

# Chapter I

# Introduction

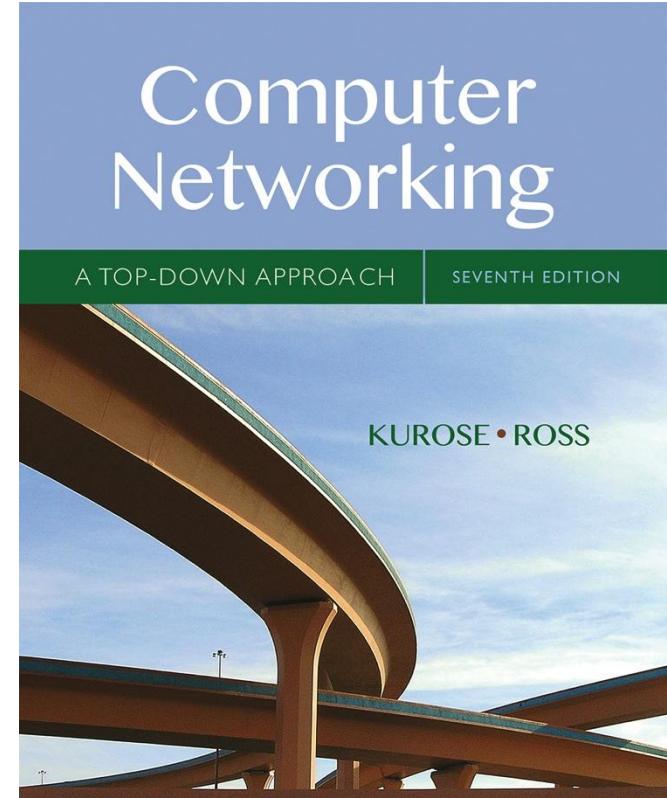
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*Computer  
Networking: A Top  
Down Approach*

7<sup>th</sup> edition

Jim Kurose, Keith Ross  
Pearson/Addison Wesley  
April 2016

# CSE2111: Computer Networking

3.75 Credits (3 credits theory + 0.75 credits lab)

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# CSE311: Computer Networking

Book: Computer Networking - A Top Down Approach - Featuring the Internet by J. Kurose and K. Ross (7E)

Reference books:

1. IEEE 802 Wireless Systems
2. Data Communications and networking by Forouzan
3. Resources from Internet

Syllabus:

- Chapter 1 - Introduction to computer networks and the Internet
- Chapter 2 - Application layer: HTTP, FTP, SMTP, DNS etc.
- Chapter 3 - Transport Layer Protocols, Congestion Control
- Chapter 4 and 5 - Network Layer (IP Addressing [Forouzan] and Routing protocols
- Chapter 6 -Data Link Layer, WLAN and IEEE 802.11 Medium Access Control

# Chapter I: introduction

## *our goal:*

- get “feel” and terminology
- more depth, detail  
*later in course*
- approach:
  - use Internet as example

## *overview:*

- what's the Internet?
- what's a protocol?
- network edge; hosts, access net, physical media
- network core: packet/circuit switching, Internet structure
- performance: loss, delay, throughput
- security
- protocol layers, service models
- history

# Chapter I: roadmap

## I.1 what *is* the Internet?

## I.2 network edge

- end systems, access networks, links

## I.3 network core

- packet switching, circuit switching, network structure

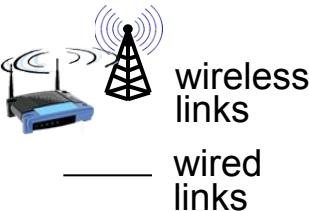
## I.4 delay, loss, throughput in networks

## I.5 protocol layers, service models

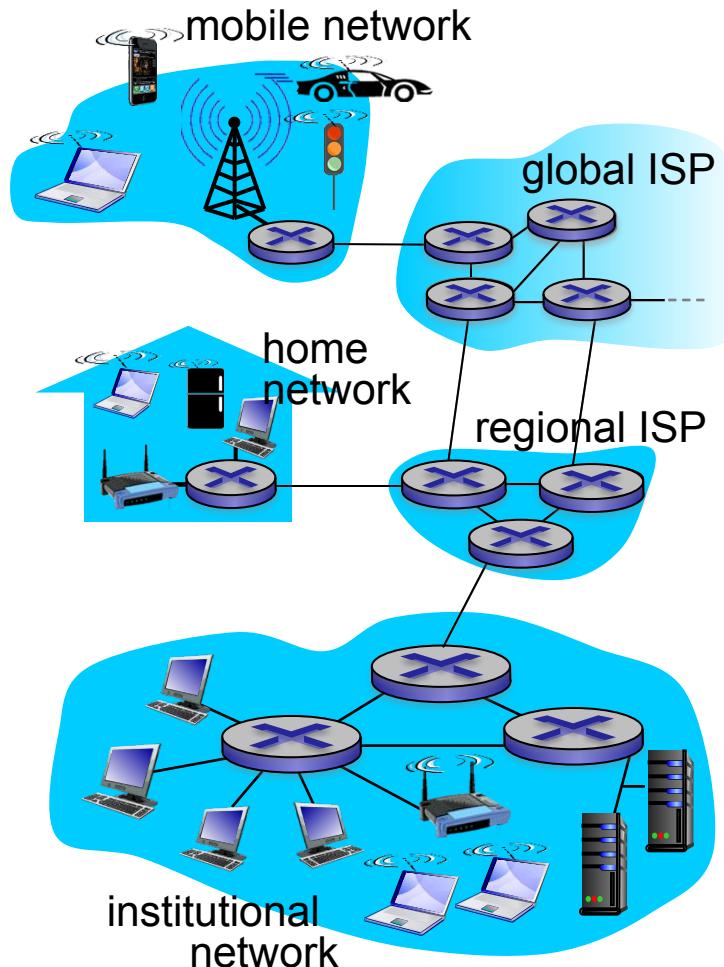
## I.6 networks under attack: security

## I.7 history

# What's the Internet: “nuts and bolts” view



- billions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: *bandwidth*
- *packet switches*: forward packets (chunks of data)
  - *routers* and *switches*



# “Fun” Internet-connected devices



IP picture frame  
<http://www.ceiva.com/>



Web-enabled toaster +  
weather forecaster



Internet  
refrigerator



Slingbox: watch,  
control cable TV remotely



sensorized,  
bed  
mattress



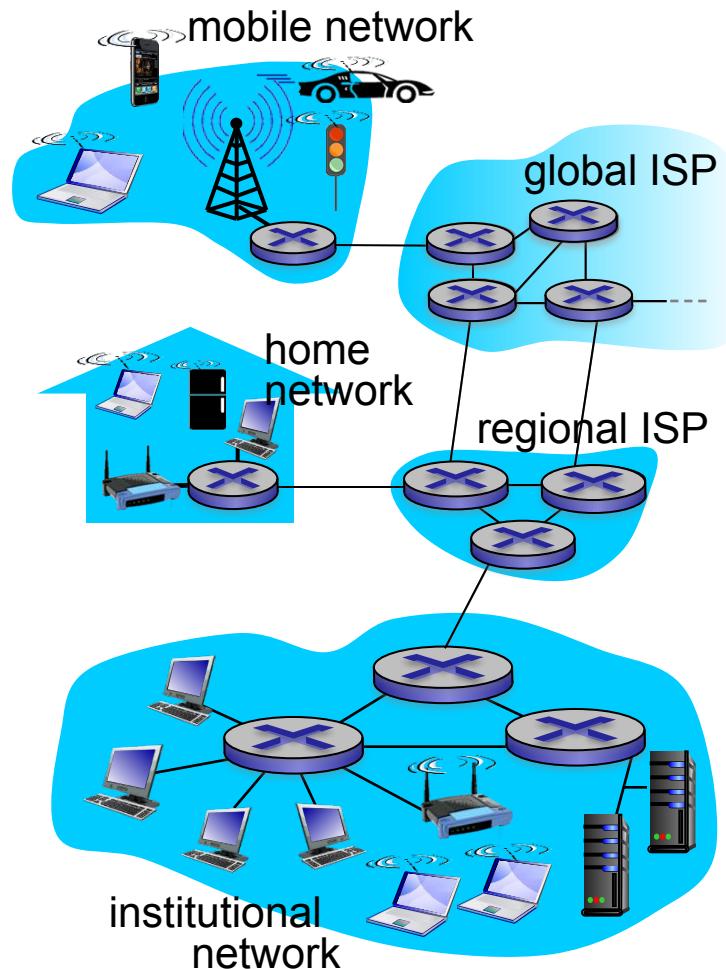
Tweet-a-watt:  
monitor energy use



Internet phones

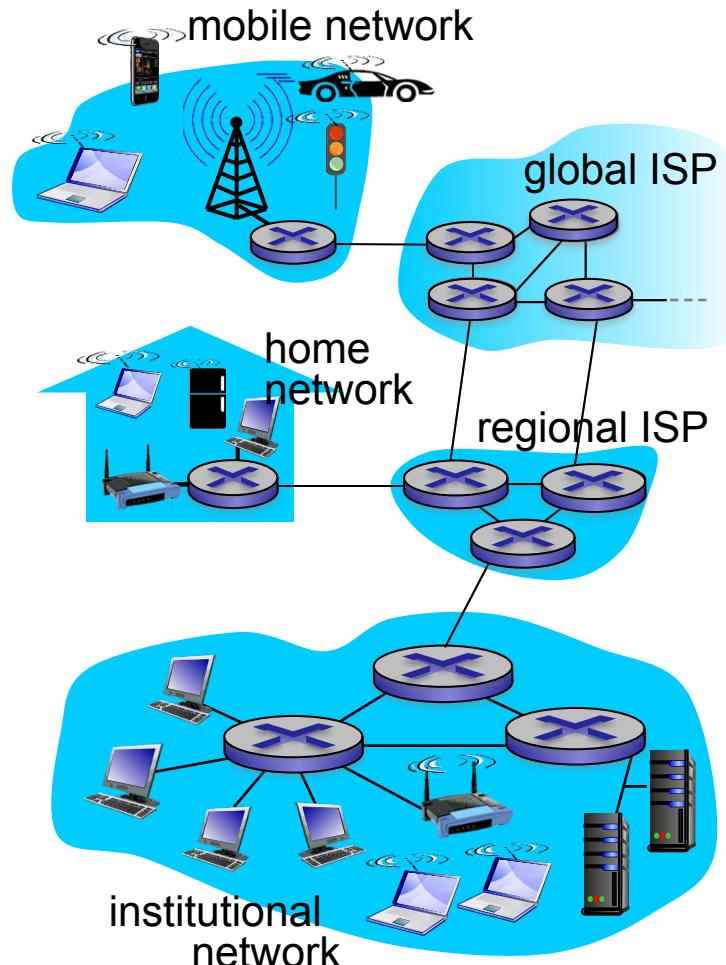
# What's the Internet: “nuts and bolts” view

- **Internet: “network of networks”**
  - Interconnected ISPs
- **protocols** control sending, receiving of messages
  - e.g., TCP, IP, HTTP, Skype, 802.11
- **Internet standards**
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



# What's the Internet: a service view

- *infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social nets, ...
- *provides programming interface to apps*
  - hooks that allow sending and receiving app programs to “connect” to Internet
  - 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 messages  
received, or other  
events

## *network protocols:*

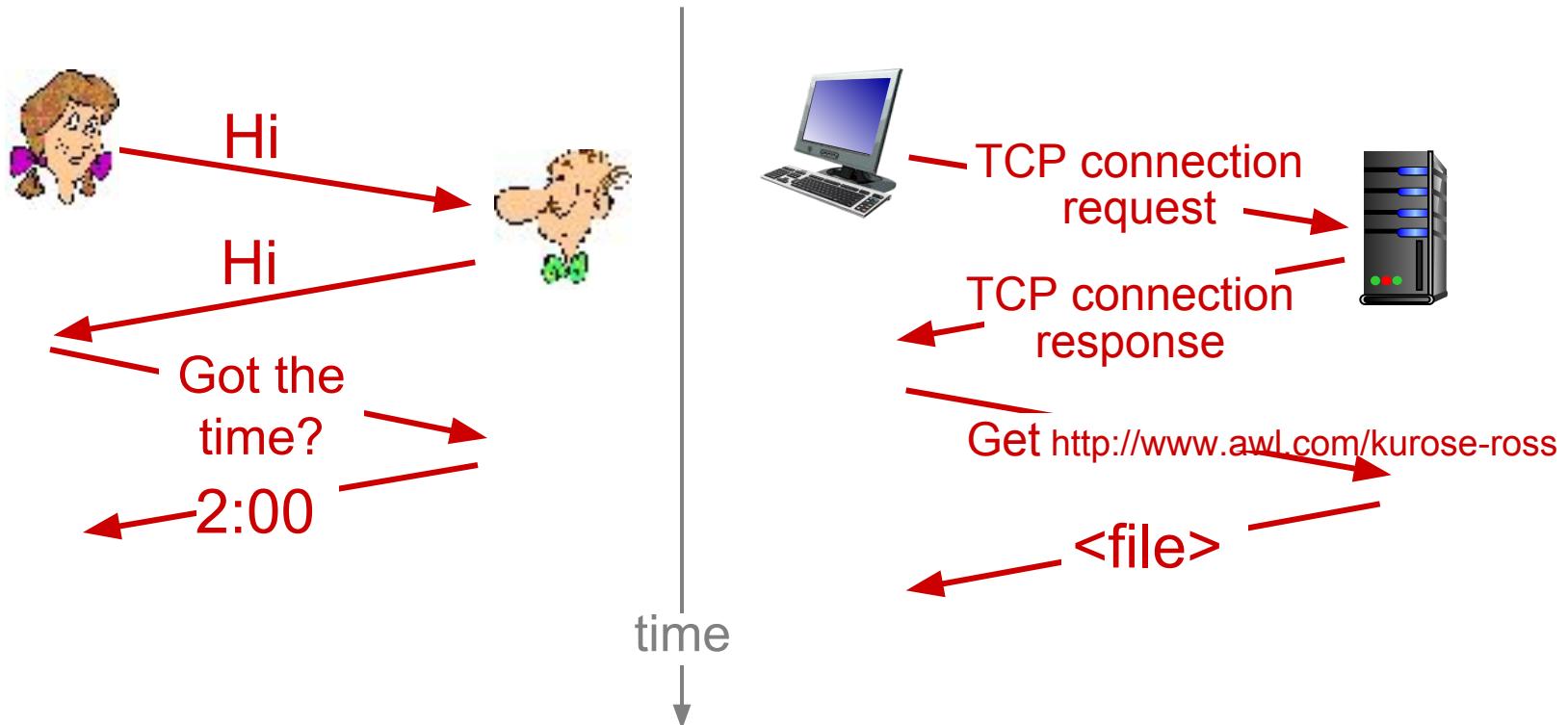
- machines rather than humans
- all communication activity in Internet governed by protocols

*protocols define 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?

