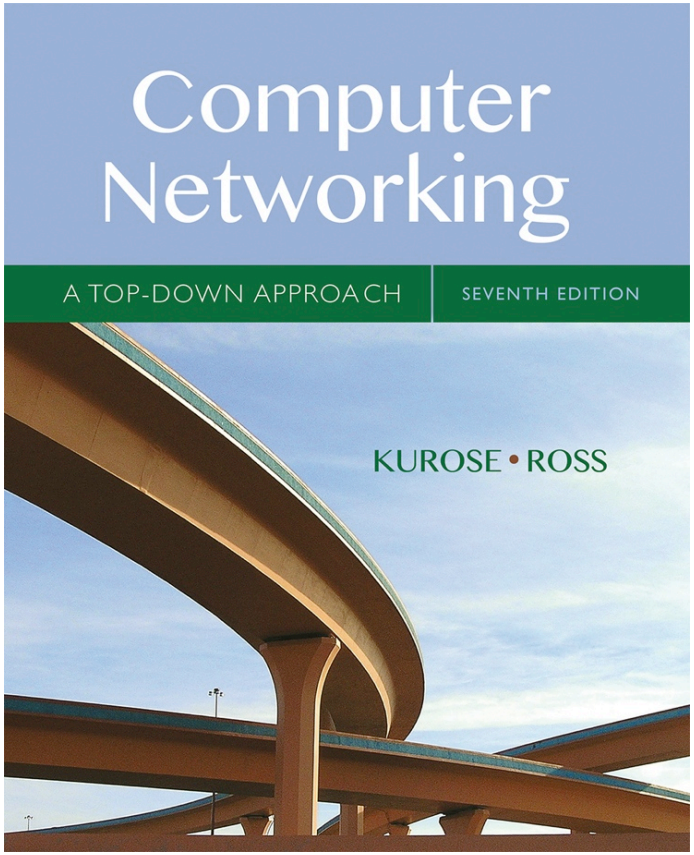
Chapter 1 Introduction



Computer Networking: A Top Down Approach

7th edition
Jim Kurose, Keith Ross
Pearson/Addison Wesley
April 2016

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Thanks and enjoy! JFK/KWR

Chapter 1: 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 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

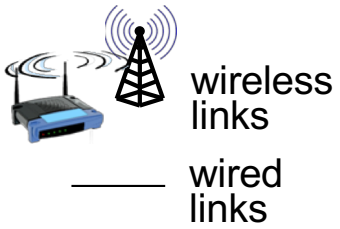
1.5 protocol layers, service models

1.6 networks under attack: security

1.7 history

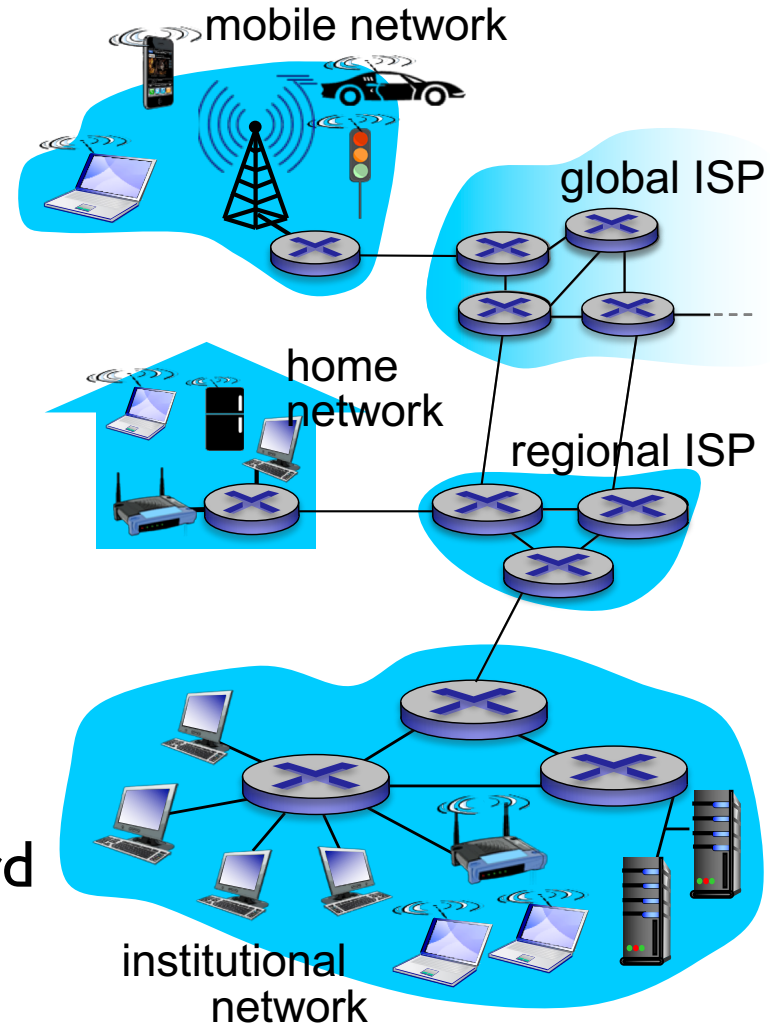
What's the Internet: "nuts and bolts" view

- billions of connected computing devices:
  - _____ = *end systems*
  - running *network apps*



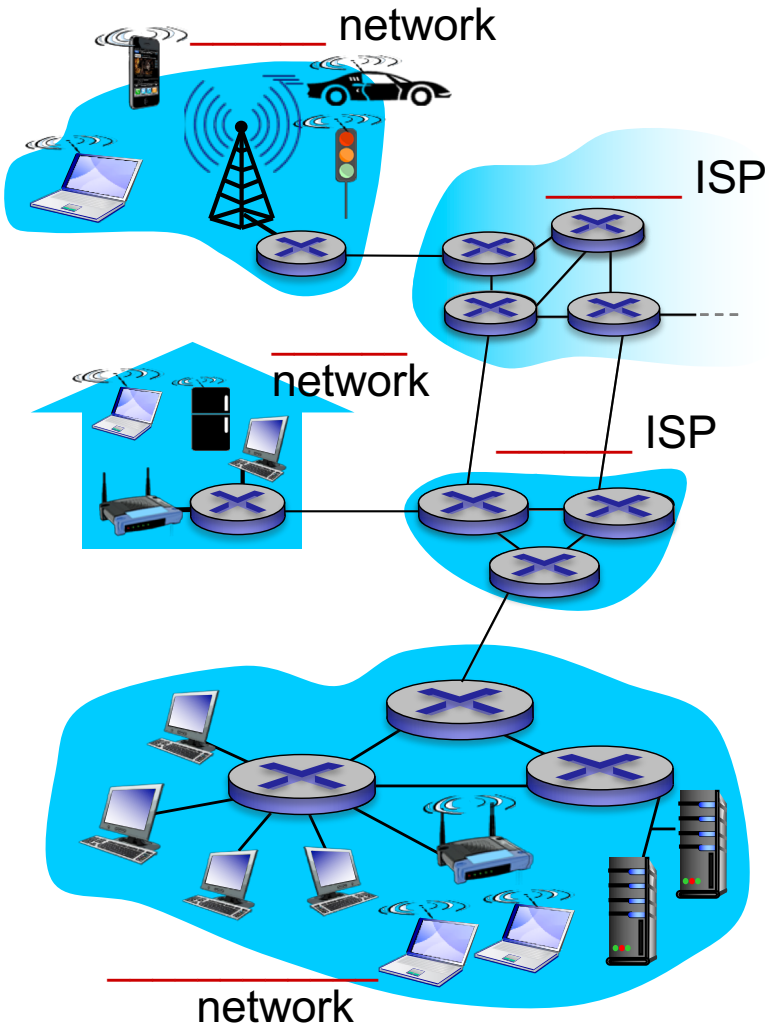
- *communication* _____
  - fiber, copper, radio, satellite
  - transmission rate: _____

- _____ _____: forward packets (chunks of data)
  - _____ and _____



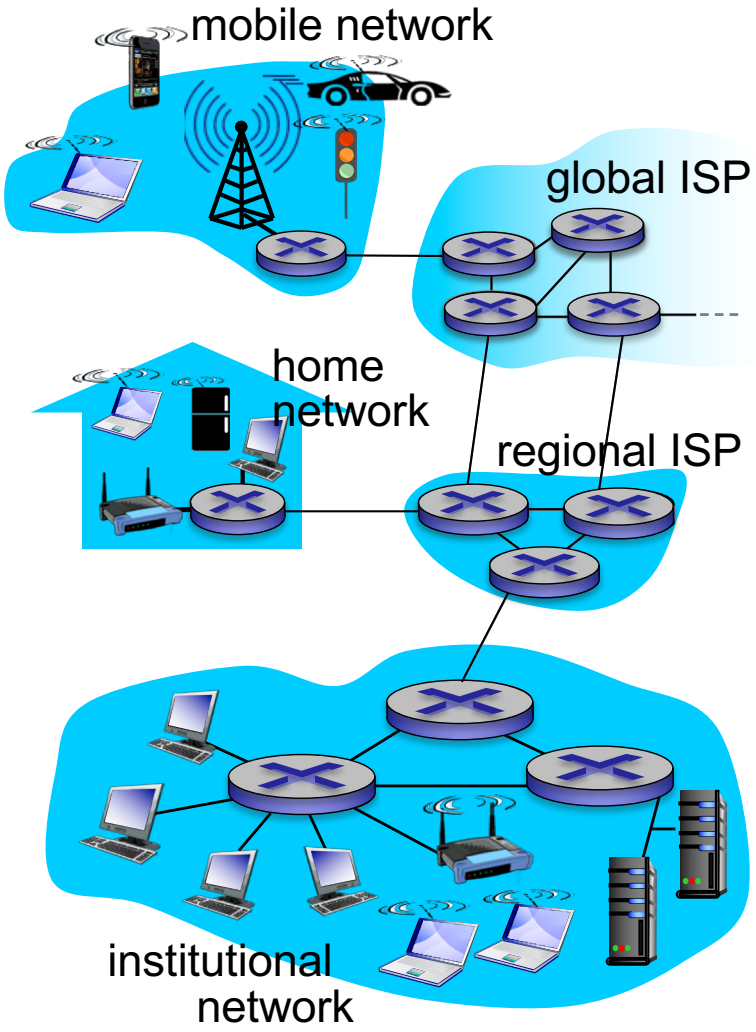
What's the Internet: "nuts and bolts" view

- *Internet:* "_____ of _____"
  - Interconnected ISPs
- _____ control sending, receiving of messages
  - e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  - RFC: _____
  - IETF: _____



What's the Internet: a _____ view

- _____ *that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social nets, …
- *provides* _____ _____ *to apps*
  - hooks that allow sending and receiving app programs to "_____" 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

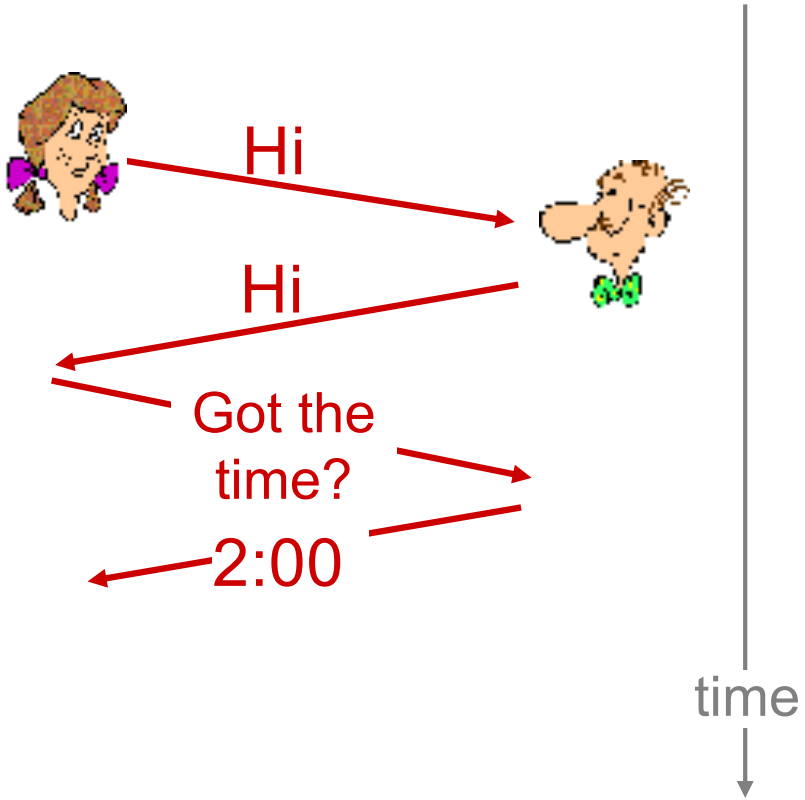
network protocols:

- machines rather than humans
- all _____ _____ in Internet governed by _____

protocols define _____, _____ of _____ _____ and _____ among network entities, and _____ _____ on message transmission, receipt

