Internet: A Brief Overview

Chapter 1: introduction

our goal:

- get "feel" and terminology
- more depth, detail *later* in course
- approach:
  - use the Internet as the 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
- protocol layers, service models

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

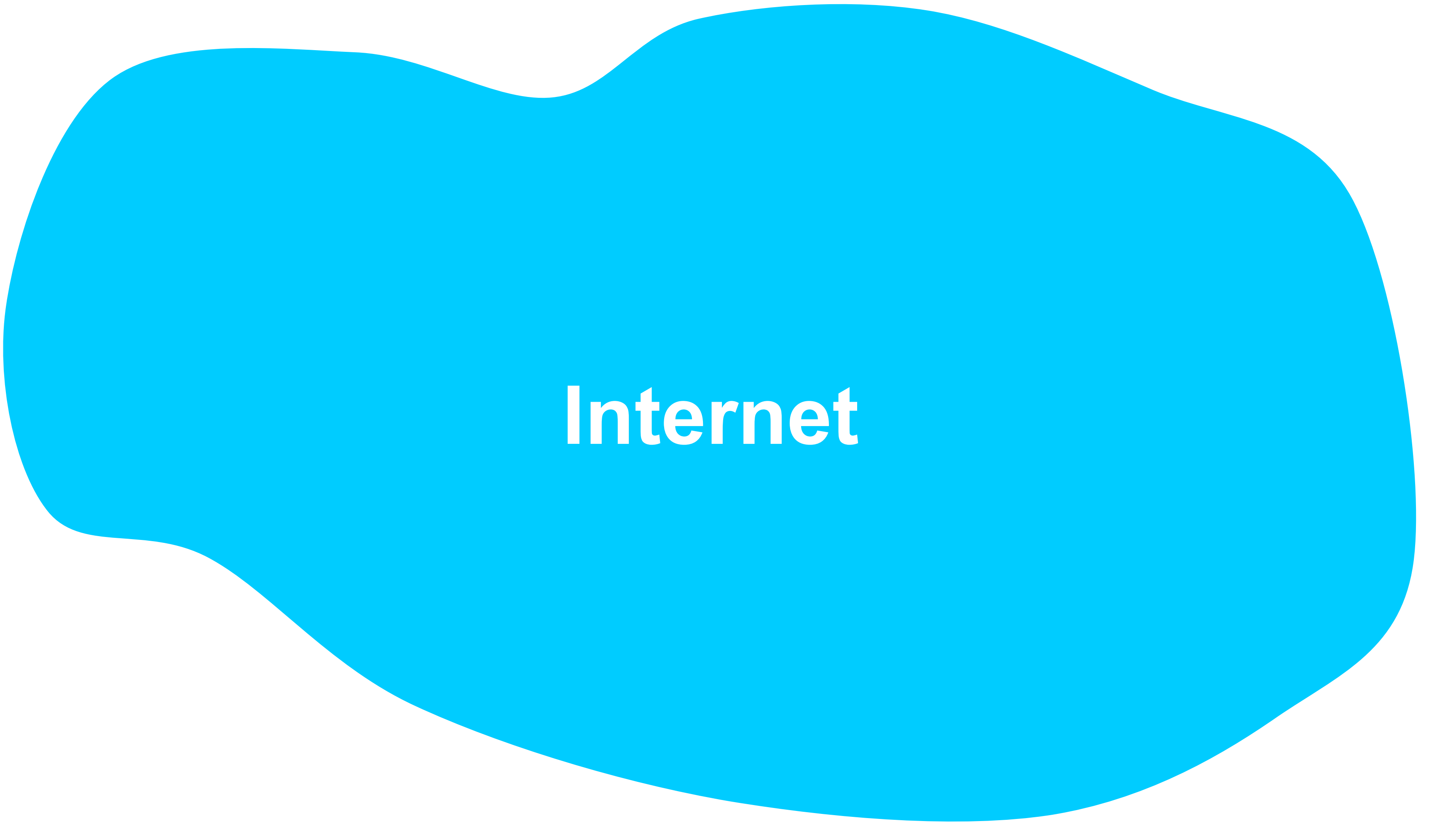
1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

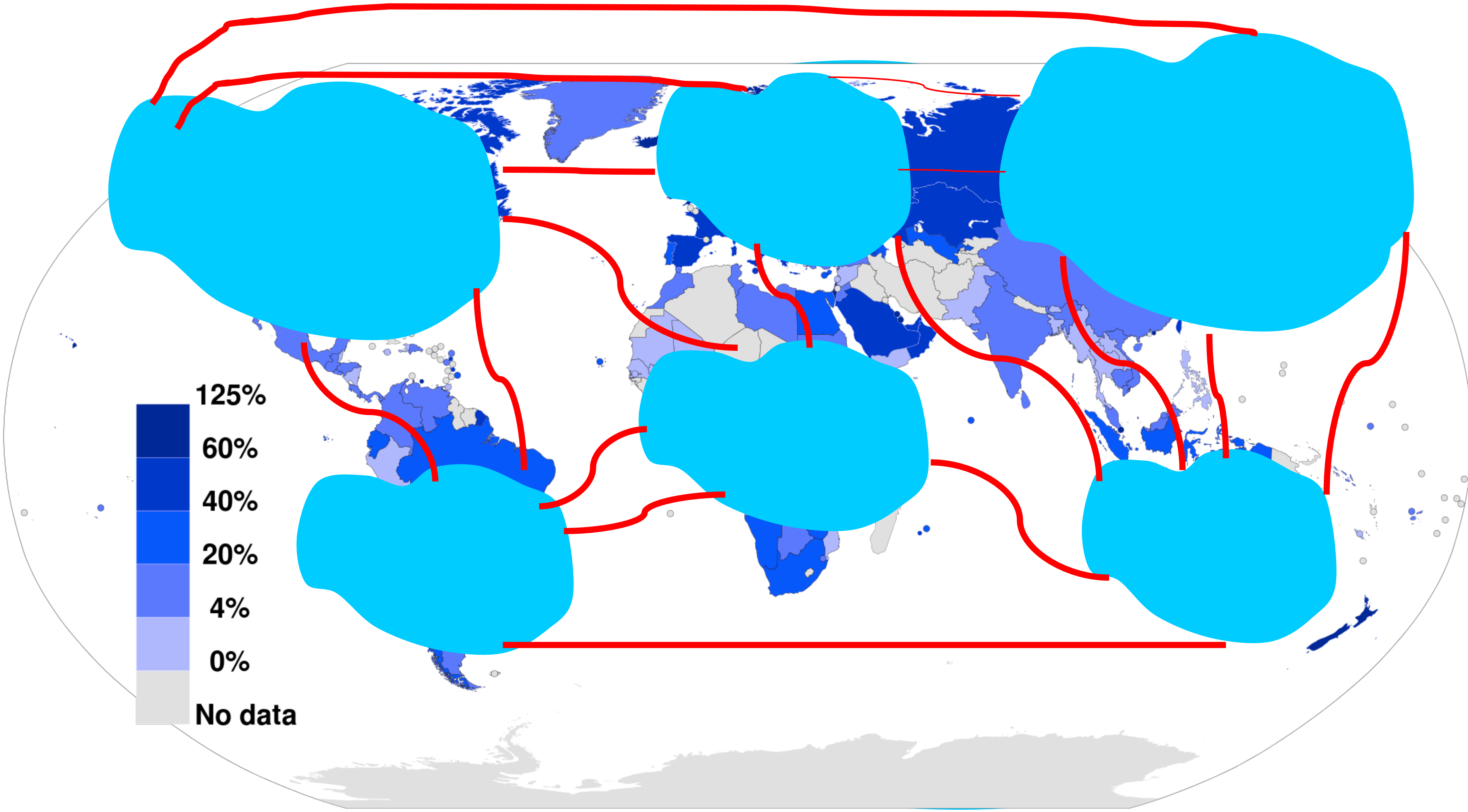
~~1.6 networks under attack: security~~

~~1.7 history~~

1.1 What is the Internet?



1.1 What is the Internet?



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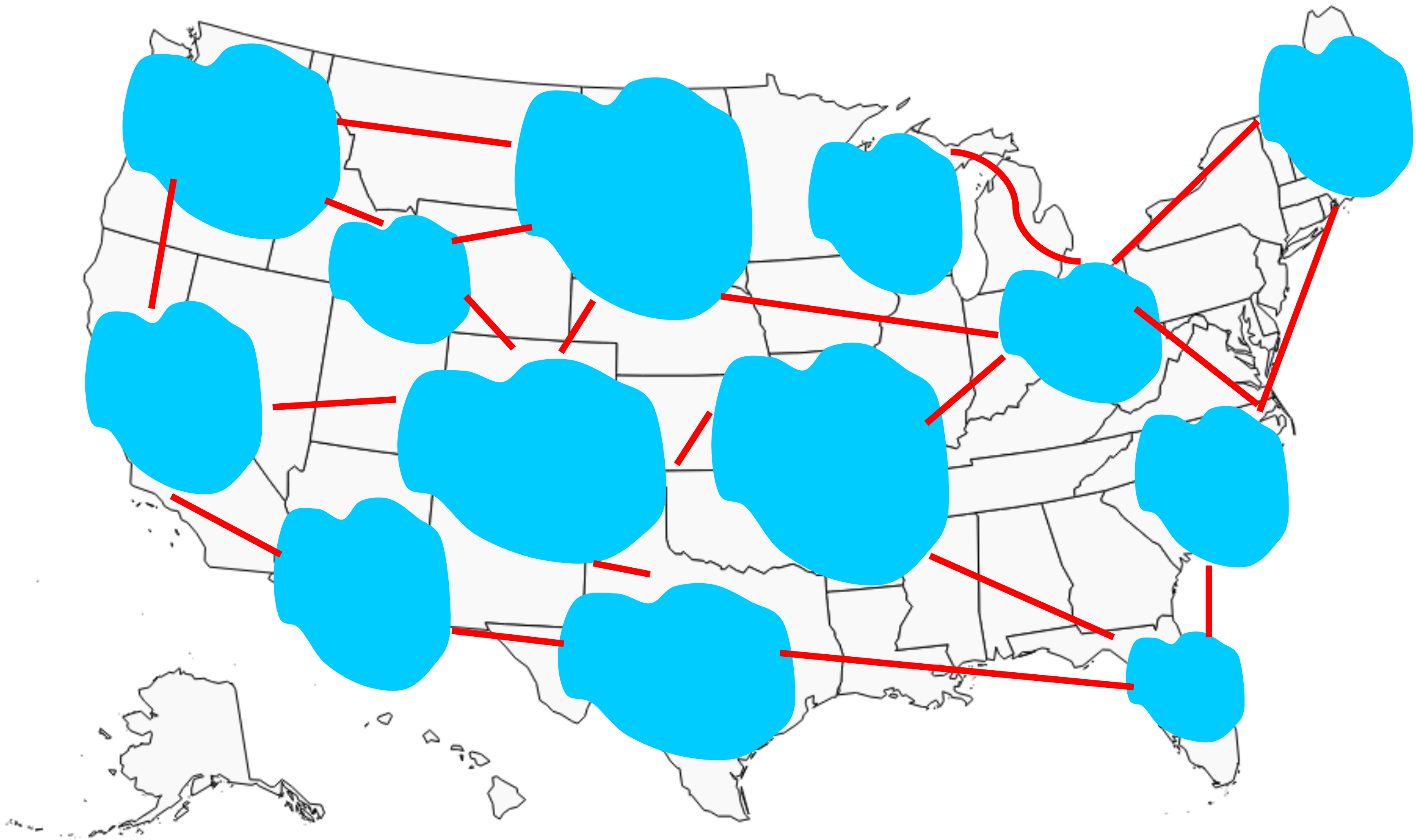