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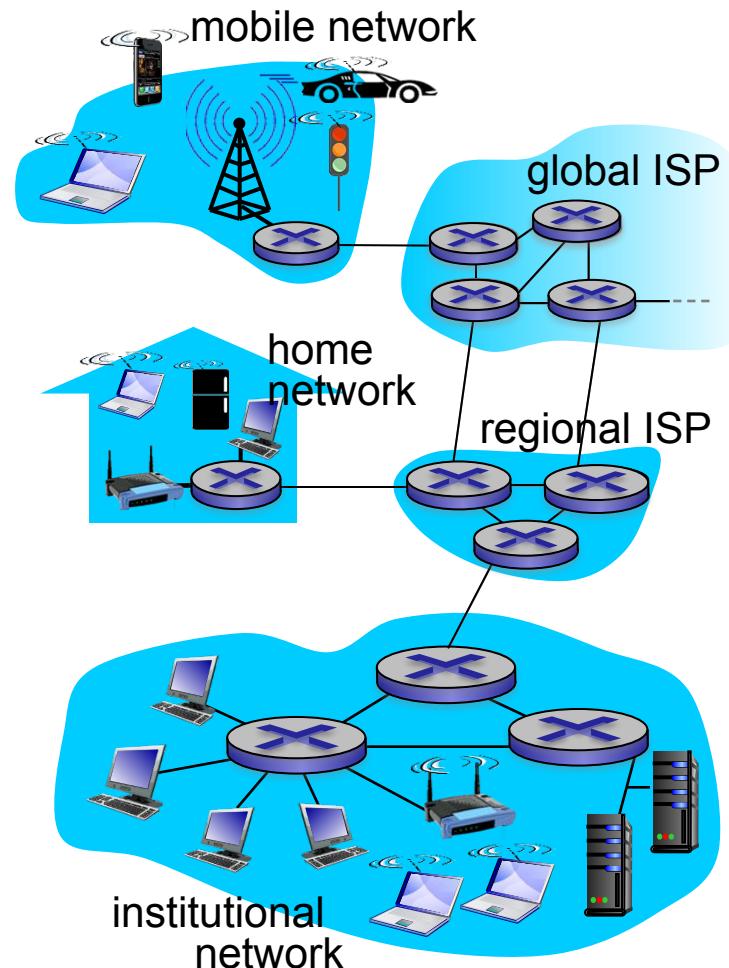
I.5 protocol layers, service models

I.6 networks under attack: security

I.7 history

# A closer look at network 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



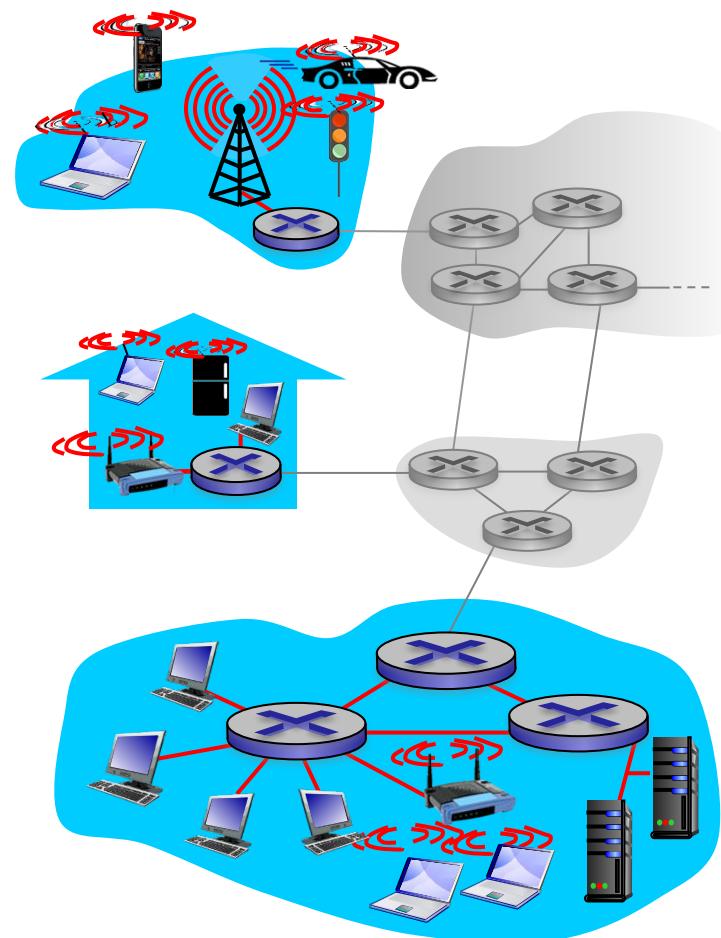
# Access networks and physical media

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

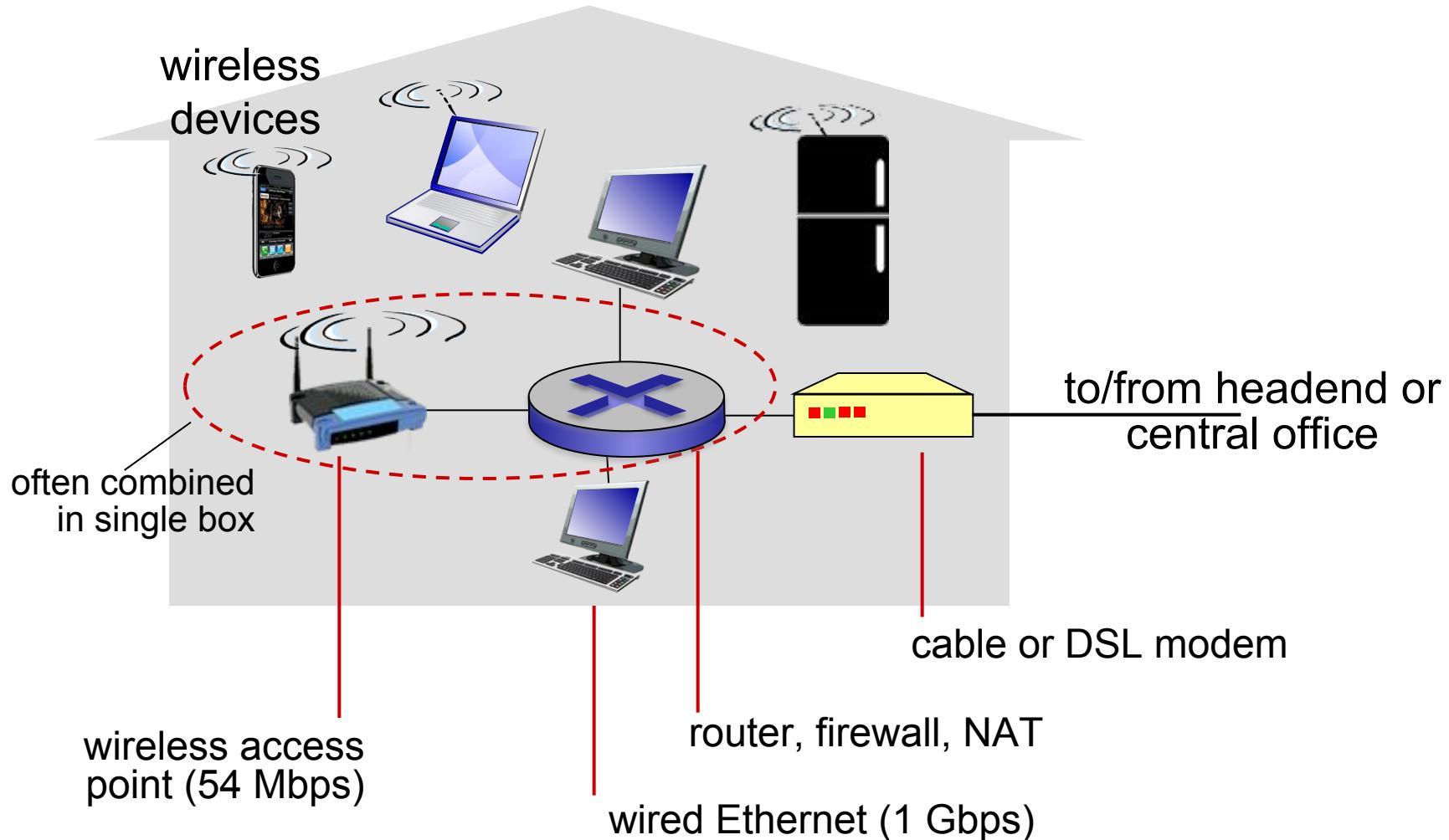
- residential access nets
- institutional access networks (school, company)
- mobile access networks

*keep in mind:*

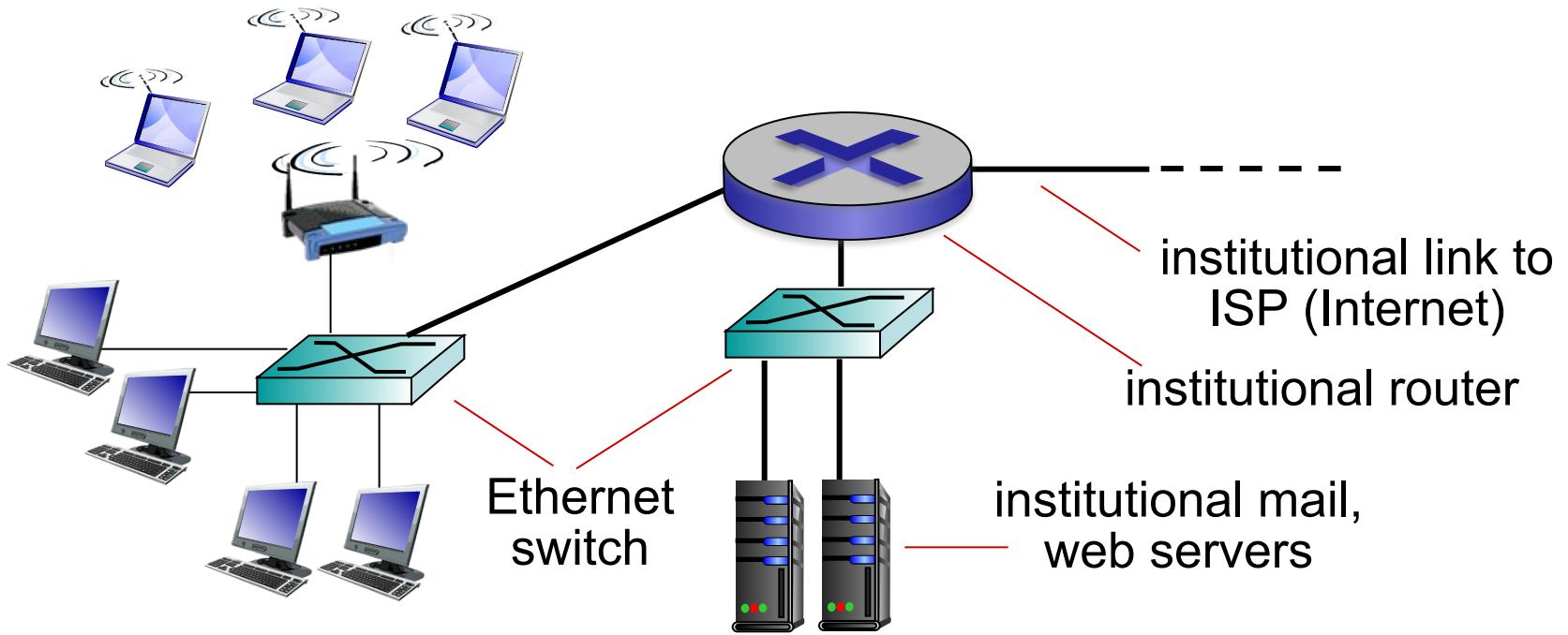
- bandwidth (bits per second) of access network?
- shared or dedicated?



# Access network: home network



# Enterprise access networks (Ethernet)



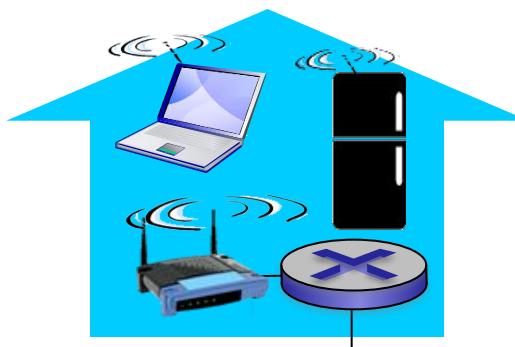
- typically used in companies, universities, etc.
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

# Wireless access networks

- shared wireless access network connects end system to router
  - via base station aka “access point”

## wireless LANs:

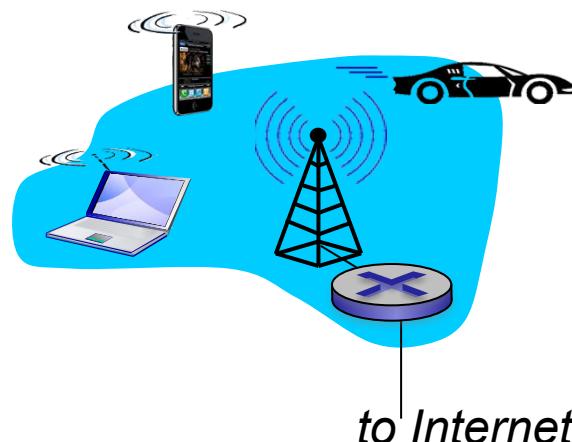
- within building (100 ft.)
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate



*to Internet*

## wide-area wireless access

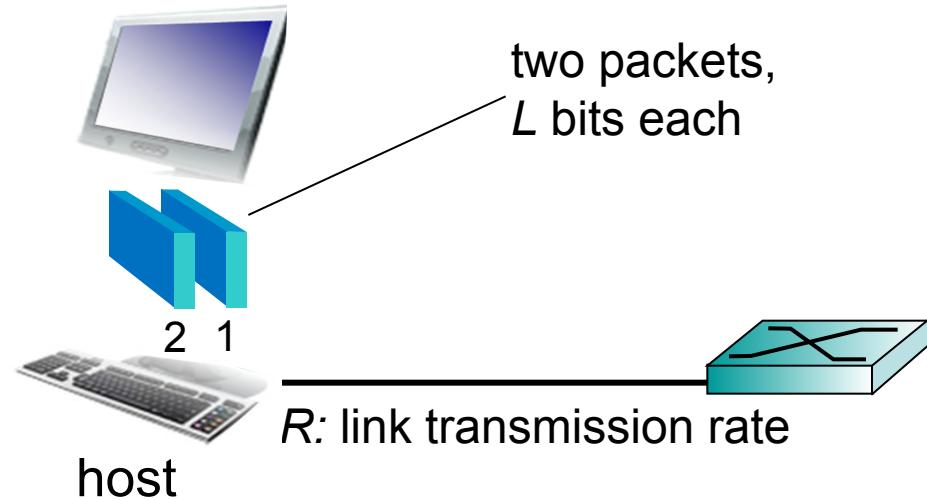
- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G