What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

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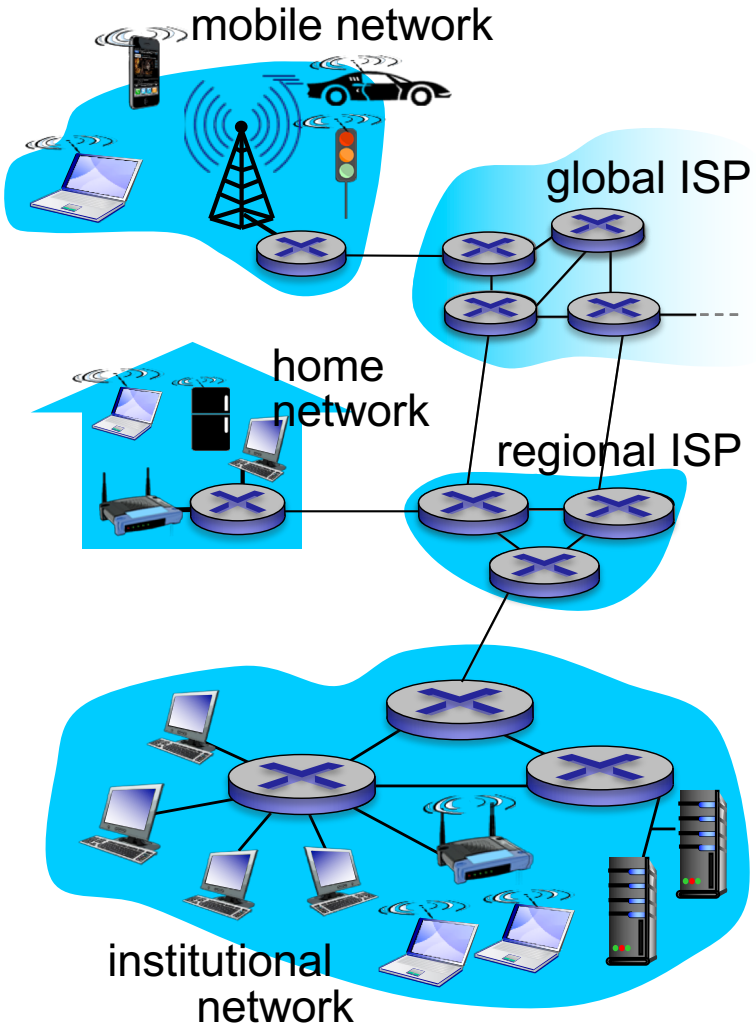
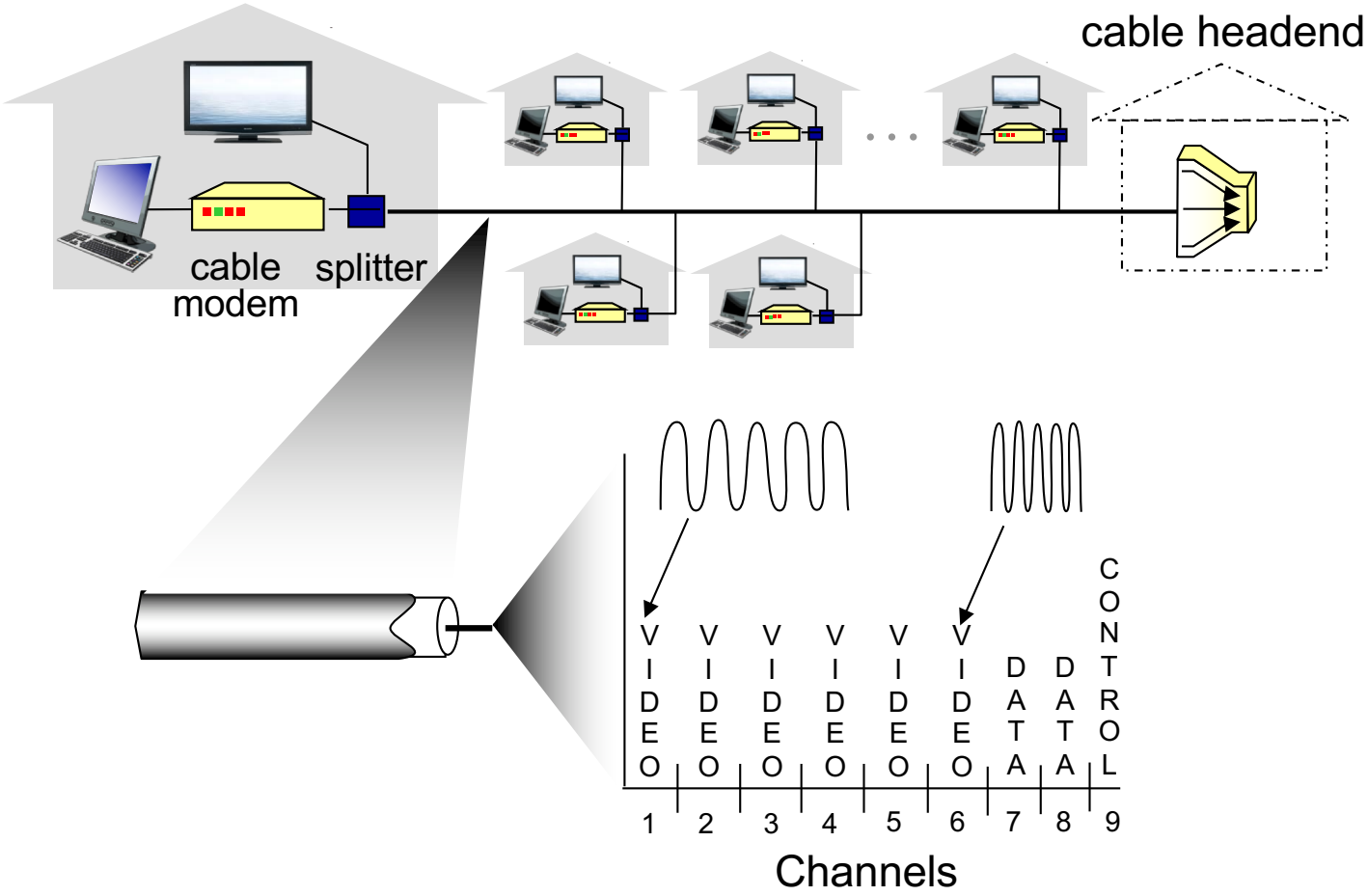
A closer look at network structure:

- *network* _____:
  - hosts: _____ and _____
  - servers often in data centers
- _____ *networks,* _____ _____: wired, wireless communication links
- *network* _____:
  - interconnected routers
  - network of networks

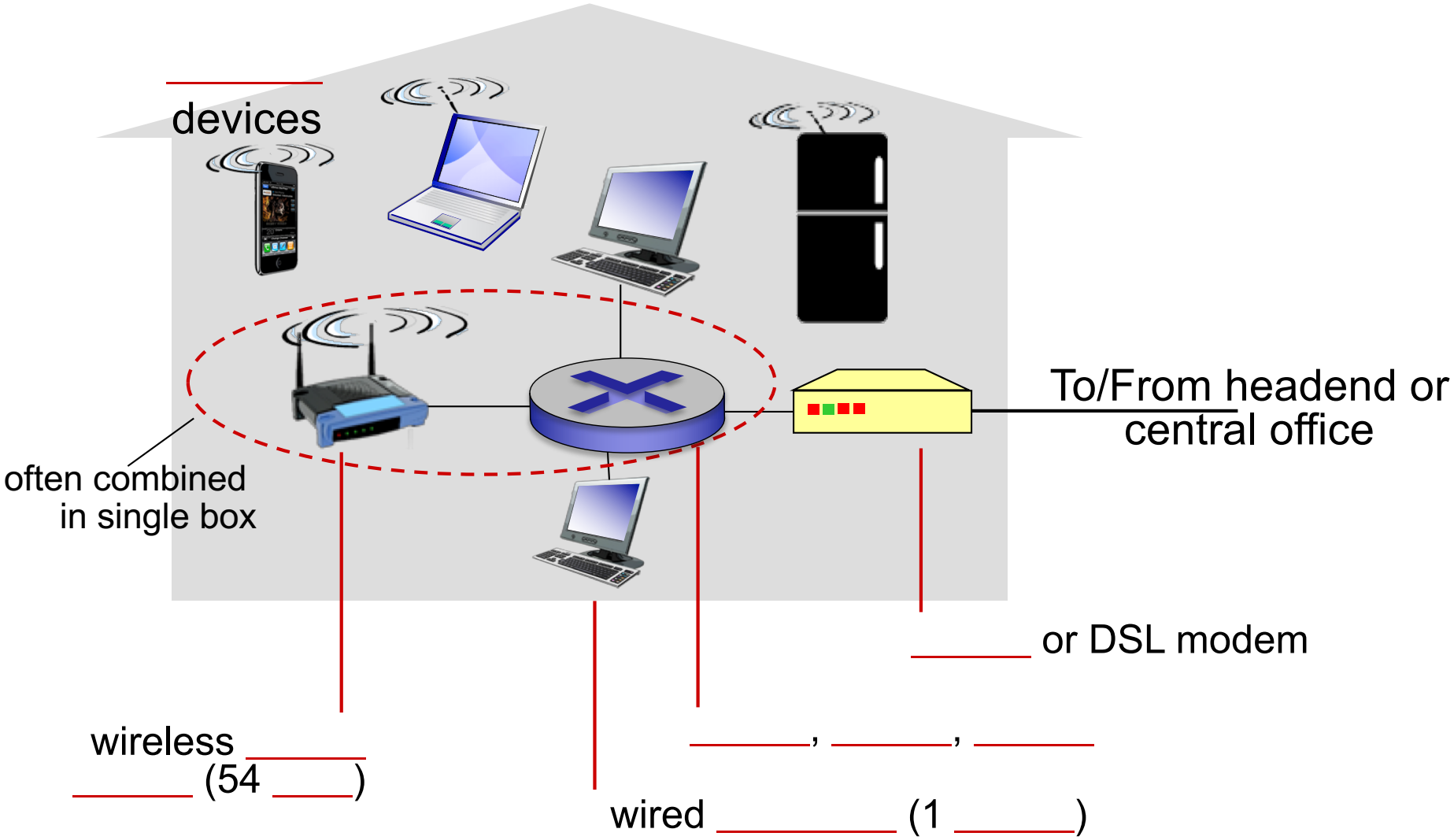


Access network: cable network

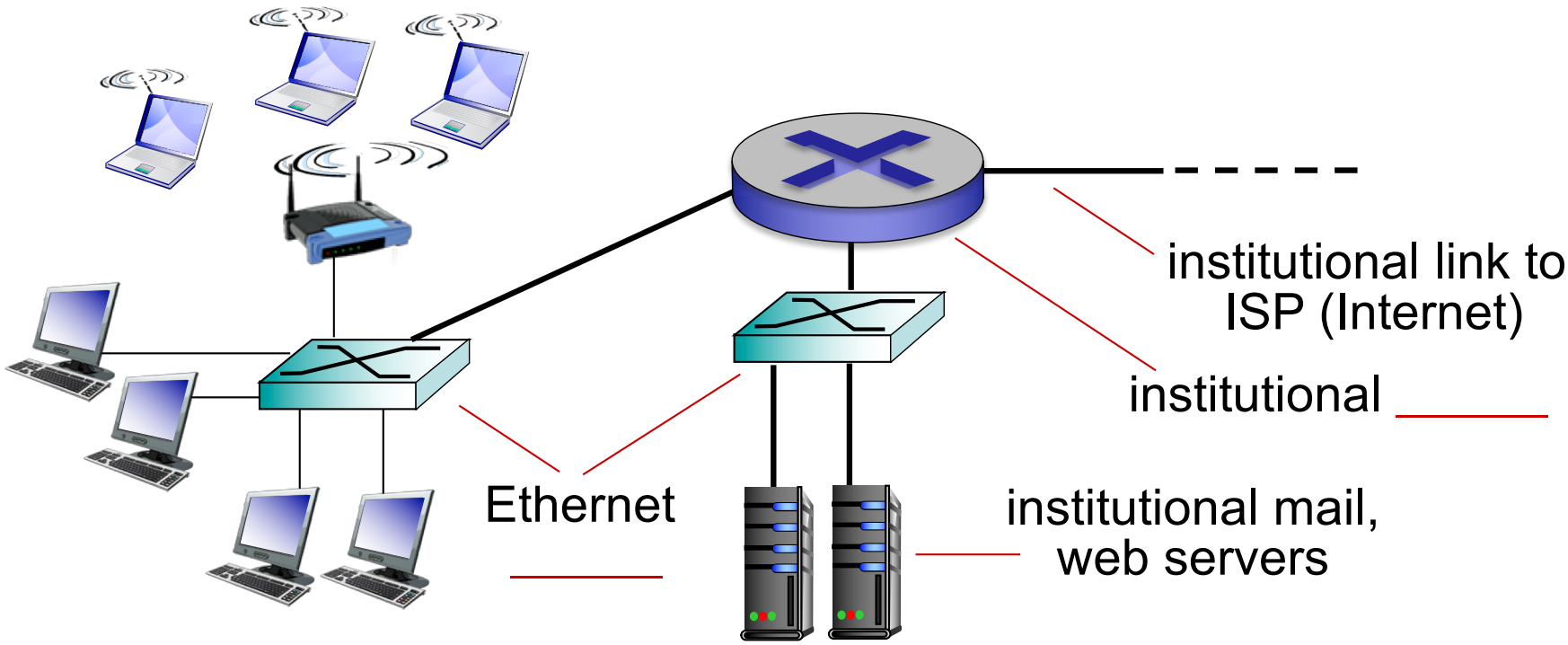


_____ _____ _____: different channels transmitted in different frequency bands

Access network: home network



Enterprise access networks (_____)



