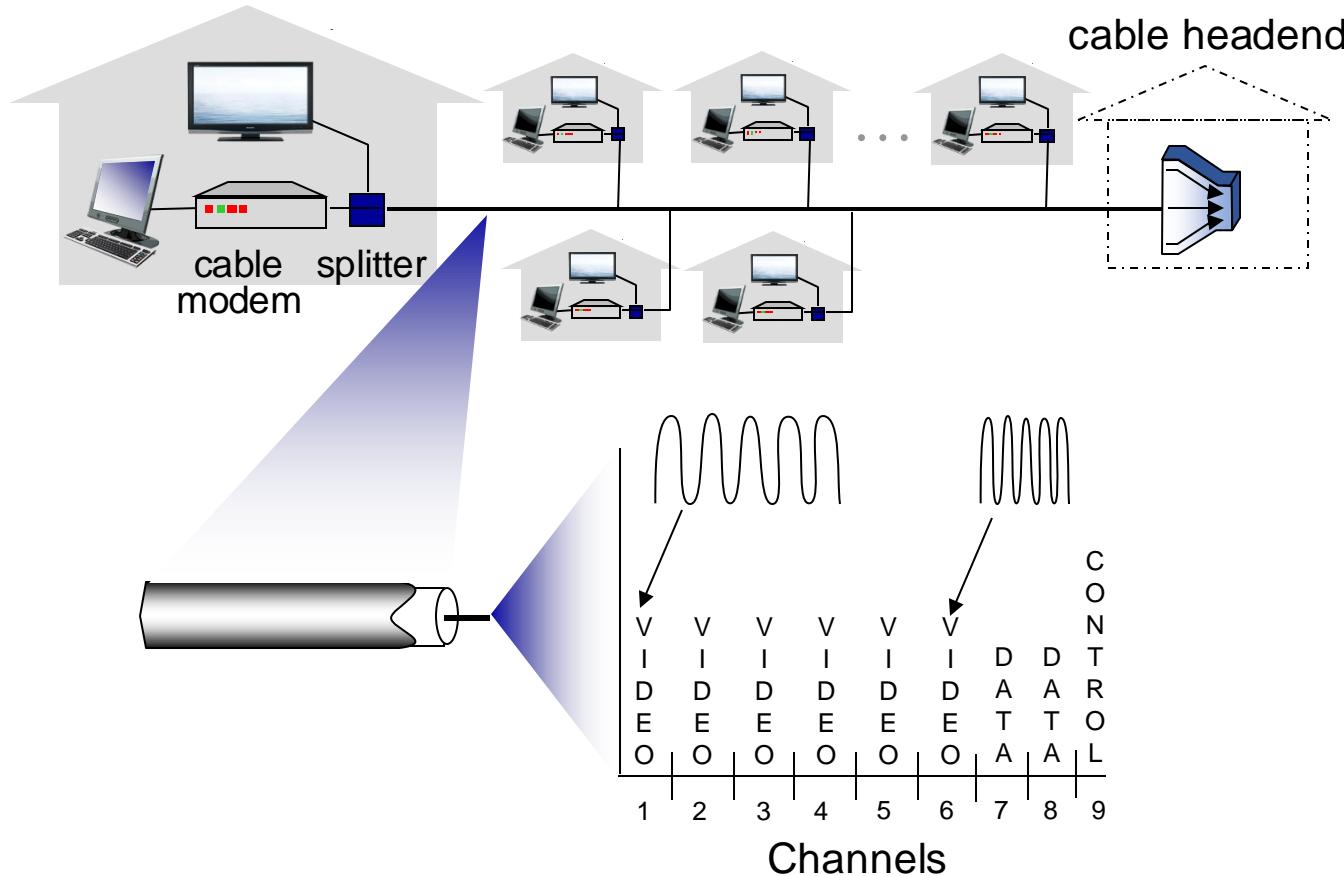
- residential access nets
- institutional access networks (school, company)
- mobile access networks (WiFi, 4G/5G)

*What to look for:*

- transmission rate (bits per second) of access network?
- shared or dedicated access among users?

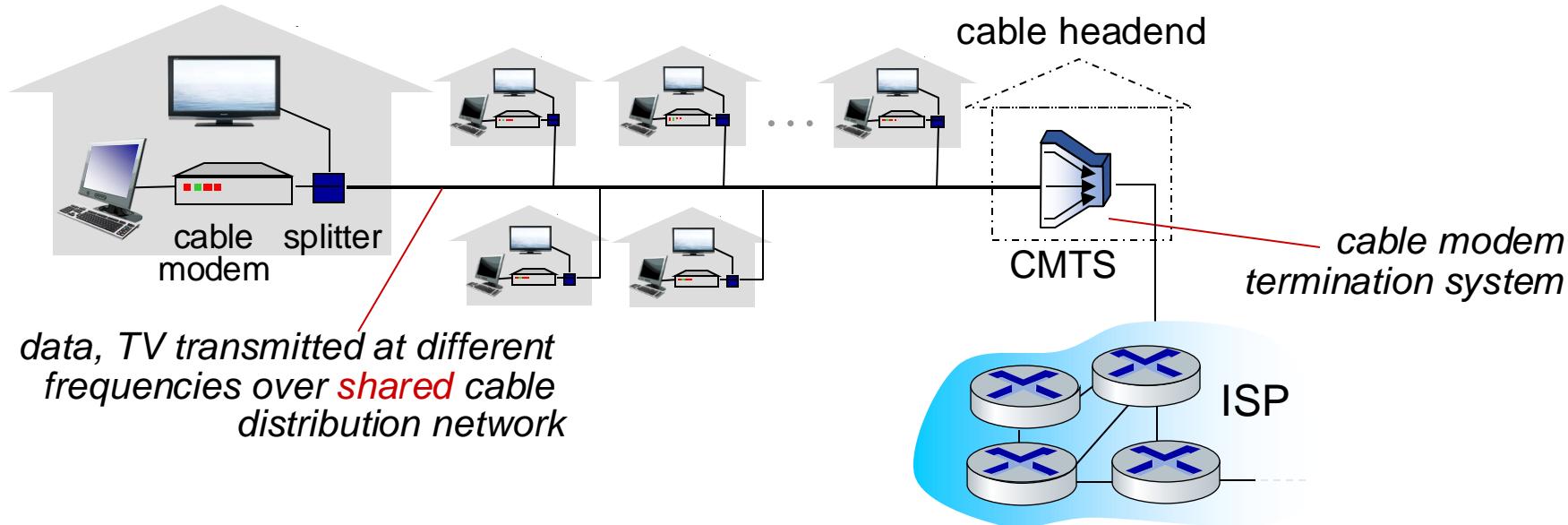


# Access networks: cable-based access



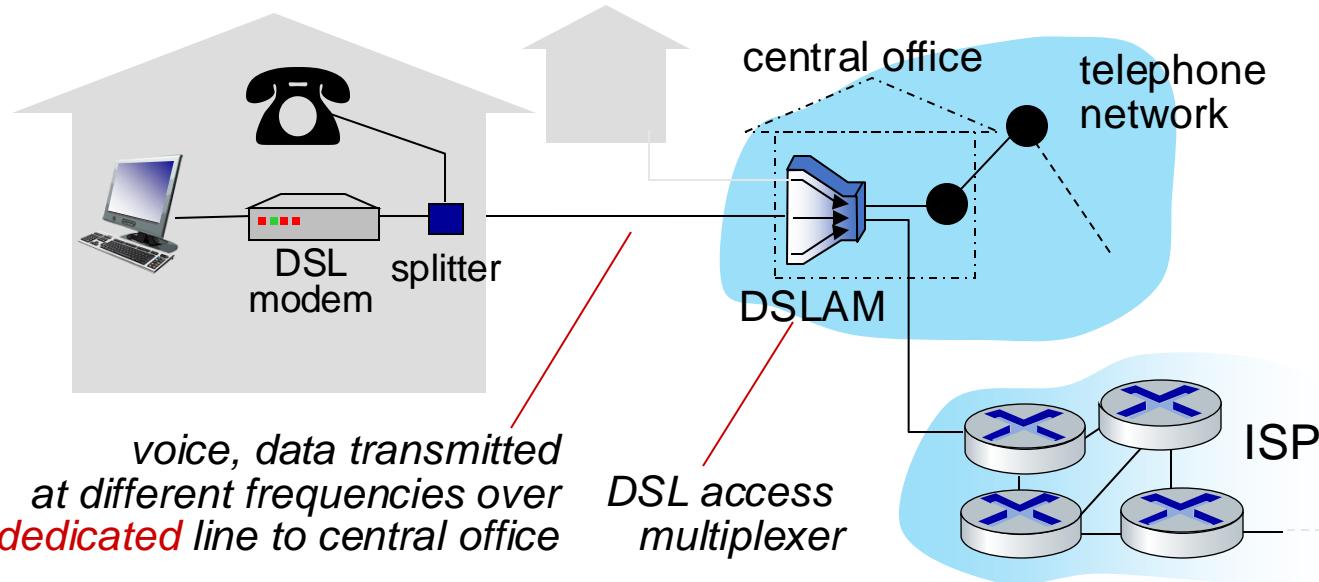
*frequency division multiplexing (FDM):* different channels transmitted in different frequency bands

# Access networks: cable-based access



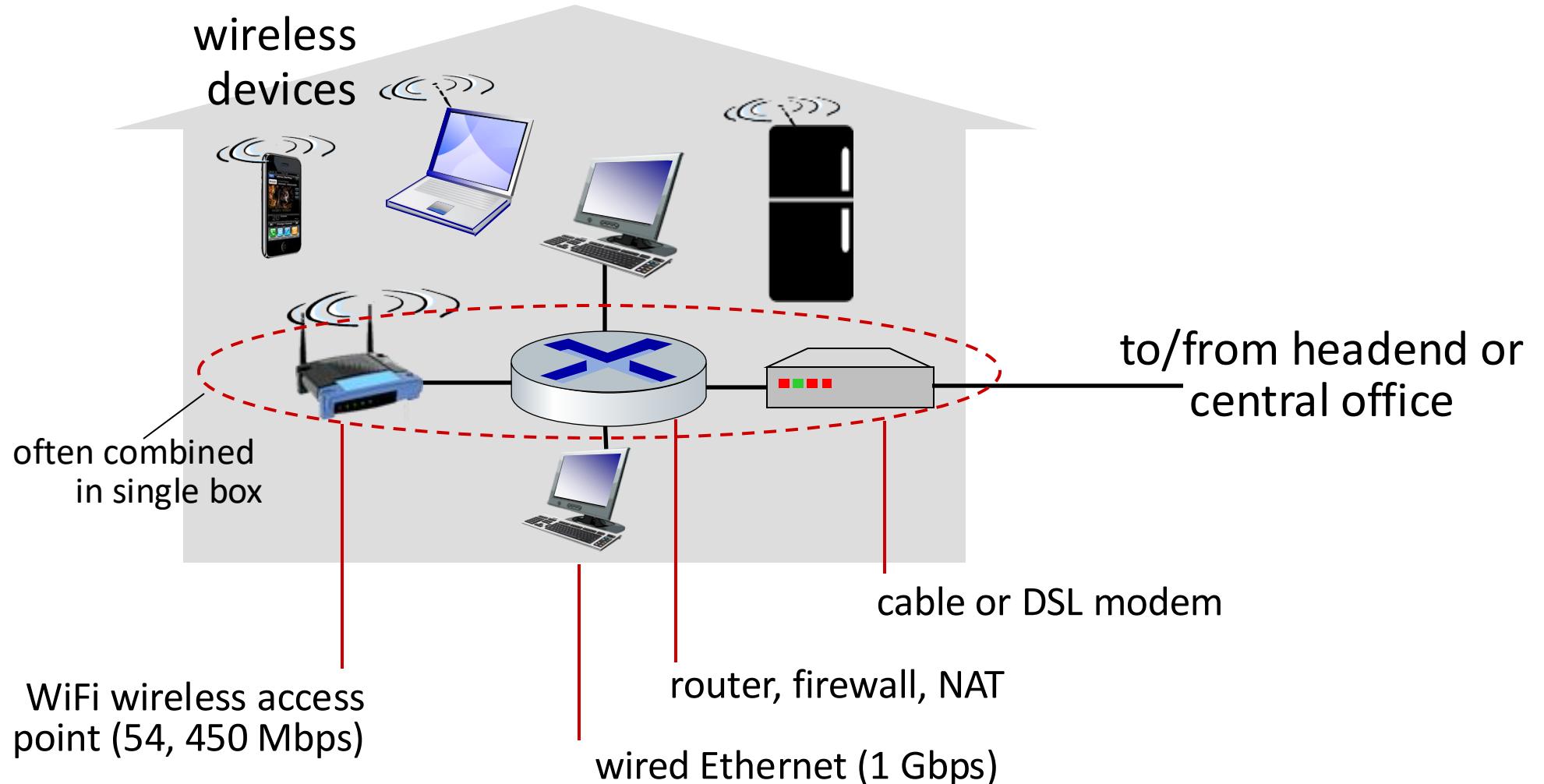
- HFC: hybrid fiber coax
  - asymmetric: up to 40 Mbps – 1.2 Gbs downstream transmission rate, 30-100 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes **share access network** to cable headend

# 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



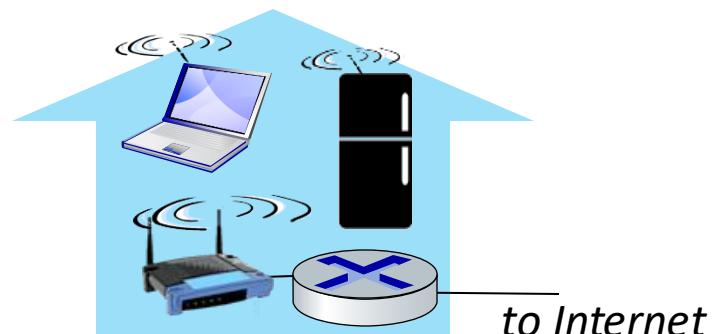
# Wireless access networks

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)



# Wireless access networks

Generation	IEEE standard	Adopted	Maximum link rate (Mbit/s)	Radio frequency (GHz)
Wi-Fi 7	<a href="#">802.11be</a>	(2024)	1376 to 46120	2.4/5/6
Wi-Fi 6E	802.11ax	2020	574 to 9608 <sup>[3]</sup>	6 <sup>[a]</sup>
Wi-Fi 6		2019		2.4/5
Wi-Fi 5	802.11ac	2014	433 to 6933	5 <sup>[b]</sup>
Wi-Fi 4	802.11n	2008	72 to 600	2.4/5
(Wi-Fi 3)*	802.11g	2003	6 to 54	2.4
	802.11a	1999		5
(Wi-Fi 2)*	802.11b	1999	1 to 11	2.4
(Wi-Fi 1)*	802.11	1997	1 to 2	2.4

\*Wi-Fi 1, 2, and 3 are by retroactive inference [\[4\]](#)[\[5\]](#)[\[6\]](#)[\[7\]](#)[\[8\]](#)

## Key Wi-Fi 7 Features\*



User Experience Data Rate



Spectrum Efficiency



Network Energy Efficiency



Connection Density

## Key Enhancements

320 MHz channels  
4096-QAM  
16 spatial streams

Multi-link operation  
Multi-AP operation  
Deterministic low latency

Multi-RU (puncturing)



Peak Data Rate



Cost Effective



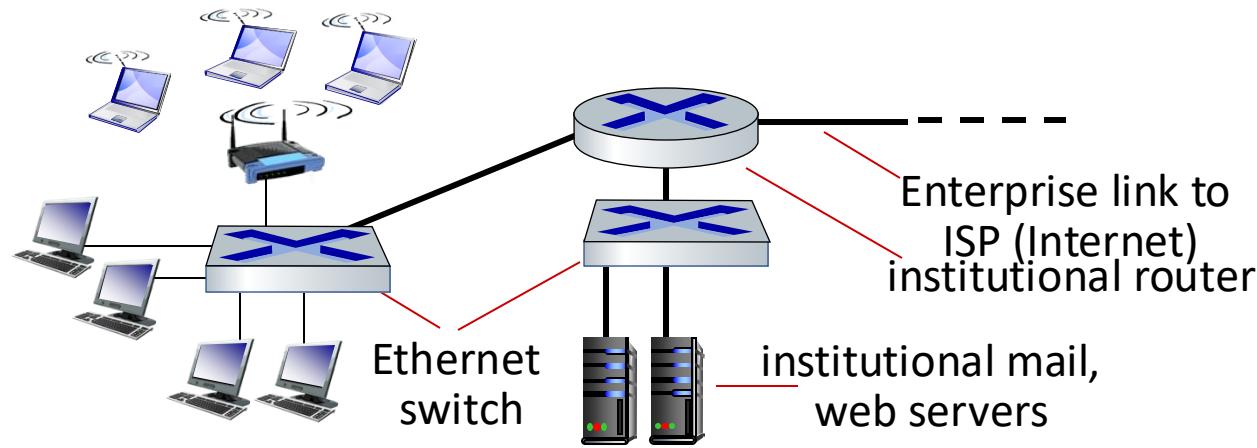
Area Capacity



Low Latency

\* Accurate as of June/2020. Feature set and their specification are subject to change.