# 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*



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

# 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



# Physical media: coax, fiber

## *coaxial cable:*

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple channels on cable
  - HFC



## *fiber optic cable:*

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



# Physical media: radio

- signal carried in electromagnetic spectrum
- no physical “wire”
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

## *radio link types:*

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 54 Mbps
- wide-area (e.g., cellular)
  - 4G cellular: ~ 10 Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

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I.3 network core

- packet switching, circuit switching, network structure

I.4 delay, loss, throughput in networks

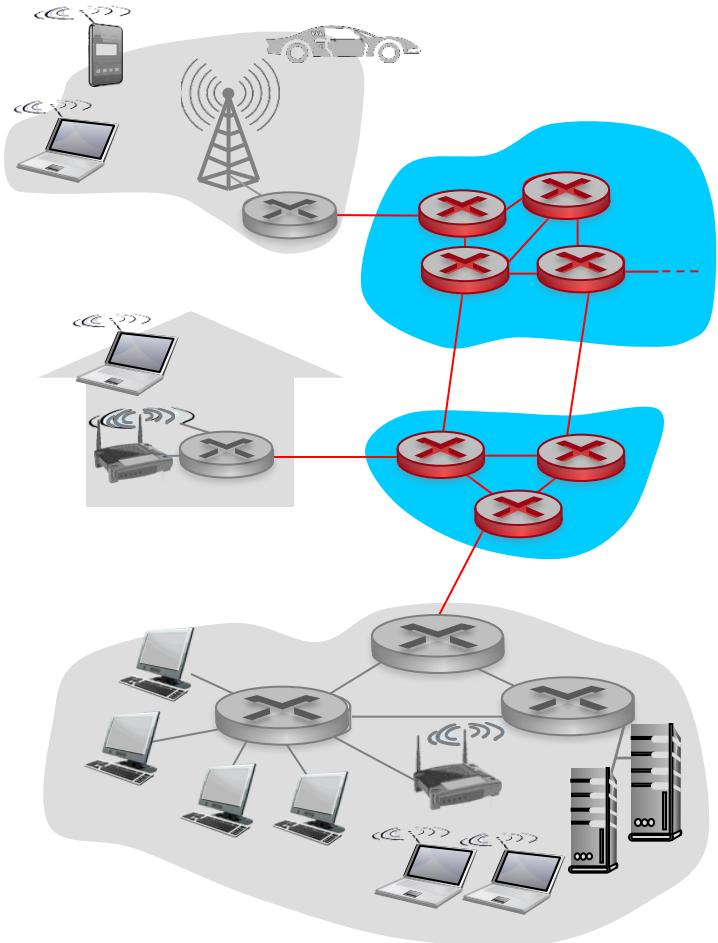
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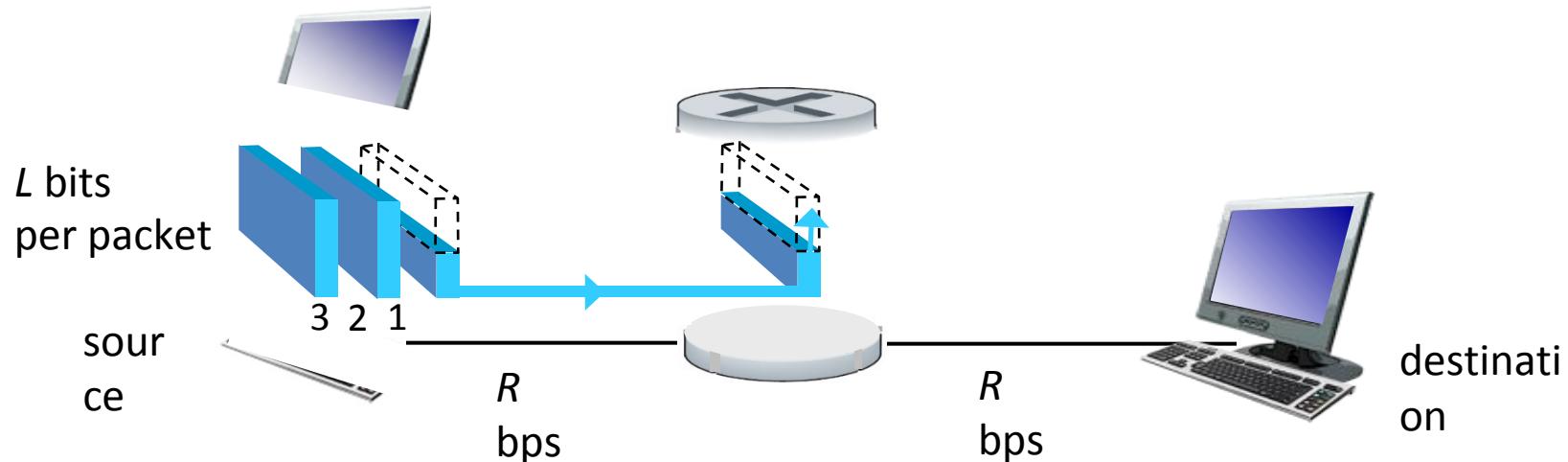
I.7 history

# 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



# Packet-switching: store-and-forward



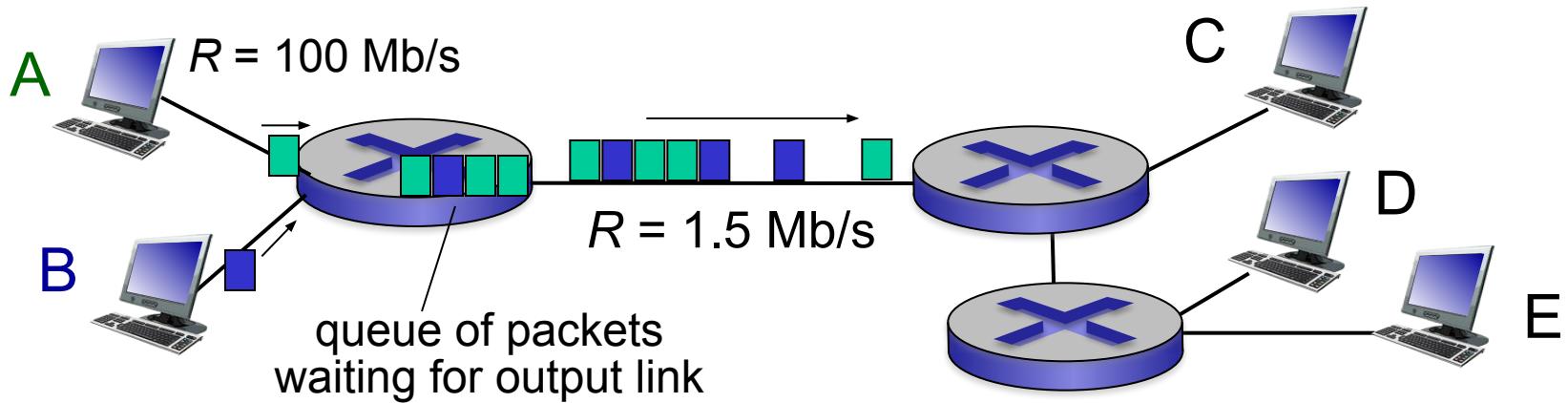
- takes  $L/R$  seconds to transmit (push out)  $L$ -bit packet into link at  $R$  bps
- **store and forward:** entire packet must arrive at router before it can be transmitted on next link
- end-end delay =  $2L/R$  (assuming zero propagation delay)

*one-hop numerical example:*

- $L = 7.5$  Mbits
- $R = 1.5$  Mbps
- one-hop transmission delay = 5 sec

} more on delay shortly ...

# Packet Switching: queueing delay, loss



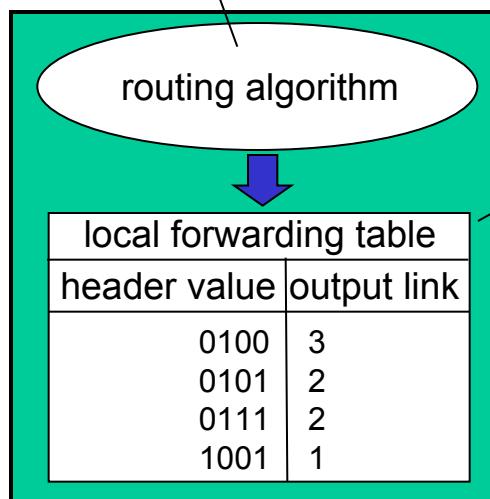
## queuing and loss:

- if arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

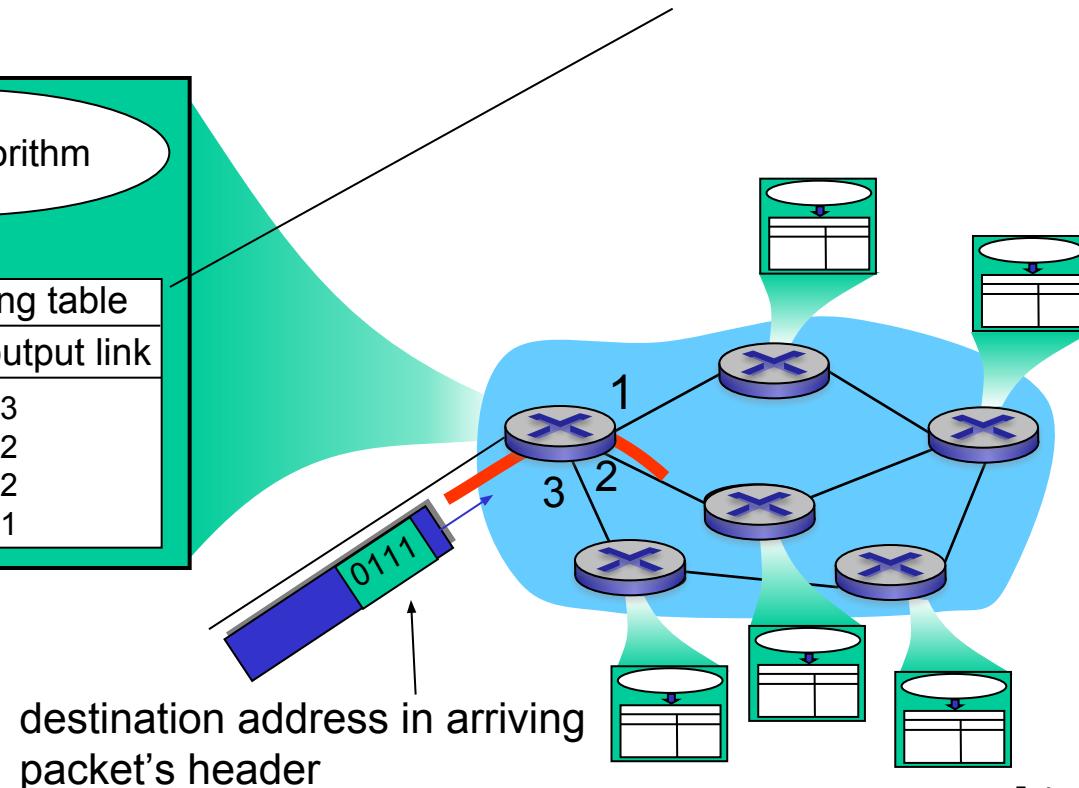
# Two key network-core functions

**routing:** determines source-destination route taken by packets

- *routing algorithms*



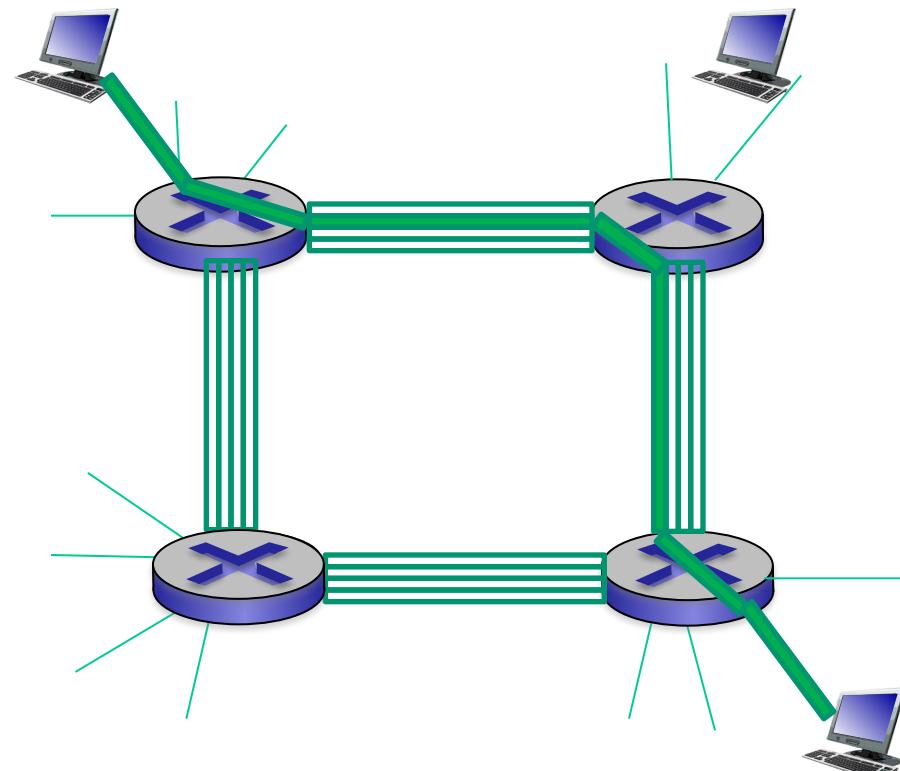
**forwarding:** move packets from router's input to appropriate router output