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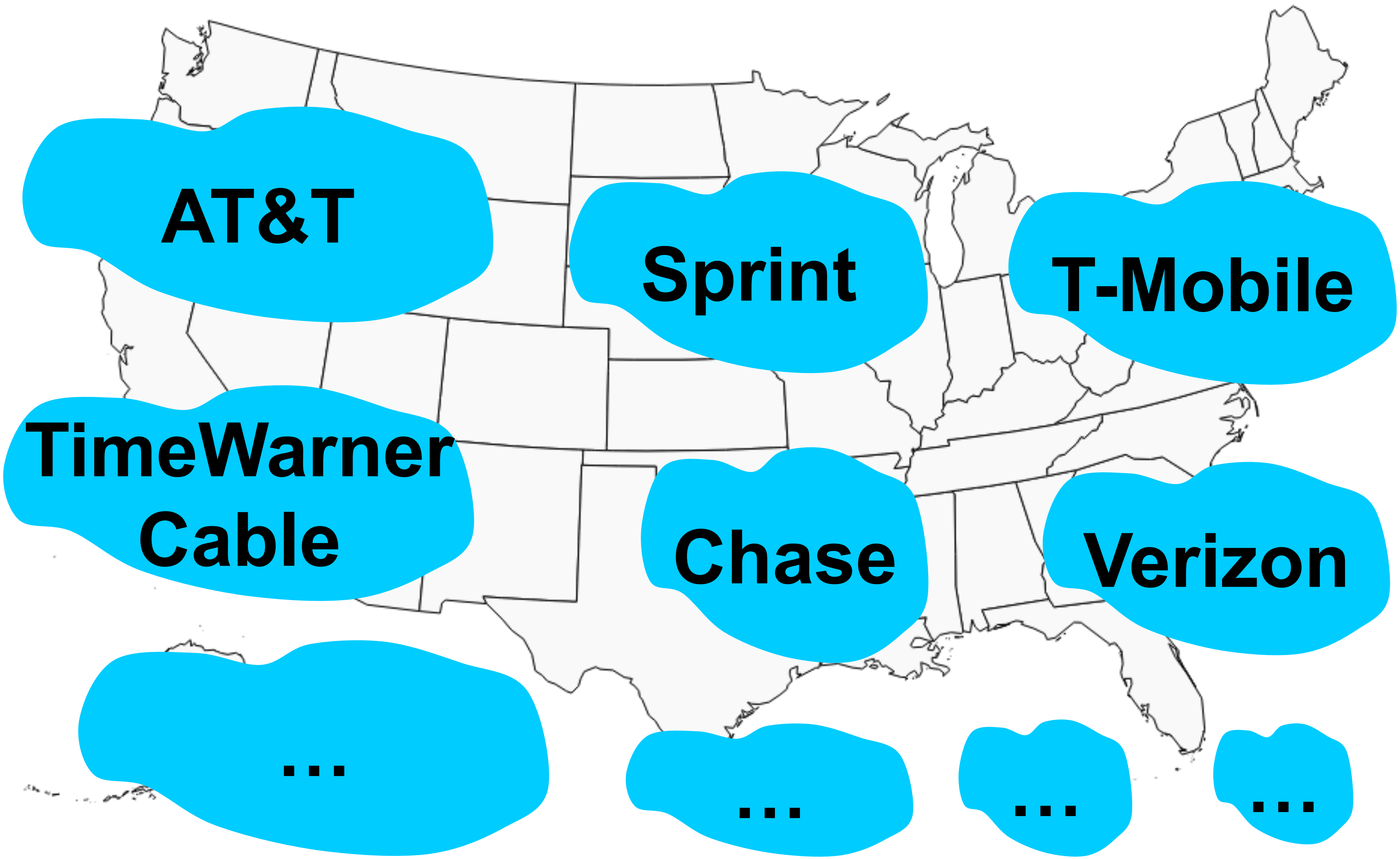
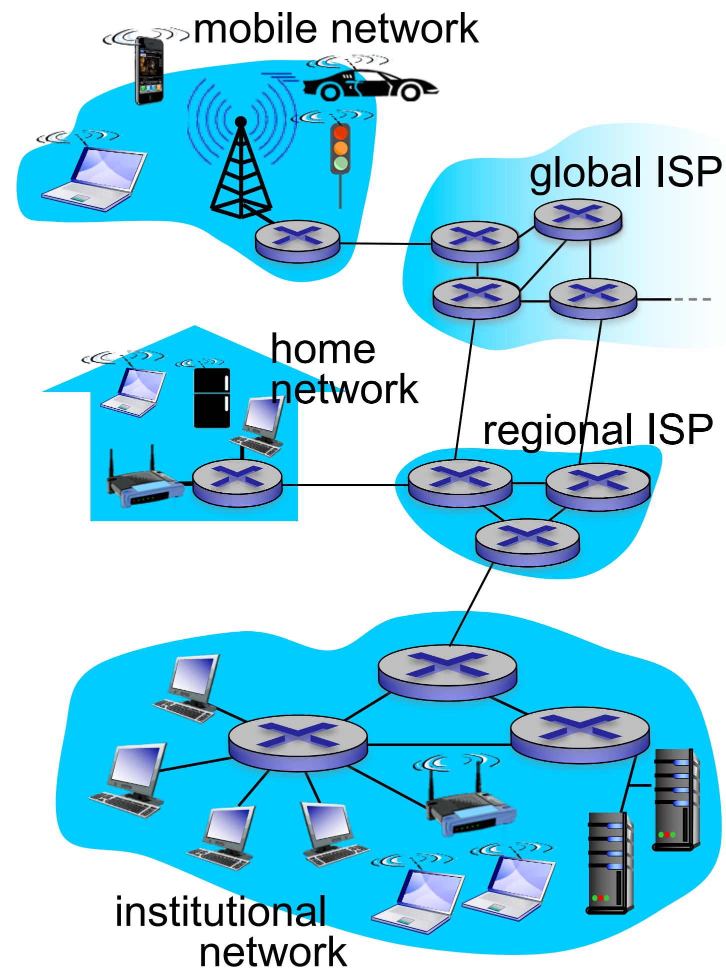


What's the Internet: "nuts and bolts" view

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

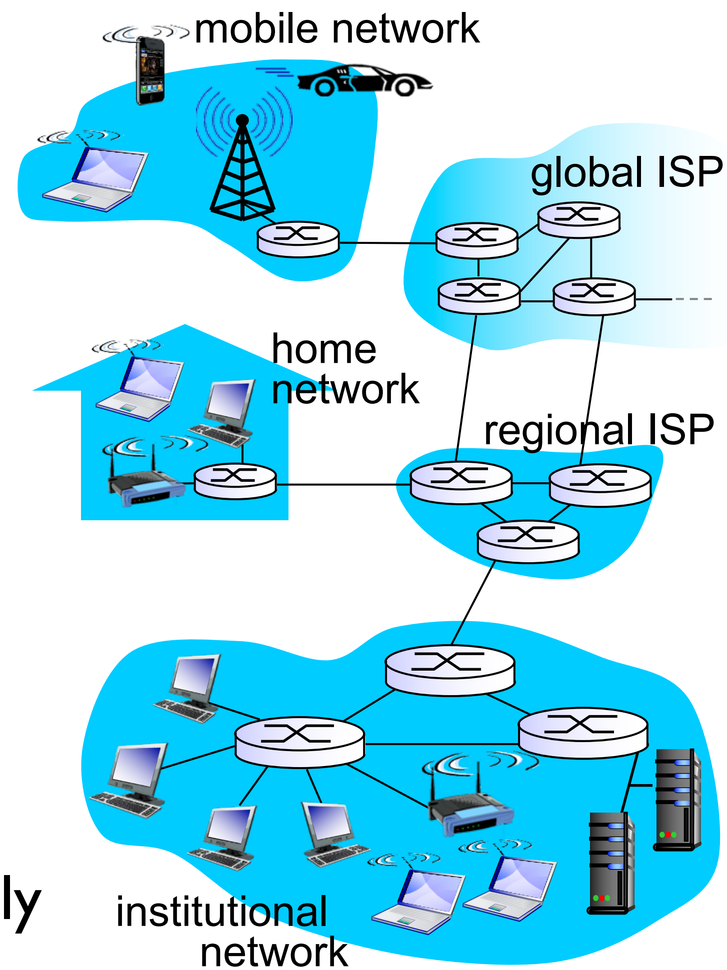


Questions on hosts, links, routers

- What else are hosts?

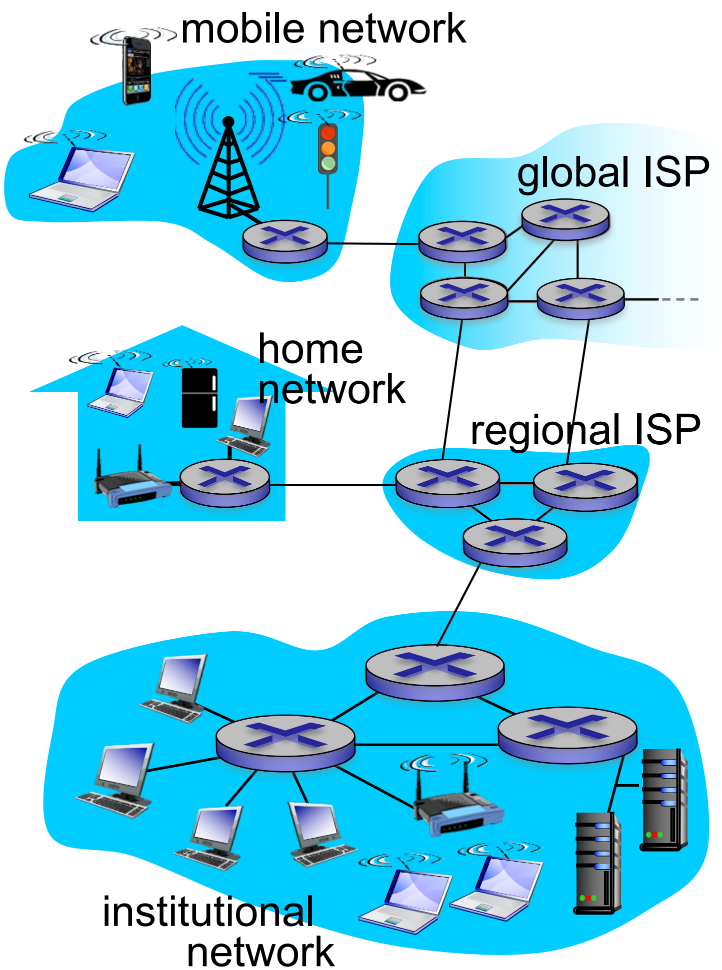
- Are they comm. Links?
  - Phone-wireless AP?
  - Phone-base station?
  - Router-to-router?
  - Router-to-server?

- How to differ routers and switches from end-hosts?
  - Routers: in-between
  - No network apps running (only interconnection, no web/email/etc)



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



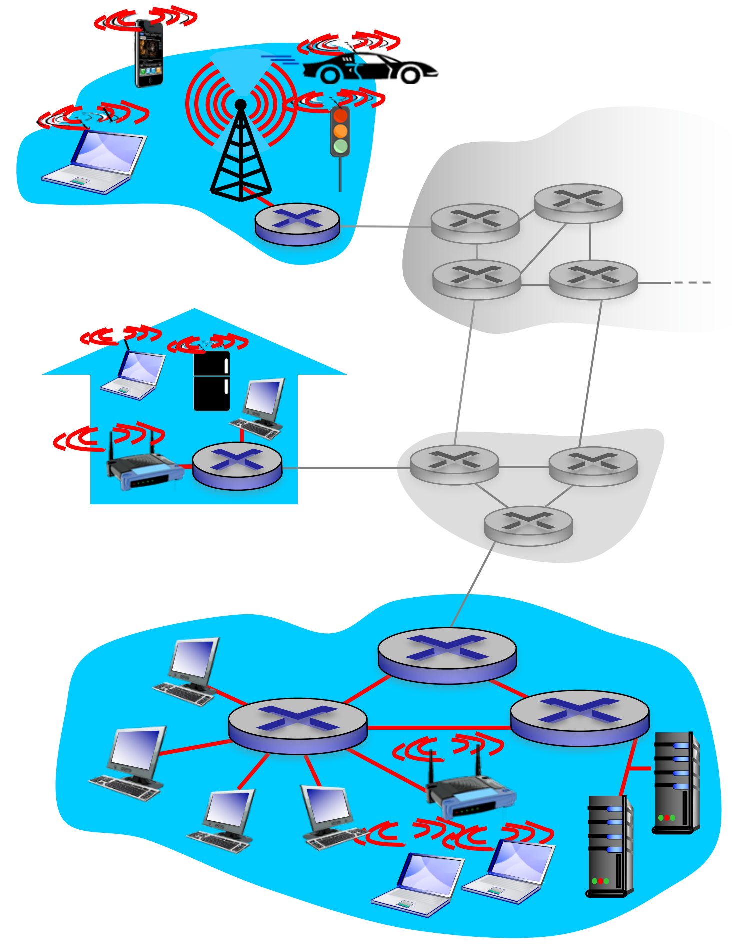
Access networks and physical media

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?

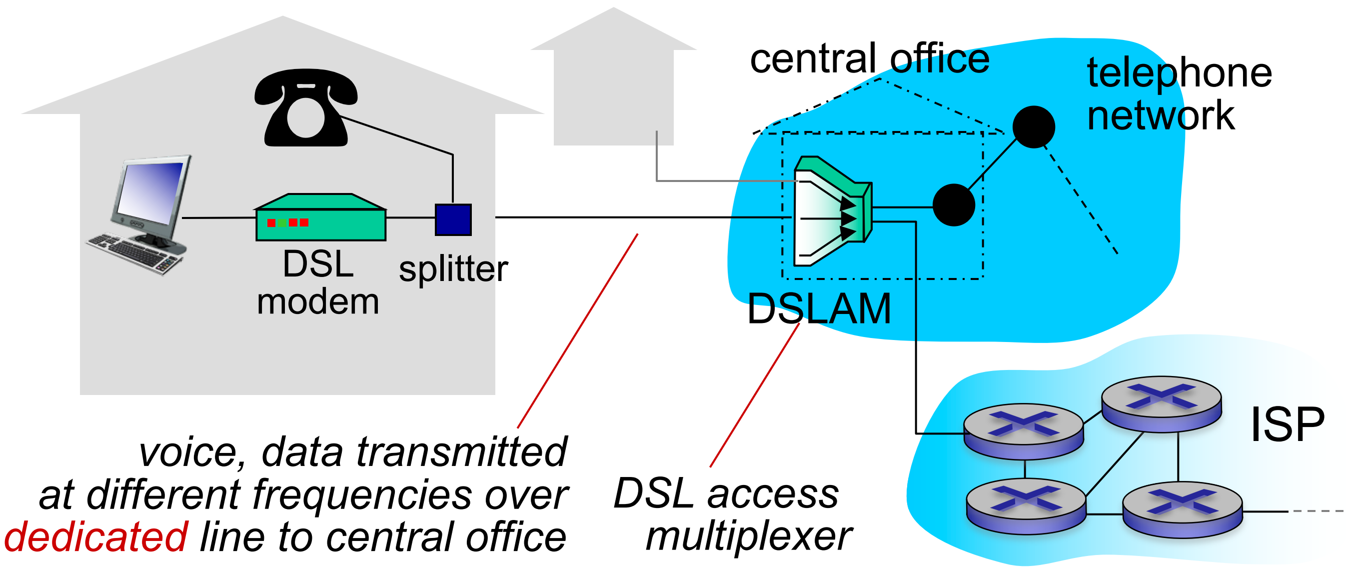


Common Access Networks

- Cable network
- Digital subscriber line (DSL)
- Home Wi-Fi Network
- Cellular (mobile) network
- Ethernet
- Fiber (optics network)
- …