# Access networks: enterprise networks



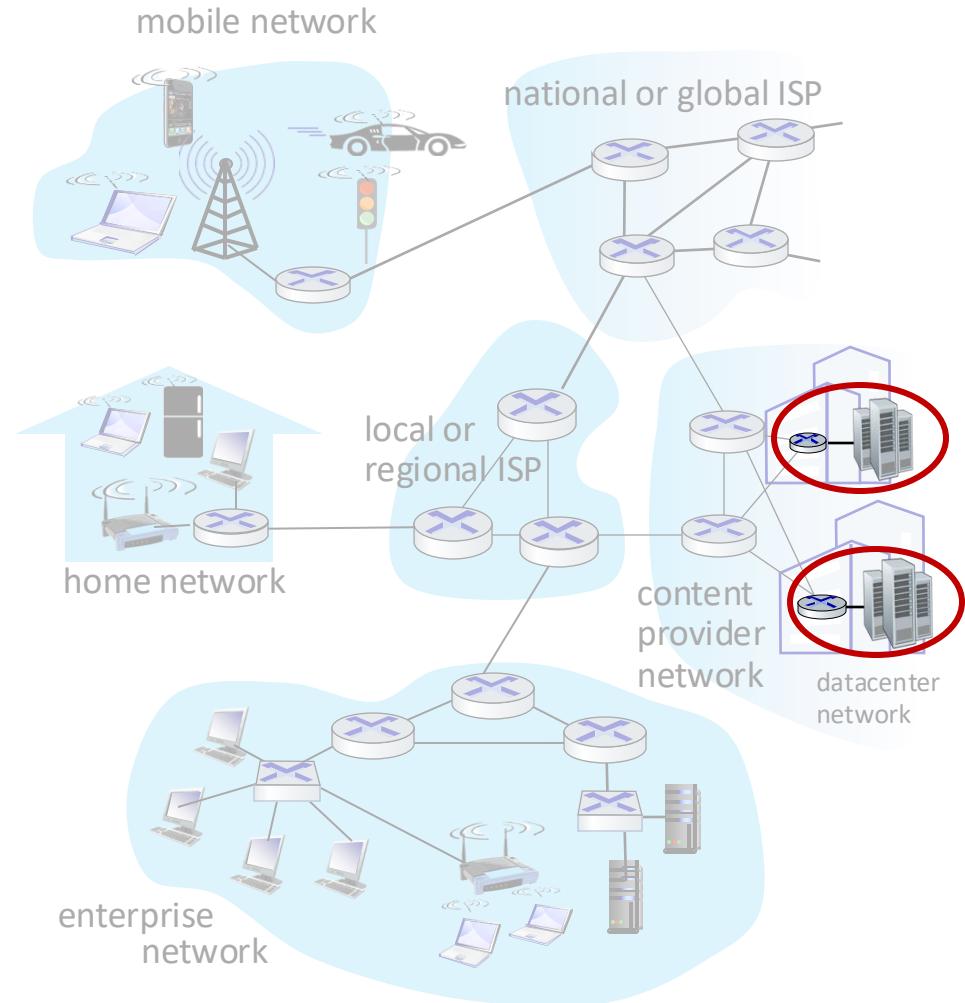
- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
  - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
  - WiFi: wireless access points at 11, 54, 450 Mbps

# Access networks: data center networks

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



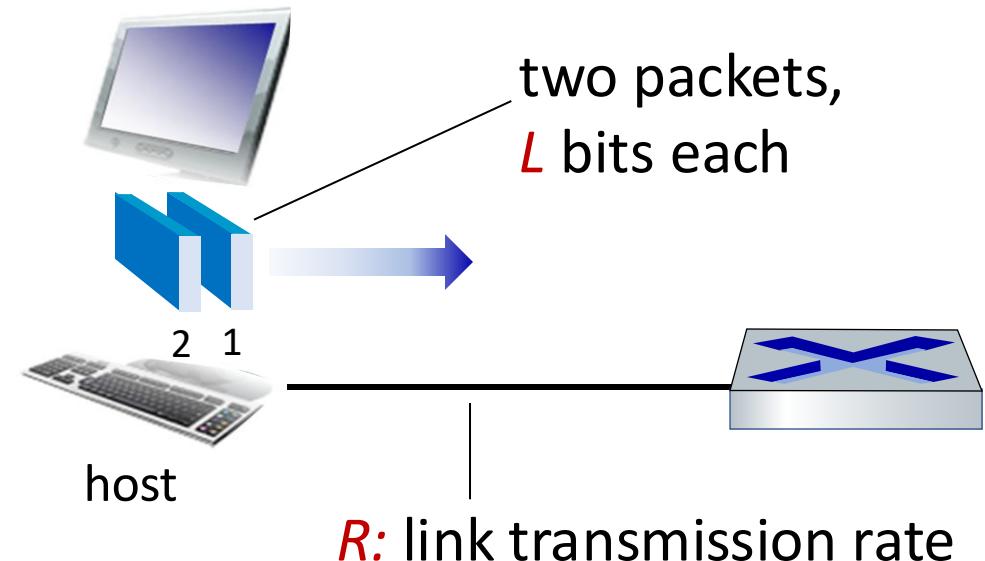
Courtesy: Massachusetts Green High Performance Computing Center ([mghpcc.org](http://mghpcc.org))



# 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*



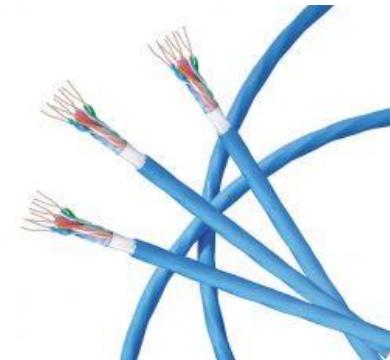
$$\text{packet transmission delay} = \frac{\text{time needed to transmit } L\text{-bit packet into link}}{R \text{ (bits/sec)}}$$

# Links: physical media

- **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

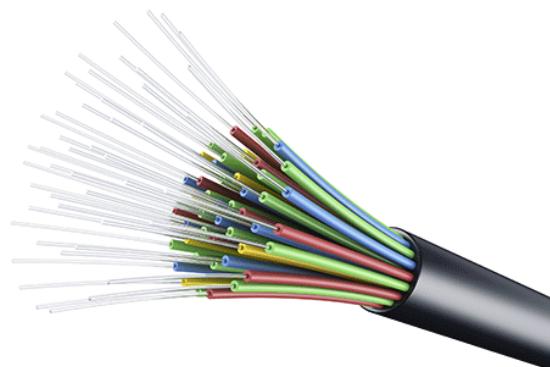
## Coaxial cable:

- 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

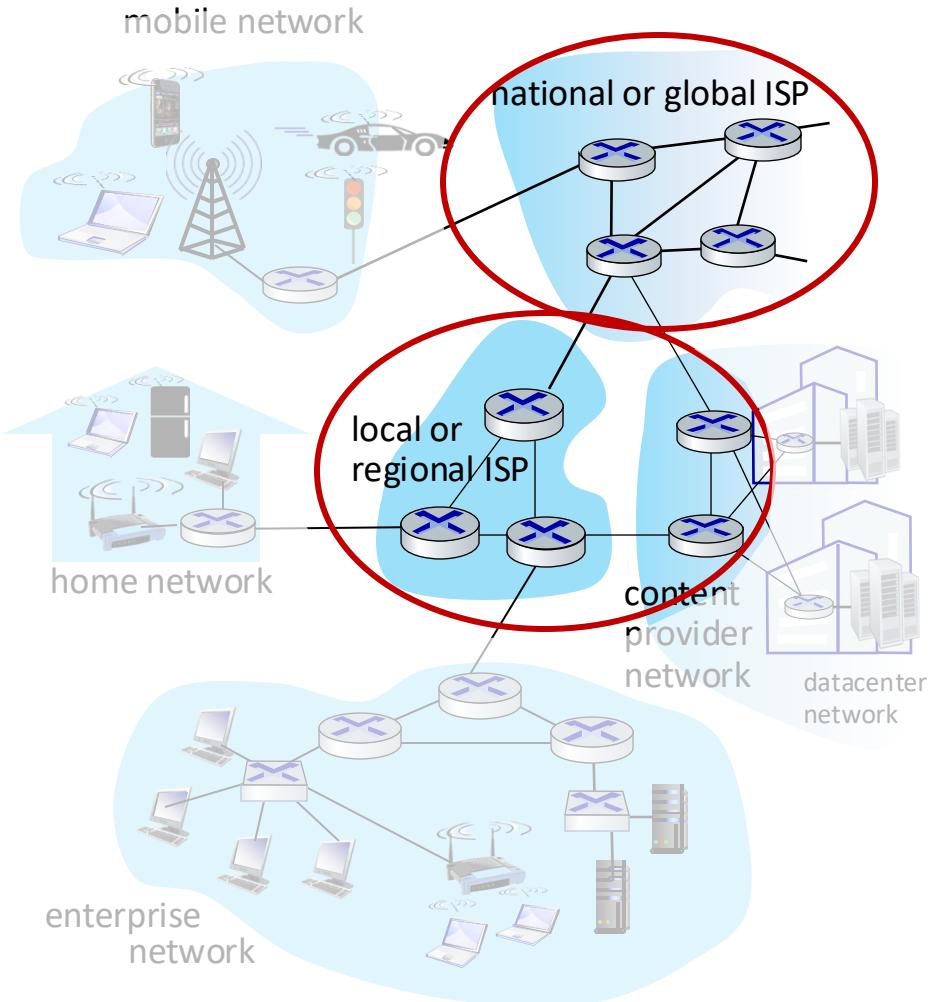
# Chapter 1: roadmap

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# The network core

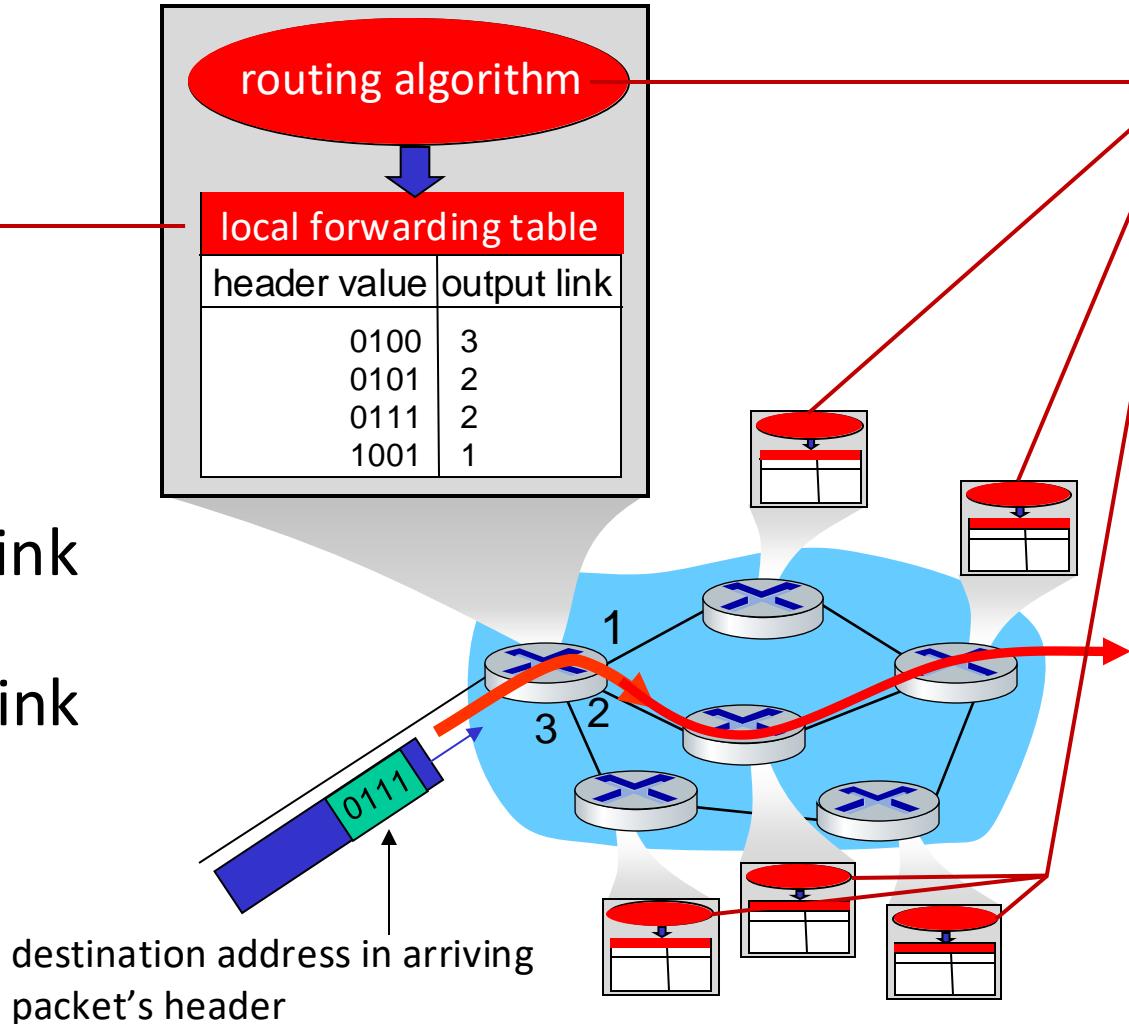
- mesh of interconnected routers
- **packet-switching:** hosts break application-layer messages into *packets*
  - forward packets from one router to the next, across links on path from **source to destination**
  - each packet transmitted at full link capacity



# Two key network-core functions

*Forwarding:* \_\_\_\_\_

- *local* action:  
move arriving  
packets from  
router's input link  
to appropriate  
router output link

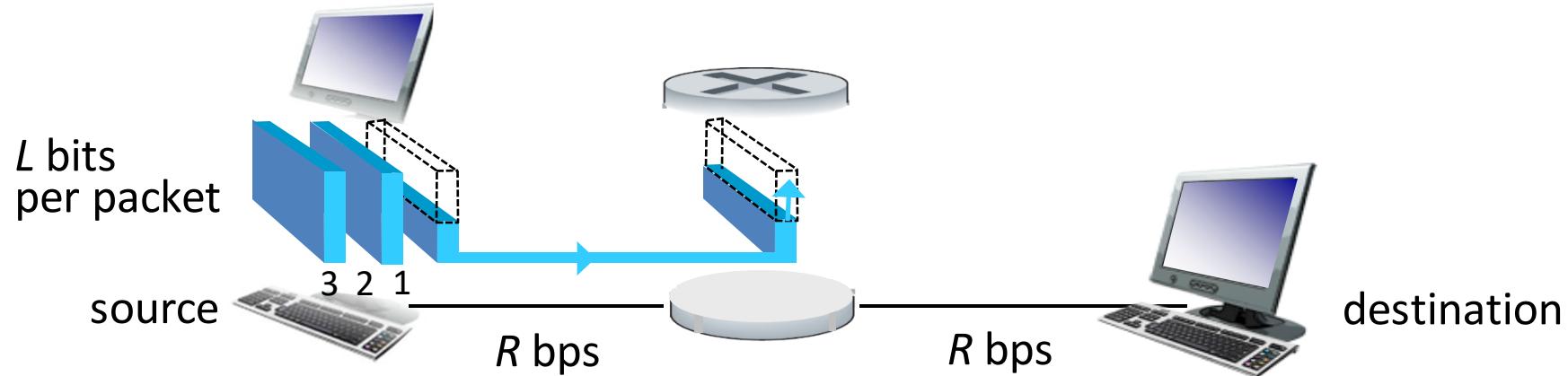


- Routing:*
- *global* action:  
determine source-destination paths taken by packets
  - routing algorithms





# Packet-switching: store-and-forward

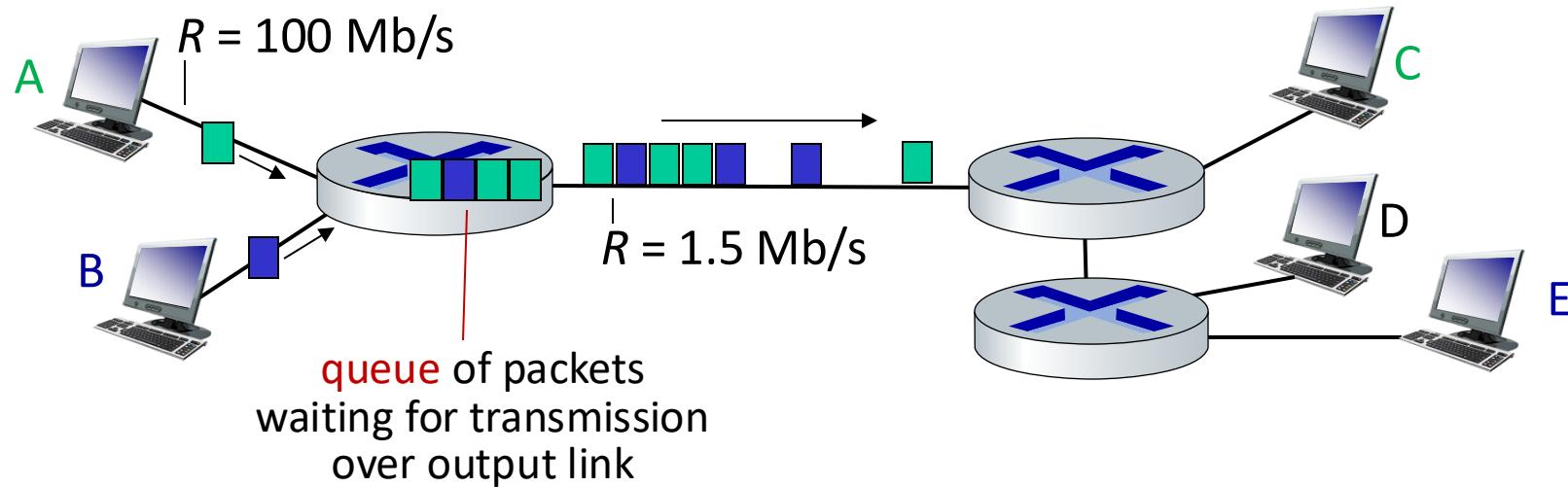


- **Transmission delay:** takes  $L/R$  seconds to transmit (push out)  $L$ -bit packet into link at  $R$  bps
- **Store and forward:** entire packet must arrive at router before it can be transmitted on next link
- **End-end delay:**  $2L/R$  (above), assuming zero propagation delay (more on delay shortly)