# Alternative core: circuit switching

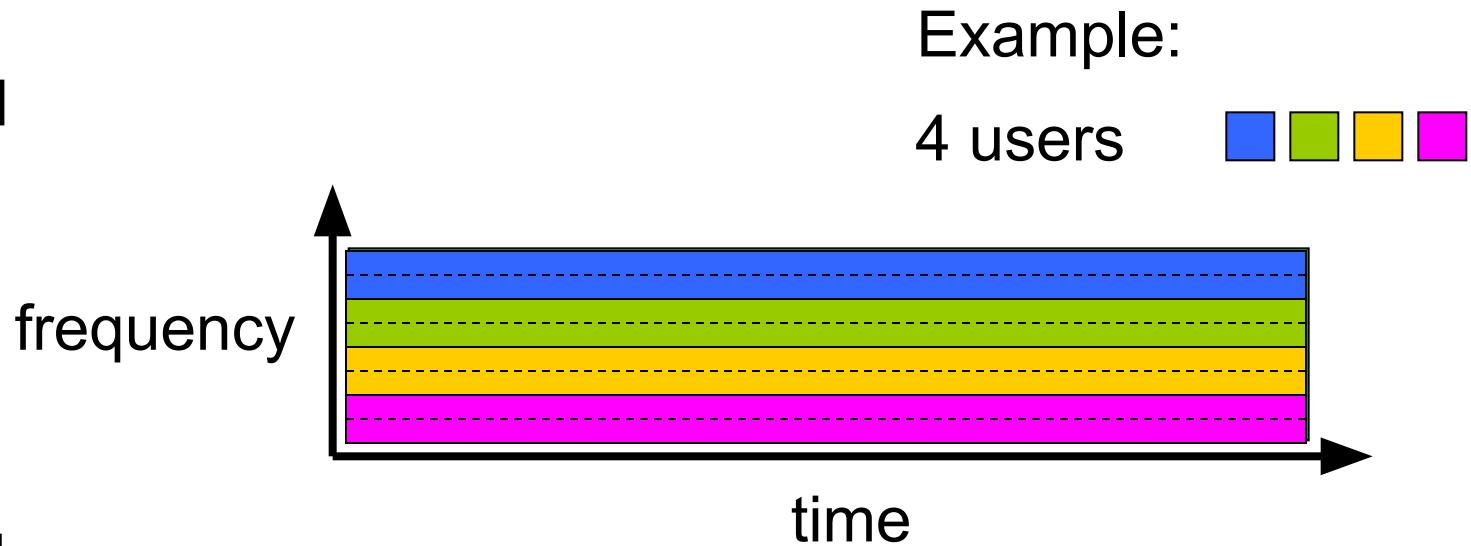
end-end resources allocated  
to, reserved for “call”  
between source & dest:

- 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

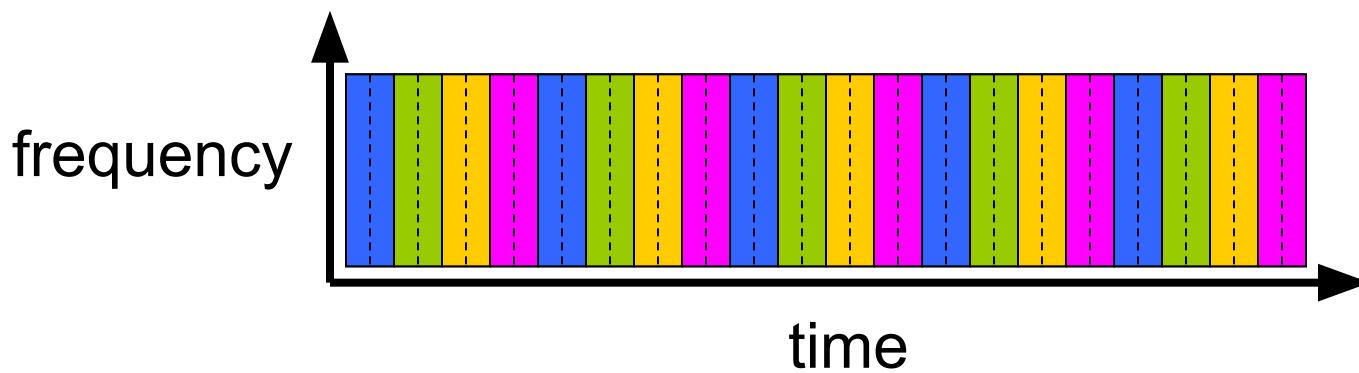


# Circuit switching: FDM versus TDM

FDM



TDM

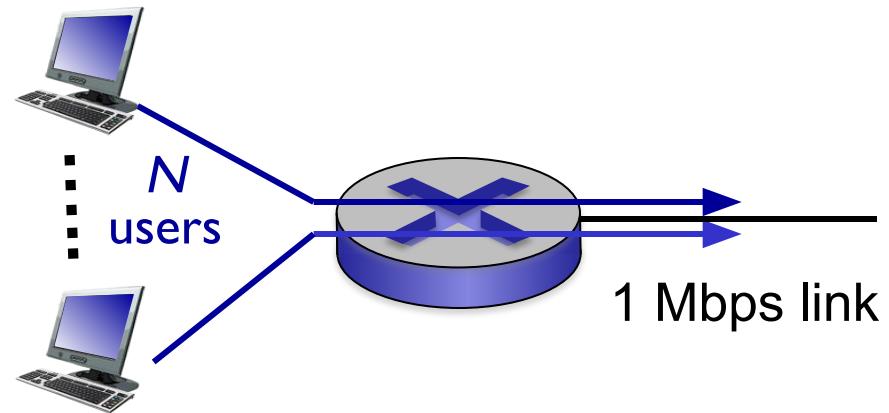


# Packet switching versus circuit switching

*packet switching allows more users to use network!*

example:

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

*Q: what happens if > 35 users  
?*

\* 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
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- Q: How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 7)

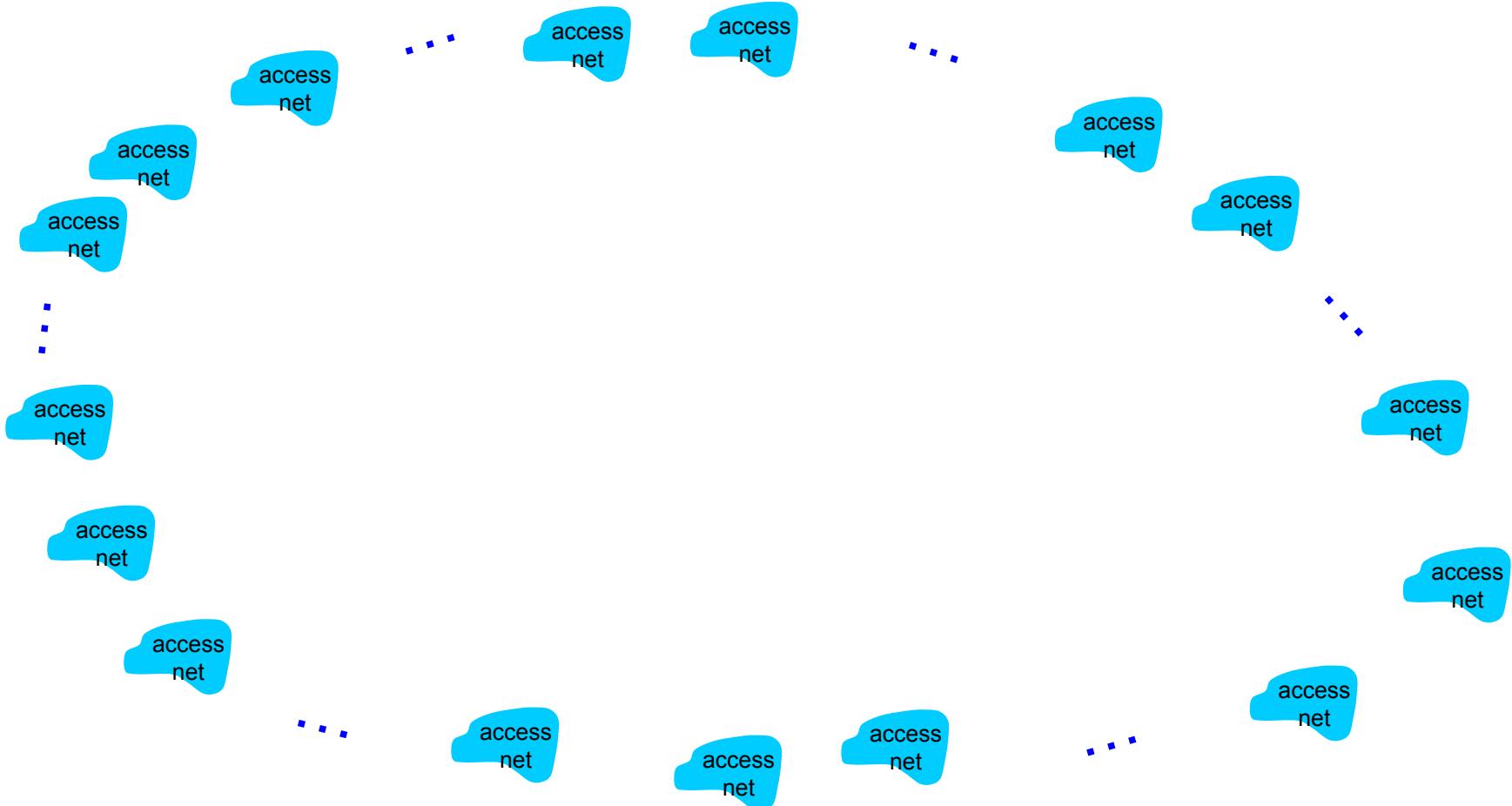
Q: human analogies of reserved resources (circuit switching)  
versus on-demand allocation (packet-switching)?

# Internet structure: network of networks

- End systems connect to Internet via **access ISPs** (Internet Service Providers)
  - residential, company and university ISPs
- Access ISPs in turn must be interconnected.
  - so that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - evolution was driven by **economics** and **national policies**
- Let's take a stepwise approach to describe current Internet structure

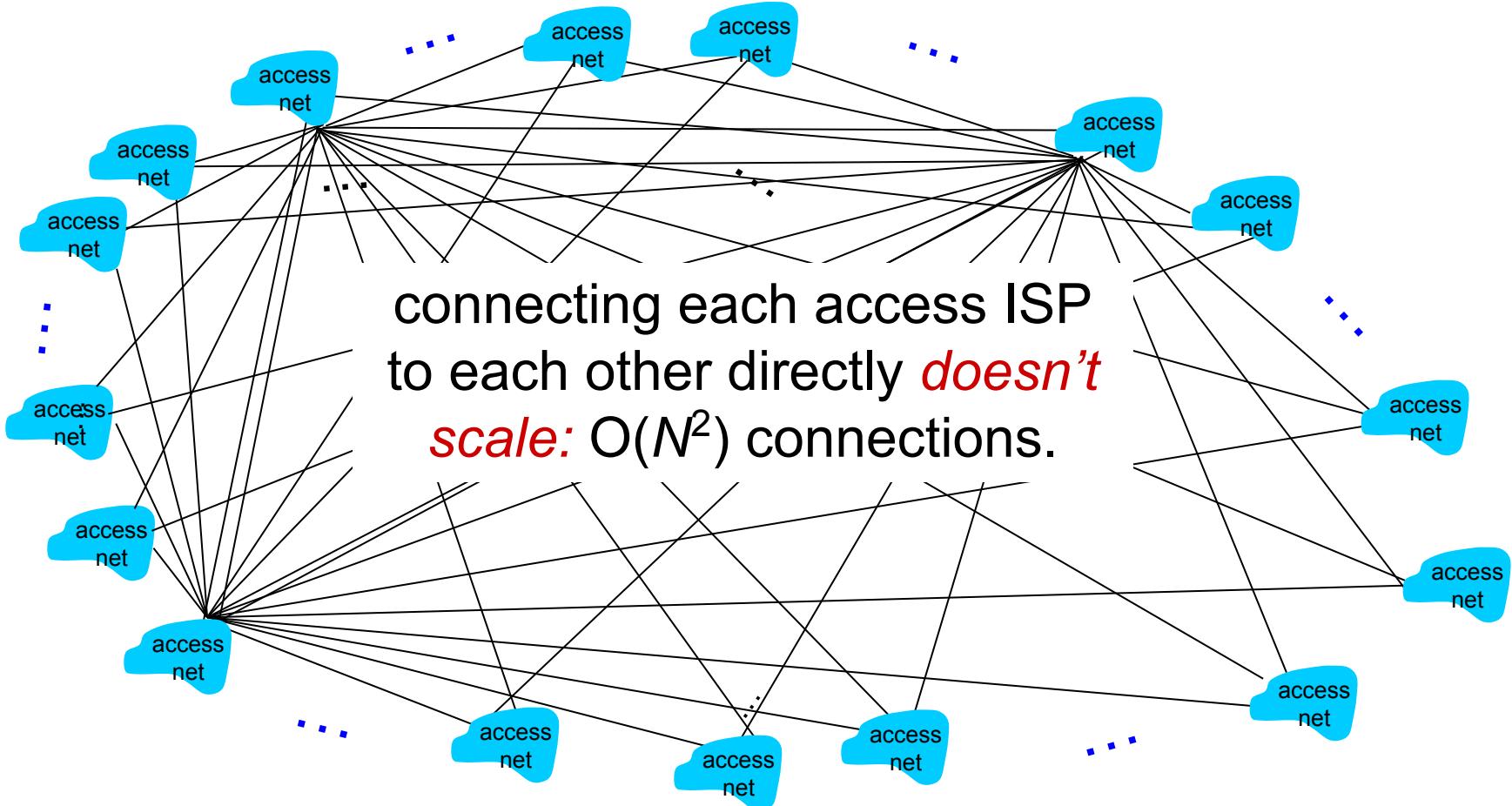
# Internet structure: network of networks