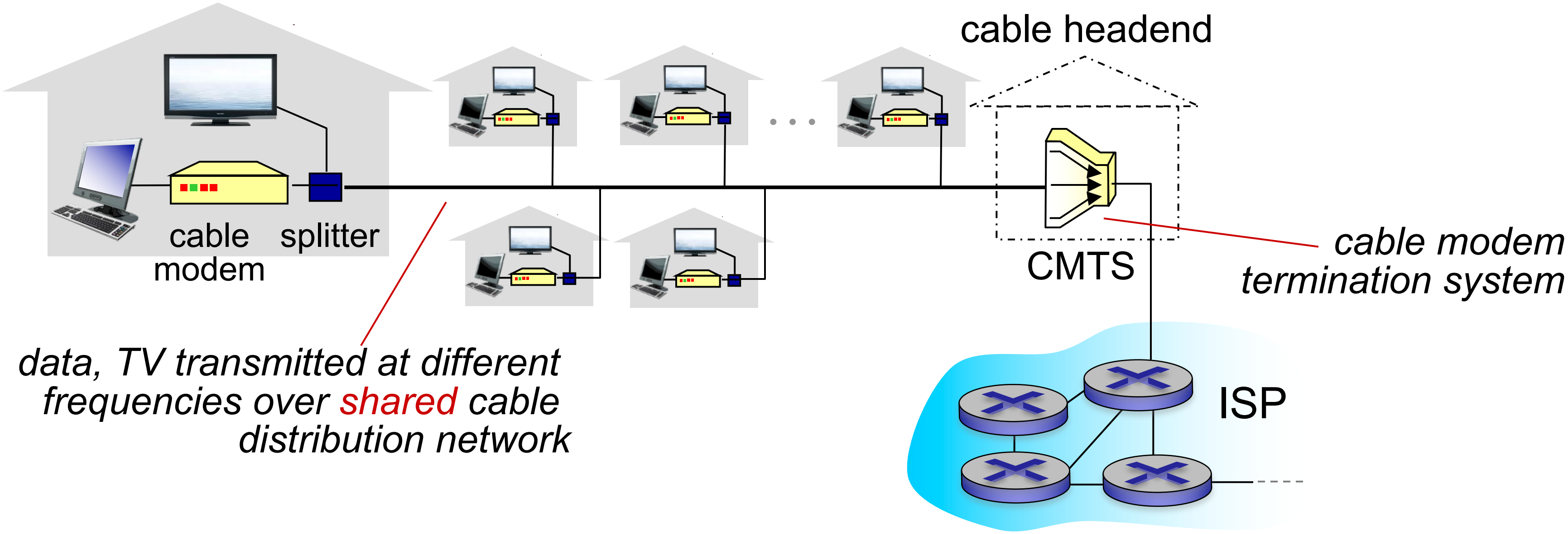
- Read Chapter 1.2 for details

Access network: digital subscriber line (DSL)



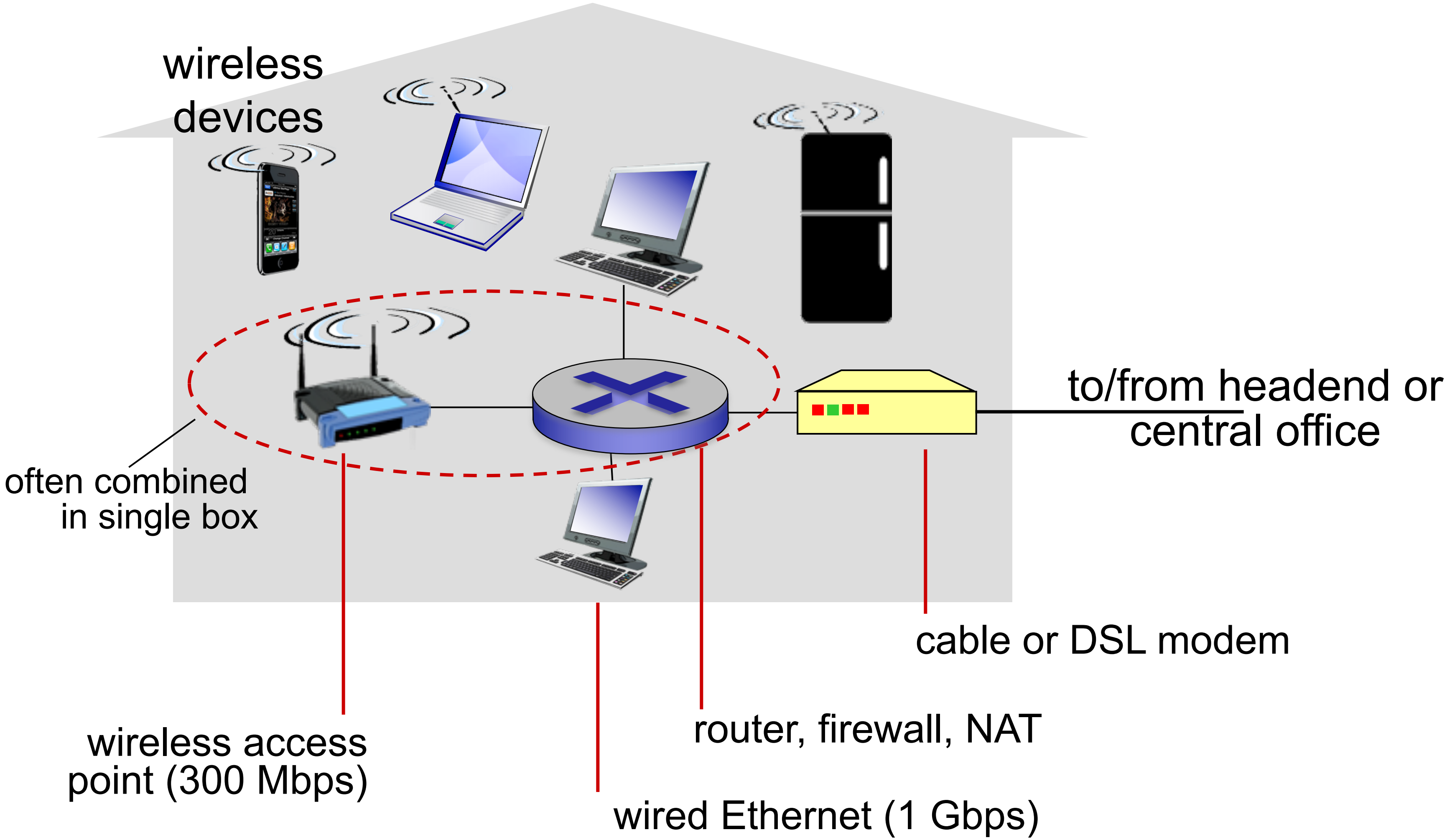
- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access network: cable network

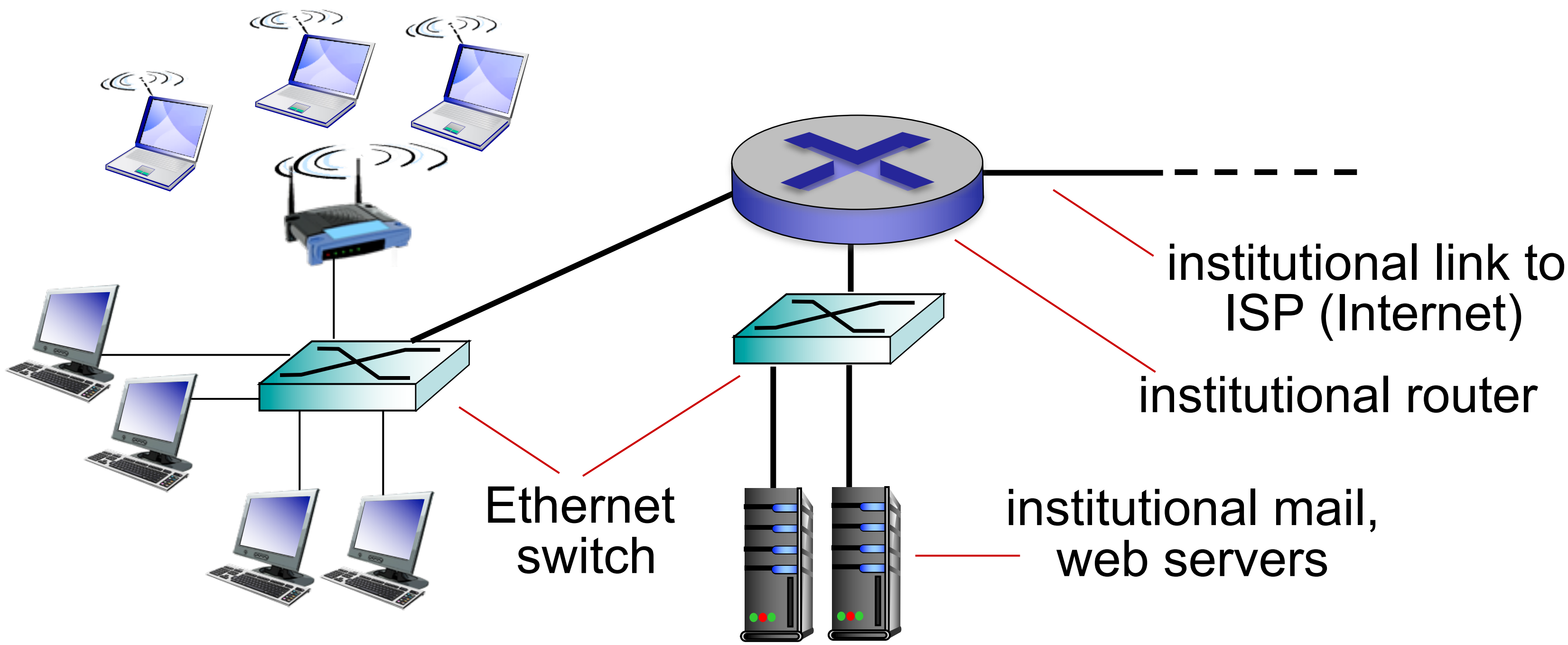


- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend
  - unlike DSL, which has dedicated access to central office

Access network: home network



Enterprise access networks (Ethernet)



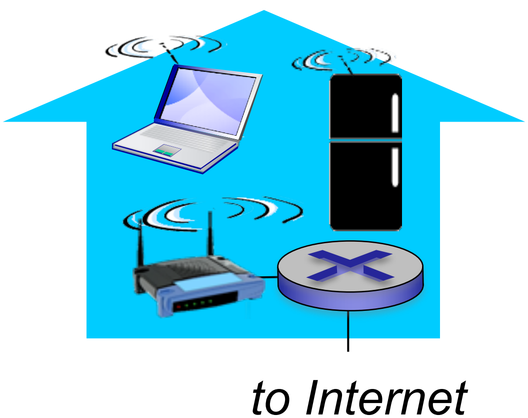
- typically used in companies, universities, etc.
- 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

Wireless access networks

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

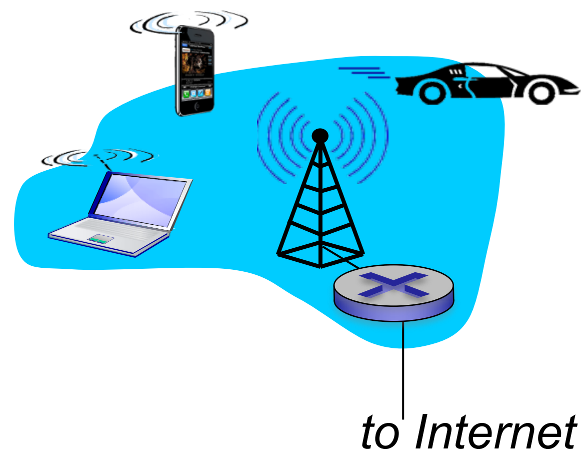
wireless LANs:

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



wide-area wireless access

- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G, 5G: 3G, LTE, LTE-A, 5G



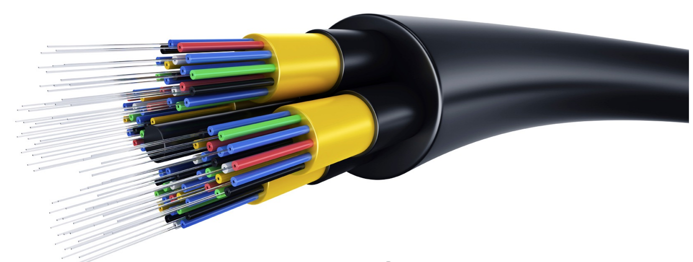
Physical media (optional)

Read chapter 1.2.2 if interested.