*One-hop numerical example:*

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

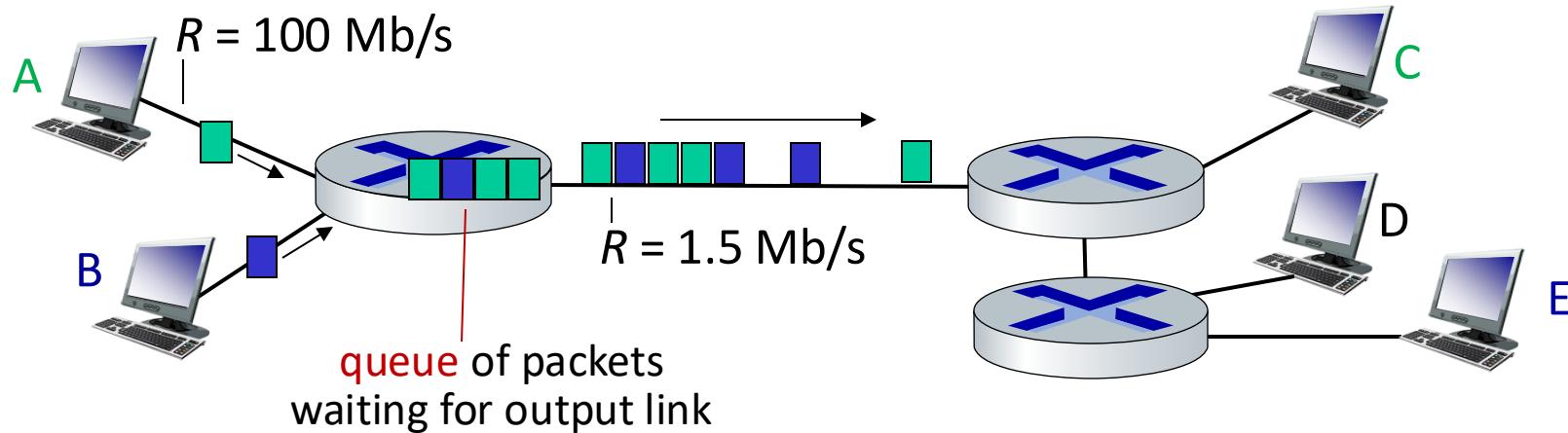
# Packet-switching: queueing



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



# Packet-switching: queueing delay, loss



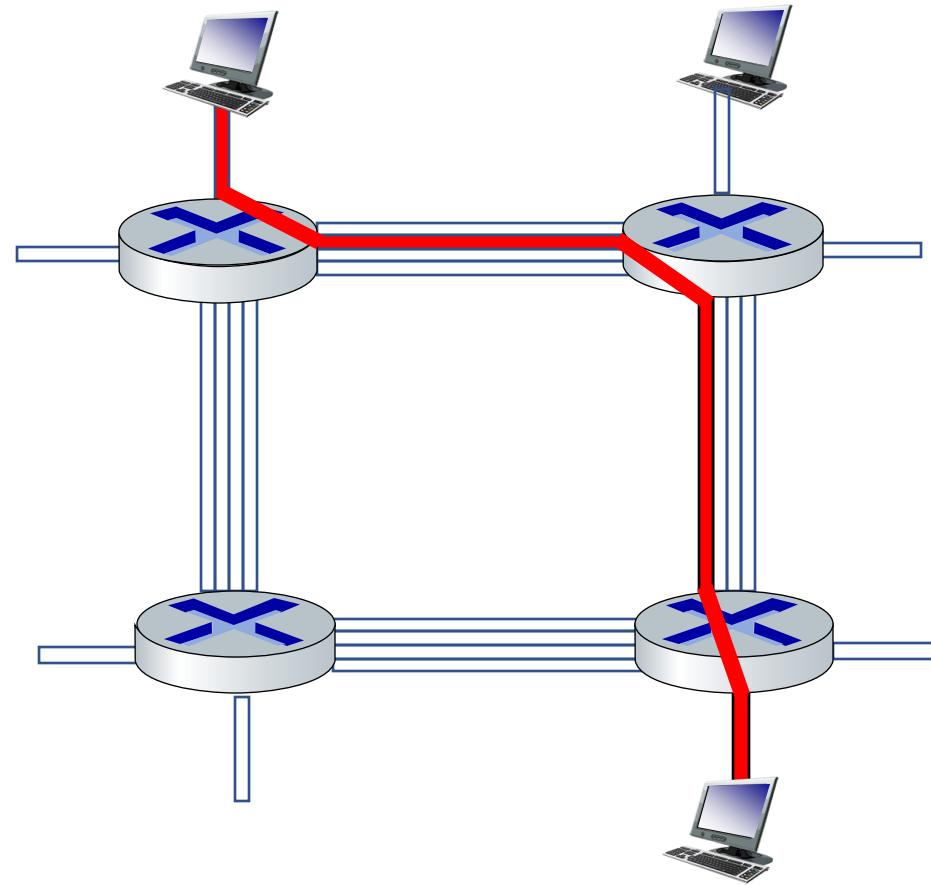
***Packet queuing and loss:*** if arrival rate (in bps) to link exceeds transmission rate (bps) of link for a period of time:

- 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 allocated to,  
reserved for “call” between source  
and destination

- in diagram, each link has four circuits.
  - call gets 2<sup>nd</sup> circuit in top link and 1<sup>st</sup> 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



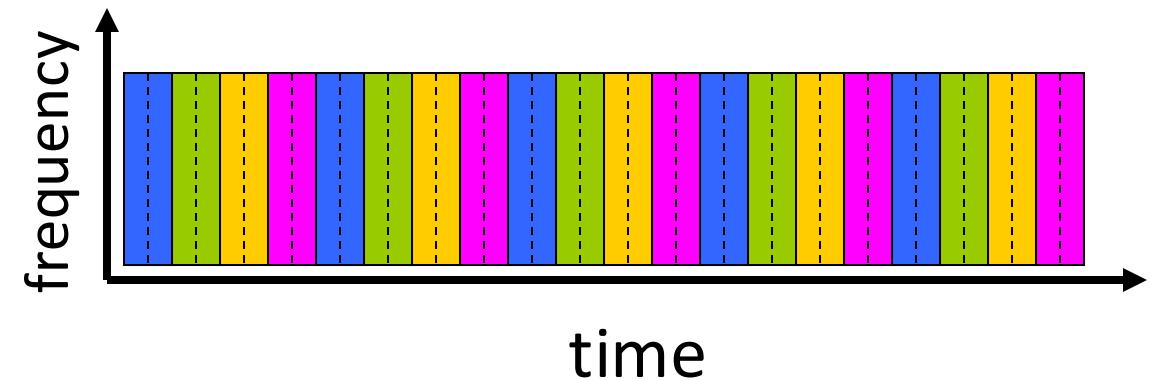
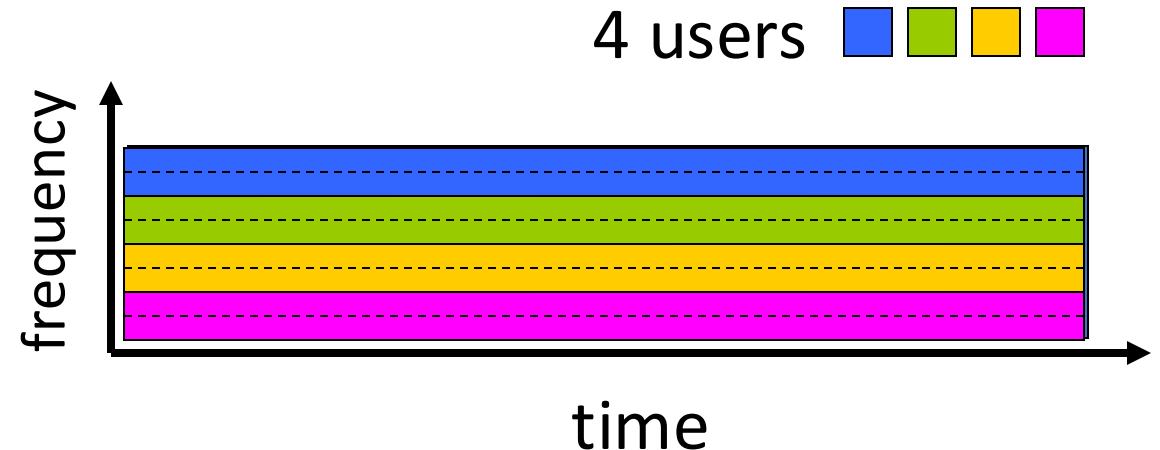
# Circuit switching: FDM and TDM

## 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

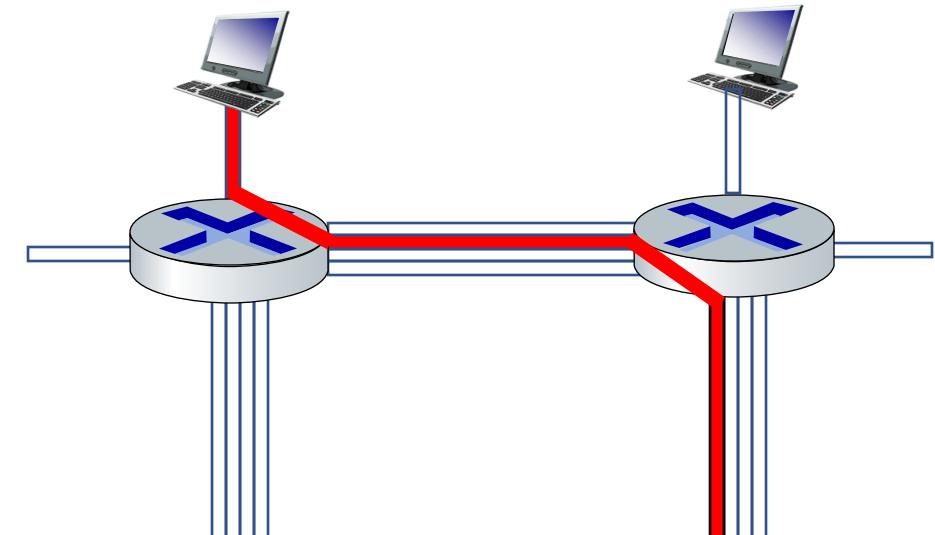
## Time Division Multiplexing (TDM)

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



# Alternative to packet switching: circuit switching

- Host A ile Host B arasında devre anahtarlamalı ağ üzerinden 640 Kbit gönderilecektir
- Ağdaki tüm bağlantılar 24 slot ile TDM kullanmaktadır ve bit oranı 1.536 Mbps.
- Uçtan uca devre kurulumu 0.5 s'de yapılmaktadır.



$$\begin{aligned}\text{Her devrenin iletim oranı} &= 1.536 \text{ Mbps} / 24 = 64 \text{ kbps} \\ \text{Dosyanın gönderim süresi} &= 640.000 / 64 \text{ kbps} = 10 \text{ s} \\ \text{Toplam süre} &= \text{Devre kurulum süresi} + \text{Gönderim süresi} \\ &= \mathbf{0.5 \text{ s} + 10 \text{ s} = 10.5 \text{ s}}\end{aligned}$$

1

# Packet switching versus circuit switching

*packet switching allows more users to use network!*

$$f(x) = \binom{n}{x} p^x (1-p)^{n-x} = \frac{n!}{x!(n-x)!} p^x (1-p)^{n-x}$$

$$f(11) = \frac{35!}{11!(35-11)!} 0,1^{11} (1-0,1)^{35-11} < 0,0004 \text{ nk}$$

*n* = toplam kullanıcı sayısı

*p* = bir kullanıcının aktif olma olasılığı

*x* = eş zamanlı kullanıcı sayısı

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

# Packet switching versus circuit switching

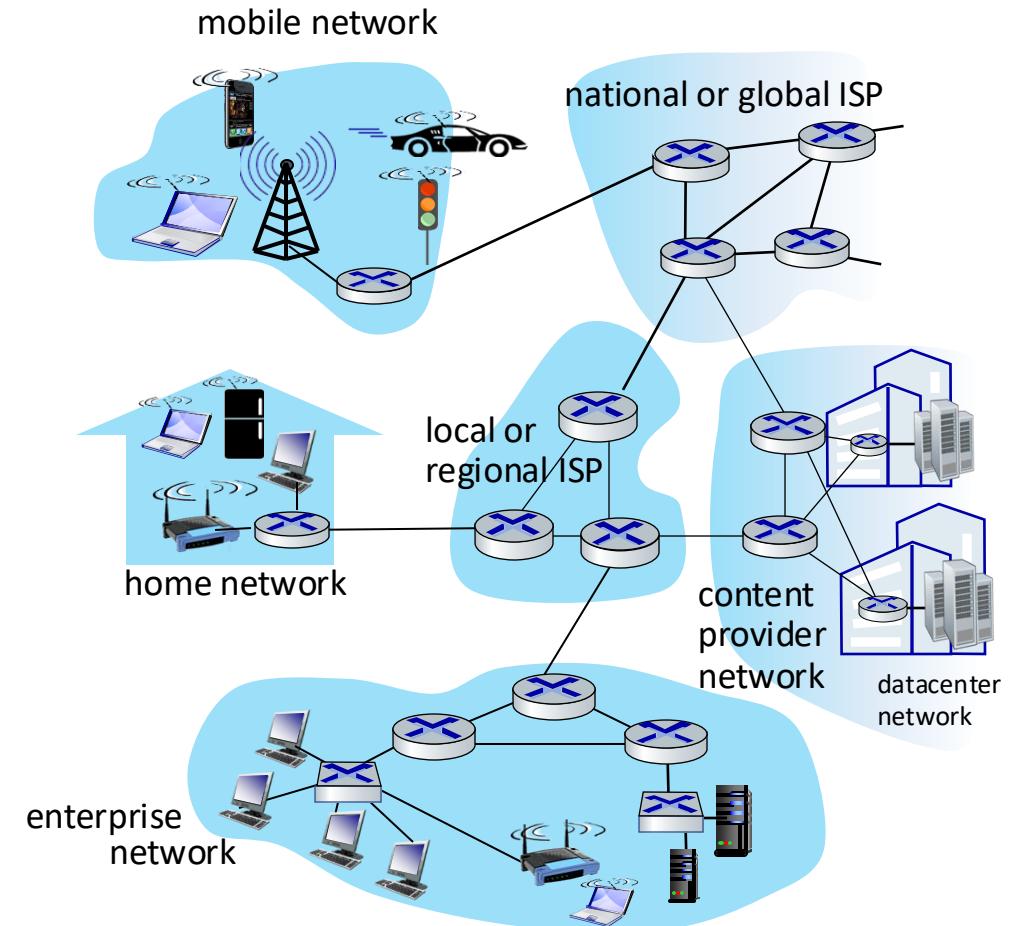
Is packet switching a “slam dunk winner”?

- great for “bursty” data – sometimes has data to send, but at other times not
  - resource sharing
  - simpler, no call setup
- **excessive congestion possible:** packet delay and loss due to buffer overflow
  - protocols needed for reliable data transfer, congestion control
- ***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.