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



# Internet structure: network of networks

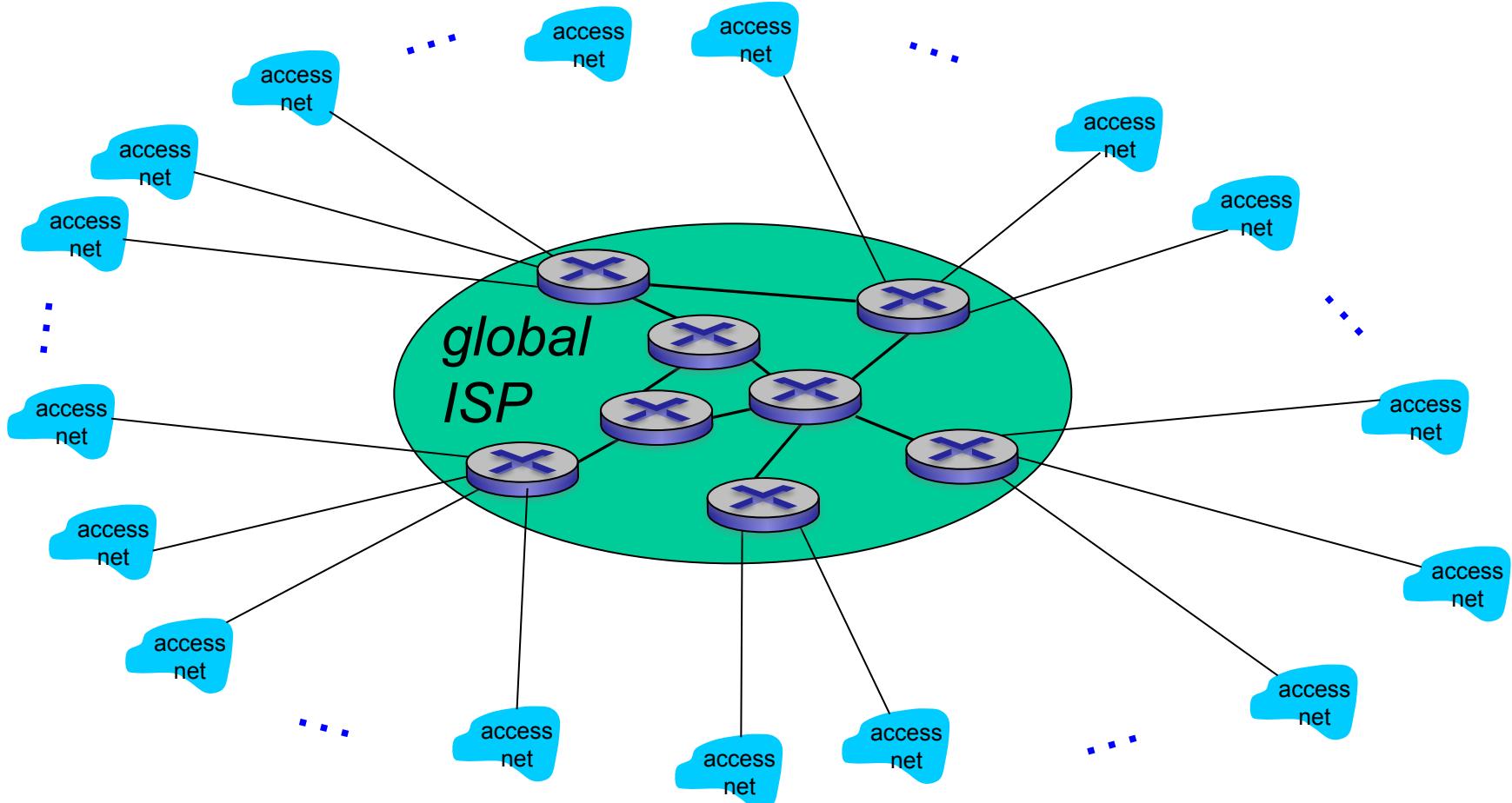
*Option: connect each access ISP to every other access ISP?*



# Internet structure: network of networks

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

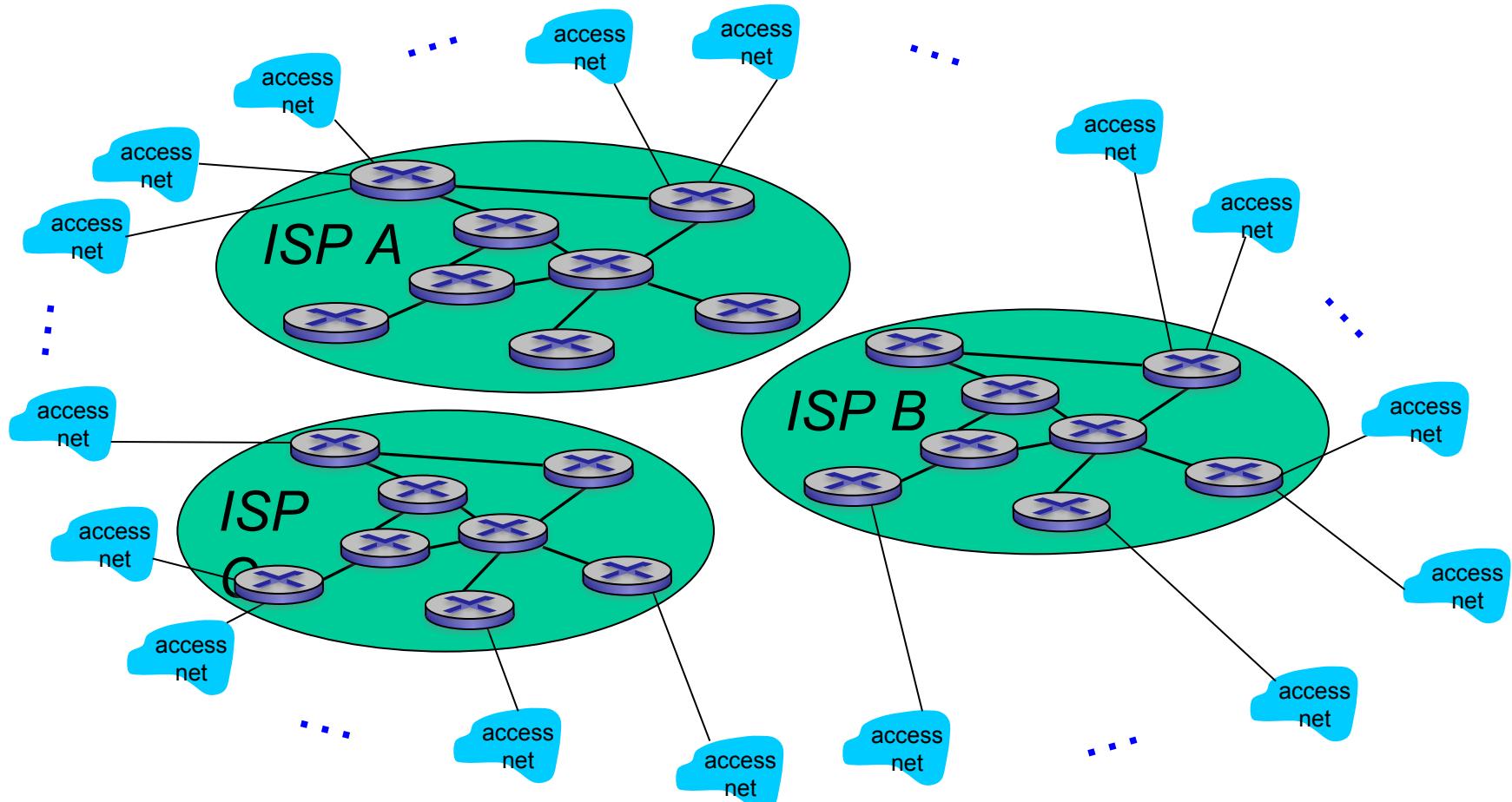
*Customer and provider ISPs have economic agreement.*



# Internet structure: network of networks

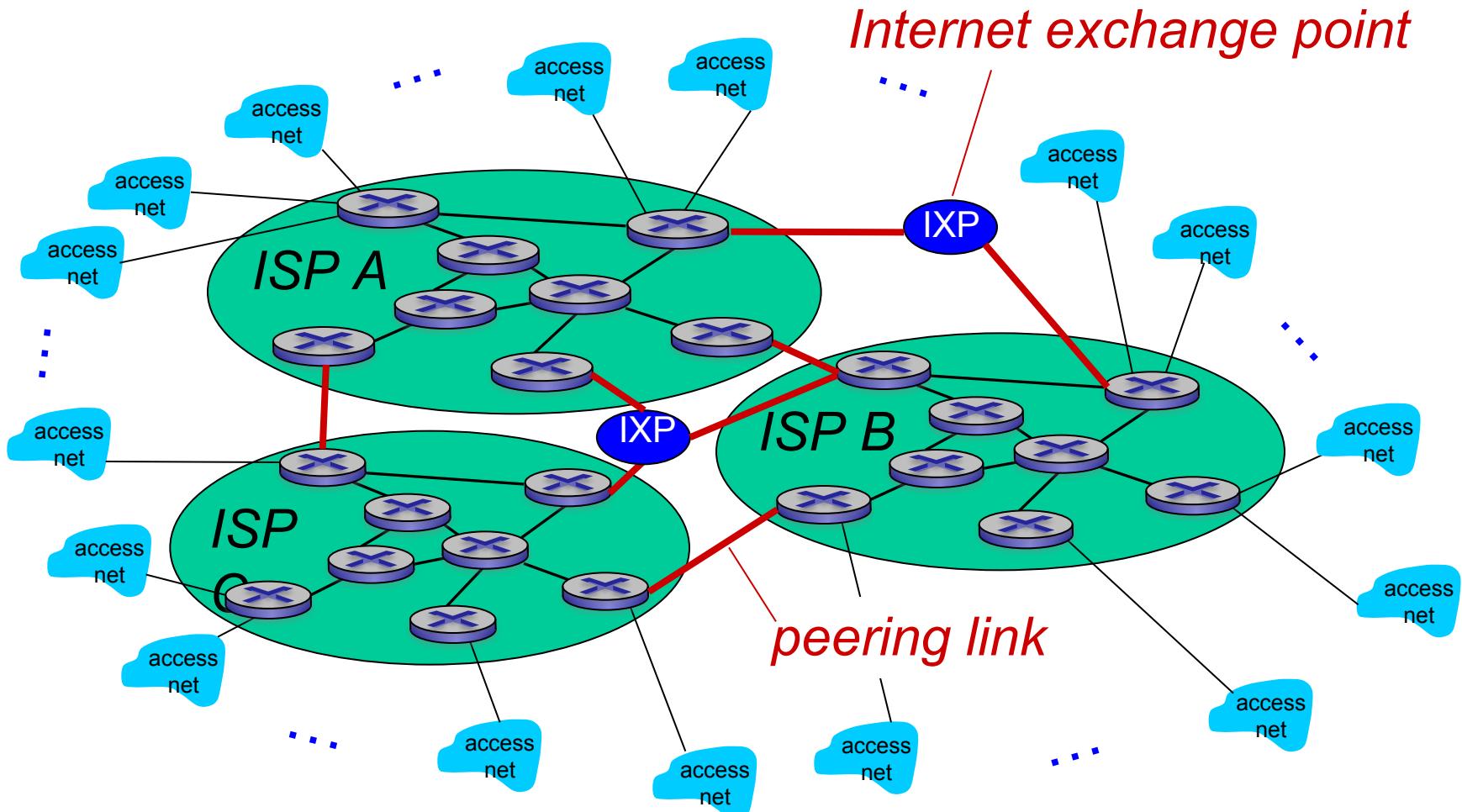
But if one global ISP is viable business, there will be competitors

....



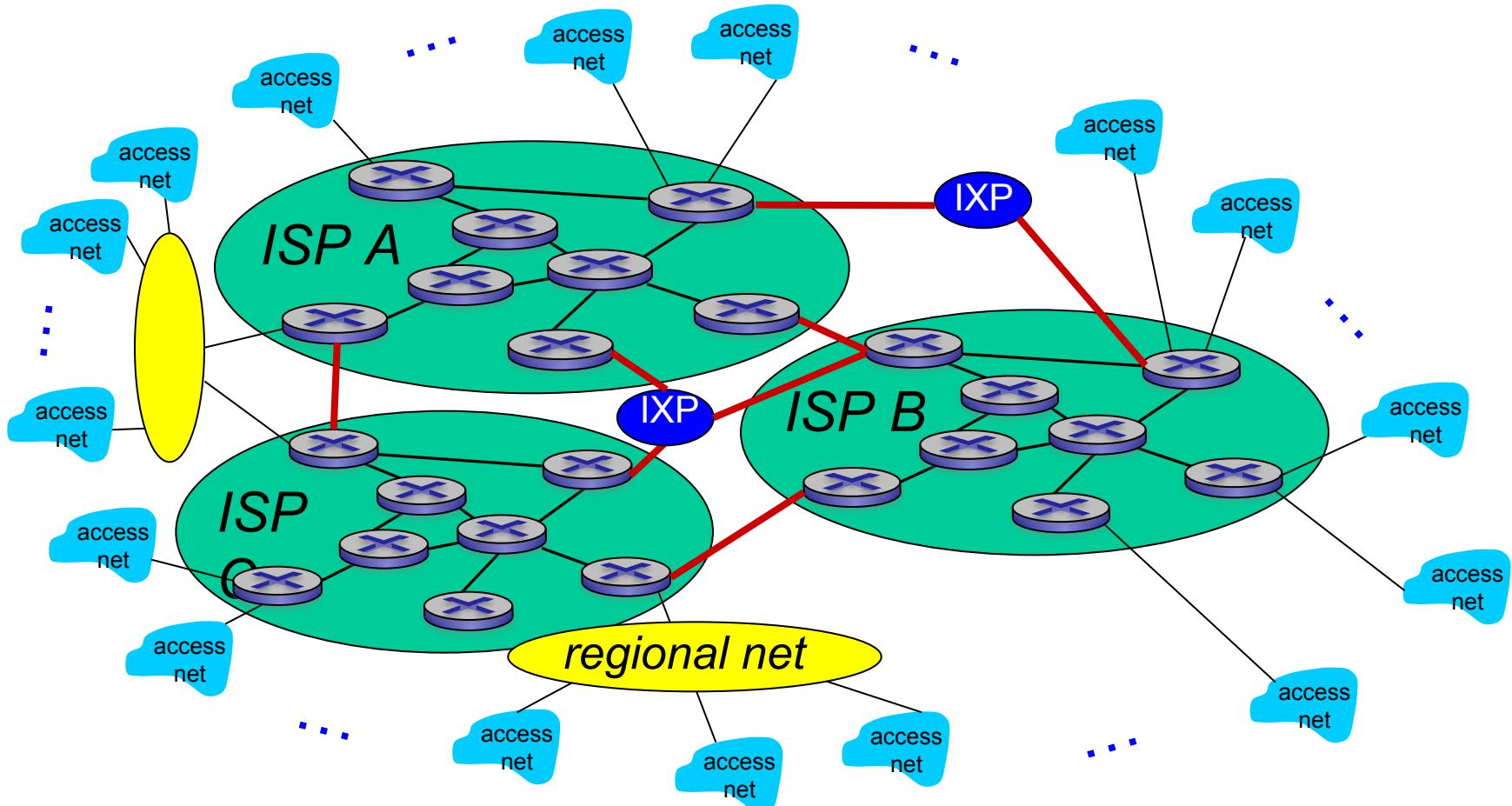
# Internet structure: network of networks