- 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)

coaxial cable



fiber optic cable

Wireless radio

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

Chapter 1: roadmap

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1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

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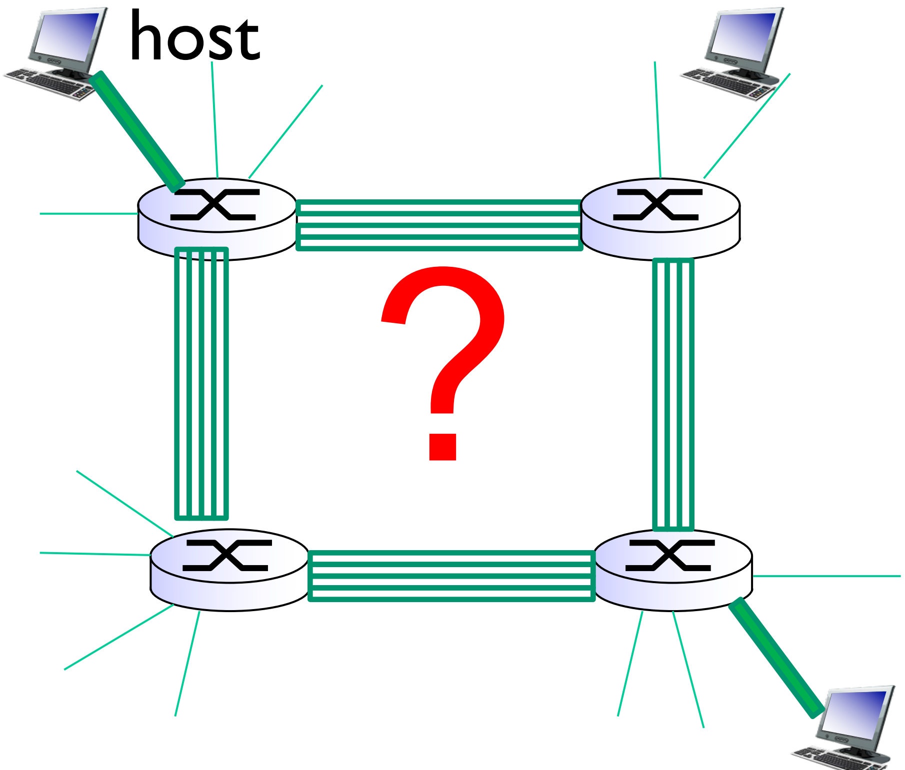
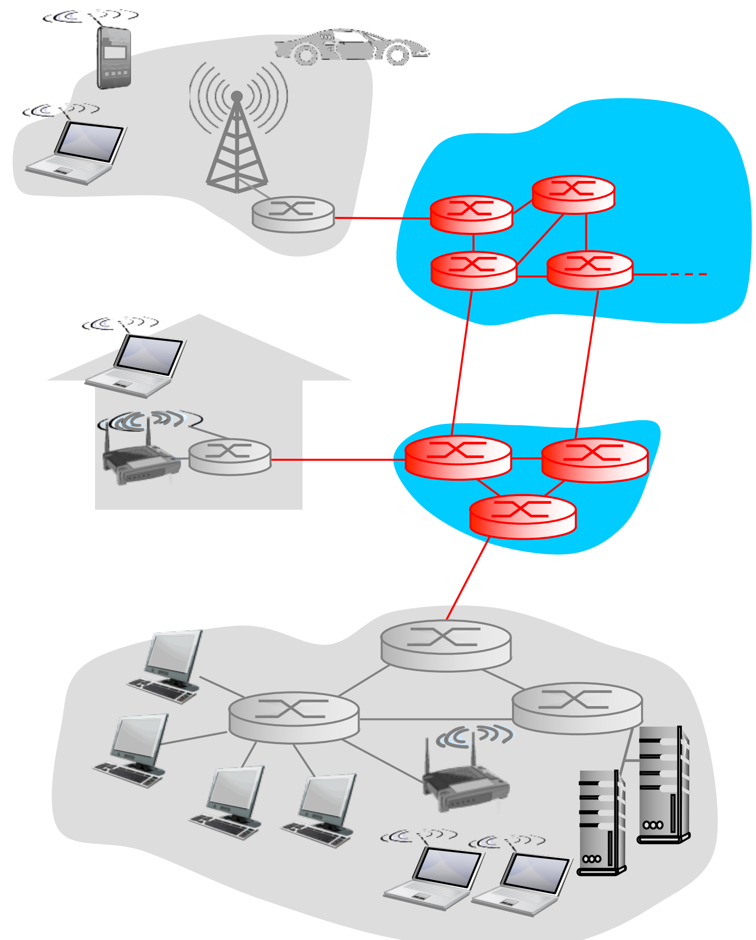
Discussion: How to transfer data?

- mesh of interconnected routers
- Role: send chunks of data from one host to another host



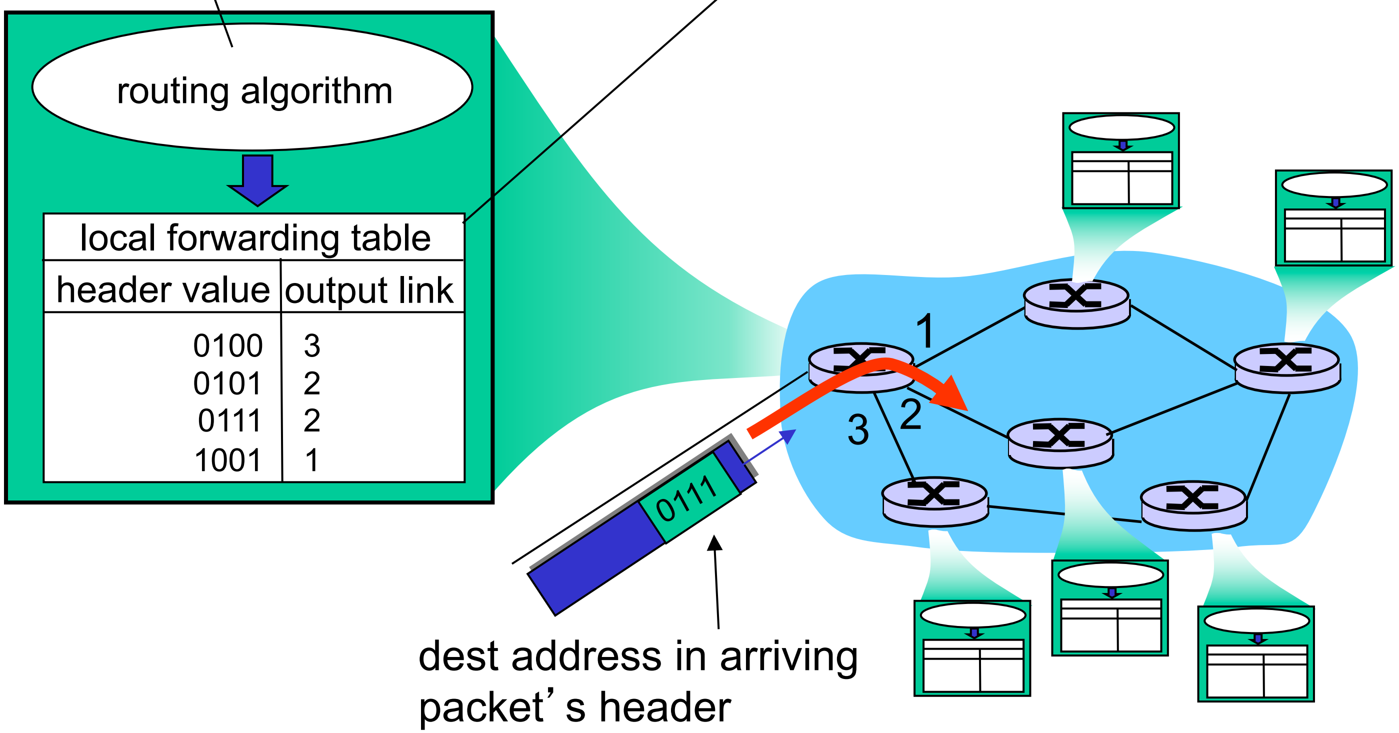


Two key network-core functions

routing: determines source-destination route taken by packets

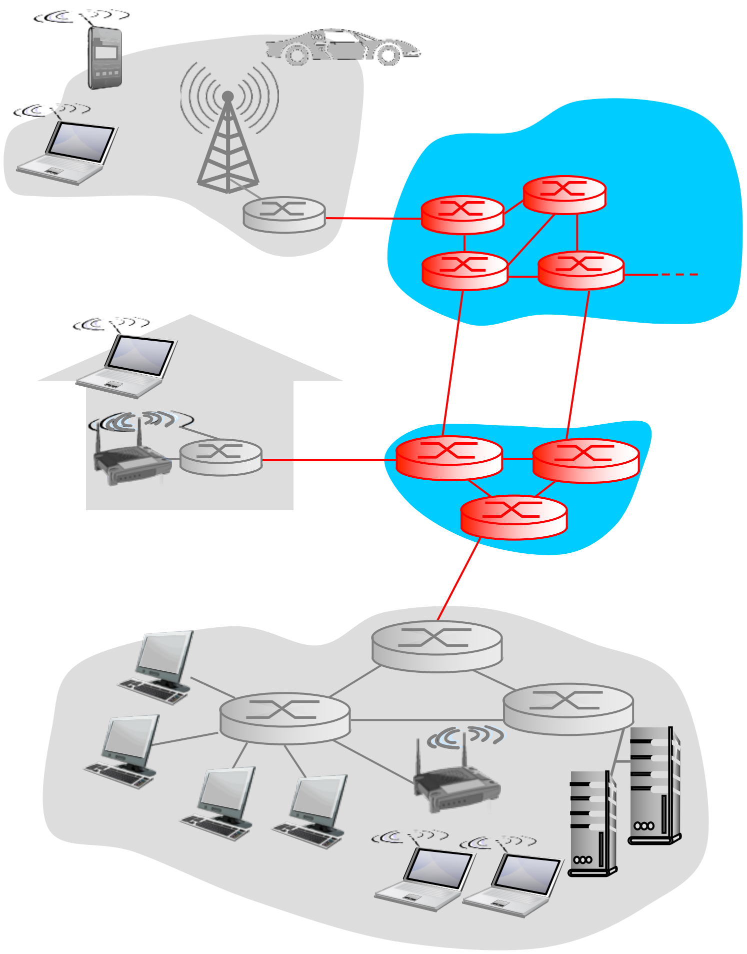
- *routing algorithms*

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



Network core: packet-switching

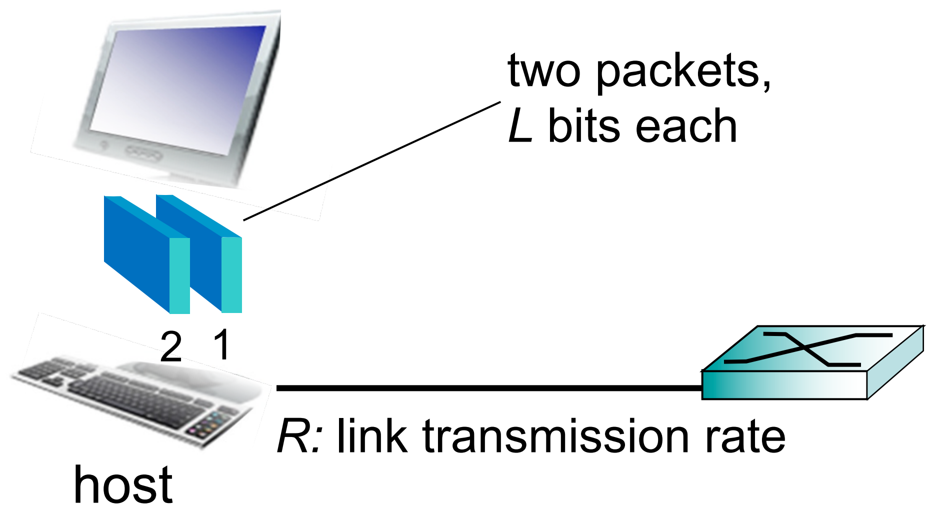
- *Packet-switching*: hosts break application-layer messages into *packets*
  - forward packets from one router to the next, across links on path from source to destination
  - each packet transmitted at ***full*** link capacity



Host: sends *packets* of data

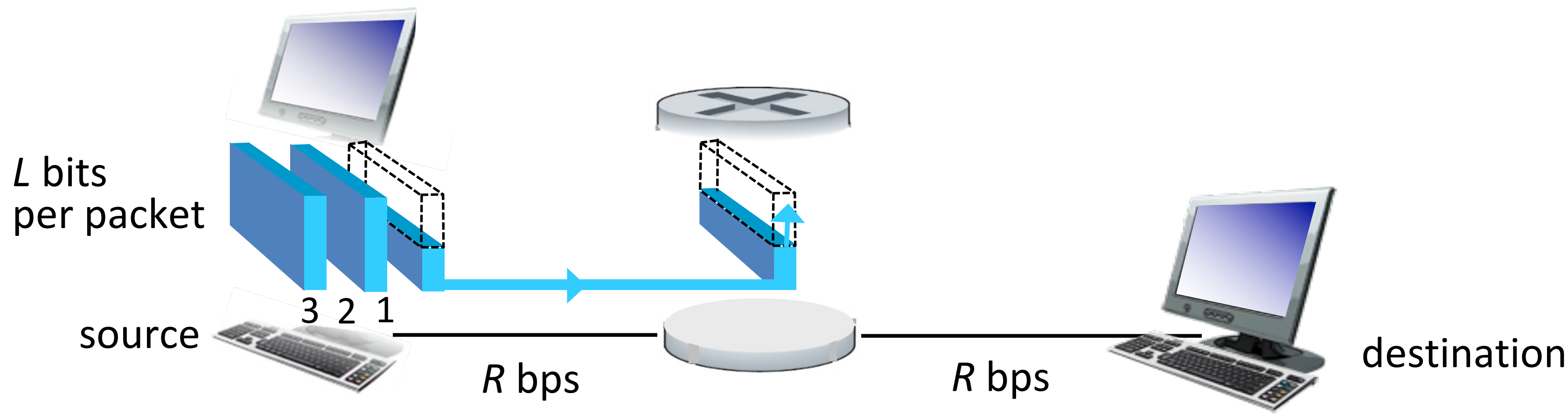
host sending function:

- 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*



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

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)

more on delay shortly …

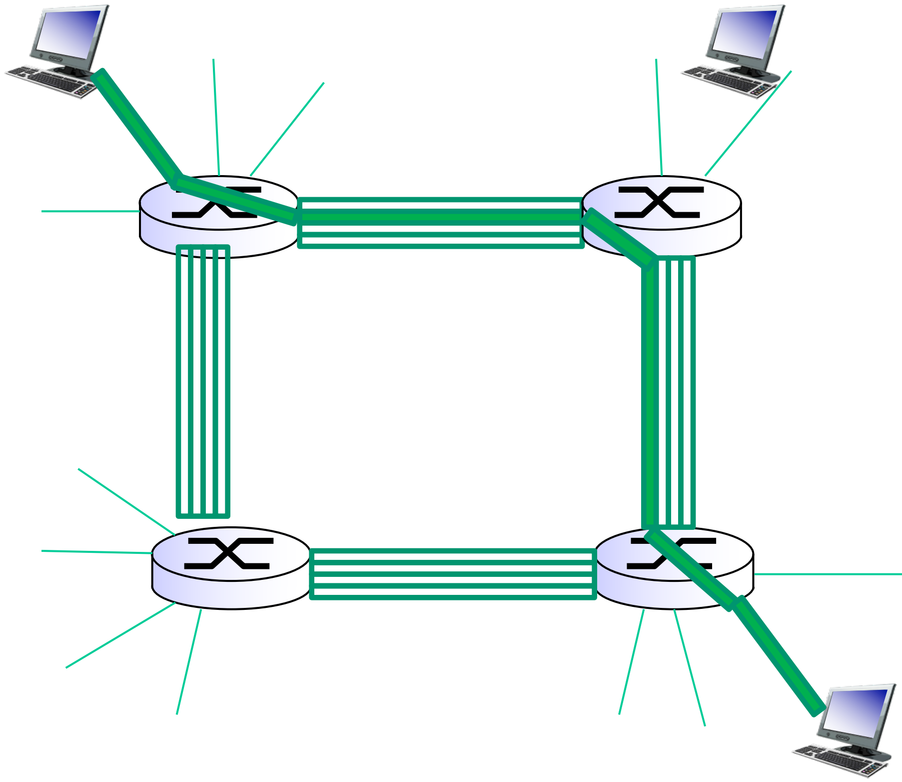
one-hop numerical example:

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

Alternative core: circuit switching

end-end resources allocated to, reserved for voice "call" btw. source & dest

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

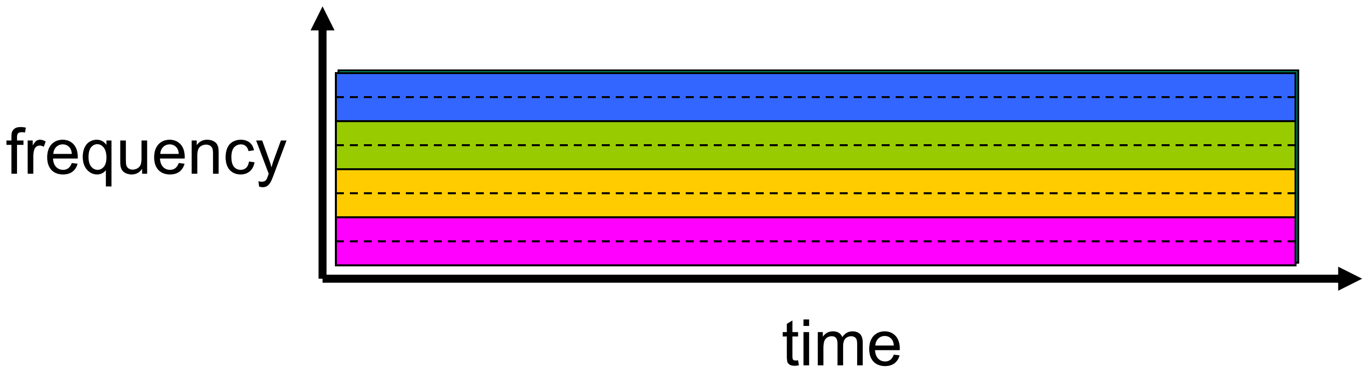


Circuit switching: FDM versus TDM

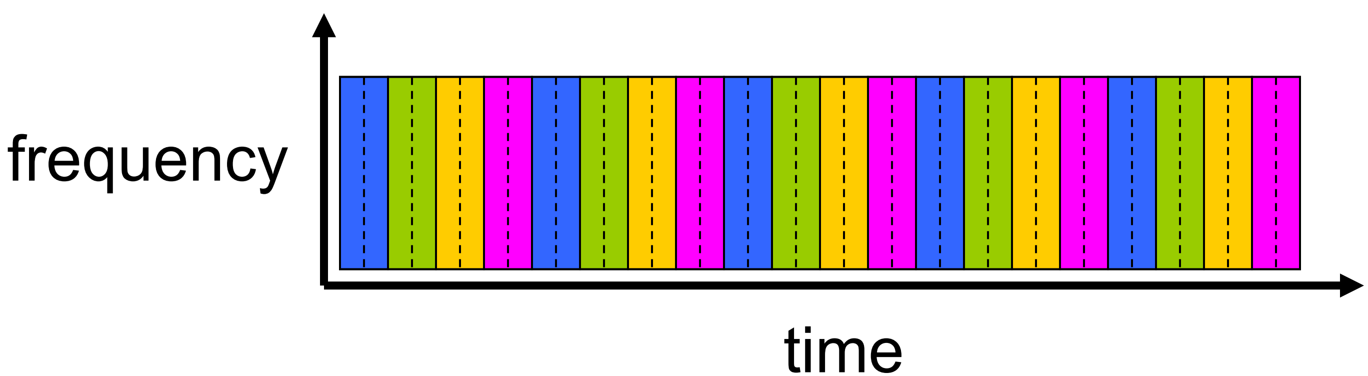
Example:

4 users

FDM



TDM



Discussion:
Packet switching vs. circuit switching

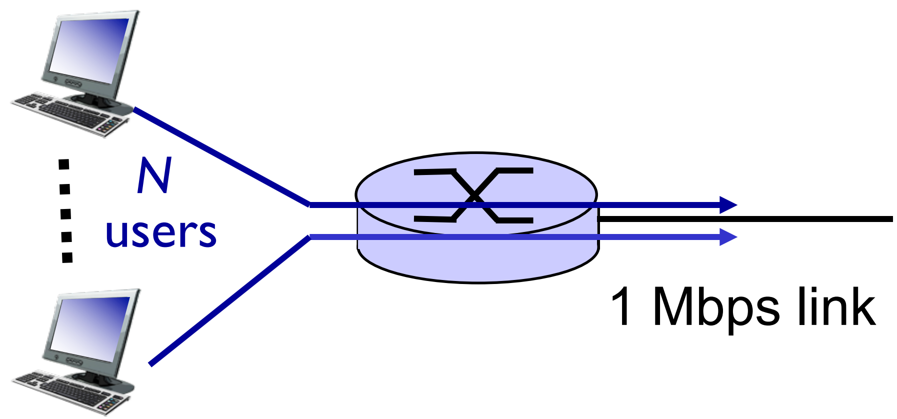
Q: Why packet switching is chosen by the Internet?

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

How to calculate N in the example?

- Given N users, the probability that x users are active is P(N,x)

$$P(N,x) = \binom{N}{x} p^x (1-p)^{N-x}$$

- In order to afford N users, the probability that more than 11 (including 11) users are active at the same should be extremely small (e.g., < 0.1%)
- Therefore,

$$\sum_{x=0}^{10} P(N,x) \geq (1-0.1\%) = 0.999$$

More on "how to calculate N?"

- Given N, we can obtain the probability of no more than x active users at the same time
  - Calculator
  - Program (sum them up)

- Given the maximal probability of no more than x active users at the same time, how to calculate N?
  - Approach #1: program (for loop, and increment N by 1 until it meets the threshold)
  - Approach #2: Approximation via central limit theorem (optional; see the hidden slides for details)

Packet switching vs circuit switching

Q: is packet switching a "slam dunk winner?"

- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss (see the following slides)
  - protocols needed for reliable data transfer, congestion control

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

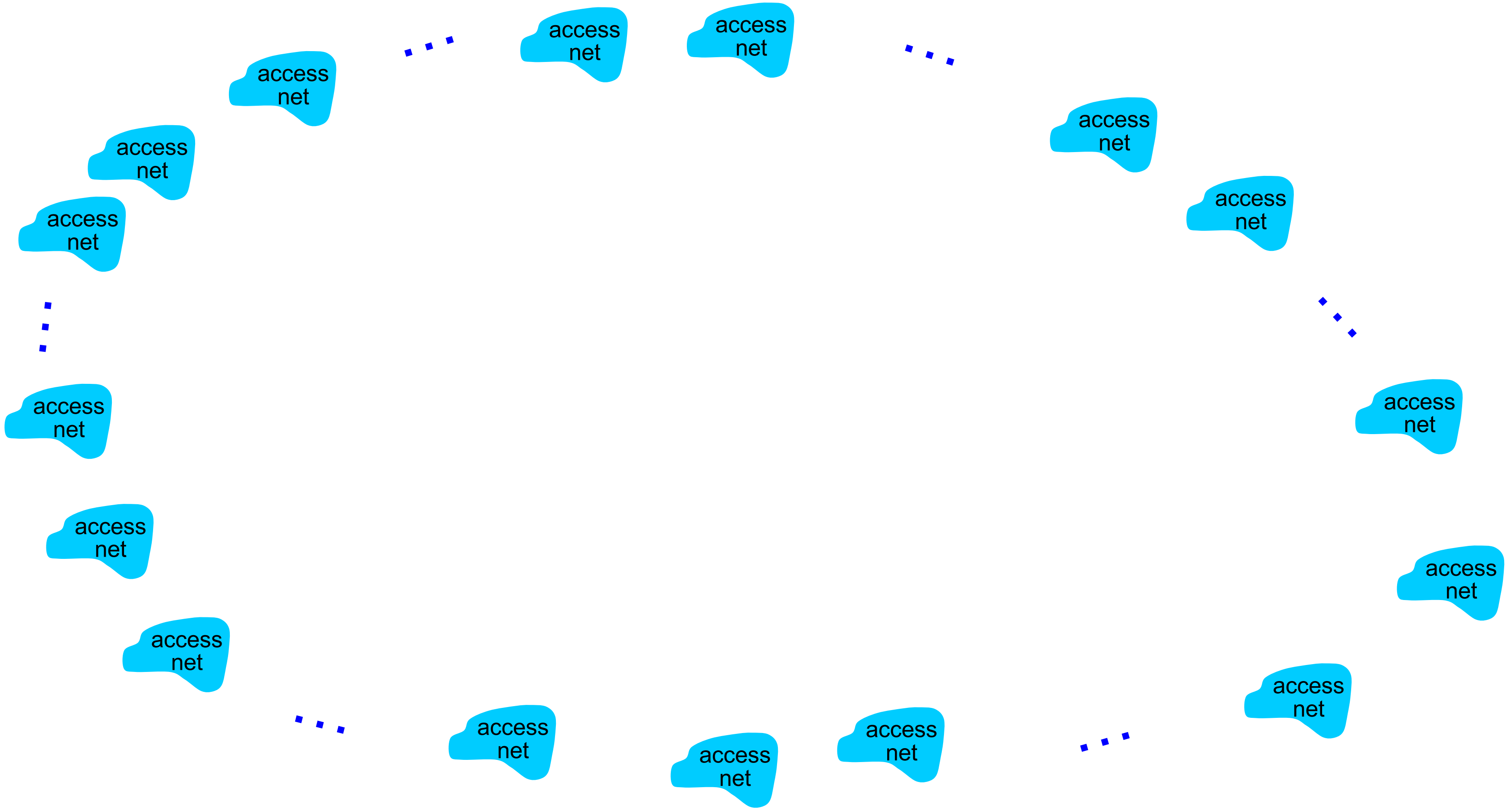
Finally,

- Let us see how to build the Internet: network of networks.