***Q:*** human analogies of reserved resources (circuit switching) versus on-demand allocation (packet switching)?

# Internet structure: a “network of networks”

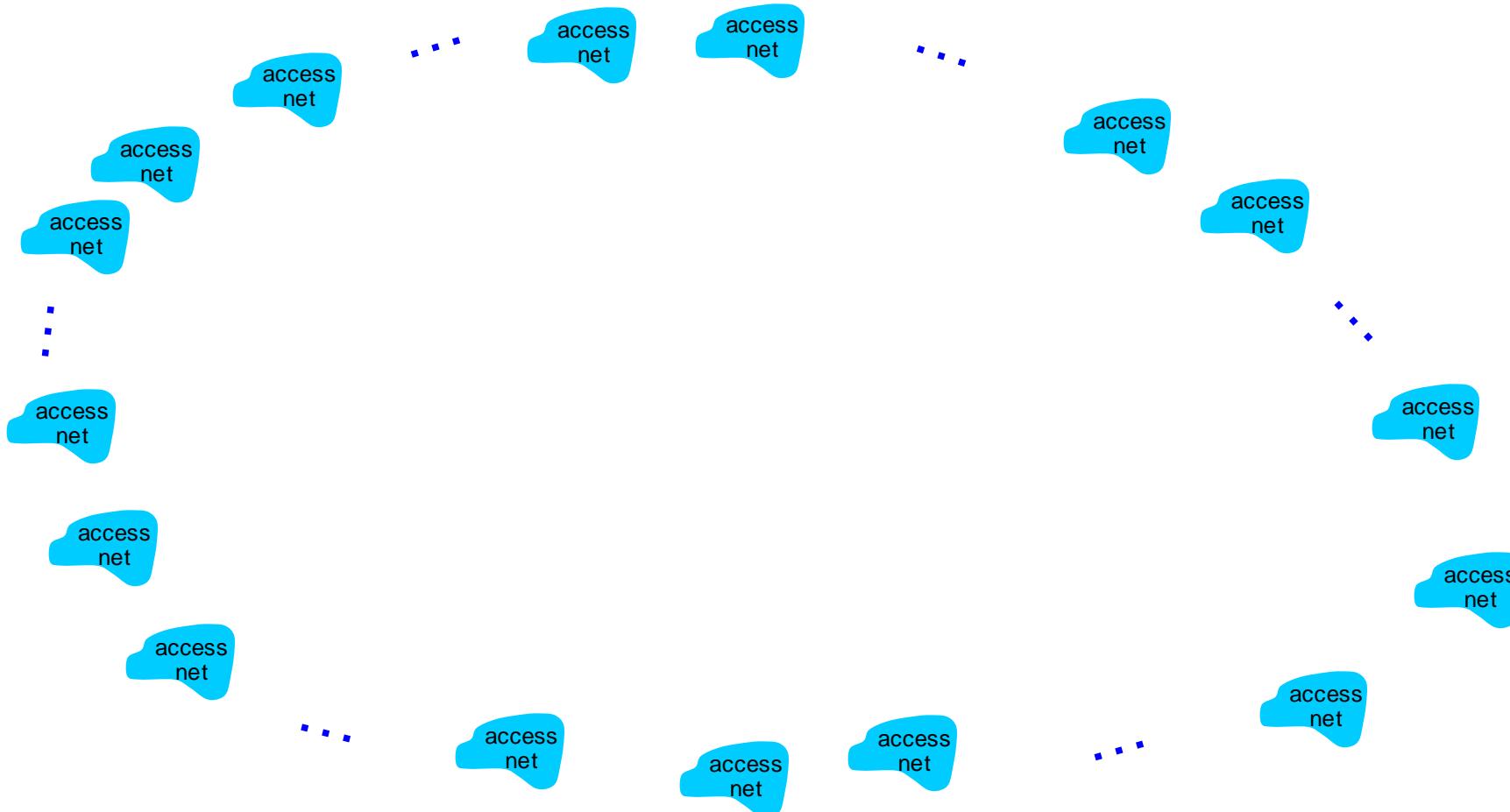
- hosts connect to Internet via **access** Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
  - so that *any* two hosts (*anywhere!*) can send packets to each other
- resulting network of networks is very complex
  - evolution driven by **economics, national policies**



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

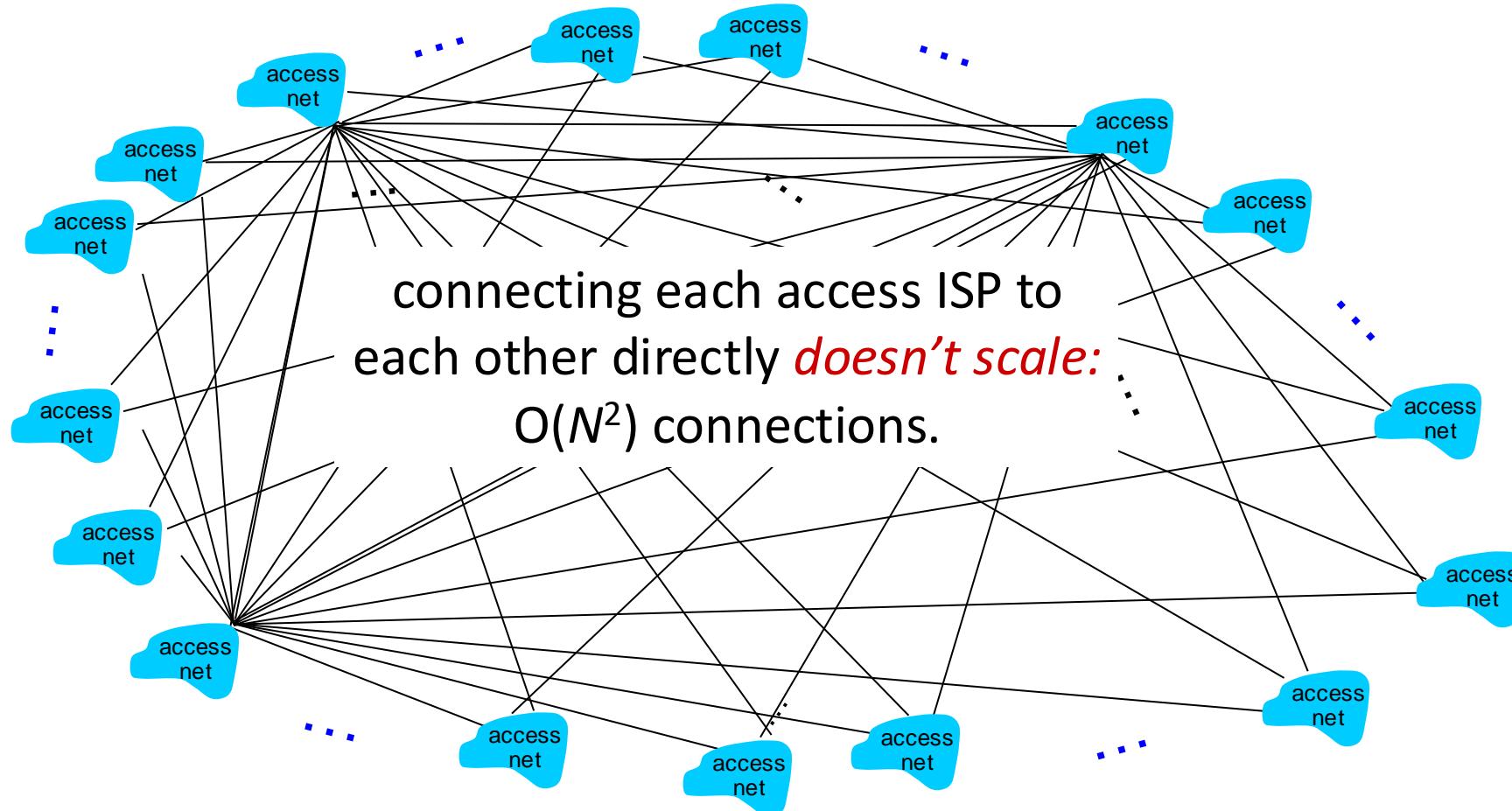
# Internet structure: a “network of networks”

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



# Internet structure: a “network of networks”

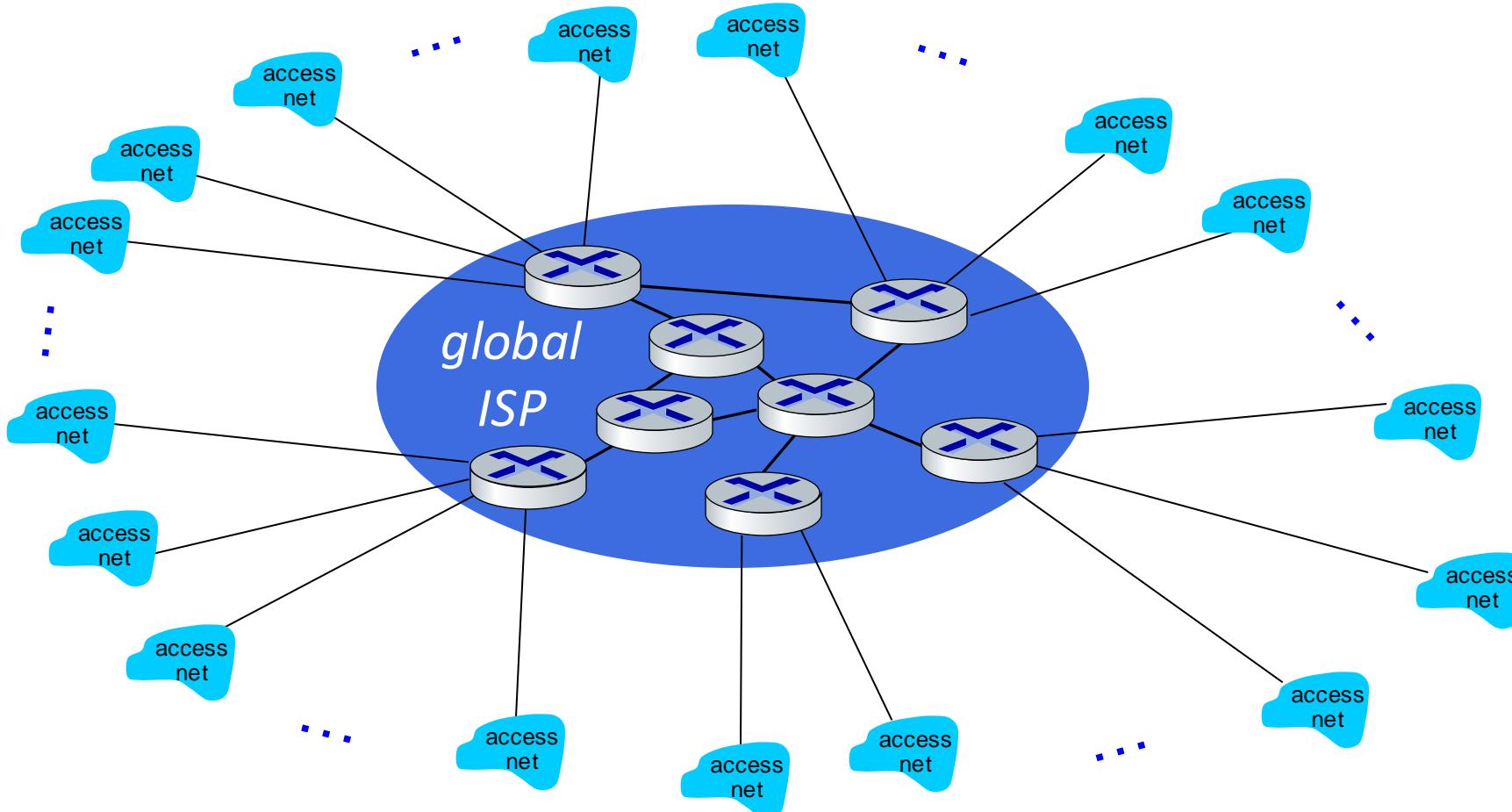
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# Internet structure: a “network of networks”

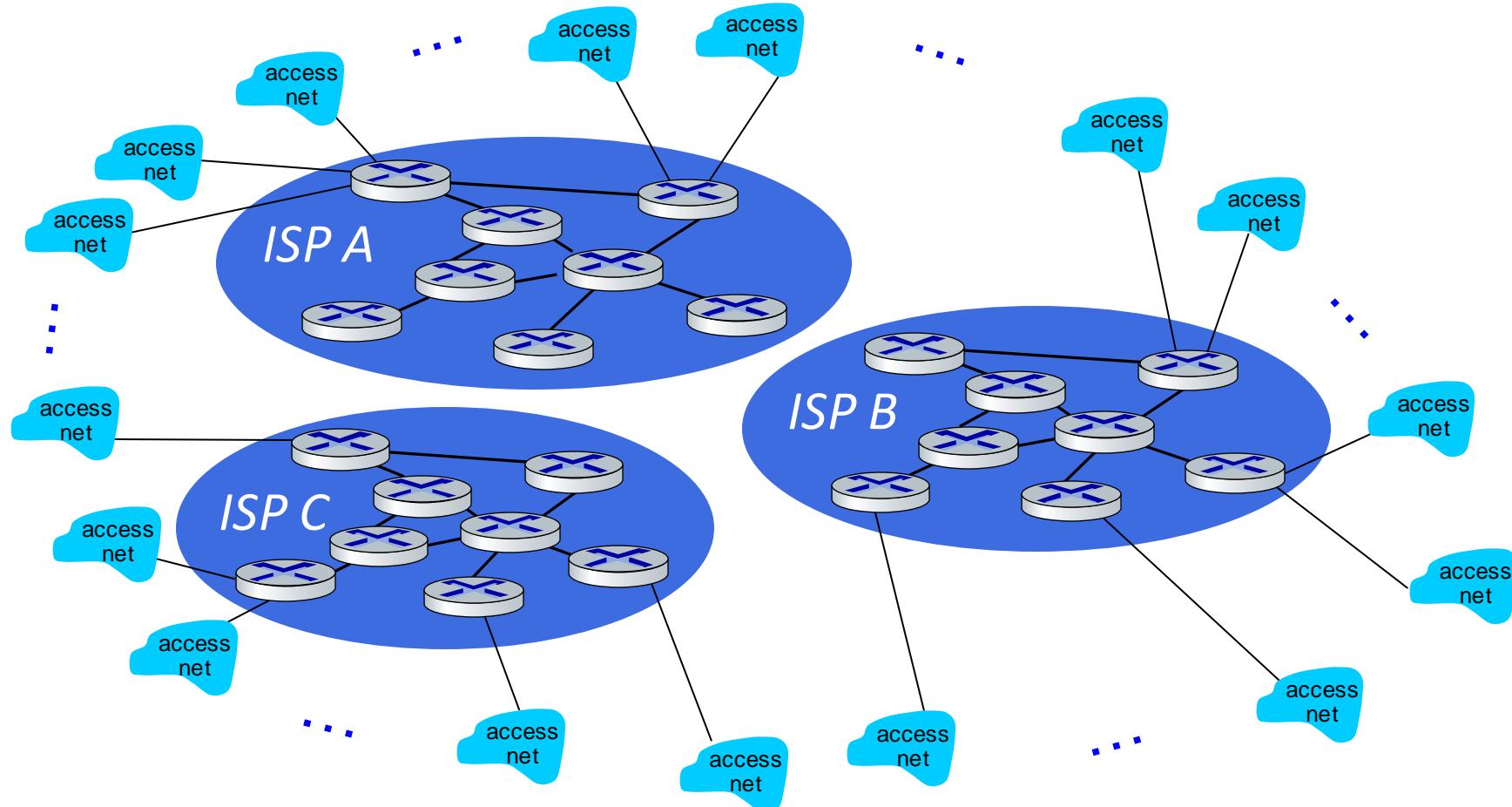
*Option: connect each access ISP to one global transit ISP?*

*Customer and provider ISPs have economic agreement.*



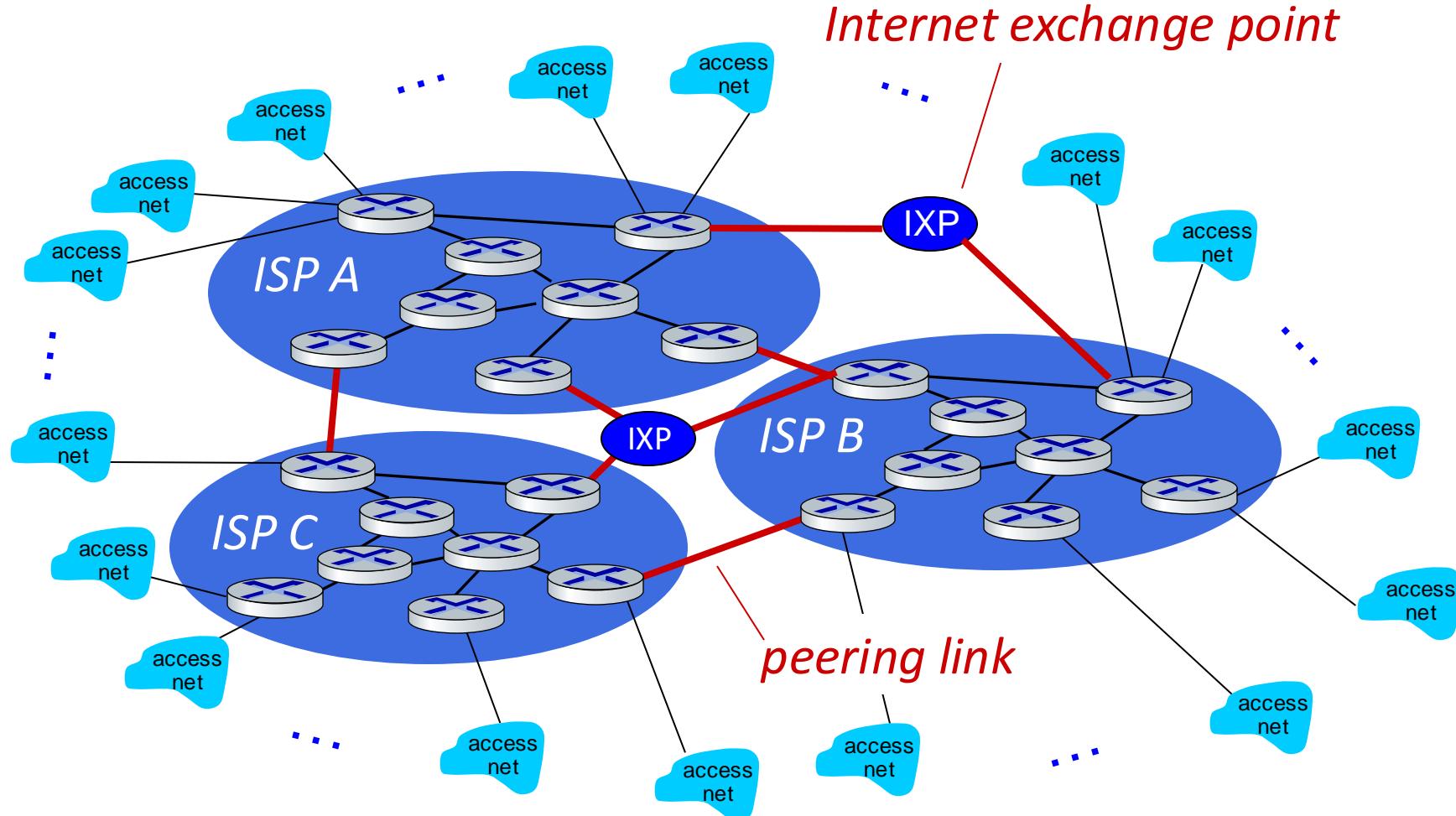
# Internet structure: a “network of networks”