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



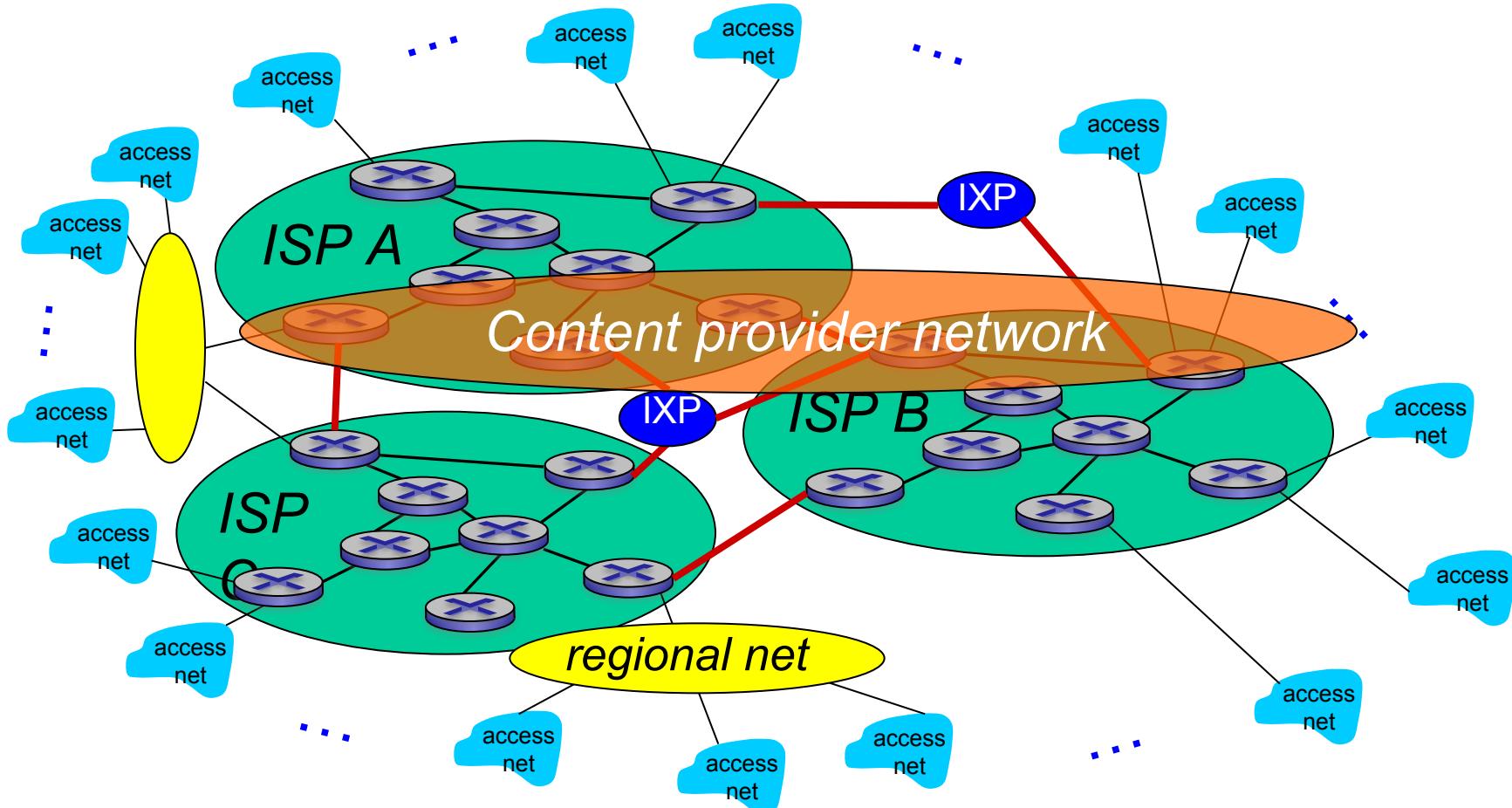
# Internet structure: network of networks

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

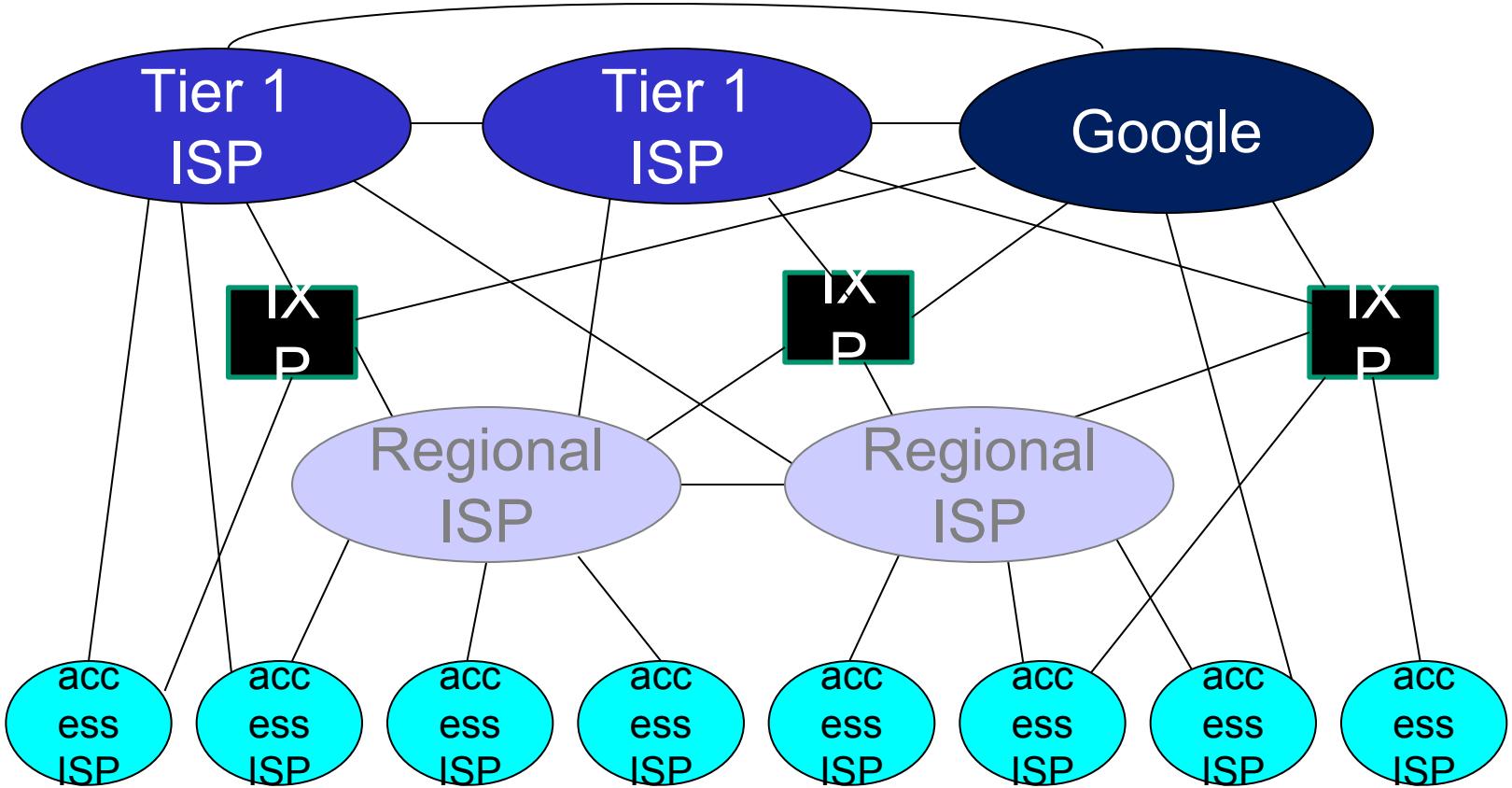


# Internet structure: network of networks

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

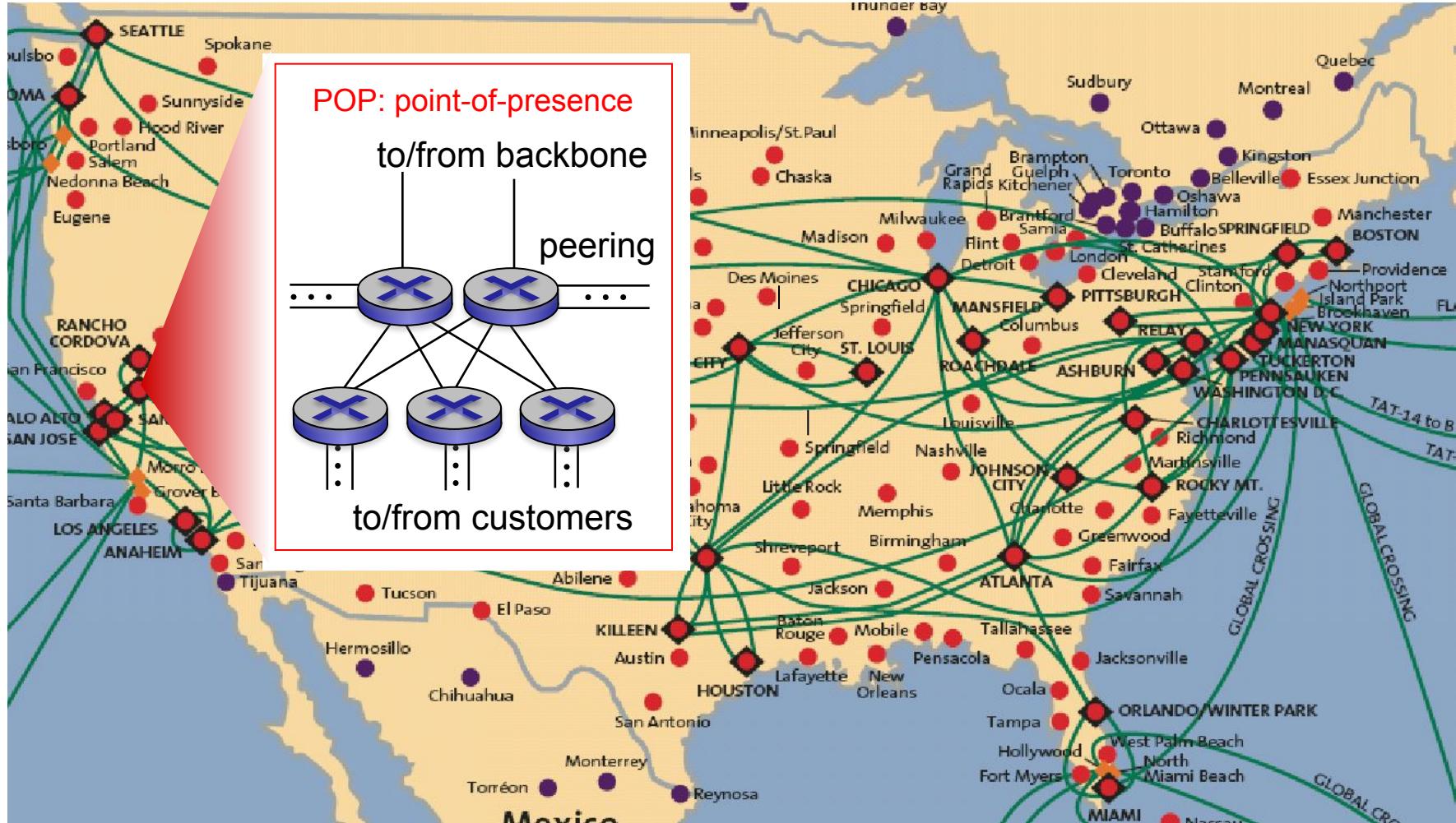


# Internet structure: network of networks



- 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 network (e.g., Google): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs

# Tier-1 ISP: e.g., Sprint



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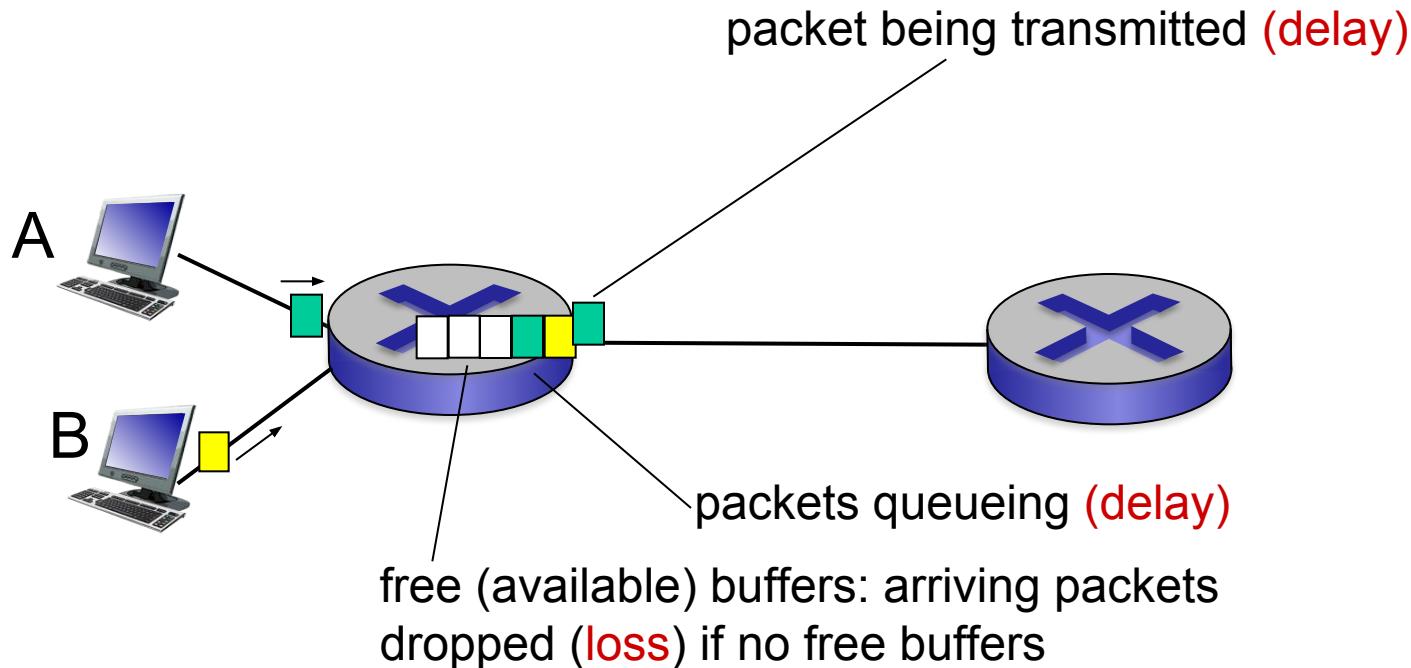
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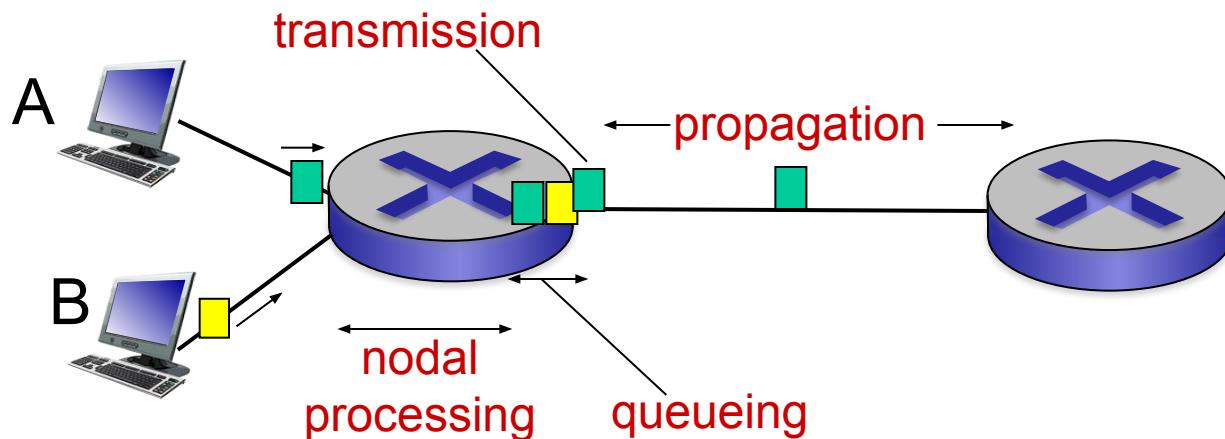
# How do loss and delay occur?