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

Wireless access networks

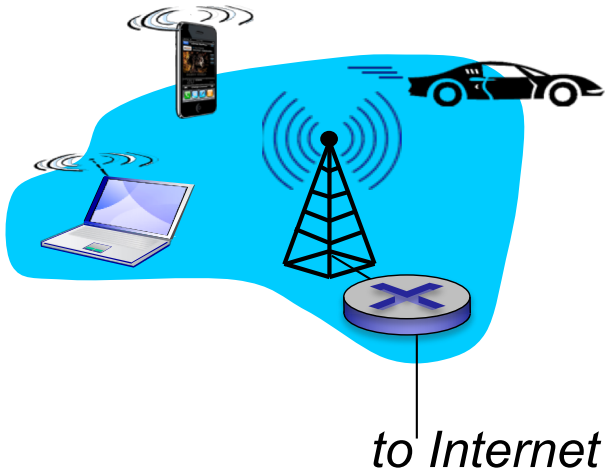
- shared *wireless* access network connects end system to router
  - via base station aka "_____ _____"

wireless _____:

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

_____wireless access

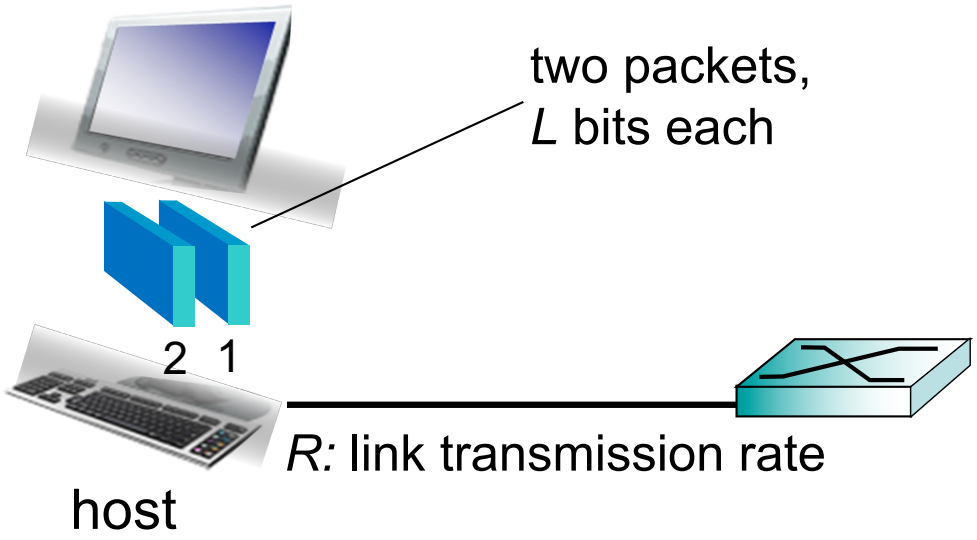
- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE



Host: sends _____ of data

host sending function:

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



packet	=	time needed to transmit *L*-bit packet into link	=	___(____)
_____				___(___/___)

Physical media

- _____: propagates between _____/_____ pairs
- _____ _____: what lies between transmitter & receiver
- _____ media:
  - signals propagate in solid media: copper, fiber, coax
- _____ media:
  - signals propagate freely, e.g., radio

_____ _____ *(TP)*

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

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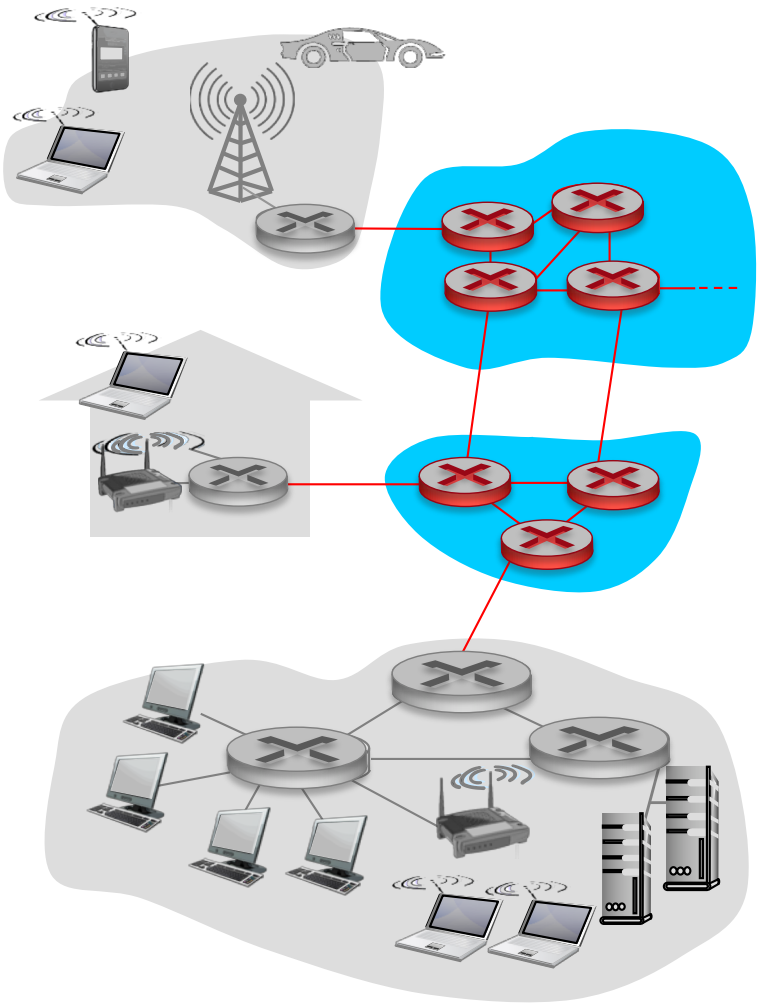
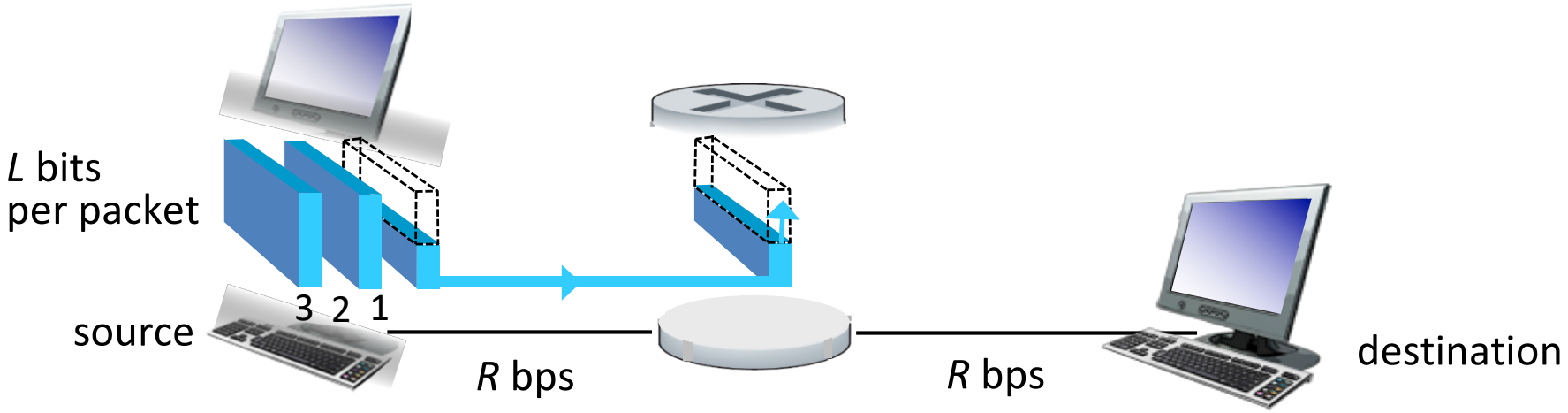
The network core

- mesh of _____ routers
- _____: hosts _____ application-layer _____ 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:



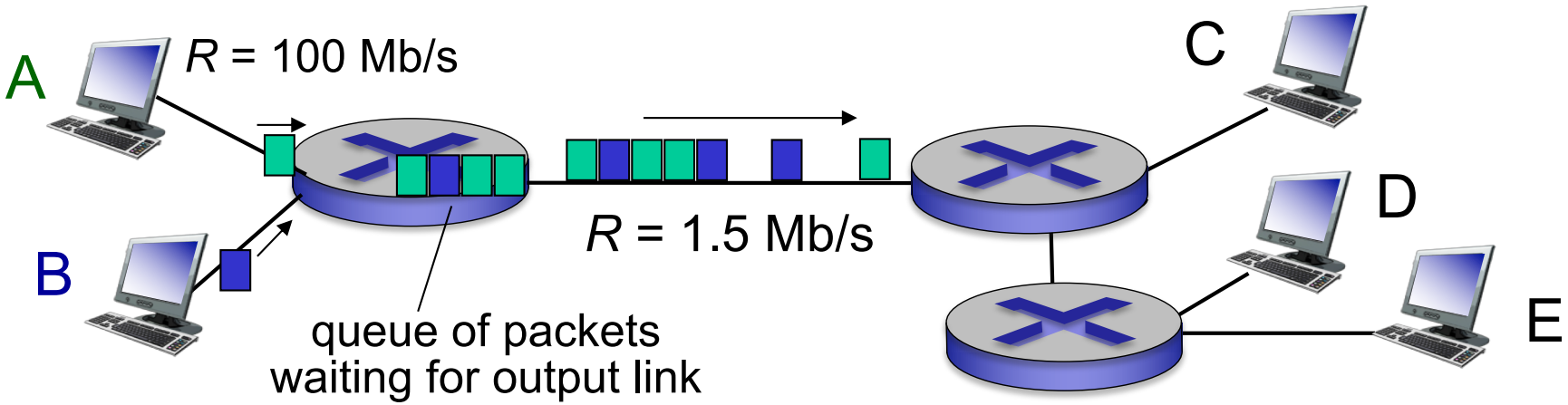
- takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- *store and forward:* _____ packet must _____ at _____ before it can be _____ on next link
- end-end delay = 2*L*/*R* (assuming zero propagation delay)

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



_____ and _____:

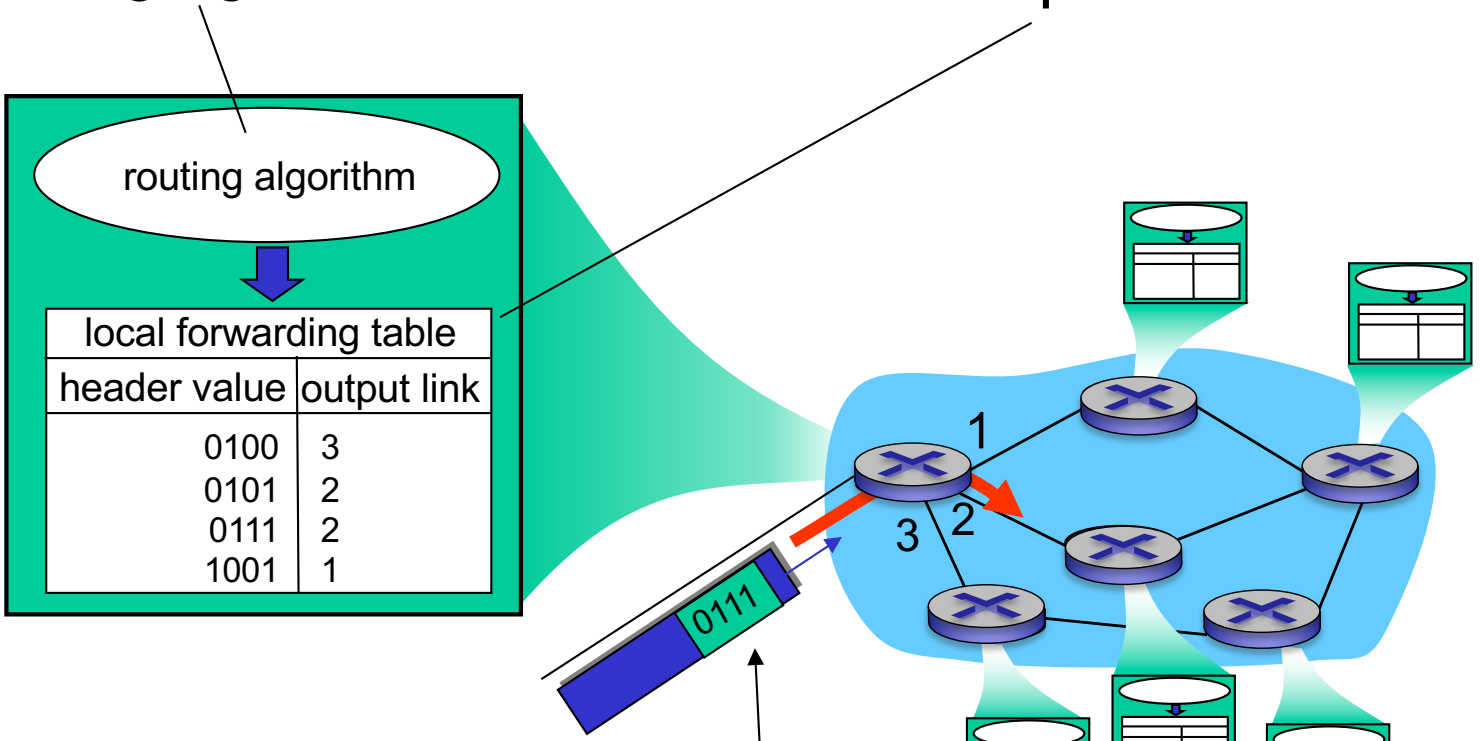
- if arrival rate (in bits) to link _____ transmission rate of link for a period of time:
  - packets will _____, wait to be transmitted on link
  - packets can be _____ (lost) if memory (buffer) fills up