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



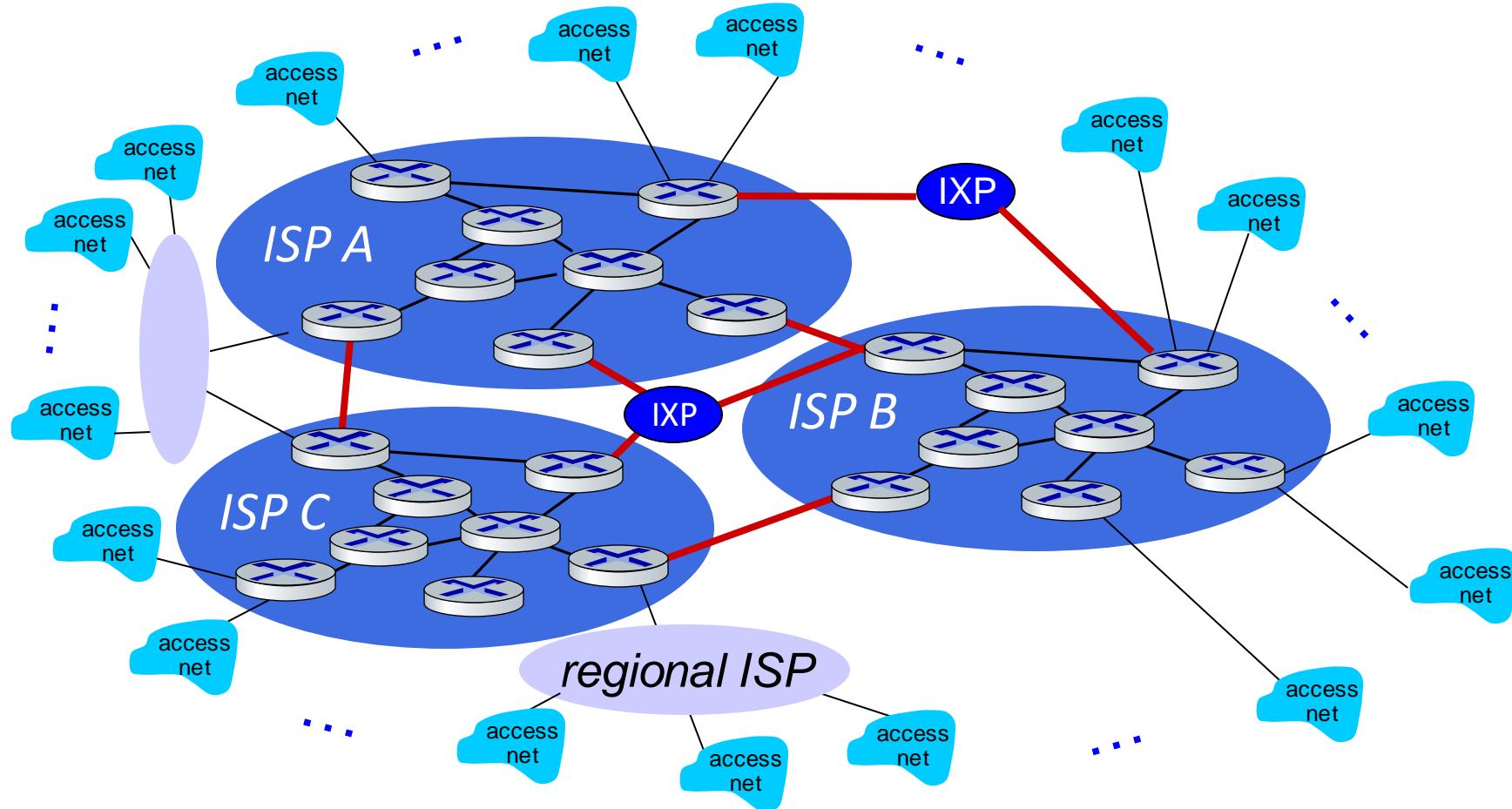
# Internet structure: a “network of networks”

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



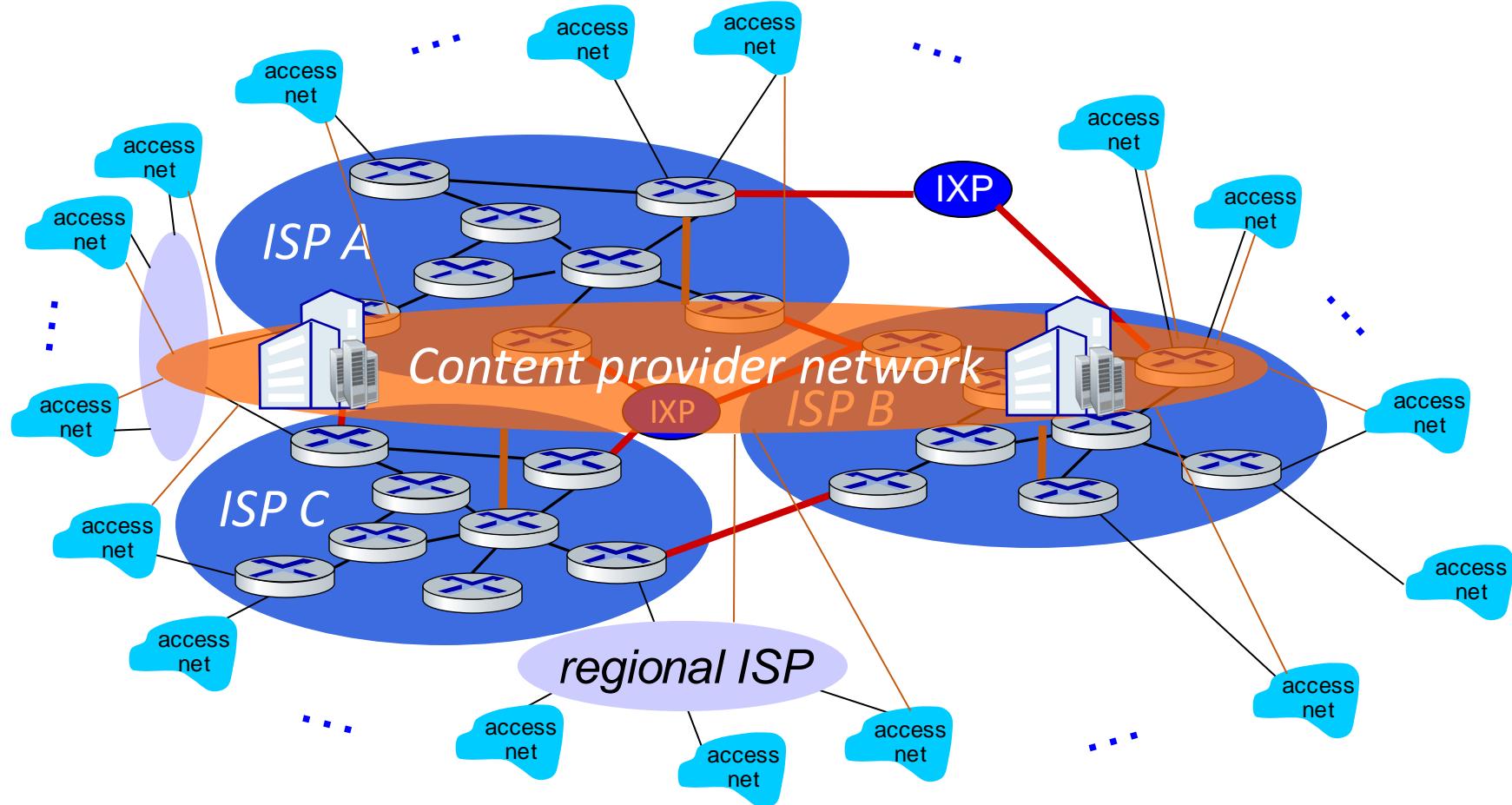
# Internet structure: a “network of networks”