- Optional. Read Chapter 1.3.3

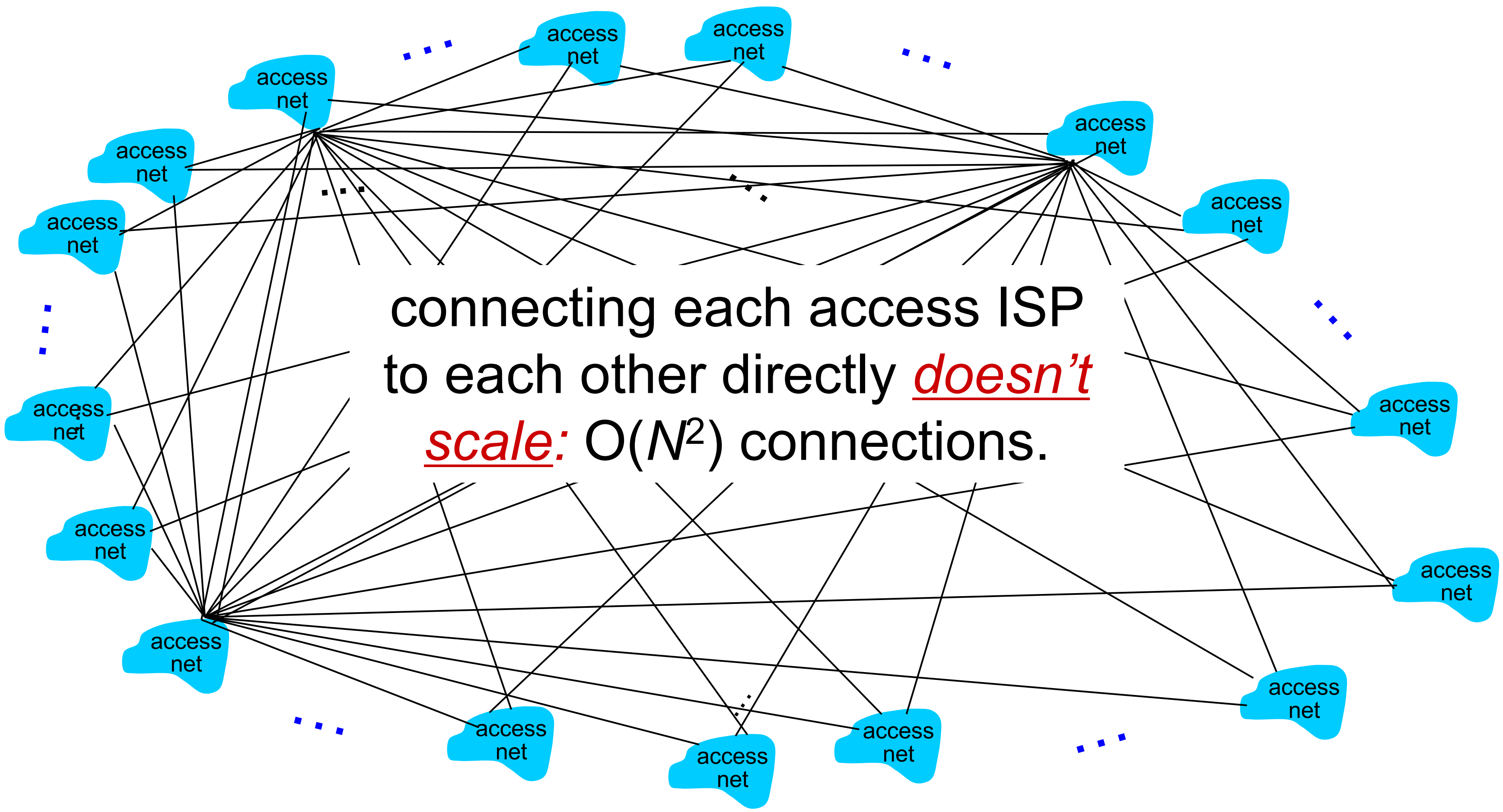
Internet structure (Optional)

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



Option 1: all inter-connected?

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

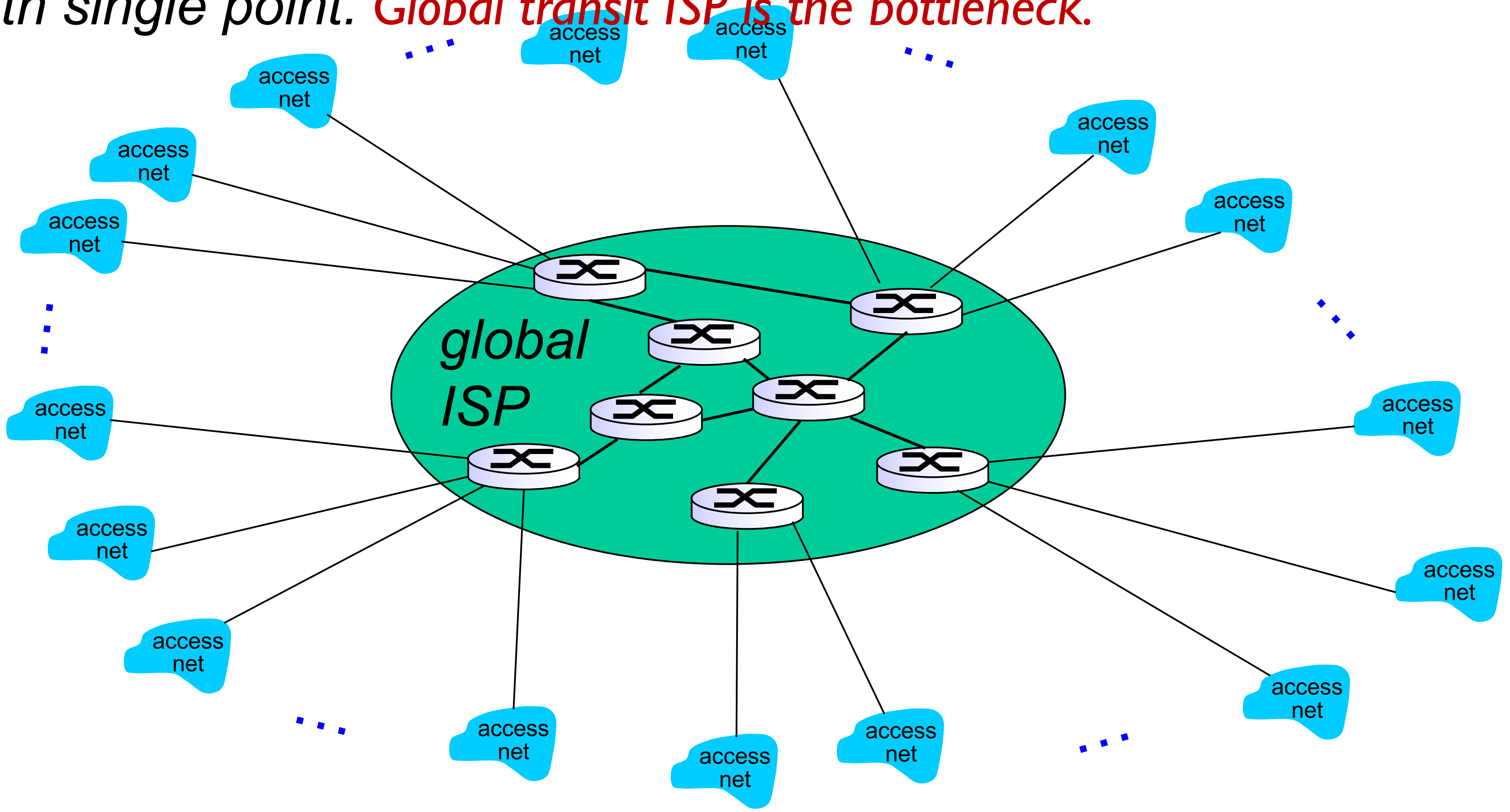


connecting each access ISP to each other directly ***doesn't scale:*** $O(N^2)$ connections.

Option 2: one Global ISP?

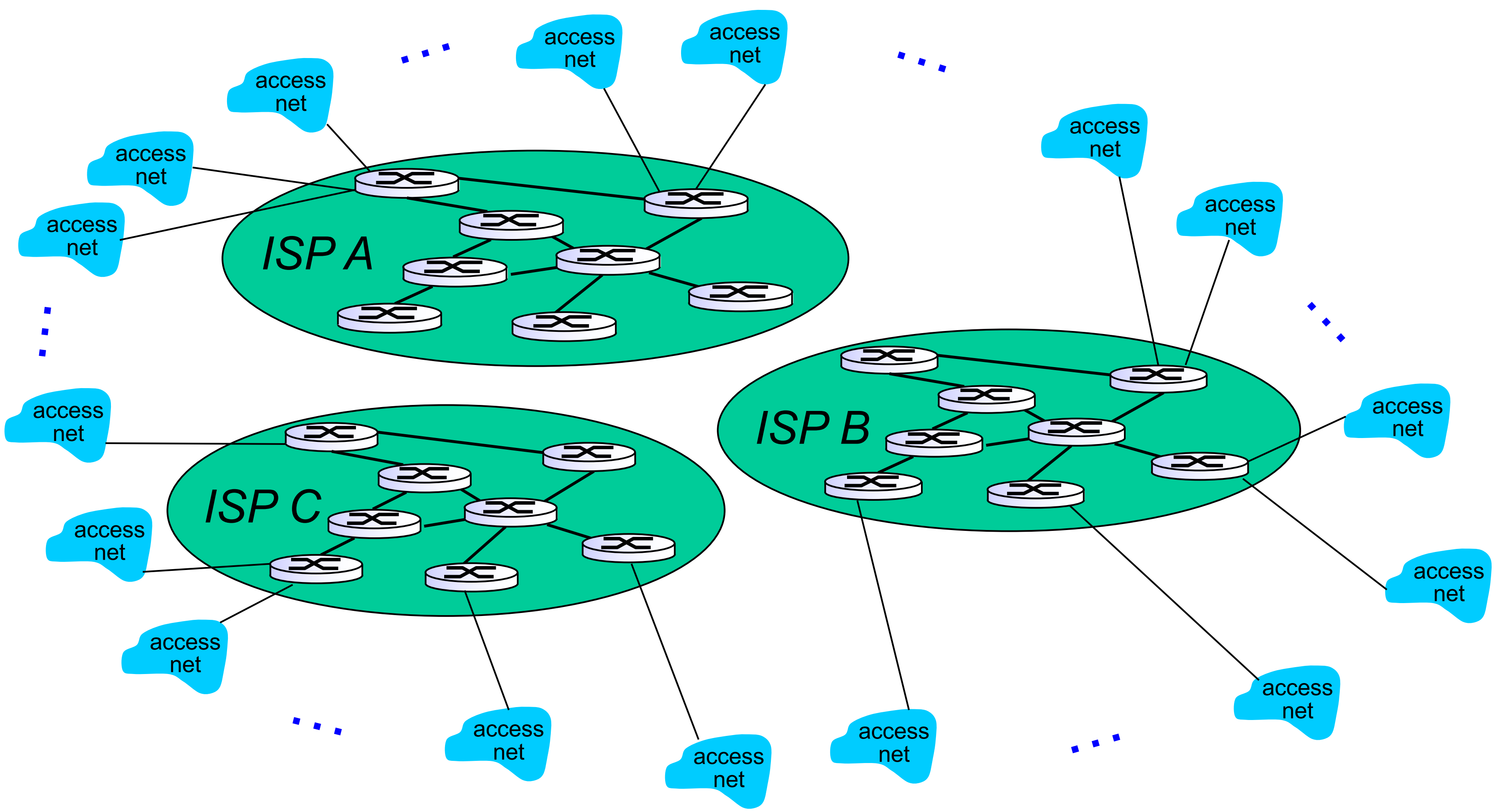
Option: connect each access ISP to a global transit ISP?

But, Customer and provider ISPs have economic agreement with single point. Global transit ISP is the bottleneck.

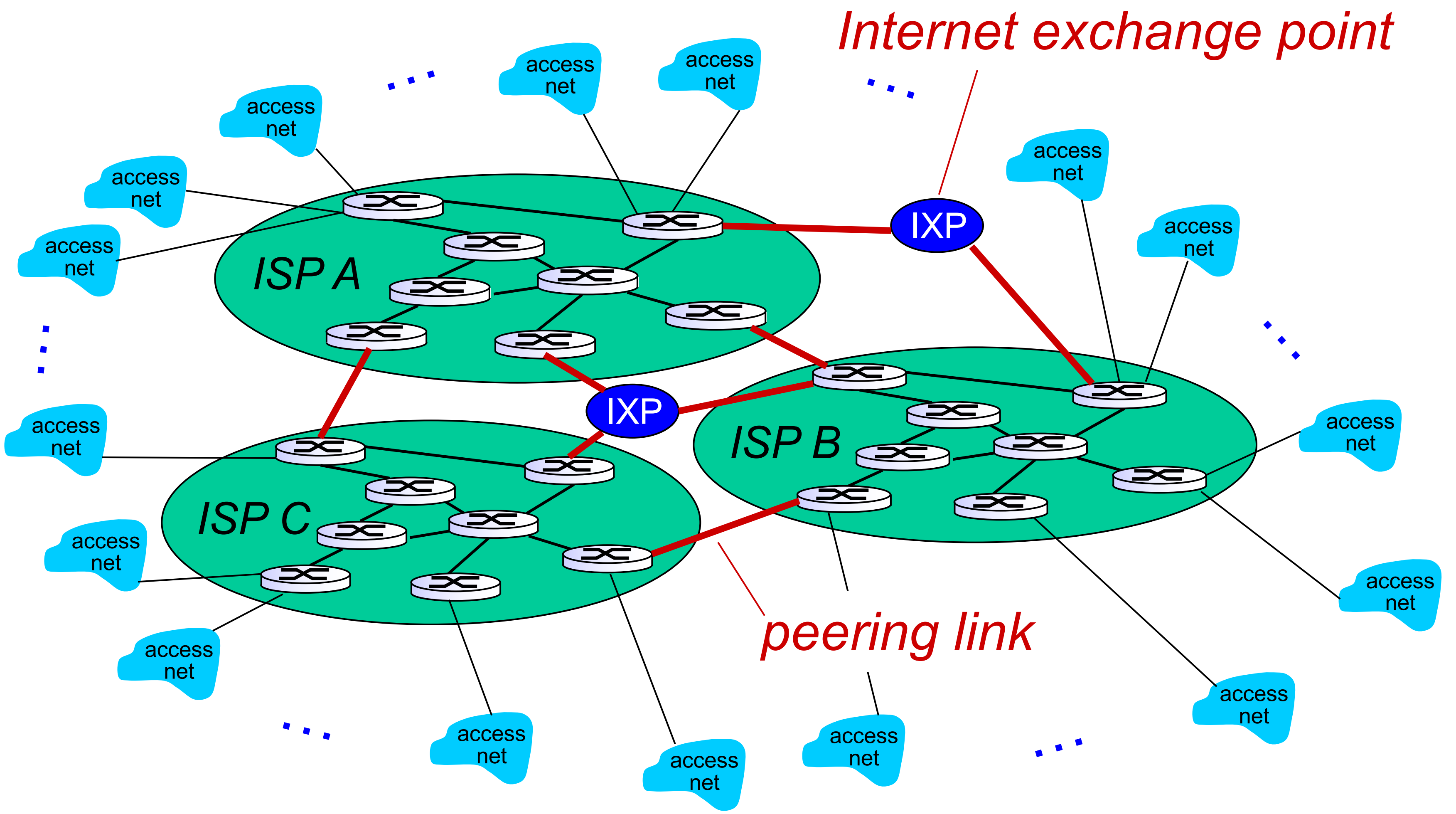


Option 2*: multiple Global ISPs?