packets *queue* in router buffers

- packet arrival rate to link (temporarily) exceeds output link capacity
- packets queue, wait for turn



# Four sources of packet delay



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

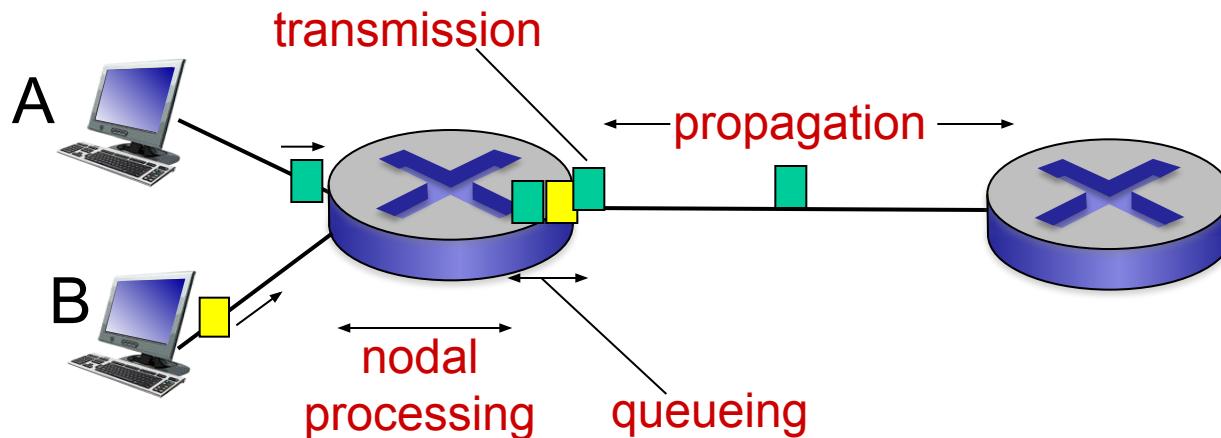
$d_{\text{proc}}$ : nodal processing

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

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

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

# Four sources of packet delay



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

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

- $L$ : packet length (bits)
- $R$ : link *bandwidth (bps)*
- $d_{\text{trans}} = L/R$  ←  $d_{\text{trans}}$  and  $d_{\text{prop}}$  →  
*very different*

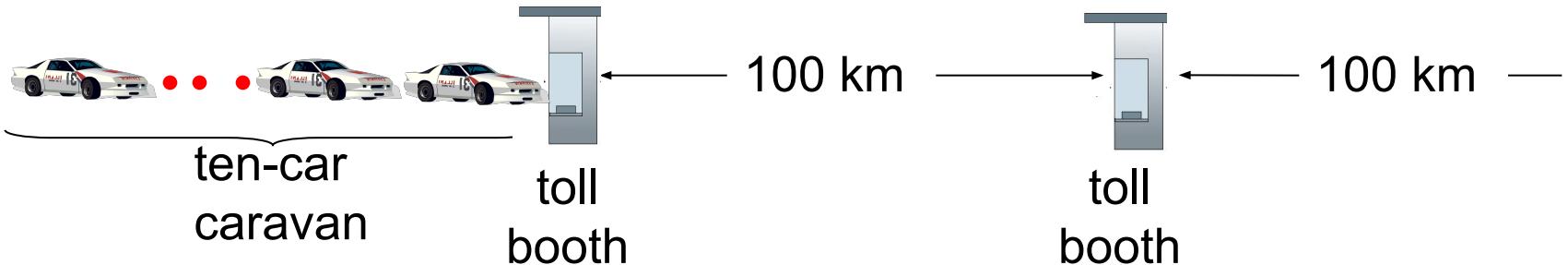
$d_{\text{prop}}$ : propagation delay:

- $d$ : 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 for more examples: [http://gaia.cs.umass.edu/kurose\\_ross/interactive/](http://gaia.cs.umass.edu/kurose_ross/interactive/)

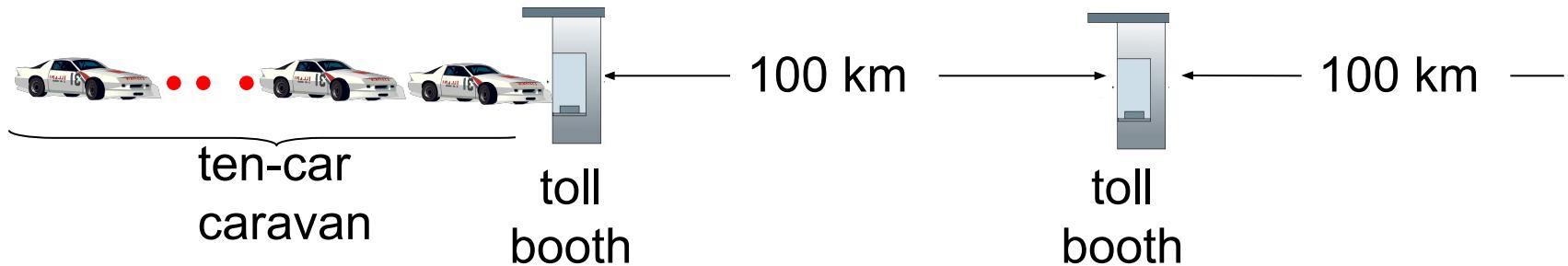
\* Check out the Java applet for an interactive animation on trans vs. prop delay

# Caravan analogy



- cars “propagate” at 100 km/hr
- toll booth takes 12 sec to service car (bit transmission time)
- car ~ bit; caravan ~ packet
- **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:  
 $100\text{km}/(100\text{km/hr})= 1\text{ hr}$
- **A: 62 minutes**

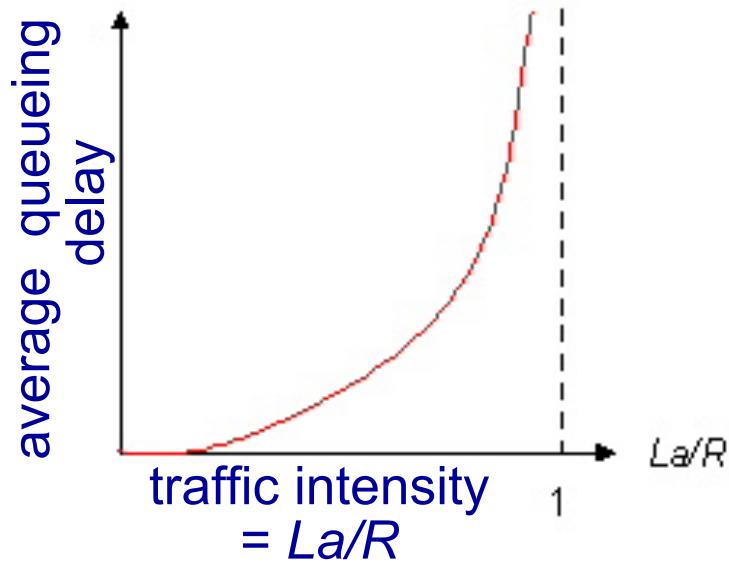
# Caravan analogy (more)



- 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

# Queueing delay (revisited)

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



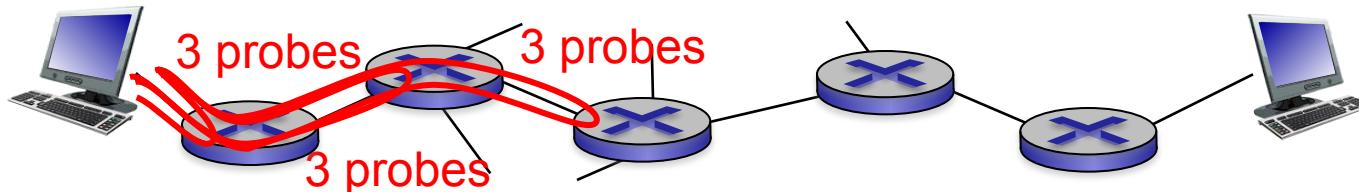
- $La/R \sim 0$ : avg. queueing delay small
- $La/R \rightarrow 1$ : avg. queueing delay large
- $La/R > 1$ : more “work” arriving than can be serviced, average delay infinite!



\* Check online interactive animation on queuing and loss

# “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
  - router  $i$  will return packets to sender
  - sender times interval between transmission and reply.



# “Real” Internet delays, 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	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

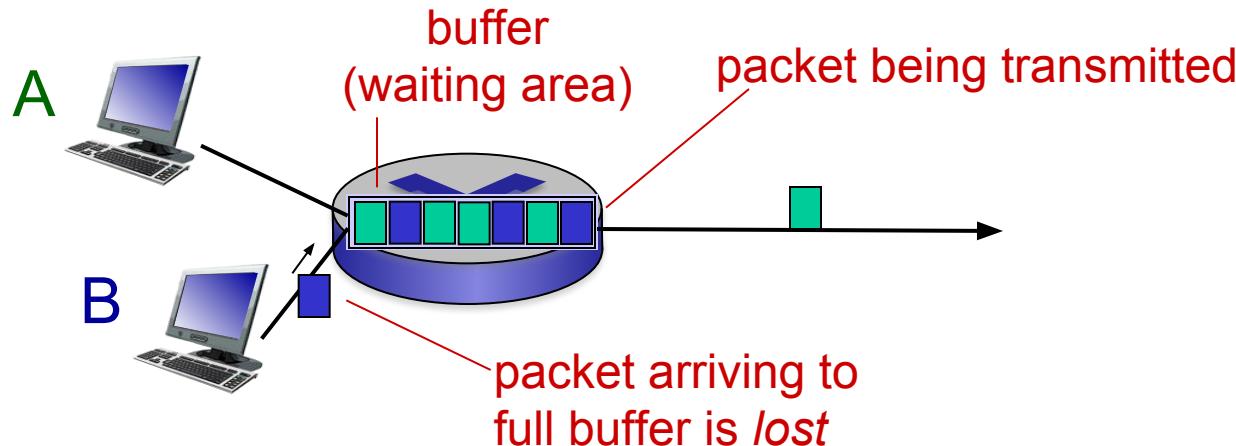
\* means no response (probe lost, router not replying)

trans-oceanic link

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

# Packet loss

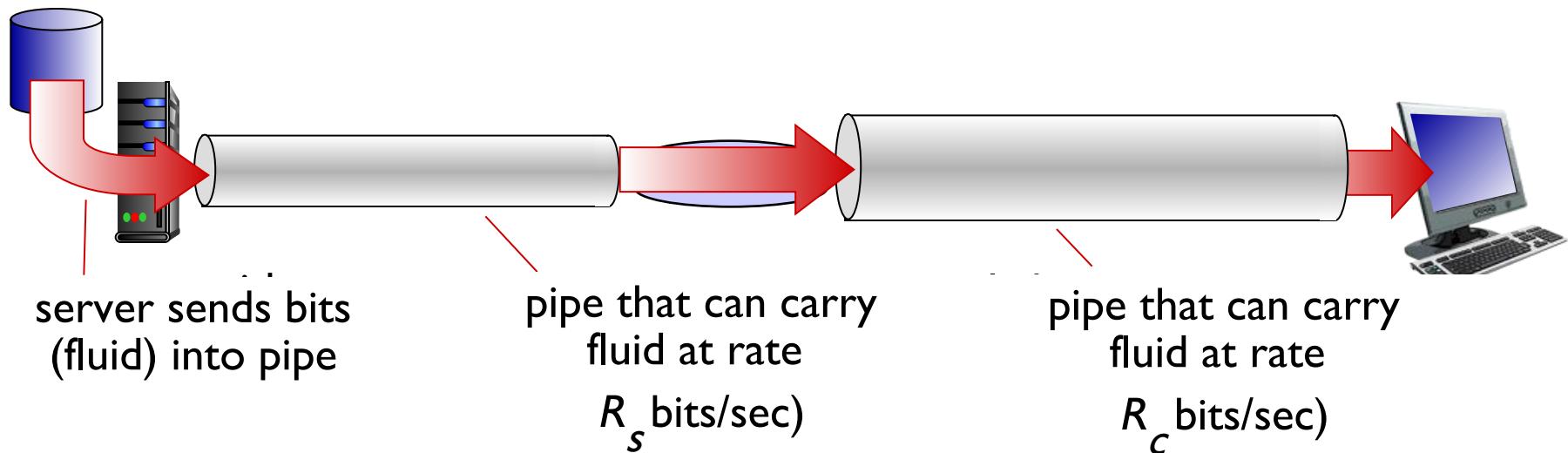
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