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

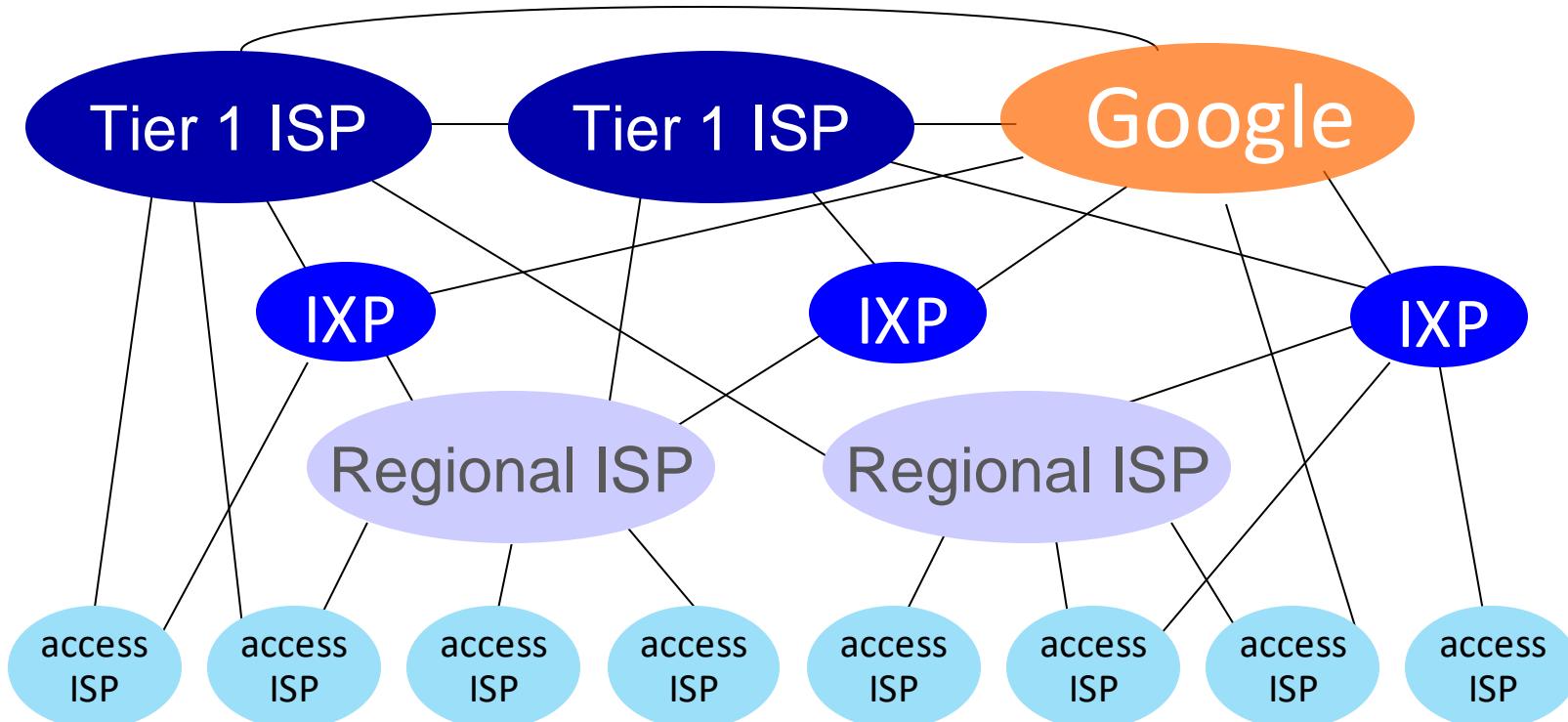


# Internet structure: a “network of networks”

... 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

# Tier-1 ISP Network map: Sprint (2019)



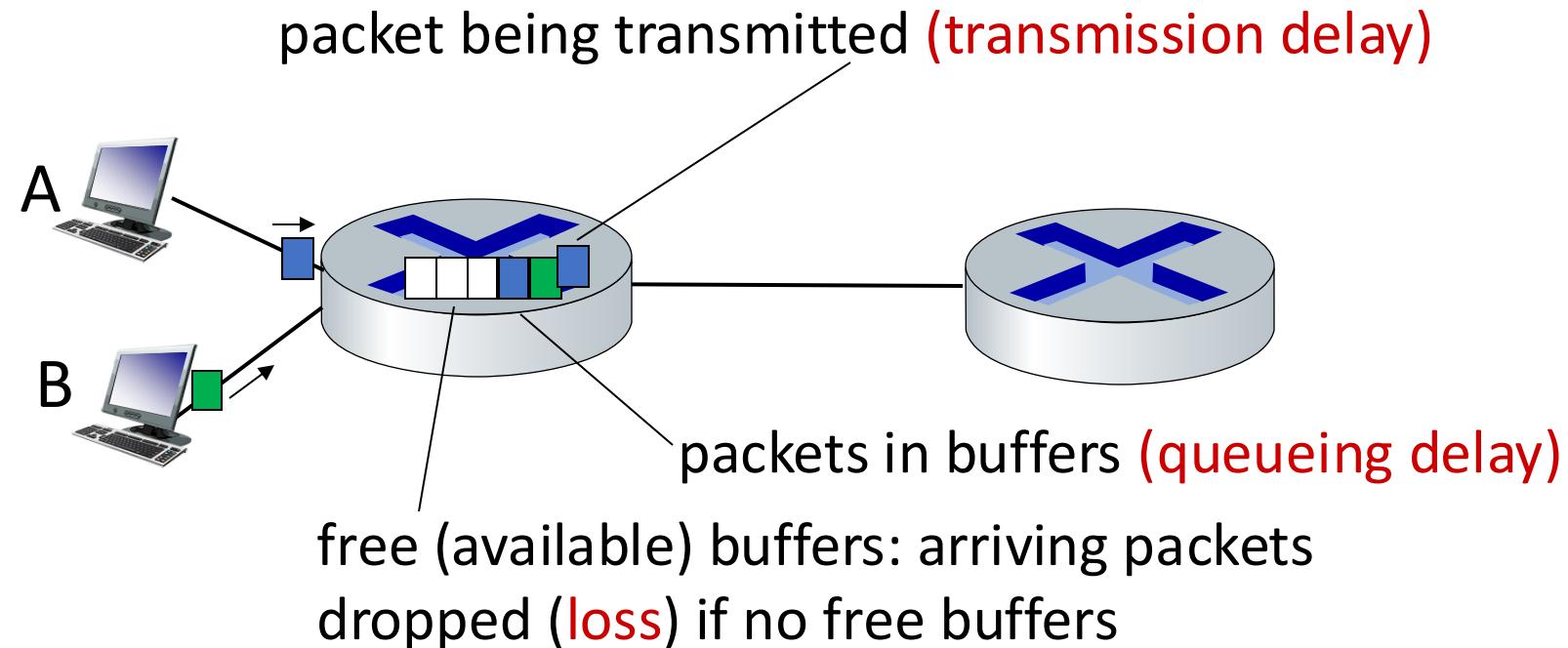
# Chapter 1: roadmap

- 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

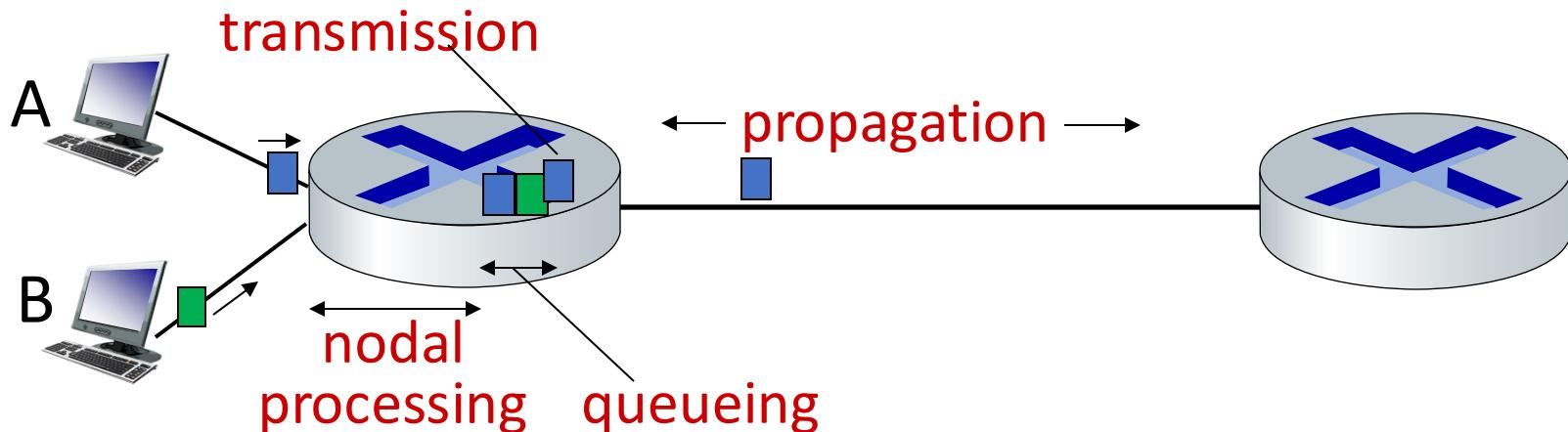


# How do packet delay and loss occur?

- 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



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

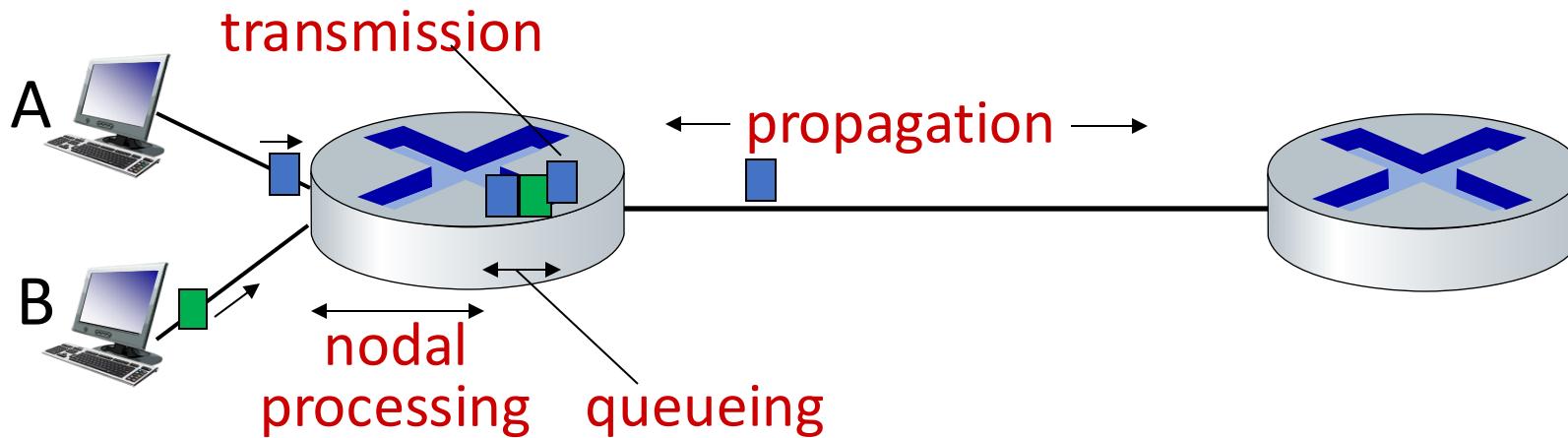
$d_{\text{proc}}$ : nodal processing

- 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)*
- $d_{\text{trans}} = L/R$

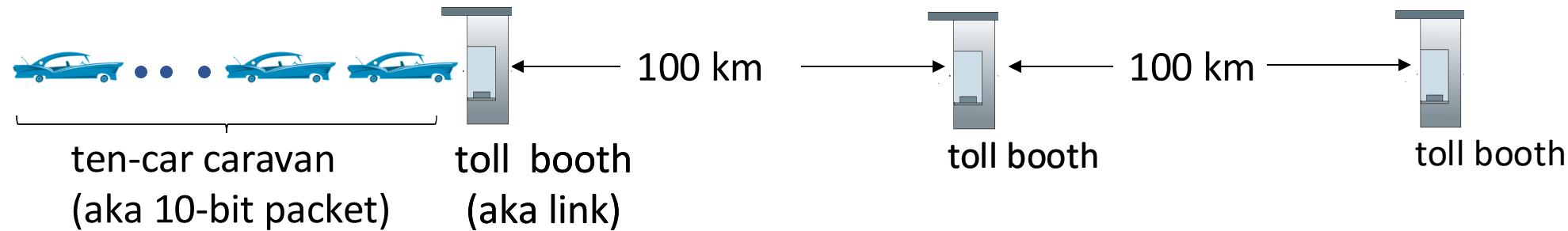
$d_{\text{trans}}$  and  $d_{\text{prop}}$   
very different

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

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

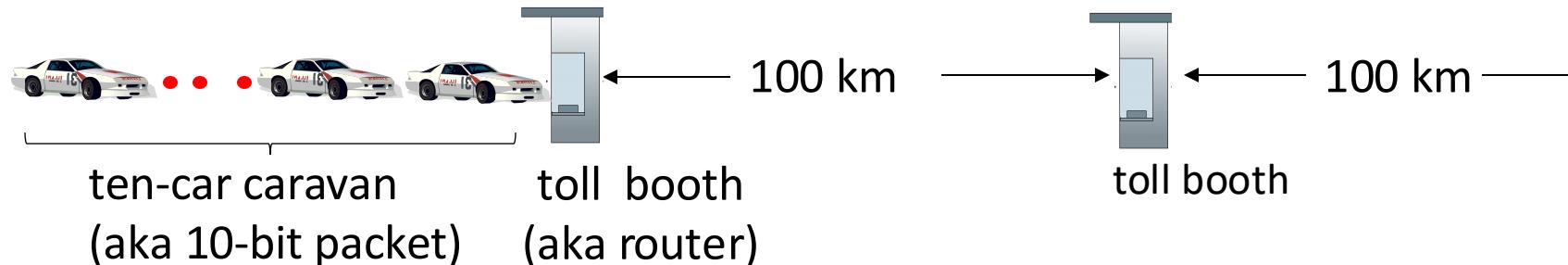
\* Check out the online interactive exercises:  
[http://gaia.cs.umass.edu/kurose\\_ross](http://gaia.cs.umass.edu/kurose_ross)

# 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



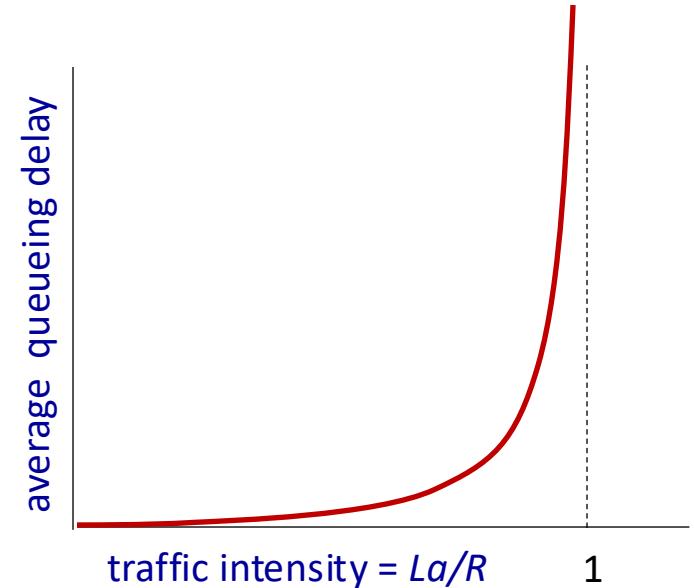
- suppose cars now “propagate” at 1000 km/hr
  - and suppose toll booth now takes one min to service a car
  - ***Q: Will cars arrive to 2nd booth before all cars serviced at first booth?***
- A: Yes!** after 7 min, first car arrives at second booth; three cars still at first booth

# 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”*



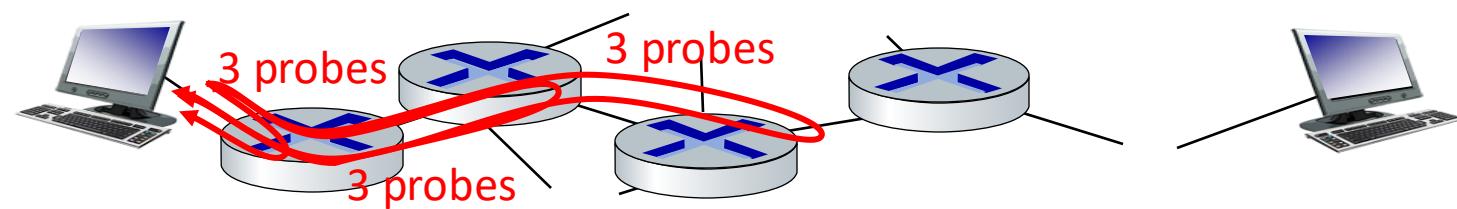
- $La/R \sim 0$ : avg. queueing delay small
- $La/R \rightarrow 1$ : avg. queueing delay large
- $La/R > 1$ : more “work” arriving is more than can be serviced - average delay infinite!

queueing delay =  $I(L/R)(1 - I)$  for  $I < 1$



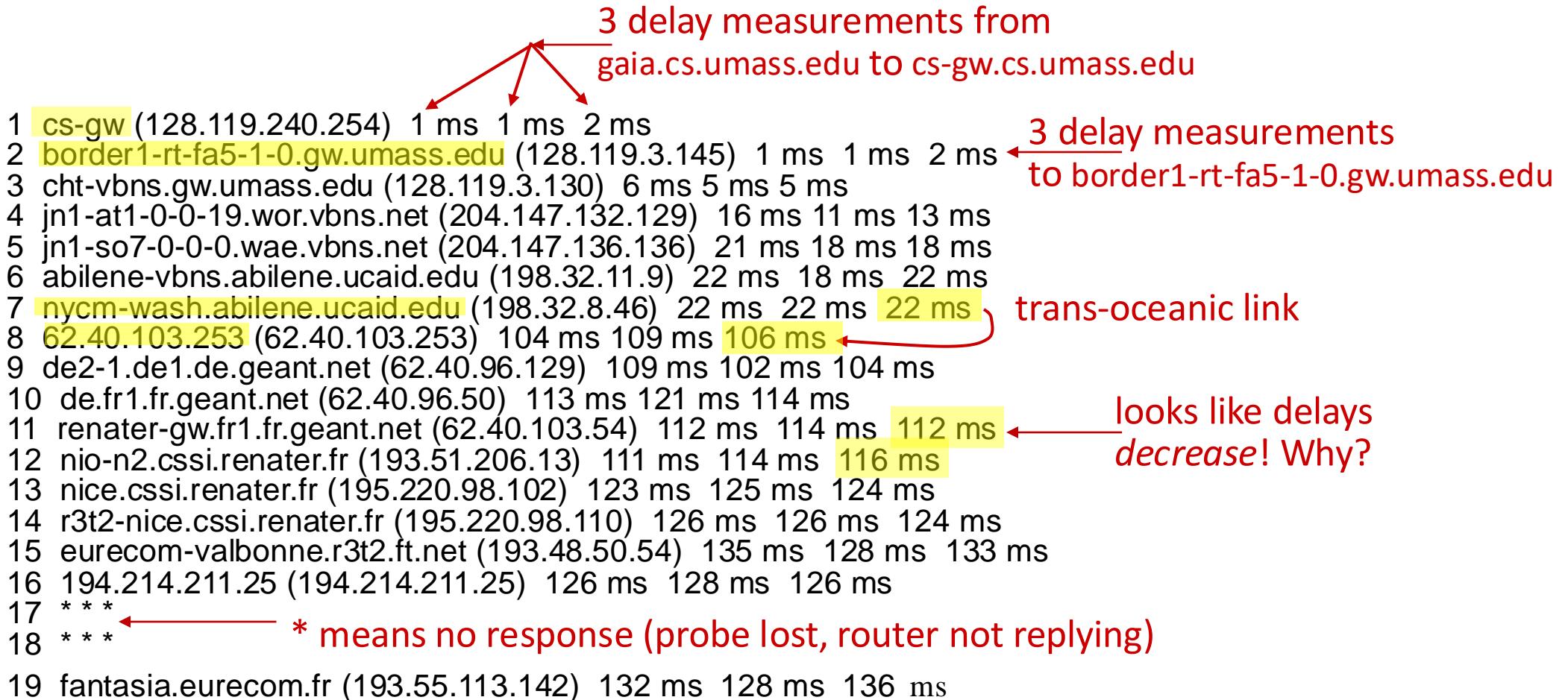
# “Real” Internet delays and routes

- 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



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

# Real Internet delays and routes

```
C:\Users\mc>tracert www.google.com
```

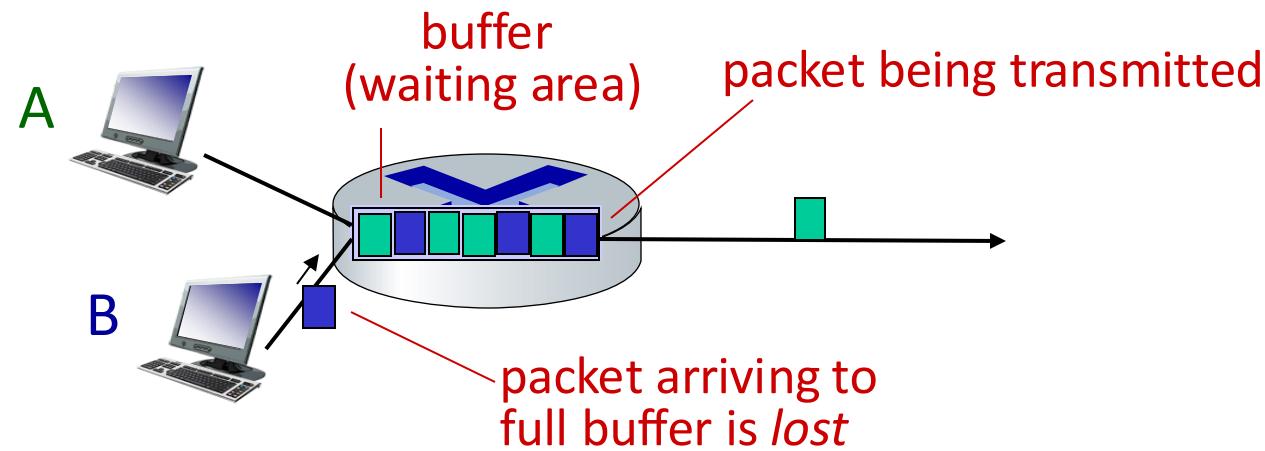
```
Tracing route to www.google.com [142.251.140.4]
over a maximum of 30 hops:
```

```
 1   1 ms    1 ms    1 ms  192.168.0.1
 2   *        *        *      Request timed out.
 3   9 ms    9 ms    9 ms  172.25.16.1
 4  12 ms   14 ms   10 ms  172.25.16.114
 5  45 ms   32 ms   27 ms  172.25.16.113
 6  13 ms   11 ms    9 ms  195.175.103.253.static.turktelekom.com.tr [195.175.103.253]
 7   9 ms   10 ms   11 ms  16-bursa-h2-2---16-cekirge-t3-2.statik.turktelekom.com.tr [81.212.246.108]
 8  15 ms   11 ms   19 ms  34-acibadem-xrs-t2-2---16-bursa-h2-2.statik.turktelekom.com.tr [195.175.174.174]
 9   *        *        *      Request timed out.
10  29 ms   30 ms   28 ms  307-sof-col-1---34-ebgp-acibadem-sr12e-k.statik.turktelekom.com.tr [212.156.104.68]
11  65 ms   56 ms   55 ms  209.85.168.140
12  56 ms   60 ms   55 ms  142.251.244.109
13  53 ms   56 ms   52 ms  142.251.247.141
14  54 ms   54 ms   53 ms  sof04s04-in-f4.1e100.net [142.251.140.4]
```

```
Trace complete.
```

# Packet loss

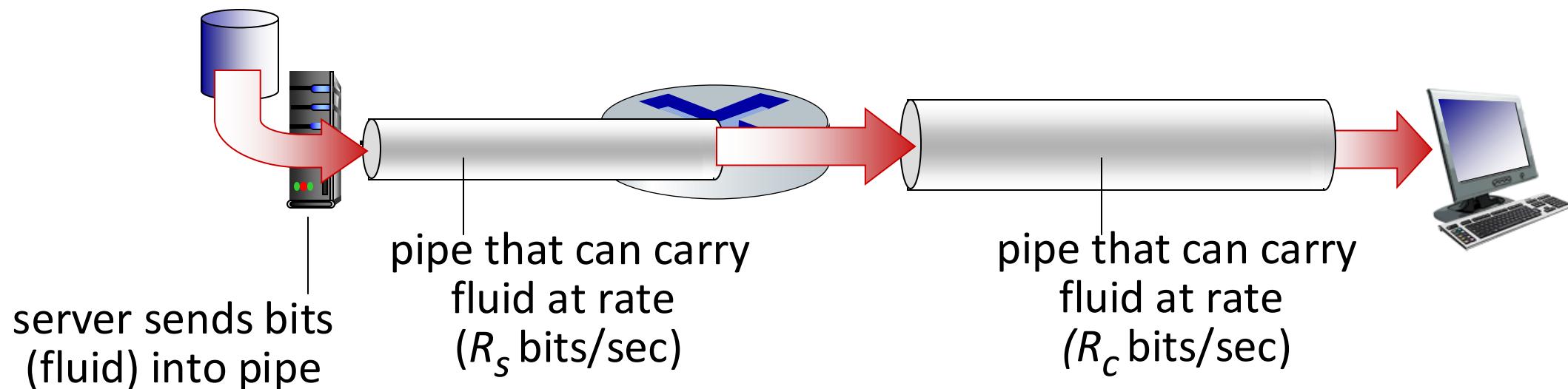
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