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

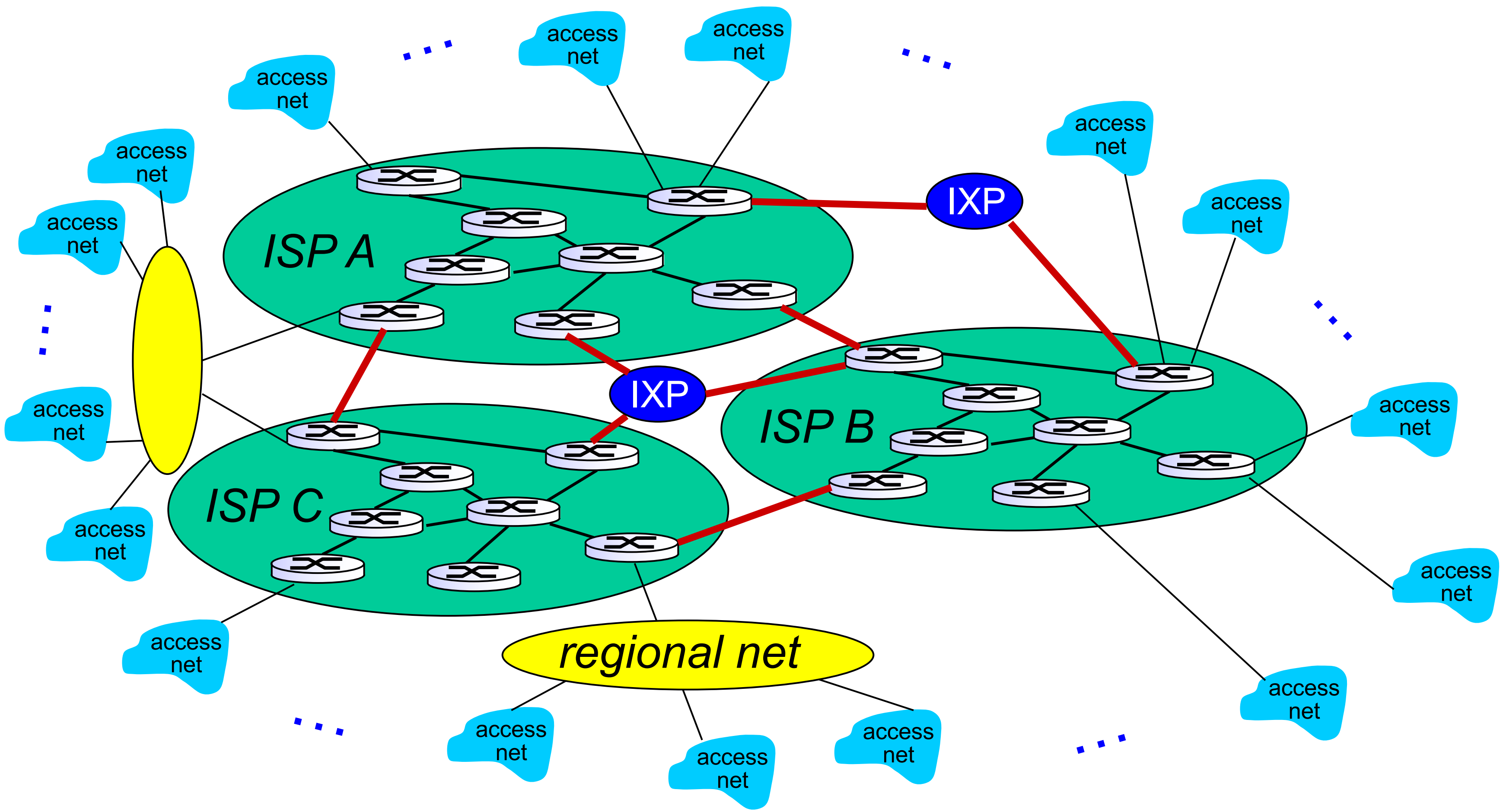


But if one global ISP is viable business, there will be competitors …. which must be interconnected



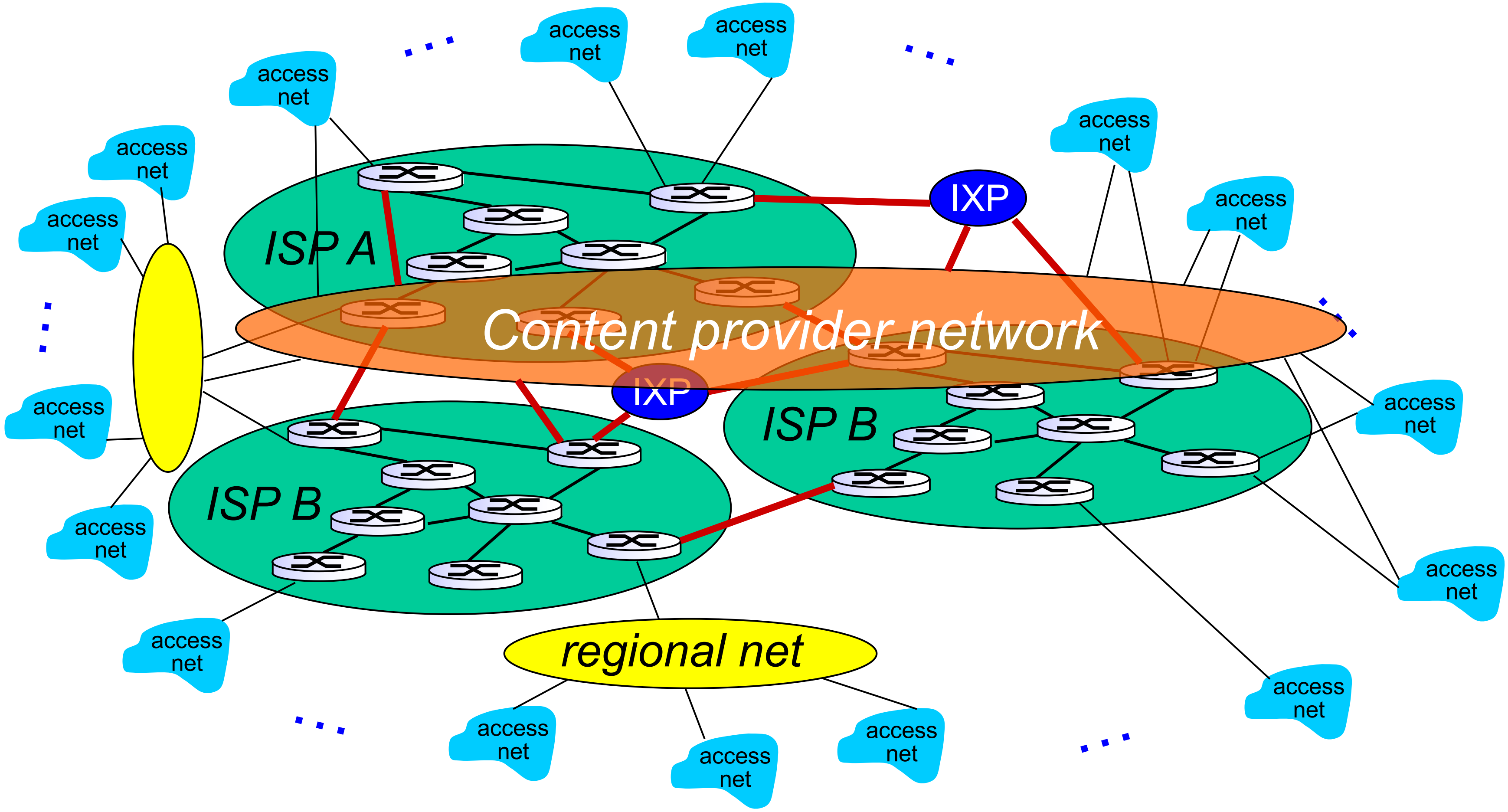
Option 3: Hierarchical structure

… 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



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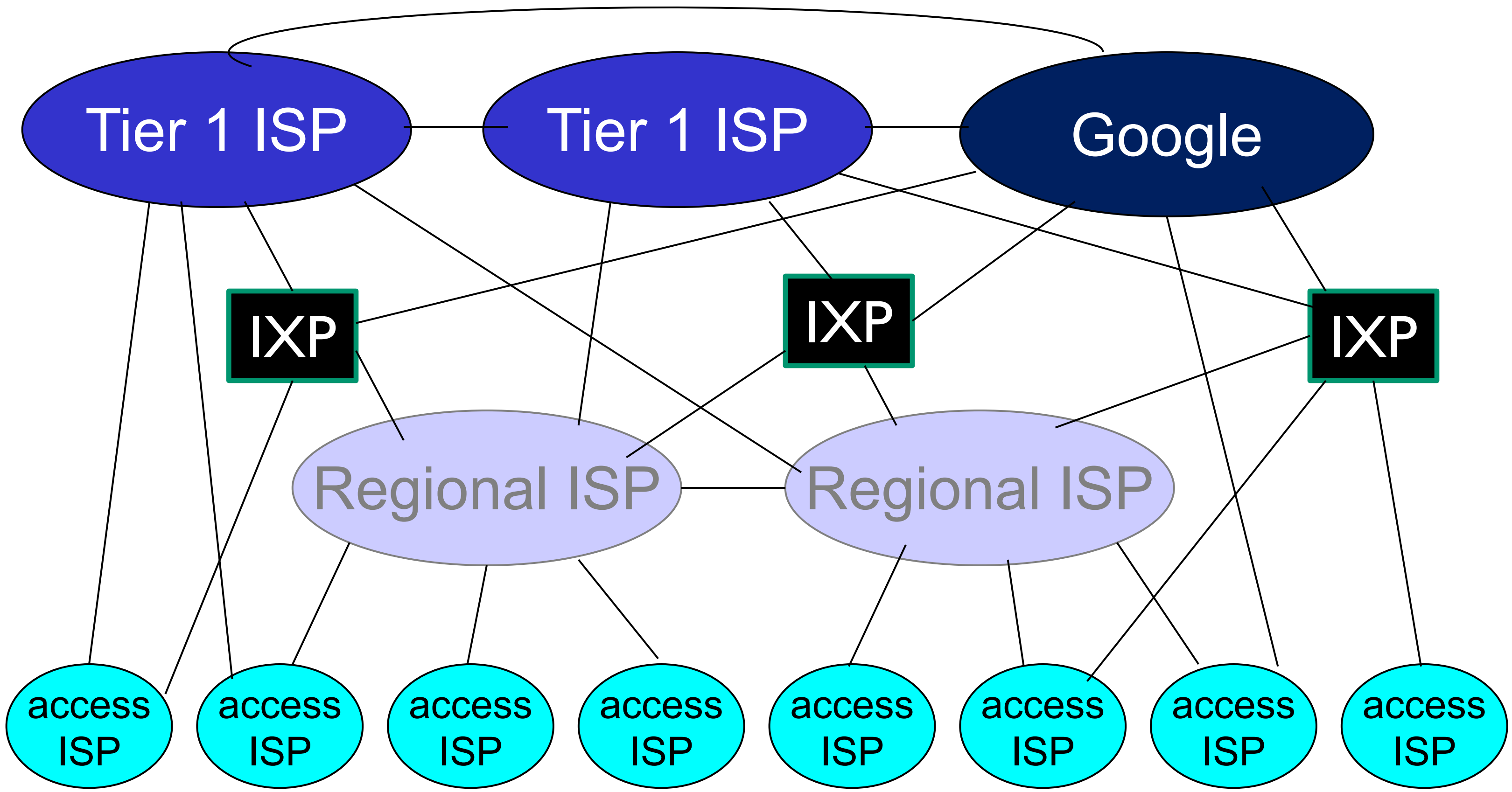

- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

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Host: sends *packets* of data (Recap)