Two key network-core functions

_____: determines source-destination route taken by packets

- *routing algorithms*

_____: move packets from router's input to appropriate router output

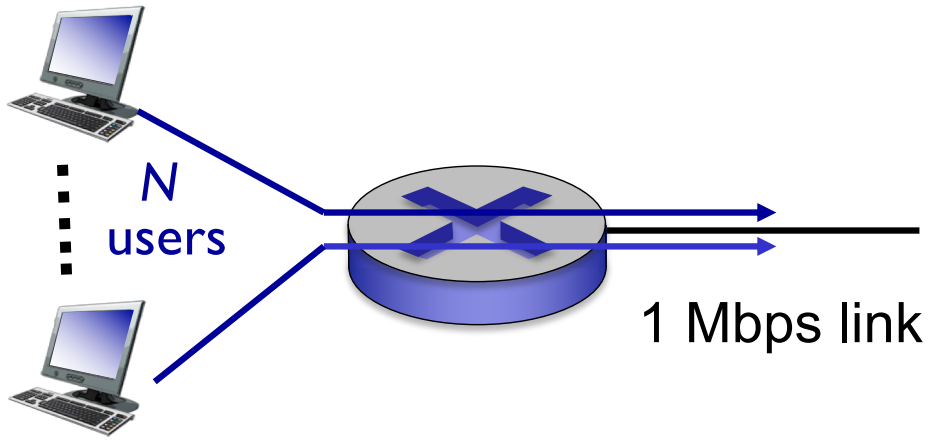


Packet switching versus circuit switching

!

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 *

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

Packet switching versus circuit switching

is packet switching a "slam dunk winner?"

- great for _____ data
  - resource sharing
  - simpler, no call setup
- excessive _____ 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)

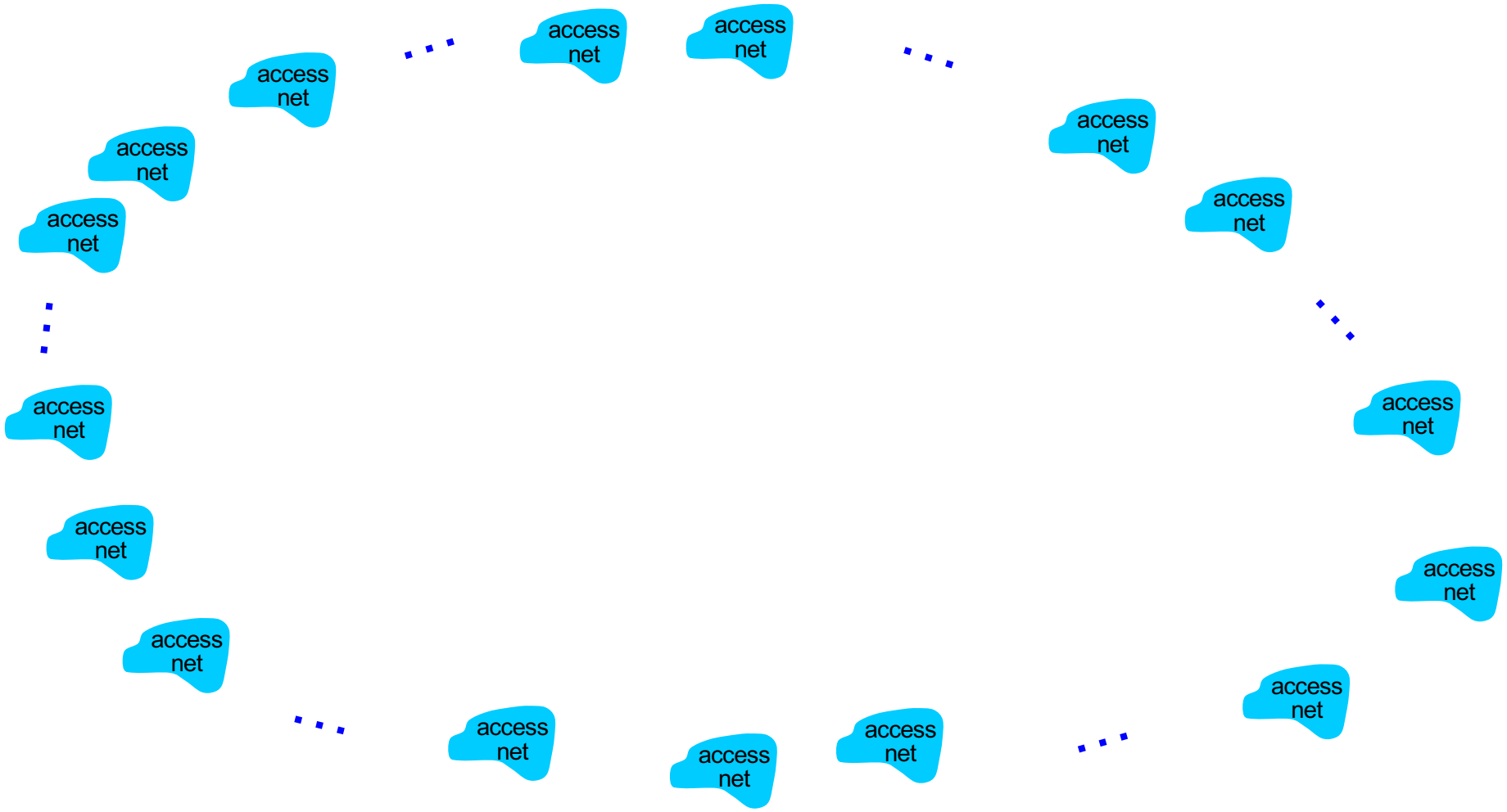
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

Internet structure: network of networks

- End systems connect to Internet via access ISPs (_____ _____ _____)
  - 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

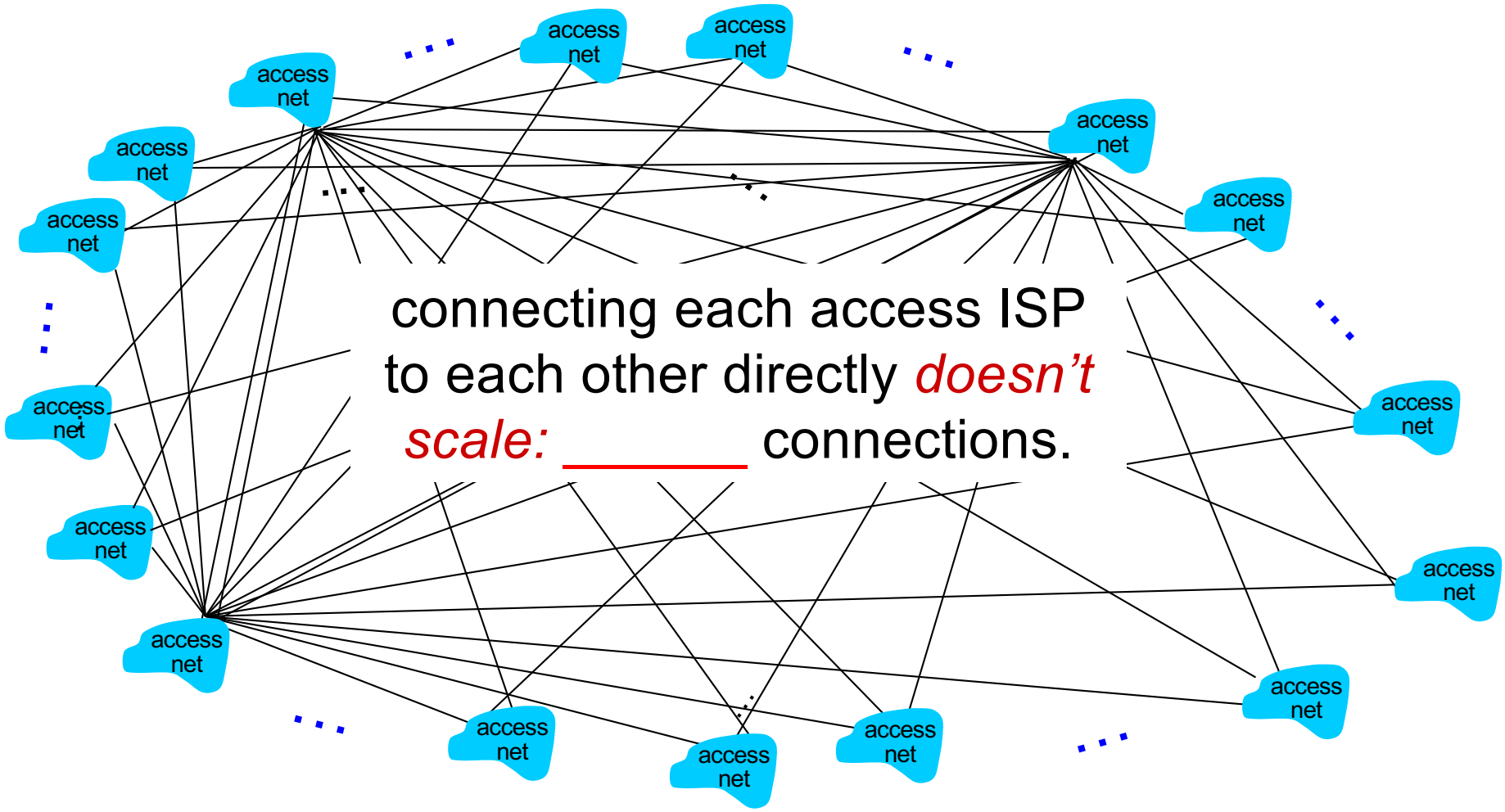
Internet structure: network of networks

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



Internet structure: network of networks

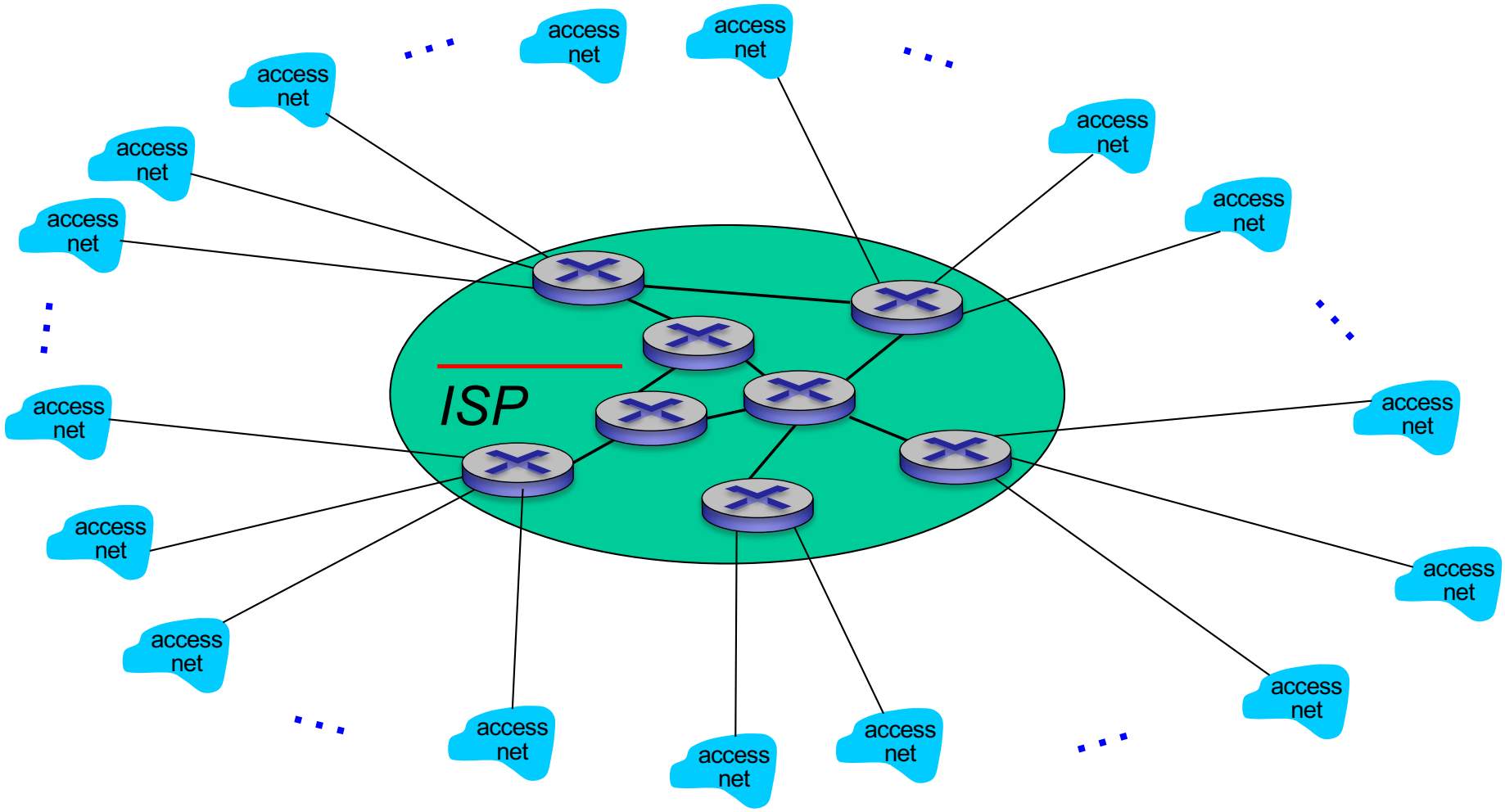
Option: connect each access ISP to _____ _____ access ISP?