\* Check out the Java applet for an interactive animation on queuing and loss

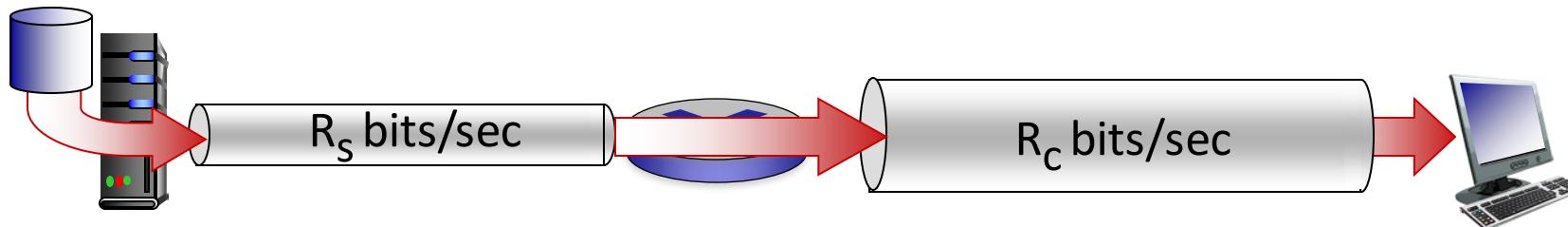
# Throughput

- *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

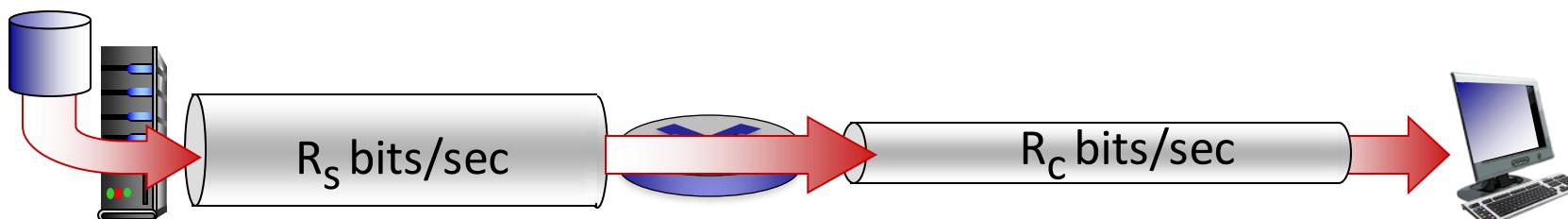


# Throughput

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



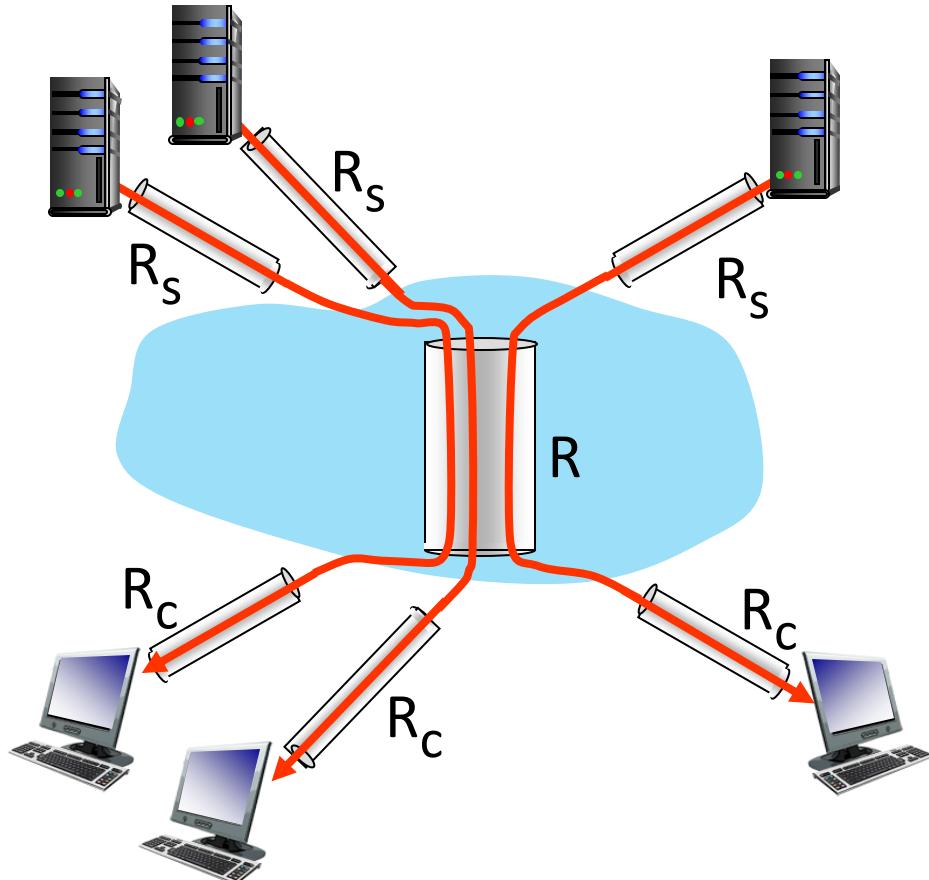
$R_s > R_c$  What is average end-end throughput?



*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?
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- Performance: loss, delay, throughput
- **Security**
- Protocol layers, service models
- History



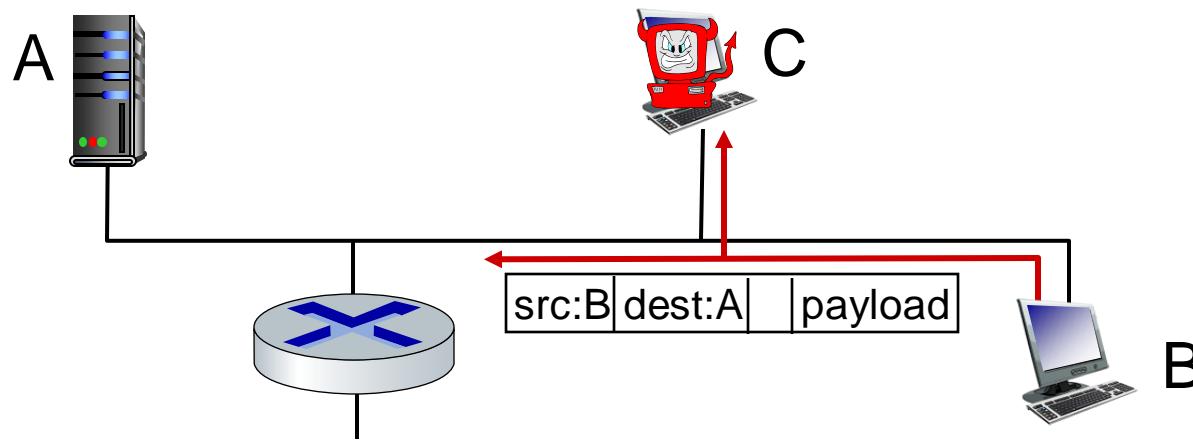
# Network security

- 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 guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks

# Bad guys: packet interception

*packet “sniffing”:*

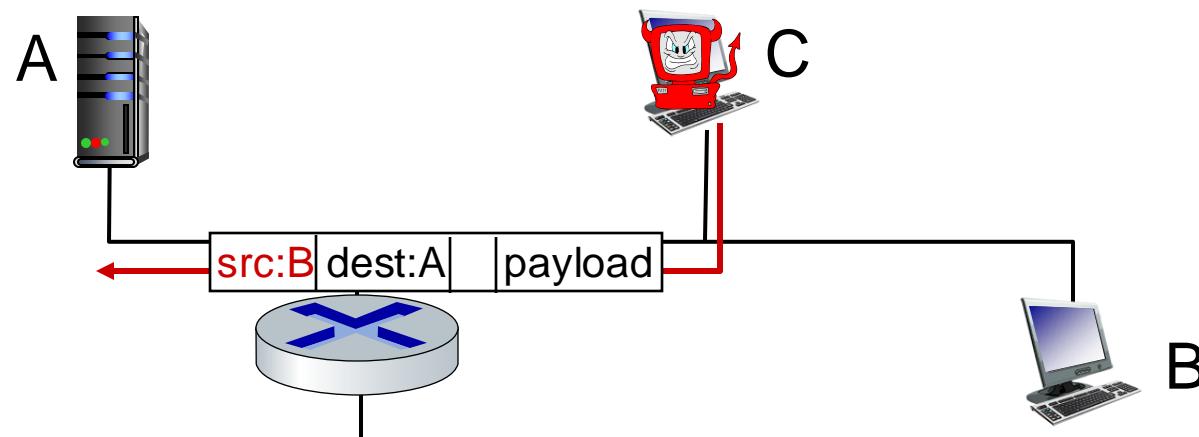
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



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

# Bad guys: fake identity

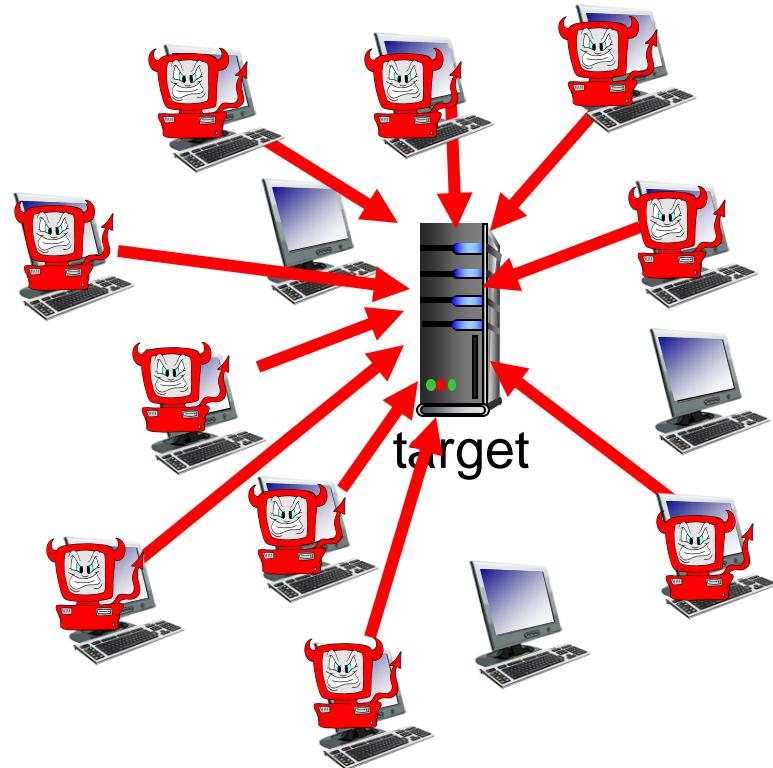
*IP spoofing:* injection of packet with false source address



# Bad guys: 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)*

# Chapter 1: roadmap

- What *is* the Internet?
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- Security
- **Protocol layers, service models**
- History



# Protocol “layers” and reference models

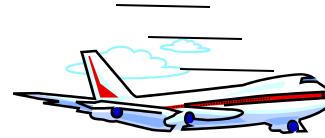
Networks are complex,  
with many “pieces”:

- 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
- relying on services provided by layer below

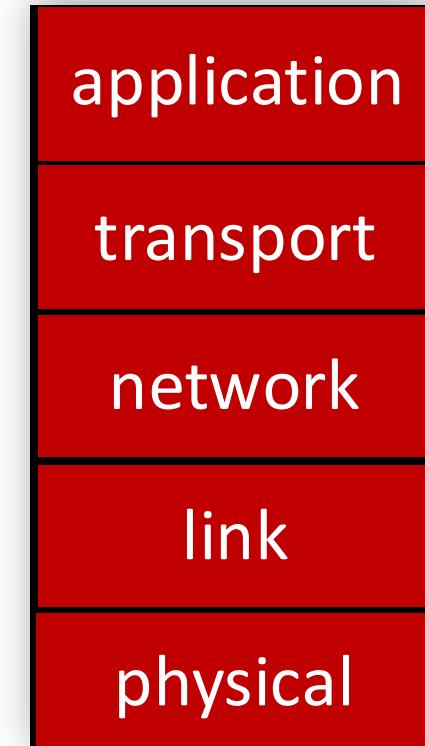
# Why layering?

Approach to designing/discussing complex systems:

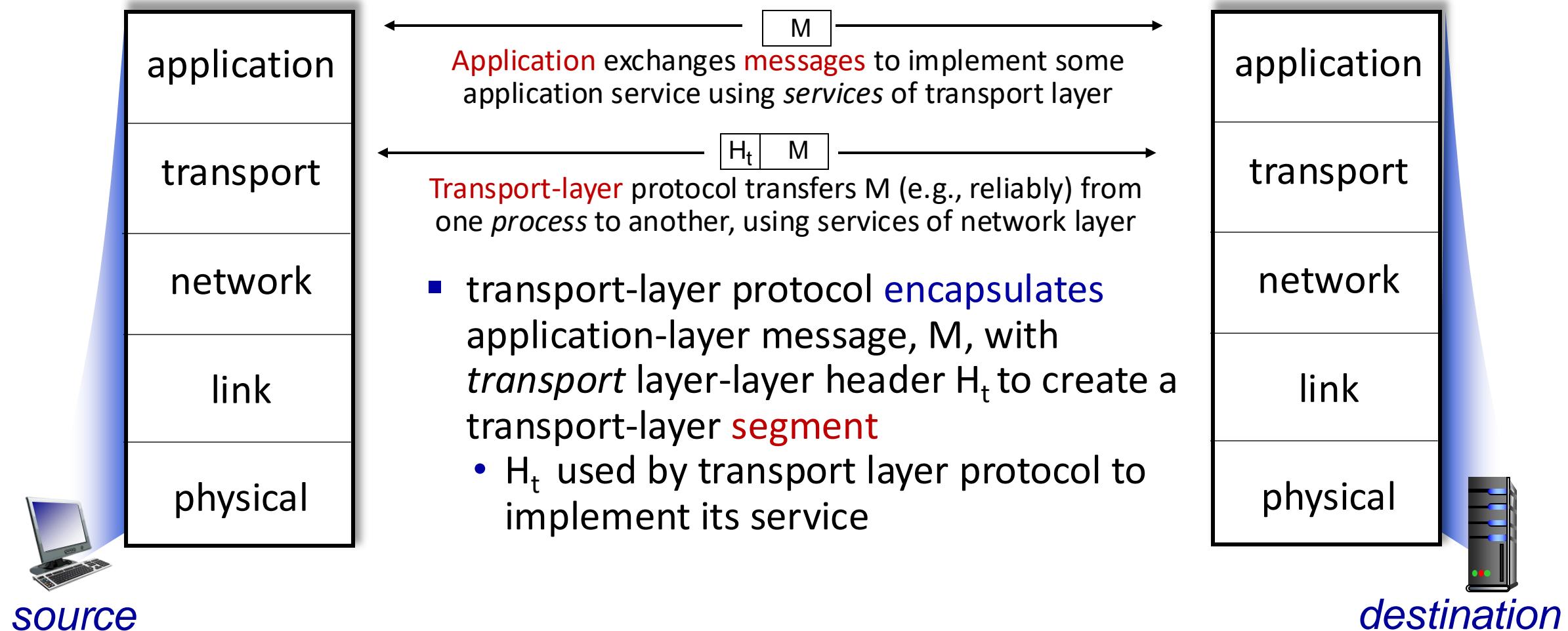
- explicit structure allows identification, relationship of system's pieces
  - layered *reference model* for discussion
- modularization eases maintenance, updating of system
  - change in layer's service *implementation*: transparent to rest of system
  - e.g., change in gate procedure doesn't affect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