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

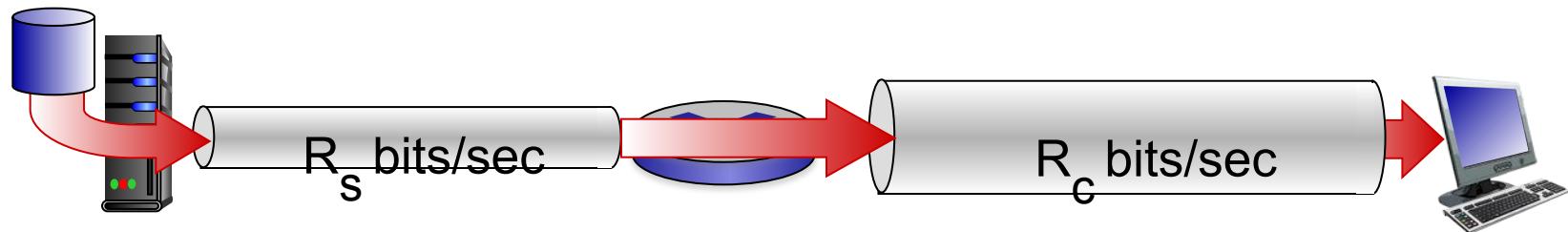
# Throughput

- **throughput:** rate (bits/time unit) at which bits transferred between sender/receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time

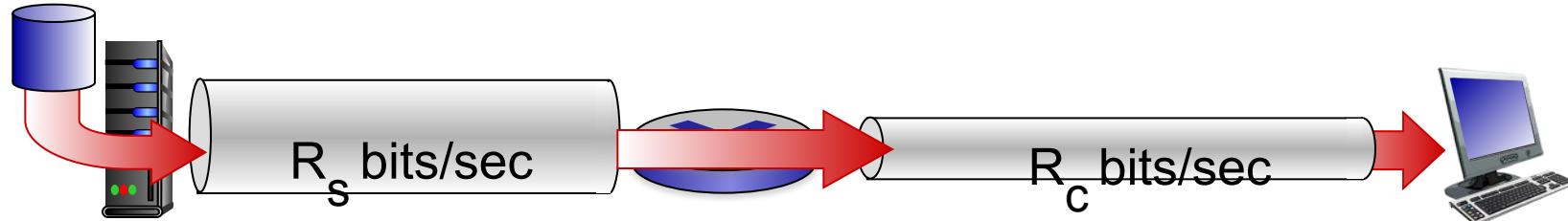


# Throughput (more)

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



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

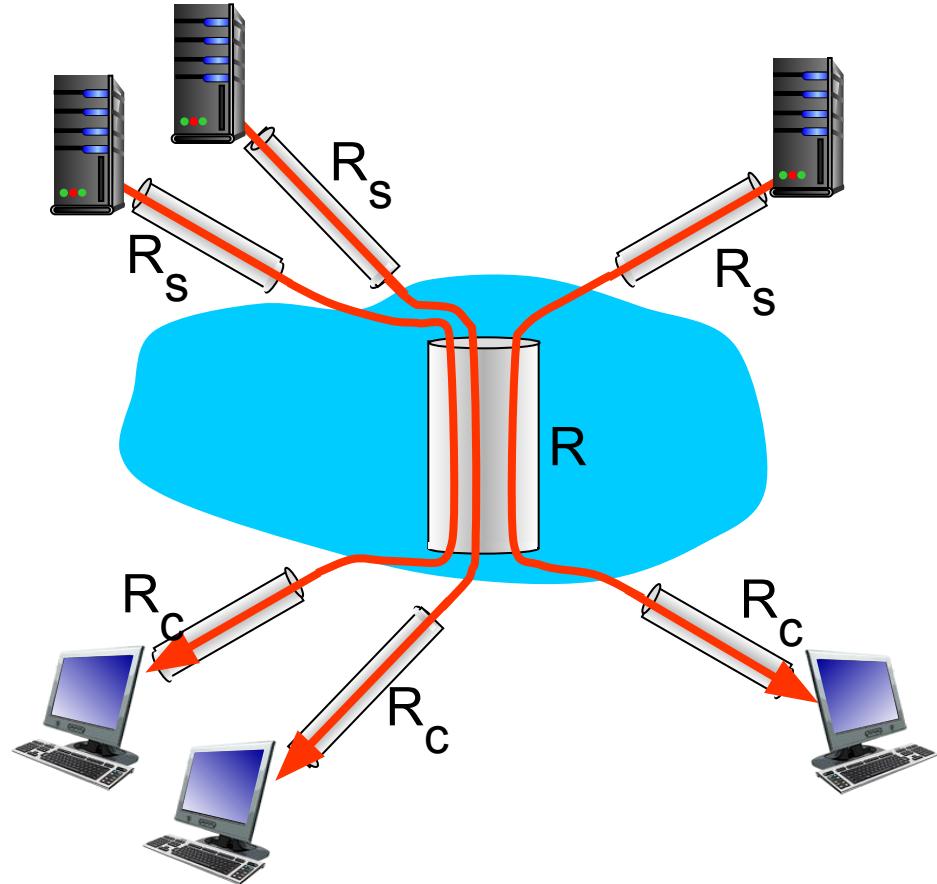


*bottleneck*

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

# Throughput: Internet scenario

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



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

\* 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/)

# Chapter I: roadmap

I.1 what *is* the Internet?

I.2 network edge

- end systems, access networks, links

I.3 network core

- packet switching, circuit switching, network structure

I.4 delay, loss, throughput in networks

I.5 protocol layers, service models

I.6 networks under attack: security

I.7 history

# Protocol “layers”

*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?*

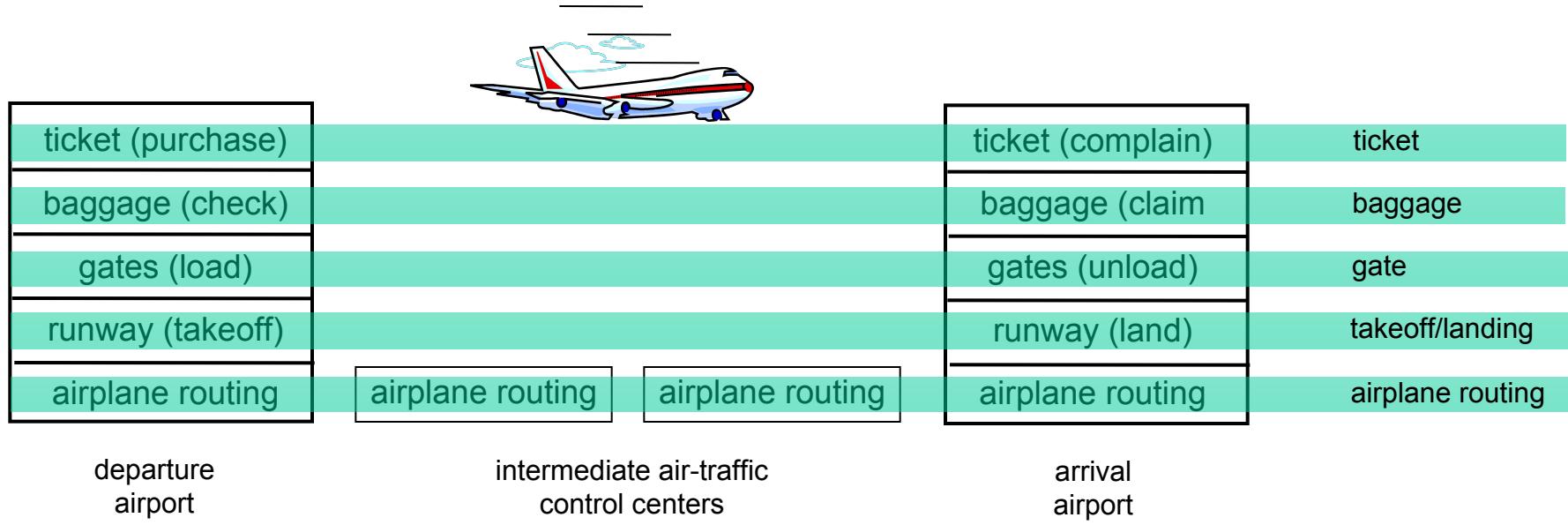
.... or at least our  
discussion of networks?

# Organization of air travel



- a series of steps

# Layering of airline functionality



*layers:* each layer implements a service

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

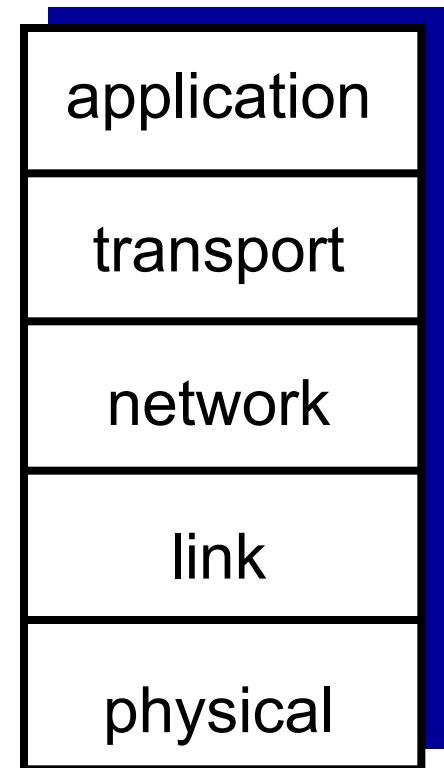
# Why layering?

dealing with complex systems:

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

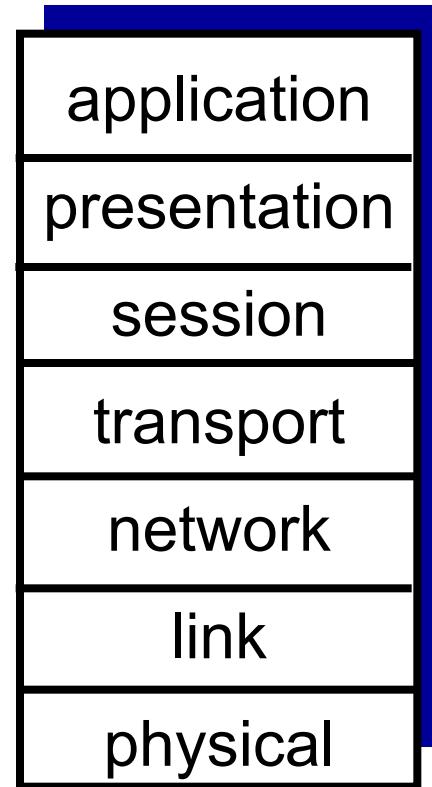
# Internet protocol stack

- *application*: supporting network applications
  - FTP, SMTP, HTTP
- *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, 802.111 (WiFi), PPP
- *physical*: bits “on the wire”

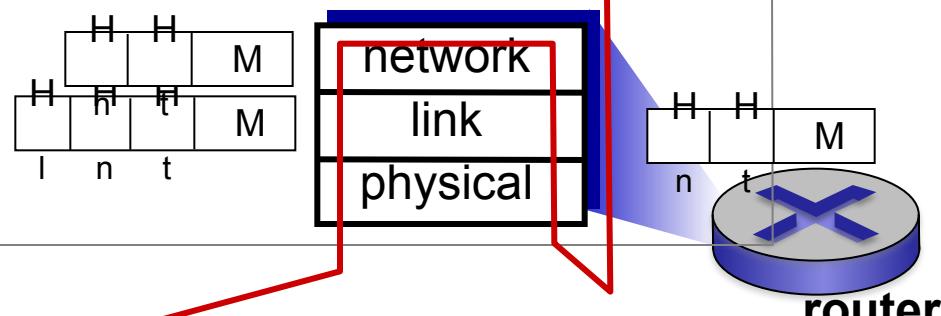
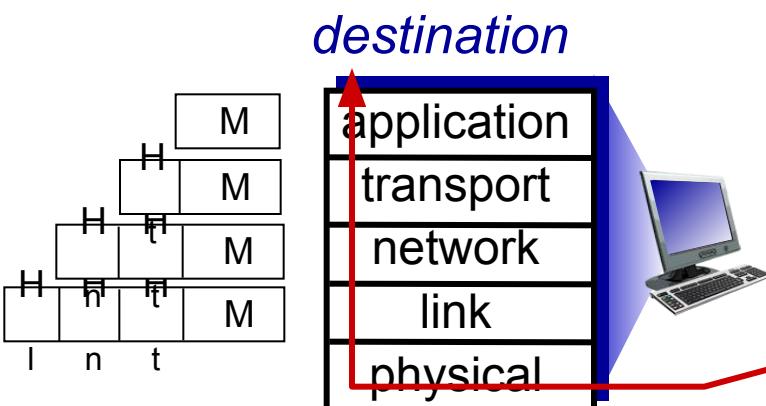
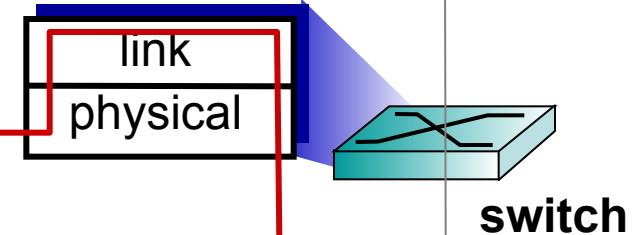
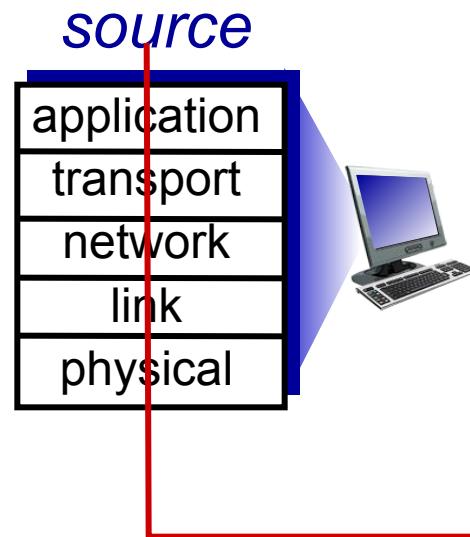
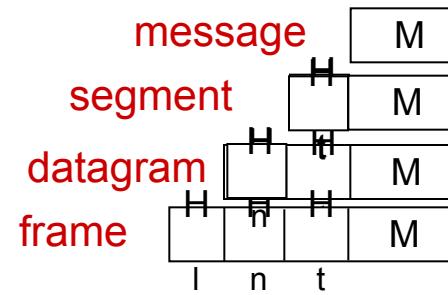


# ISO/OSI reference model

- ***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?



# Encapsulation



# Chapter I: roadmap

## I.1 what *is* the Internet?

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## I.5 protocol layers, service models

## I.6 networks under attack: security

## I.7 history

# Introduction: summary

*covered a “ton” of material!*

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

*you now have:*

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