Internet structure: network of networks

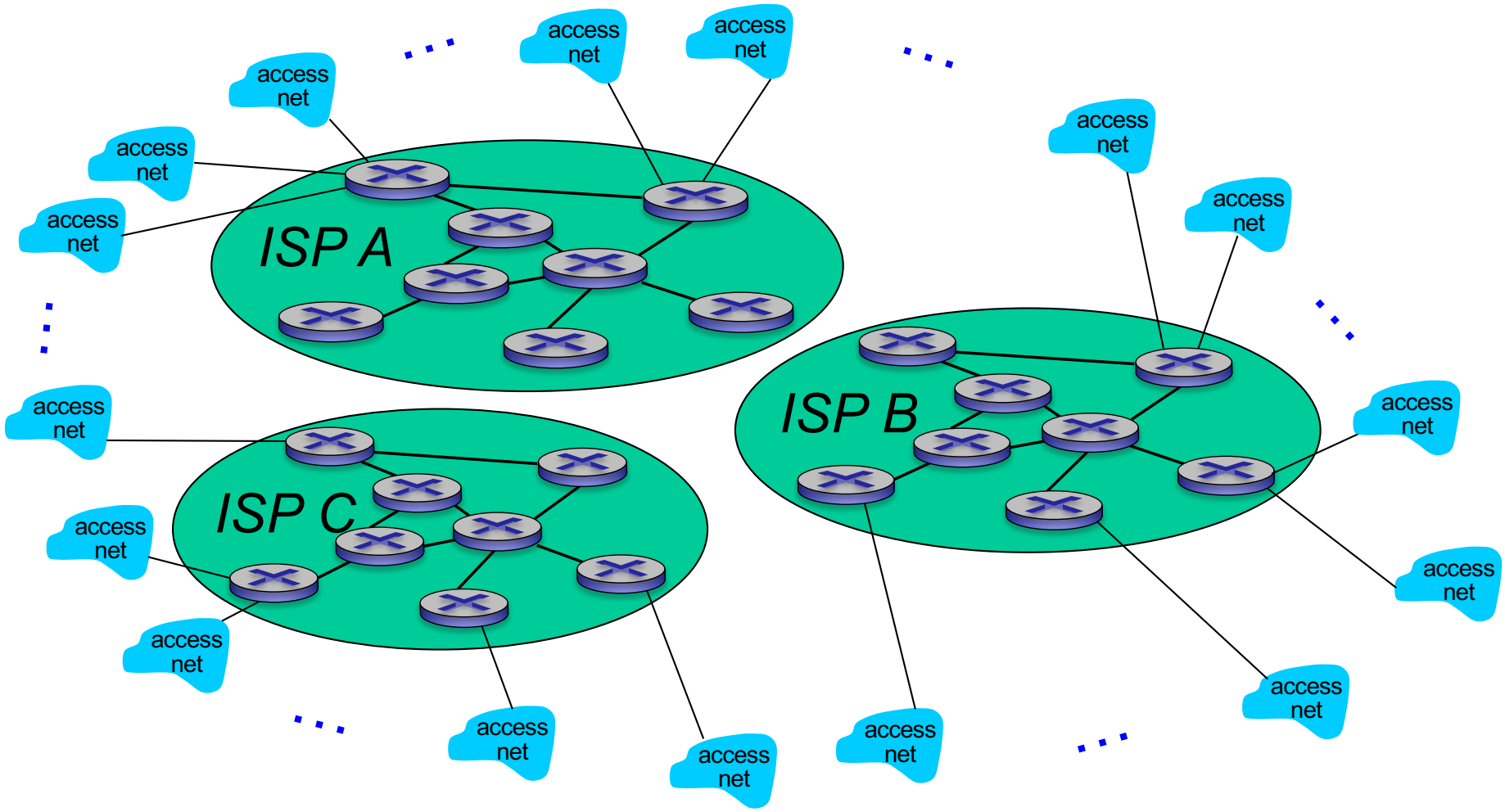
Option: connect each access ISP to _____ _____ transit ISP?

Customer and provider ISPs have economic agreement.



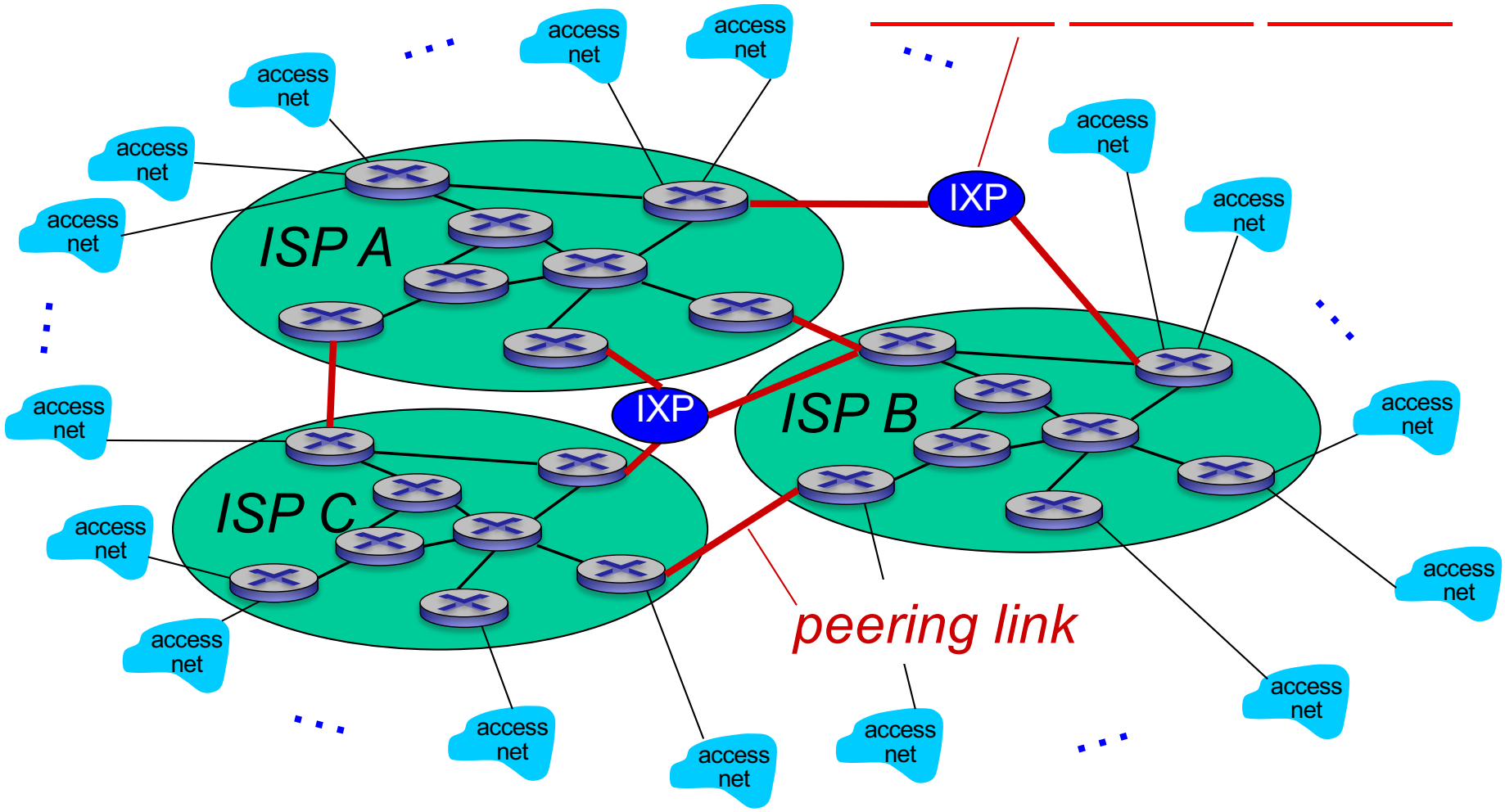
Internet structure: network of networks

But if one global ISP is viable _____, there will be _____ ….