# Layered Internet protocol stack

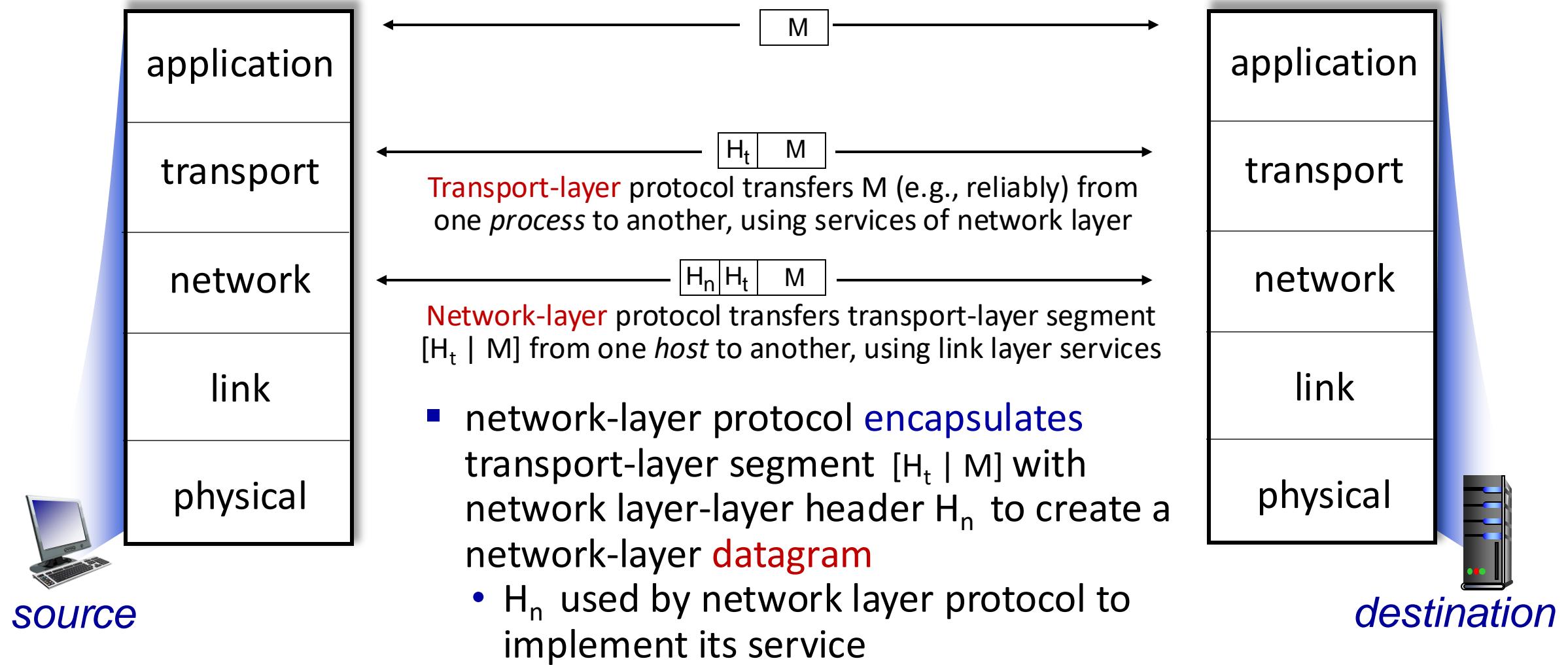
- *application*: supporting network applications
  - HTTP, IMAP, SMTP, DNS
- *transport*: process-process data transfer
  - TCP, UDP
- *network*: routing of datagrams from source to destination
  - IP, routing protocols
- *link*: data transfer between neighboring network elements
  - Ethernet, 802.11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



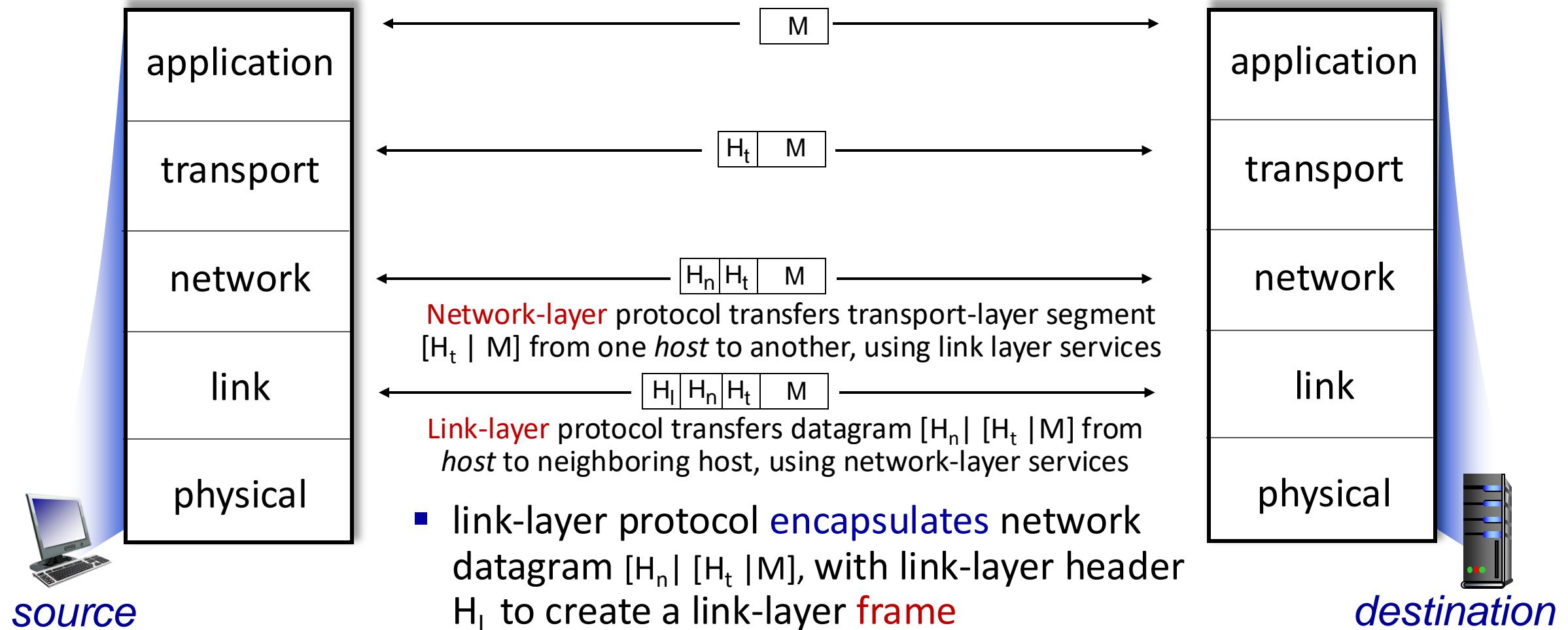
# Services, Layering and Encapsulation



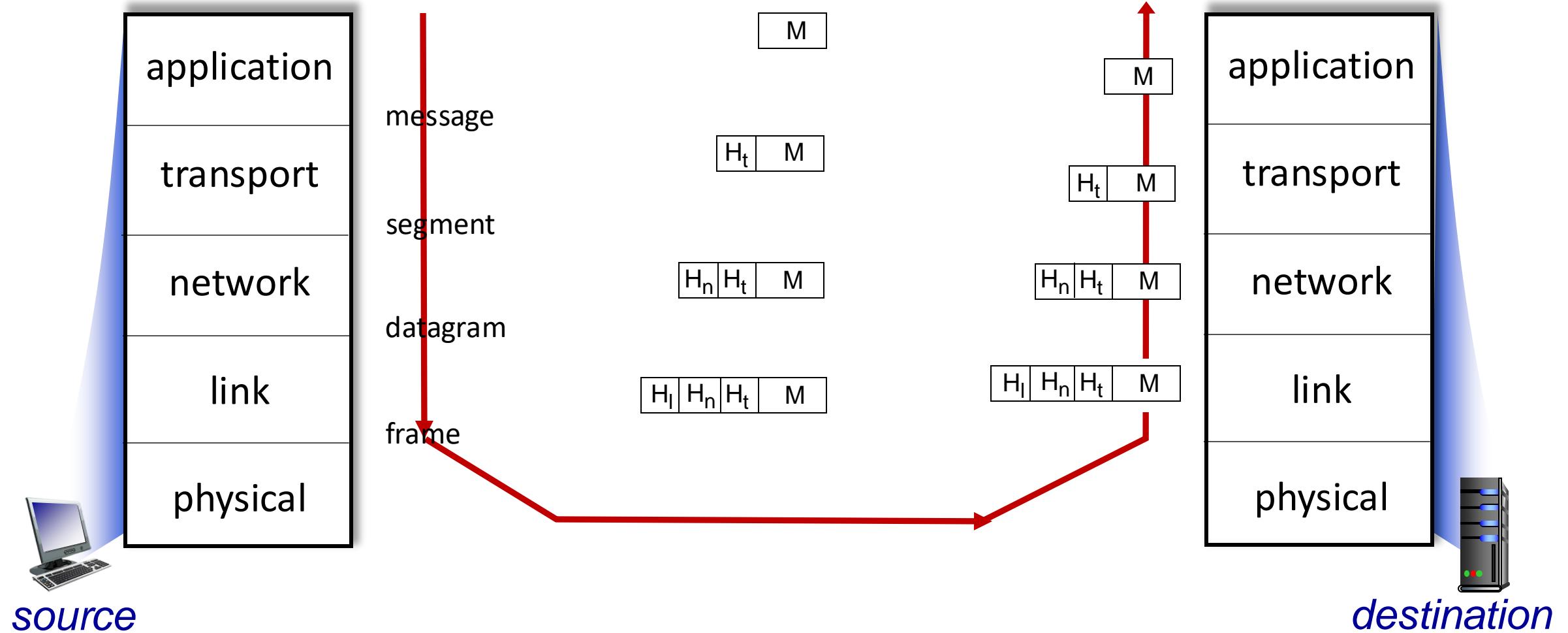
# Services, Layering and Encapsulation



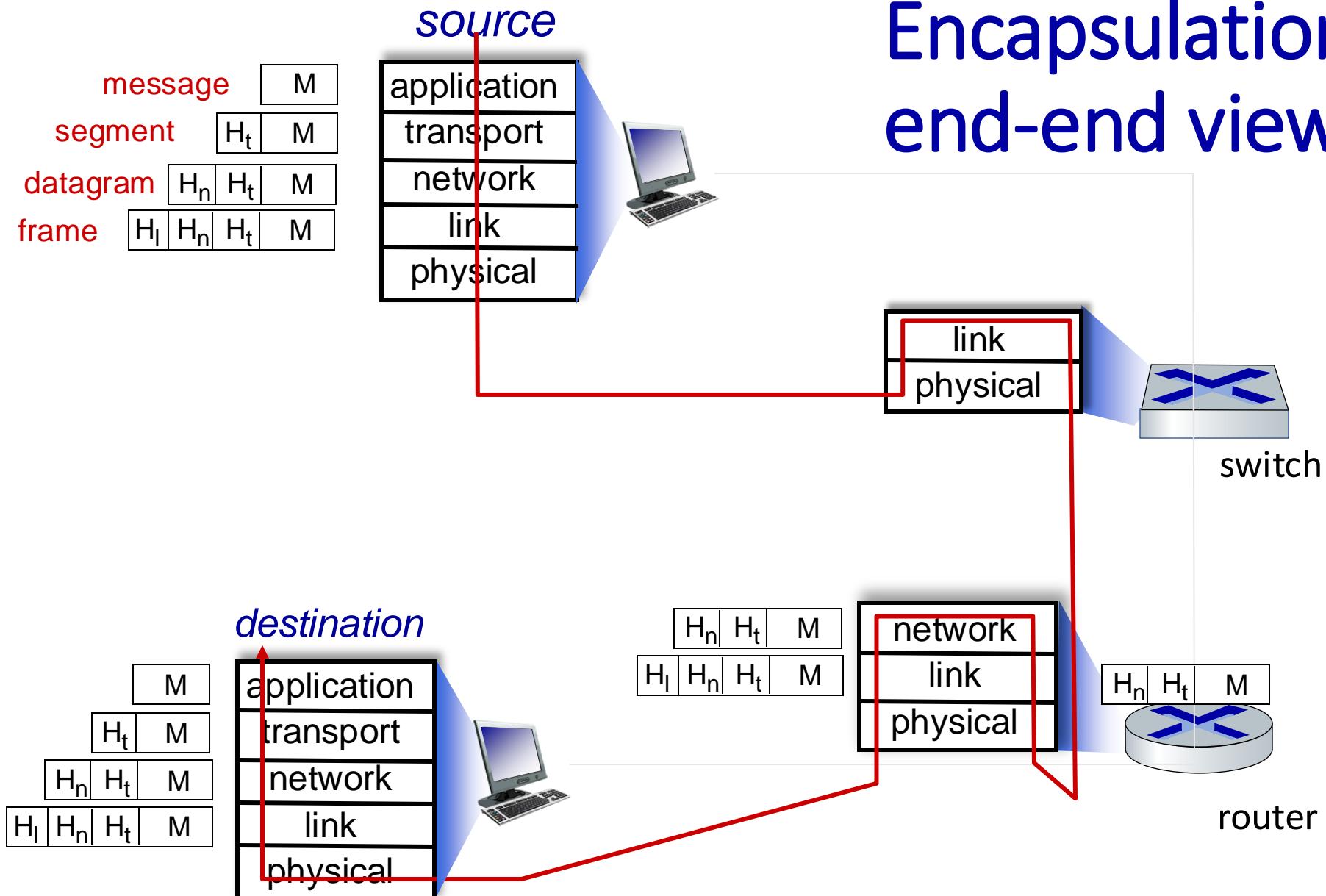
# Services, Layering and Encapsulation



# Services, Layering and Encapsulation



# Encapsulation: an end-end view



# Chapter 1: roadmap

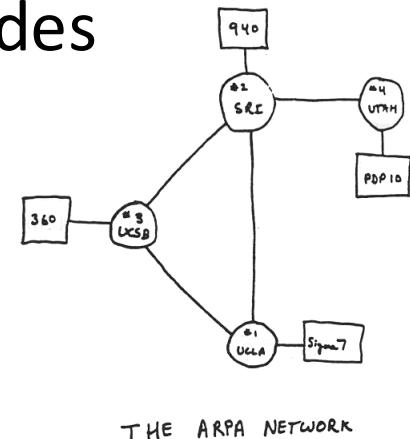
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- Protocol layers, service models
- History



# Internet history

## 1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1972:
  - ARPAnet public demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



# Internet history

## 1972-1980: Internetworking, new and proprietary networks

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late 70's: proprietary architectures: DECnet, SNA, XNA
- 1979: ARPAnet has 200 nodes

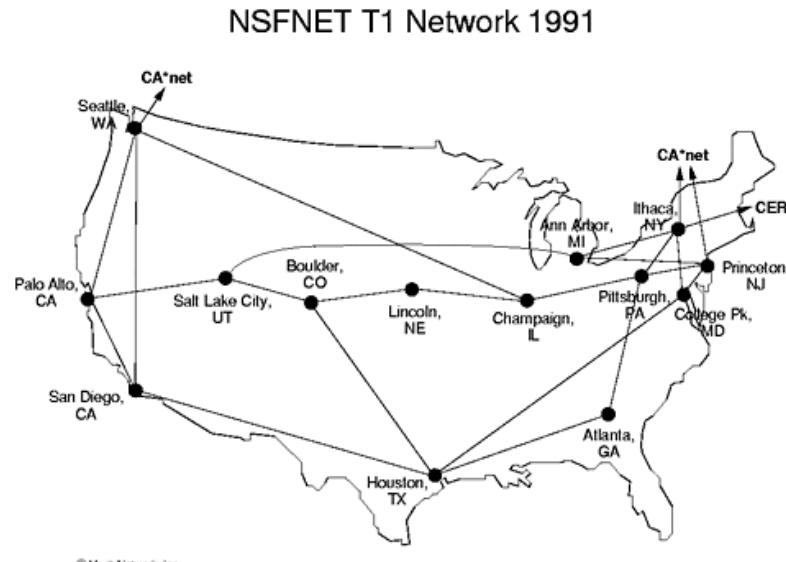
Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
  - best-effort service model
  - stateless routing
  - decentralized control
- define today's Internet architecture

# Internet history

## 1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control
- new national networks: CSnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks



# Internet history

## *1990, 2000s: commercialization, the Web, new applications*

- early 1990s: ARPAnet decommissioned
  - 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
  - early 1990s: Web
    - hypertext [Bush 1945, Nelson 1960's]
    - HTML, HTTP: Berners-Lee
    - 1994: Mosaic, later Netscape
    - late 1990s: commercialization of the Web
- late 1990s – 2000s:
- more killer apps: instant messaging, P2P file sharing
  - network security to forefront
  - est. 50 million host, 100 million+ users
  - backbone links running at Gbps

# Internet history

## *2005-present: scale, SDN, mobility, cloud*

- aggressive deployment of broadband home access (10-100's Mbps)
- 2008: software-defined networking (SDN)
- increasing ubiquity of high-speed wireless access: 4G/5G, WiFi
- service providers (Google, FB, Microsoft) create their own networks
  - bypass commercial Internet to connect “close” to end user, providing “instantaneous” access to social media, search, video content, ...
- enterprises run their services in “cloud” (e.g., Amazon Web Services, Microsoft Azure)
- rise of smartphones: more mobile than fixed devices on Internet (2017)
- ~18B devices attached to Internet (2017)

# 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:*

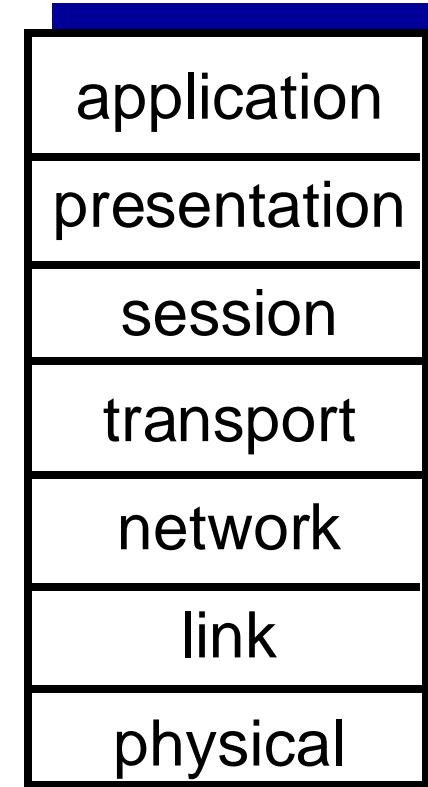
- context, overview, vocabulary, "feel" of networking
- more depth, detail, *and fun* to follow!

# Additional Chapter 1 slides

# 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

# Wireshark