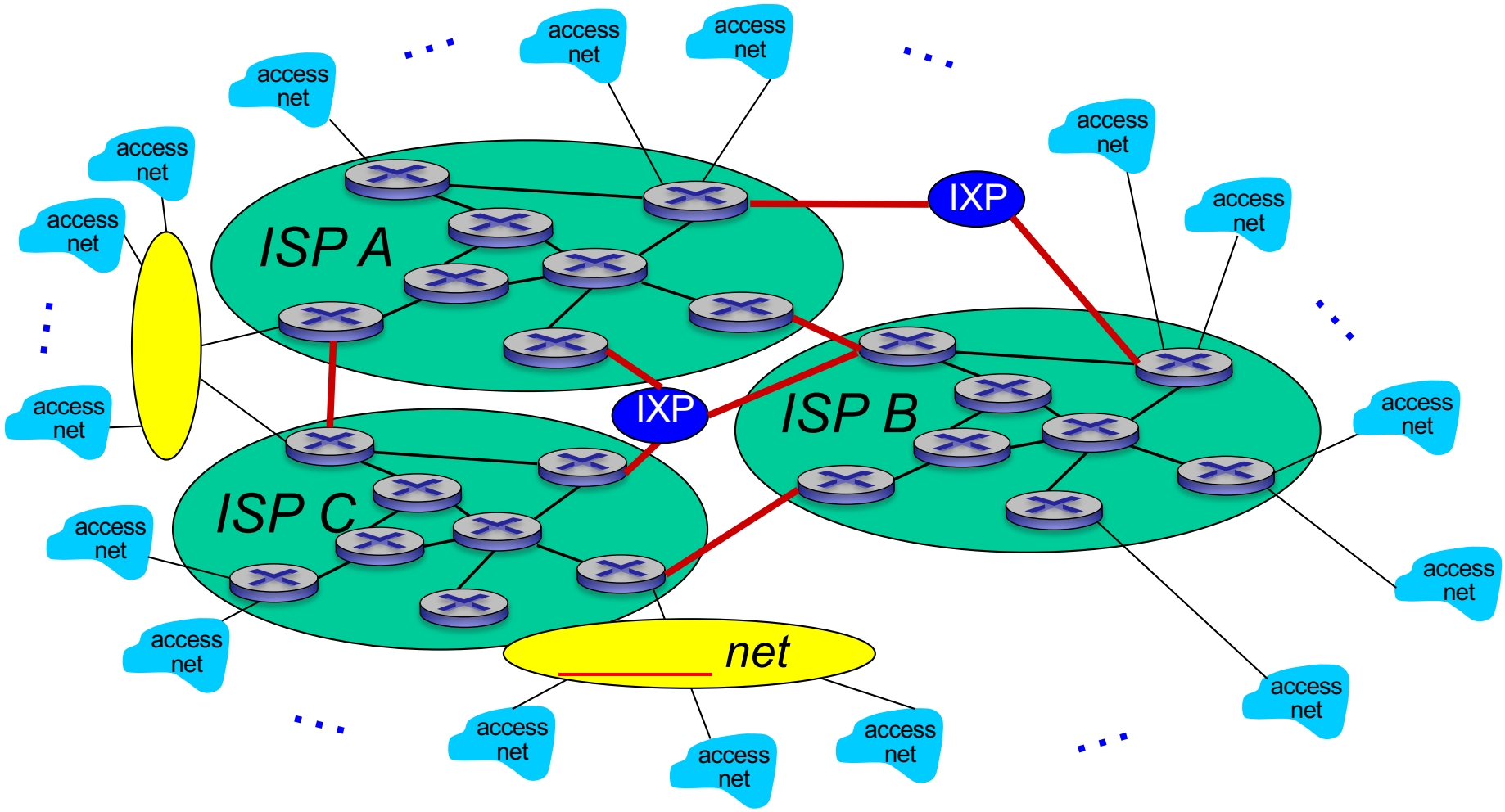
Internet structure: network of networks

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



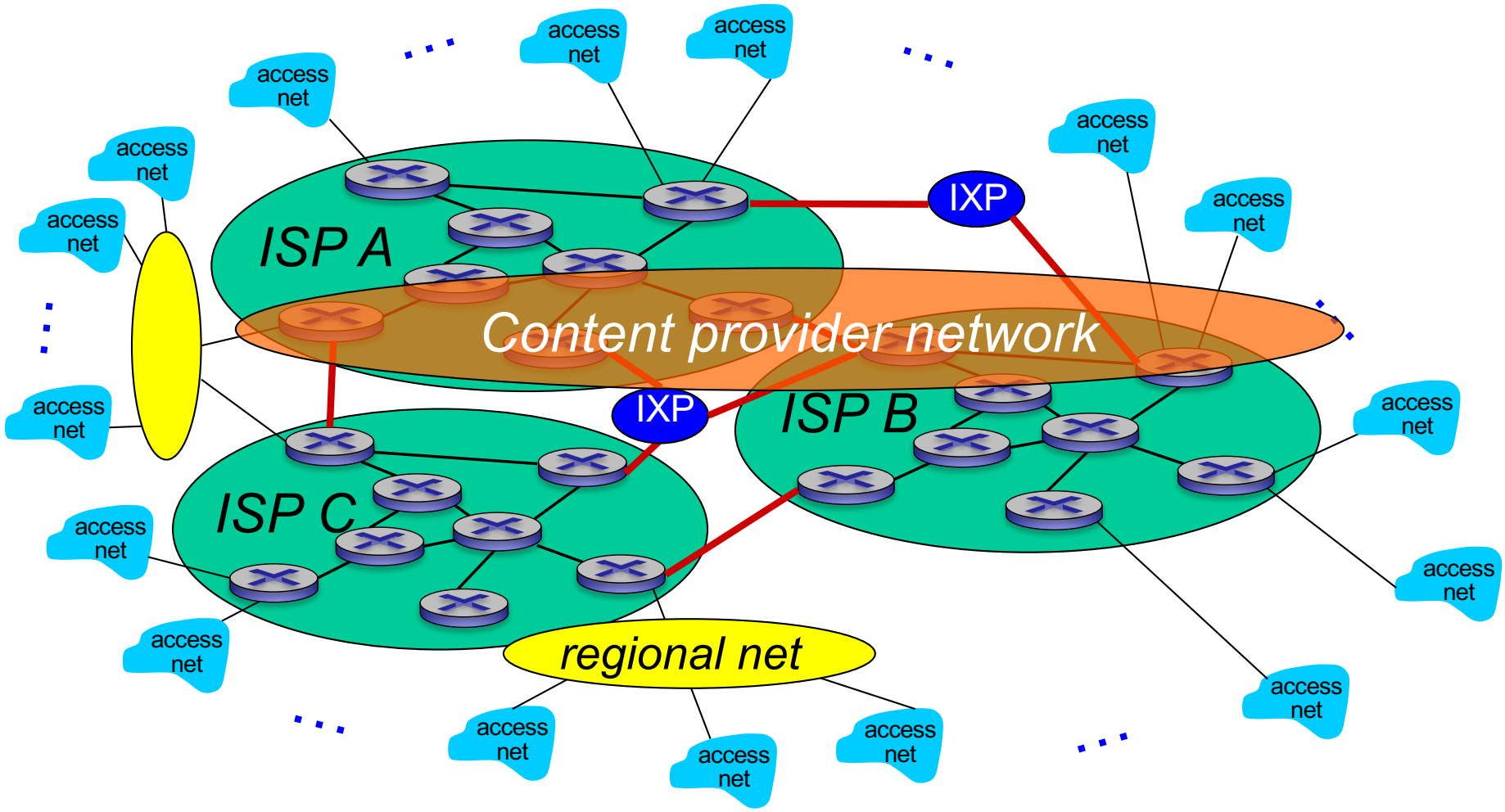
Internet structure: network of networks

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



Internet structure: network of networks

… and _____ _____ _____(e.g., Google, Microsoft, Akamai) may run _____ _____ network, to bring services, content close to end users



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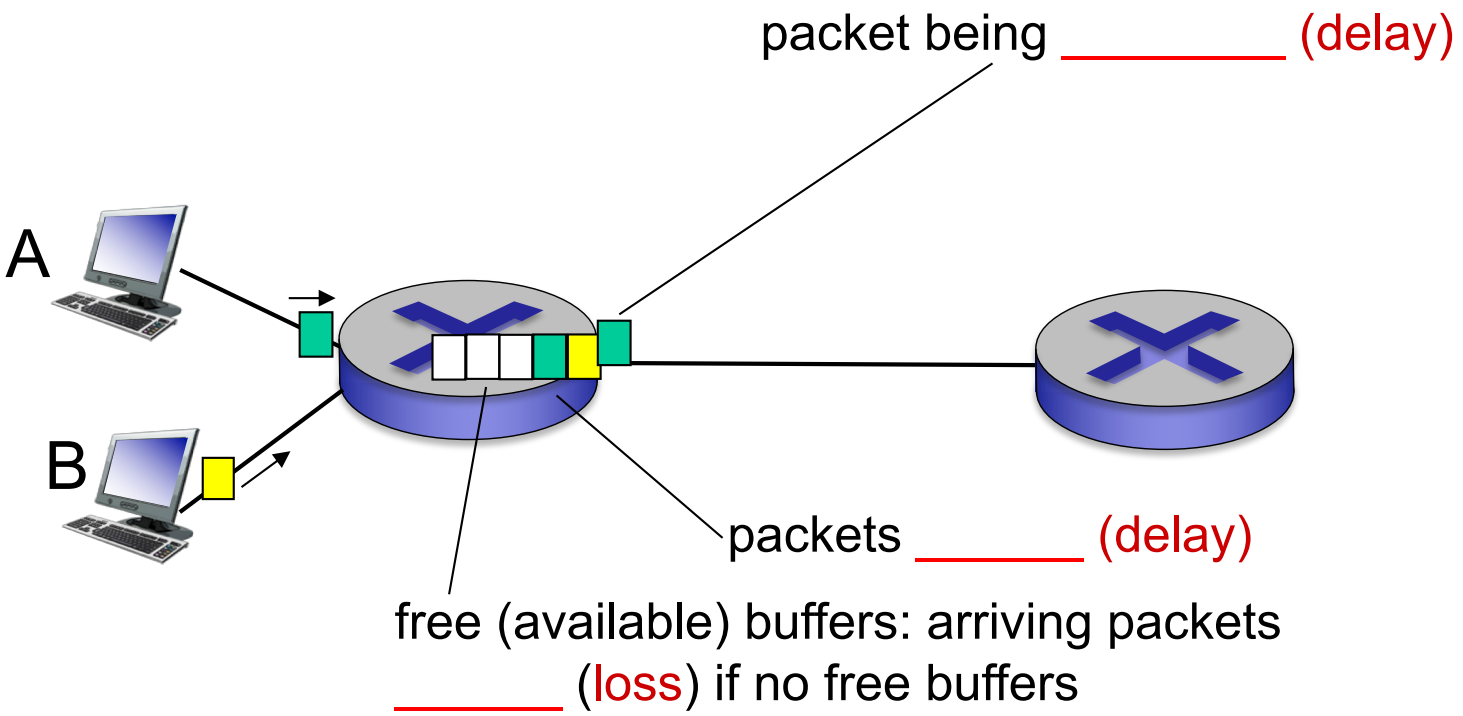
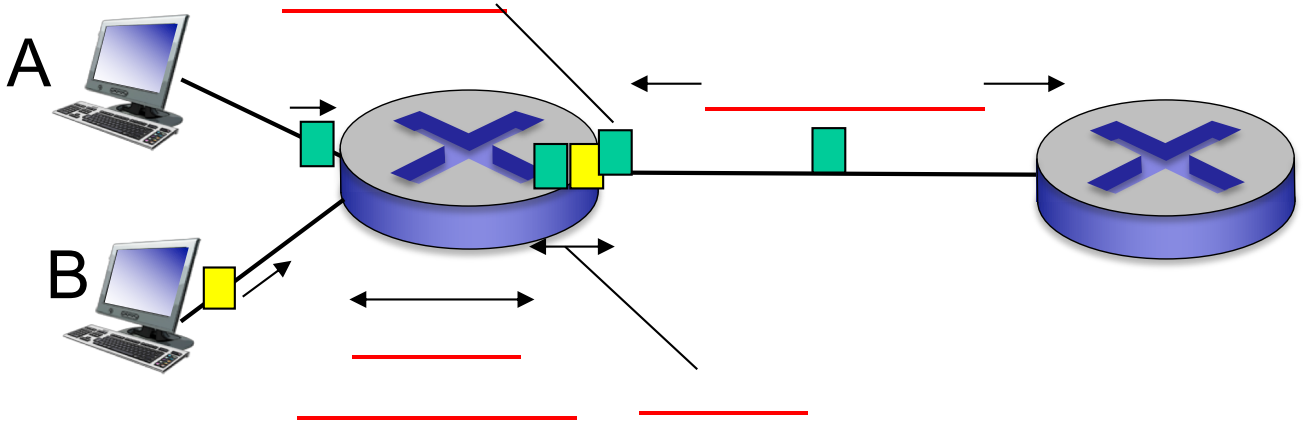
How do loss and delay occur?

packets *queue* in router buffers

- packet arrival rate to link (temporarily) exceeds output link capacity
- _____ _____, _____ for _____



Four sources of packet delay



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

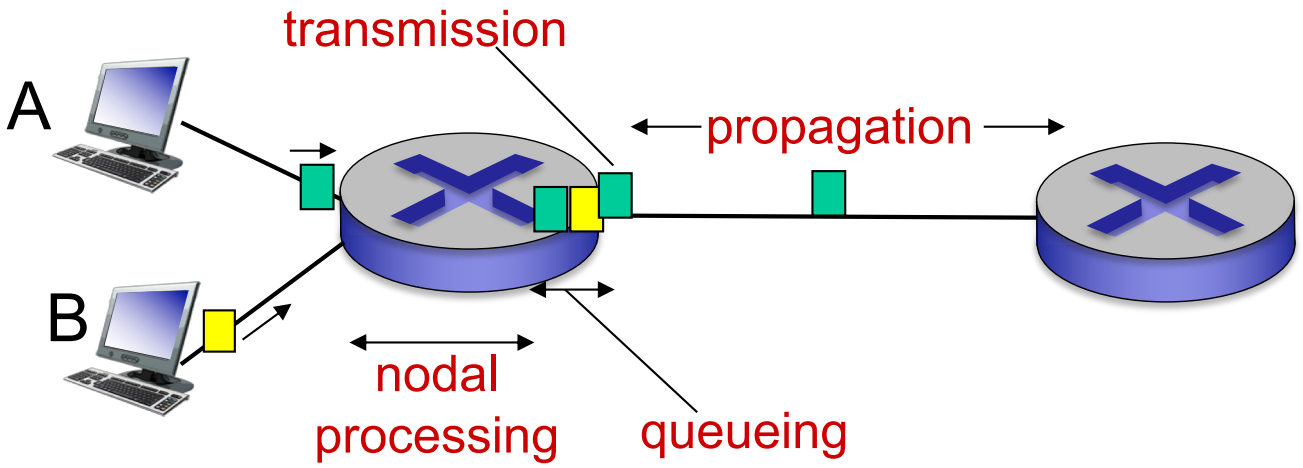
_____ : nodal processing

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

_____ : queueing delay

- time _____ at output link _____ _____
- depends on congestion level of router

Four sources of packet delay



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

_____ : transmission delay:

- *L*: packet length (bits)
- *R*: link *bandwidth (bps)*
- $d_{trans} = L/R$

d_{trans} and d_{prop} *very* different

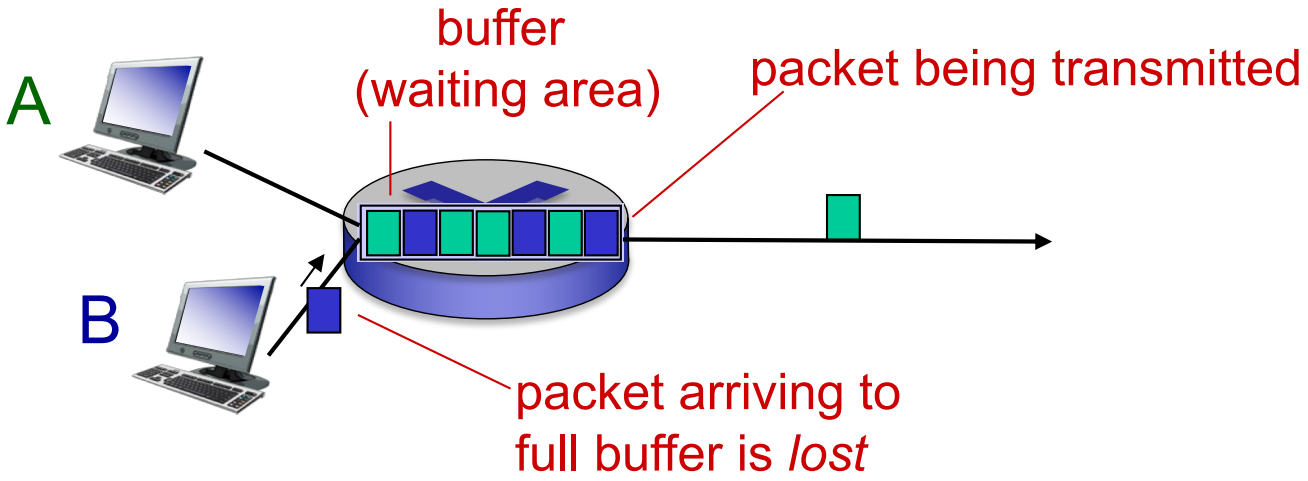
_____ : propagation delay:

- *d*: length of physical link
- *s*: propagation speed (~2×10^8 m/sec)
- $d_{prop} = d/s$

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/
* Check out the Java applet for an interactive animation on trans vs. prop delay

Packet loss

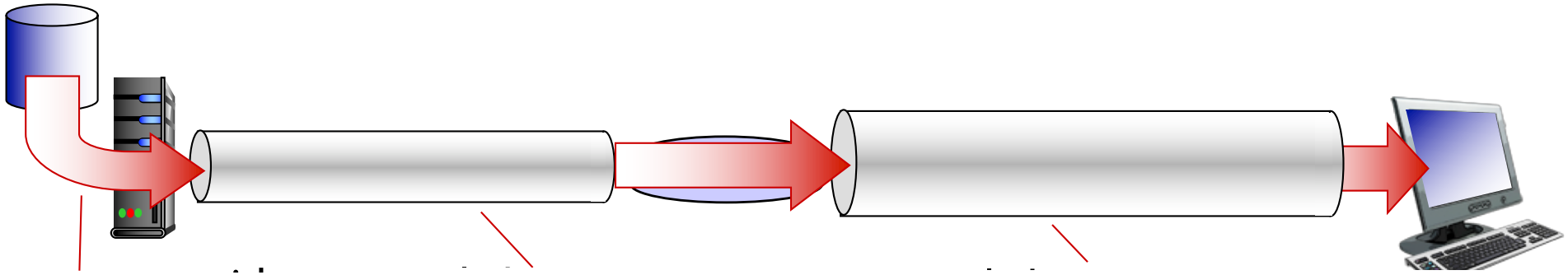
- queue (aka buffer) preceding link in buffer has _____ _____
- packet arriving to full queue _____ (aka lost)
- lost packet may be _____ by previous node, by source end system, or not at all



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

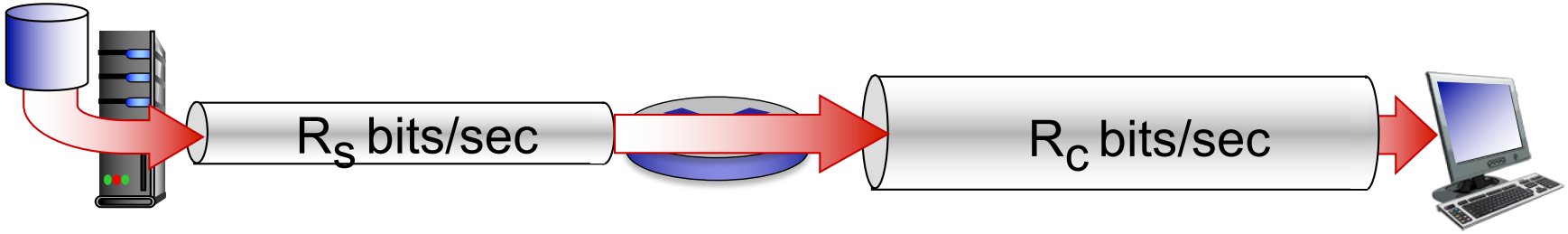
Throughput

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

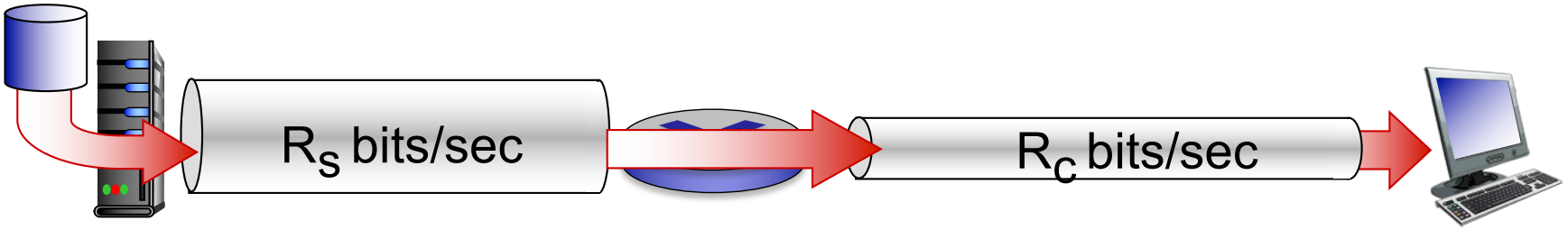


Throughput (more)

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



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



_____ _____

link on end-end path that _____ end-end throughput

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Protocol "_____"

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?

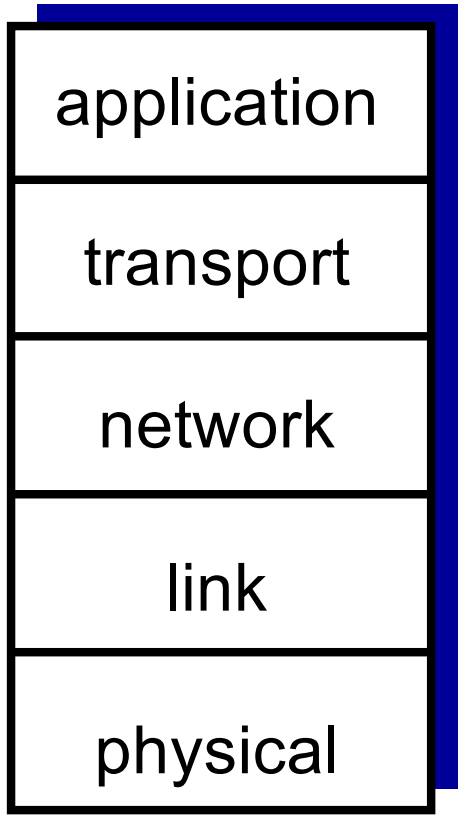
Why layering?

dealing with complex systems:

- explicit structure allows identification, relationship of complex system's pieces
  - layered _____ _____ for discussion
- _____ eases _____, _____ 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?

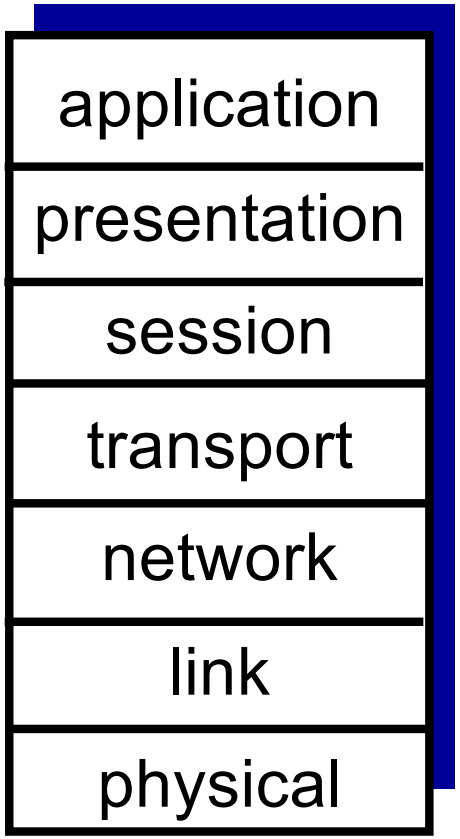
Internet protocol stack

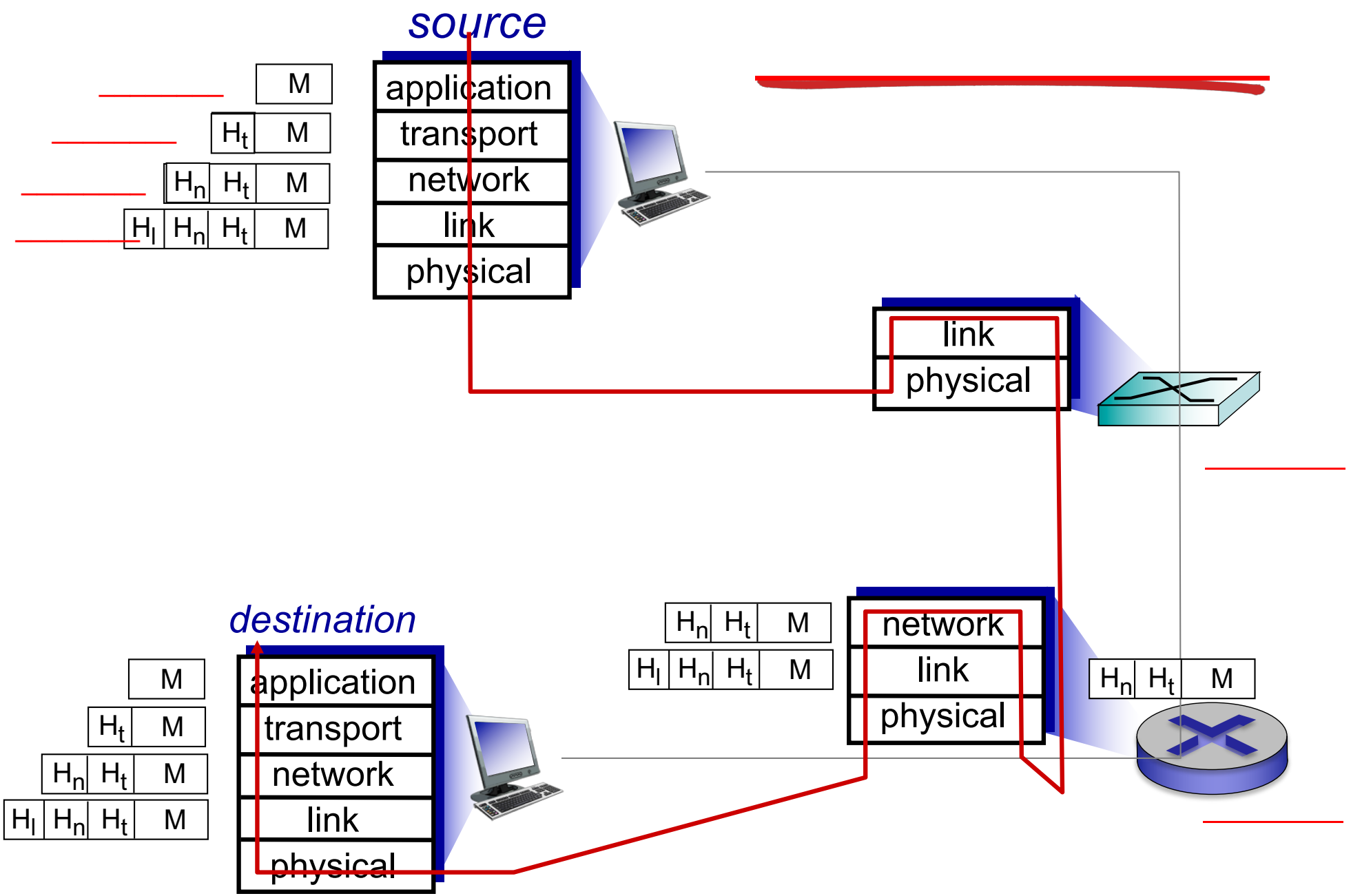
- _____ : supporting network applications
  - FTP, SMTP, HTTP
- _____ : process-process data transfer
  - TCP, UDP
- _____ : routing of datagrams from source to destination
  - IP, routing protocols
- _____ : data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- _____ : bits "on the wire"



ISO/OSI reference model

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

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Network security

- field of network security:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks
- 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!

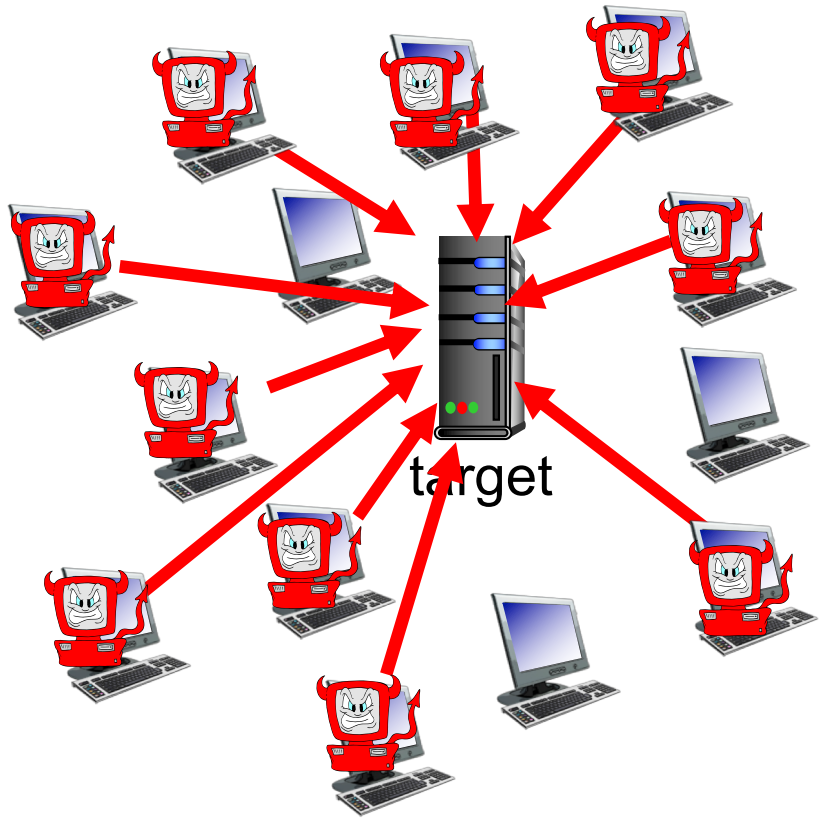
Bad guys: put malware into hosts via Internet

- _____ can get in host from:
  - _____ : _____ infection by receiving/executing object (e.g., e-mail attachment)
  - _____ : self-replicating infection by passively receiving object that gets itself _____
- _____ _____ can record keystrokes, web sites visited, upload info to collection site
- infected host can be enrolled in _____, used for spam. DDoS attacks

Bad guys: attack server, network infrastructure

_____ *of* _____ *(DoS):* attackers make resources (_____, _____) _____ to legitimate traffic by overwhelming resource with _____ traffic

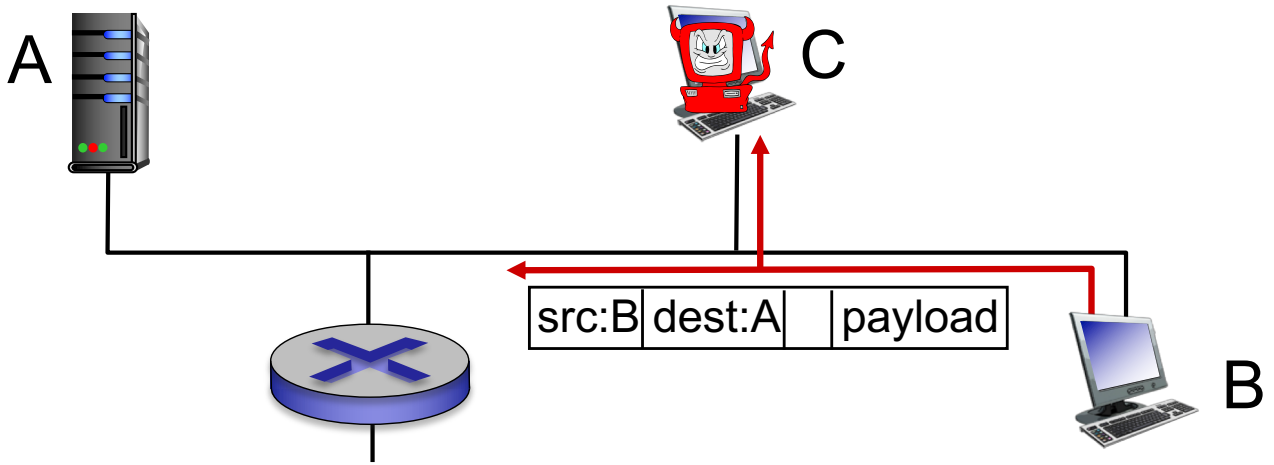
1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts



Bad guys can sniff packets

packet "_____":

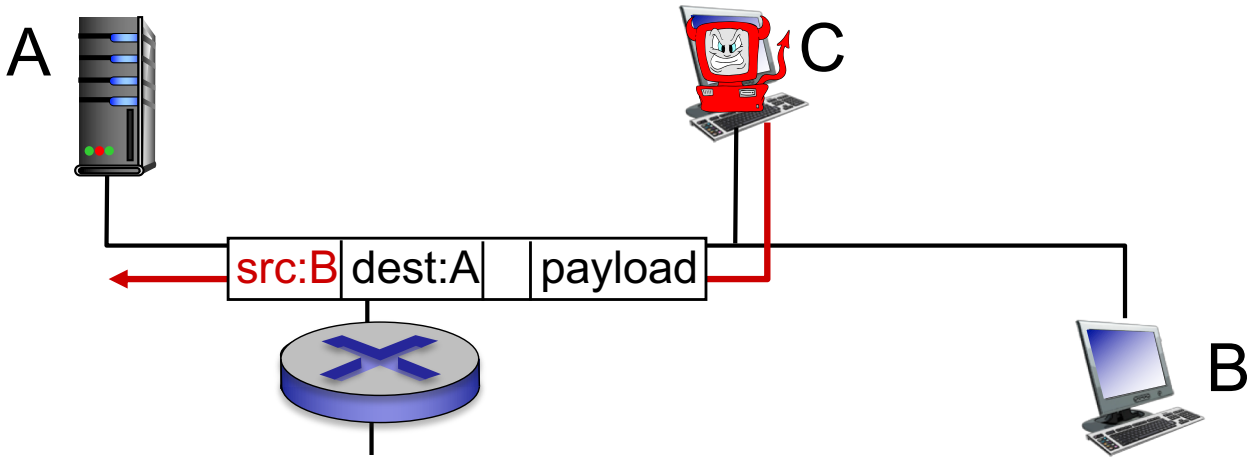
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



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

Bad guys can use fake addresses

IP _____ *:* send packet with false source address



… lots more on security (throughout, Chapter 8)

Chapter 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

1.6 networks under attack: security

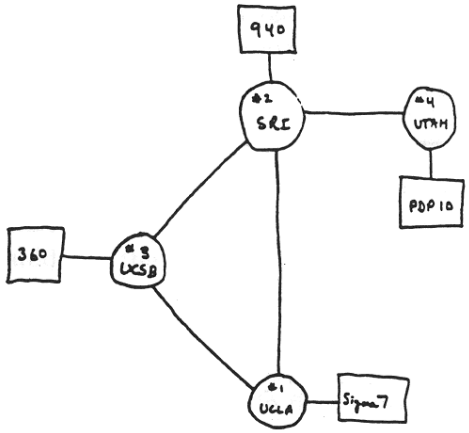
1.7 history

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



THE ARPA NETWORK

Internet history

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 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 routers
- 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

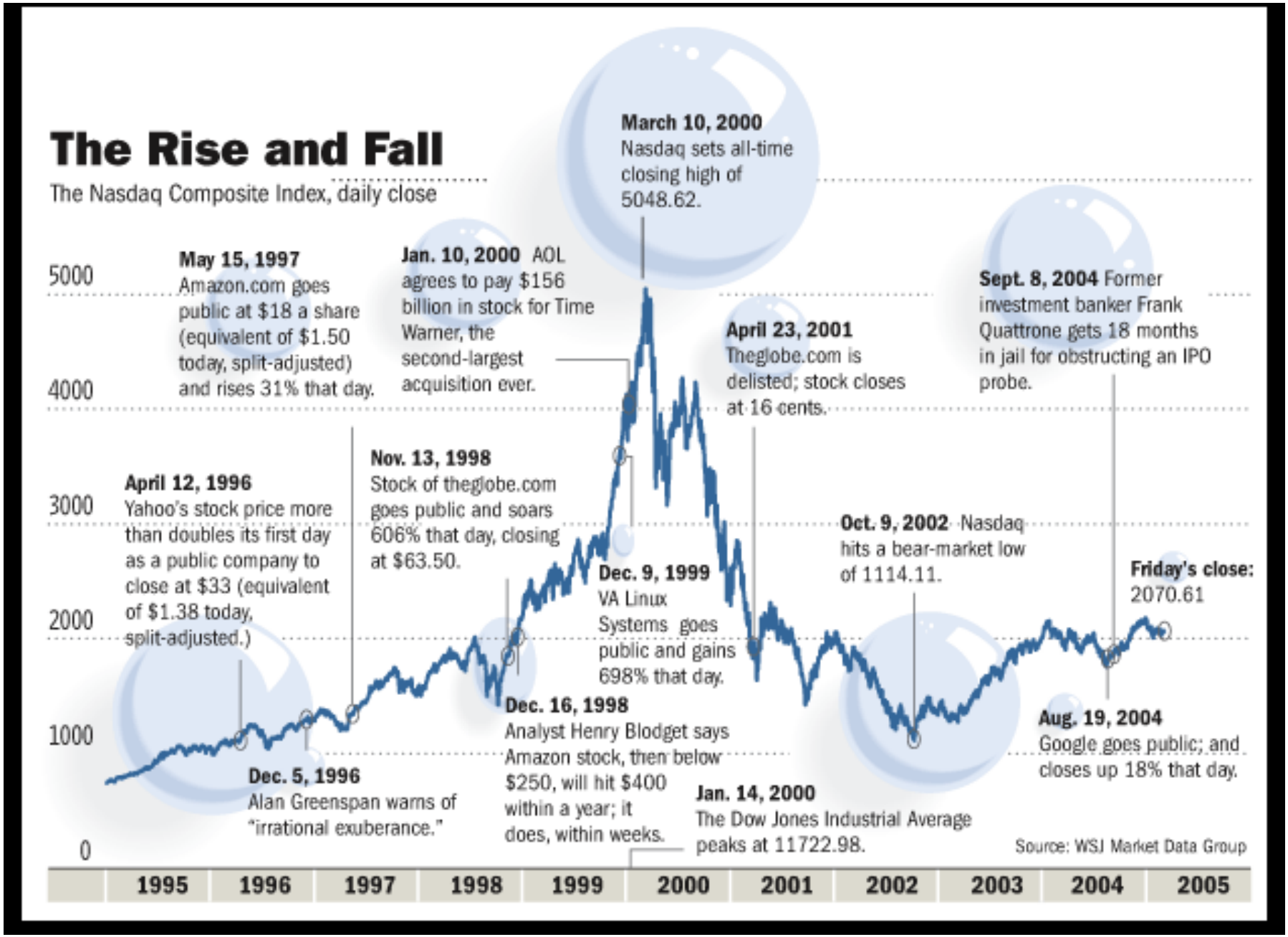
Internet history

1990, 2000's: commercialization, the Web, new apps

- early 1990's: 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 1990's: commercialization of the Web

late 1990's – 2000's:

- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps


The Rise and Fall
The Nasdaq Composite Index, daily close
March 10, 2000
Nasdaq sets all-time closing high of 5048.62.
May 15, 1997
Amazon.com goes public at $18 a share (equivalent of $1.50 today, split-adjusted) and rises 31% that day.
Jan. 10, 2000 AOL agrees to pay $156 billion in stock for Time Warner, the second-largest acquisition ever.
April 23, 2001
Theglobe.com is delisted; stock closes at 16 cents.
Sept. 8, 2004 Former investment banker Frank Quattrone gets 18 months in jail for obstructing an IPO probe.
April 12, 1996
Yahoo's stock price more than doubles its first day as a public company to close at $33 (equivalent of $1.38 today, split-adjusted.)
Nov. 13, 1998
Stock of theglobe.com goes public and soars 606% that day, closing at $63.50.
Dec. 9, 1999
VA Linux Systems goes public and gains 698% that day.
Oct. 9, 2002 Nasdaq hits a bear-market low of 1114.11.
Friday's close: 2070.61
Dec. 16, 1998
Analyst Henry Blodget says Amazon stock, then below $250, will hit $400 within a year; it does, within weeks.
Aug. 19, 2004
Google goes public; and closes up 18% that day.
Dec. 5, 1996
Alan Greenspan warns of "irrational exuberance."
Jan. 14, 2000
The Dow Jones Industrial Average peaks at 11722.98.
Source: WSJ Market Data Group
5000
4000
3000
2000
1000
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005

Internet history

2005-present

- ~5B devices attached to Internet (2016)
  - smartphones and tablets
- aggressive deployment of broadband access
- increasing ubiquity of high-speed wireless access
- emergence of online social networks:
  - Facebook: ~ one billion users
- service providers (Google, Microsoft) create their own networks
  - bypass Internet, providing "instantaneous" access to search, video content, email, etc.
- e-commerce, universities, enterprises running their services in "cloud" (e.g., Amazon EC2)

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!*