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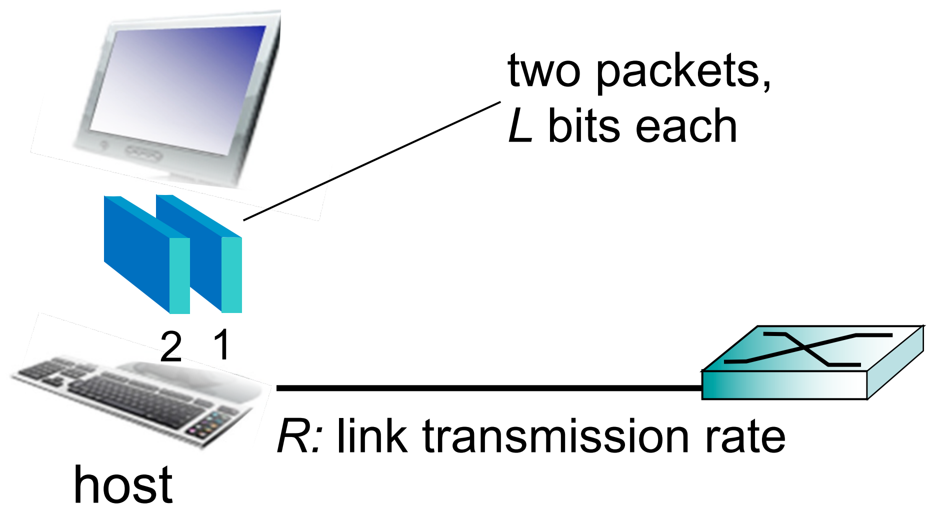
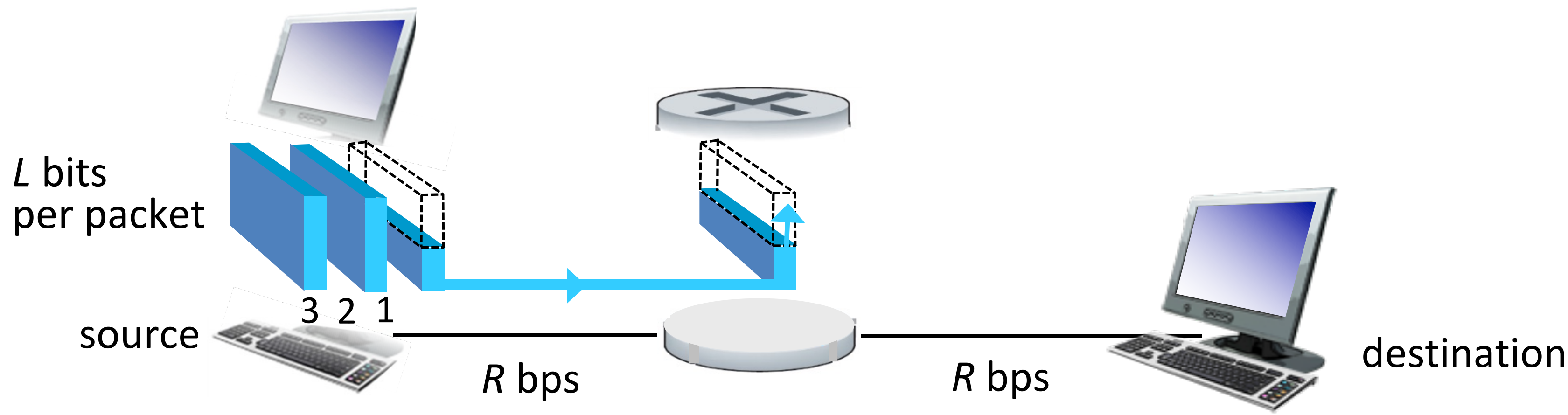


packet transmission delay = time needed to transmit *L*-bit packet into link = $\frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$

Store-and-forward: transmission delay



- takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
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more on delay shortly …

one-hop numerical example:

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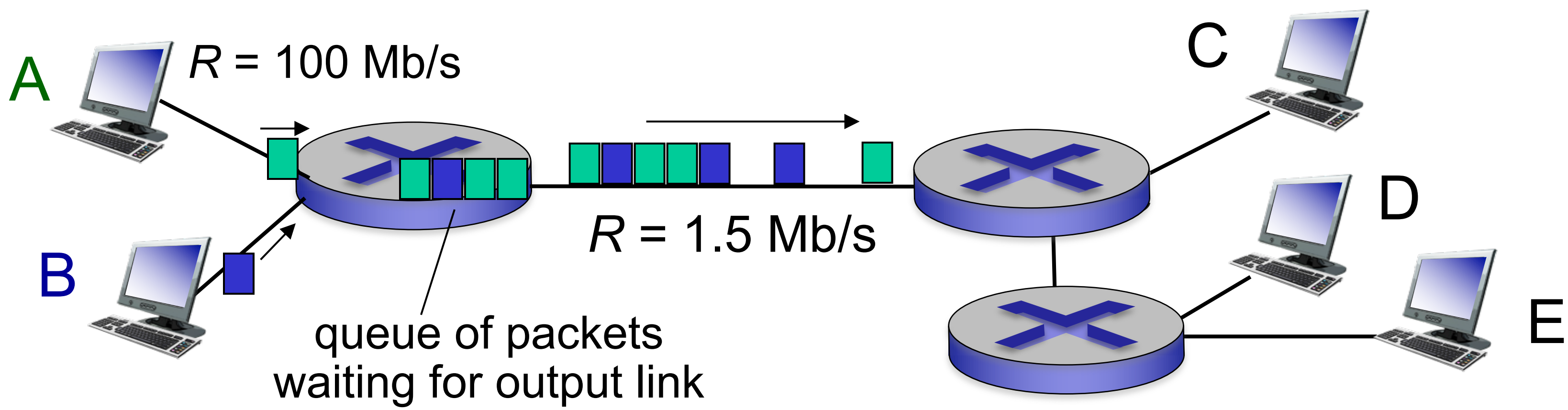
Follow-up questions

- What if we have N hops?

- What if we have P packets?
  - Back-to-back

Packet Switching: queueing delay, loss



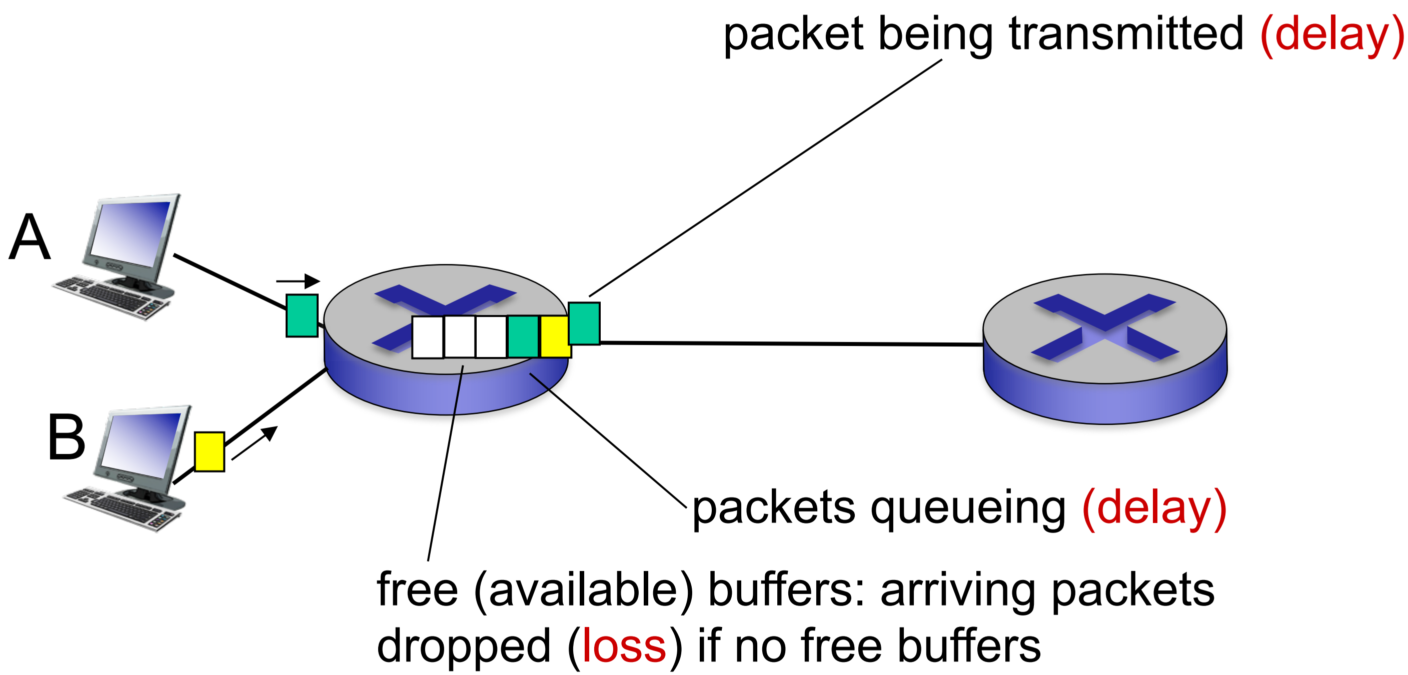
queuing and loss:

- 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

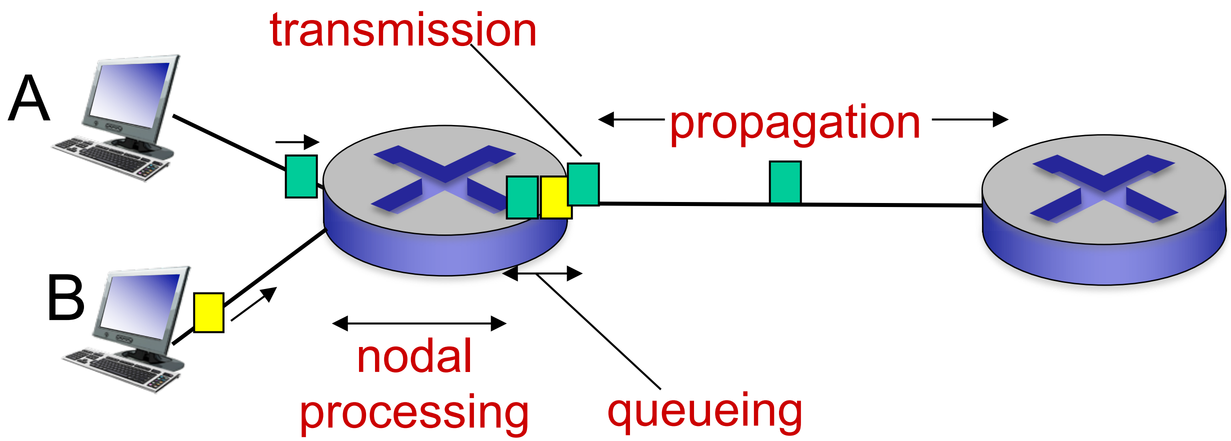
How do loss and delay occur?

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



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

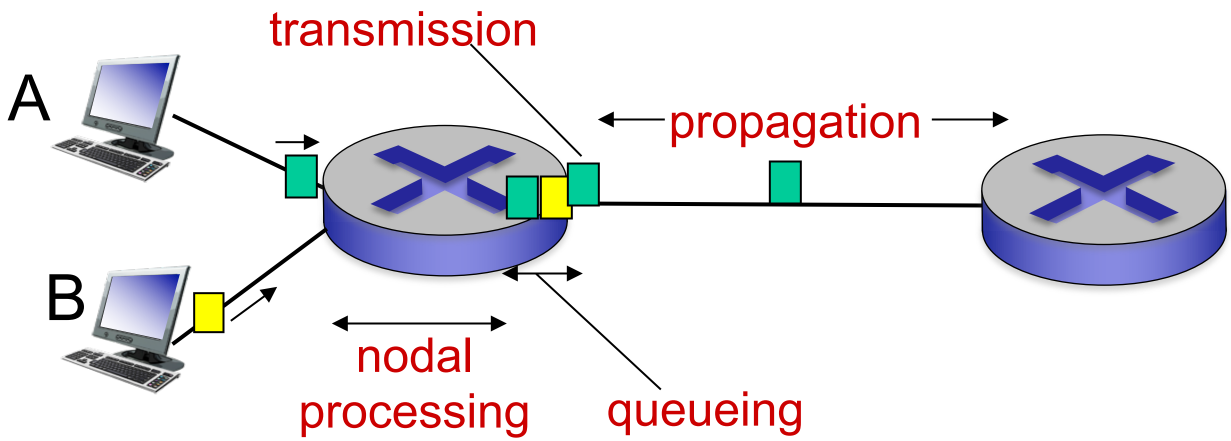
d_{proc}: nodal processing

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

d_{queue}: queueing delay

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

Four sources of packet delay



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

d_{trans}: transmission delay:

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

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

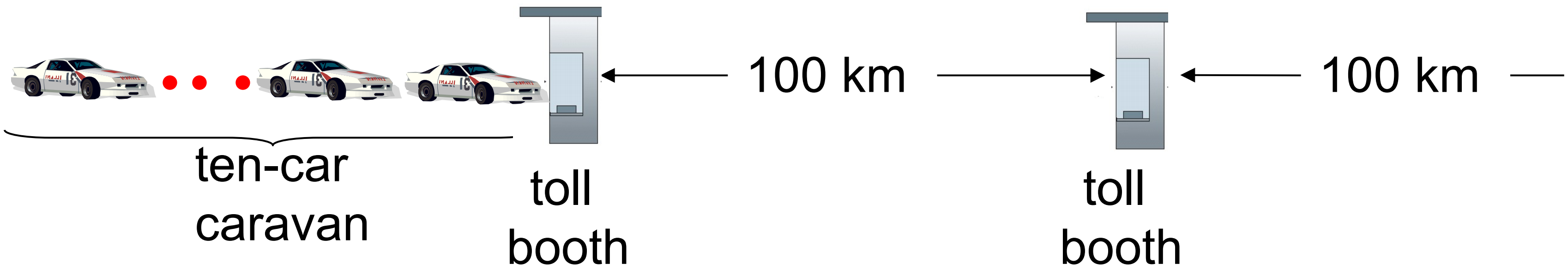
d_{prop}: propagation delay:

- d: length of physical link
- s: propagation speed (~2x10^8 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

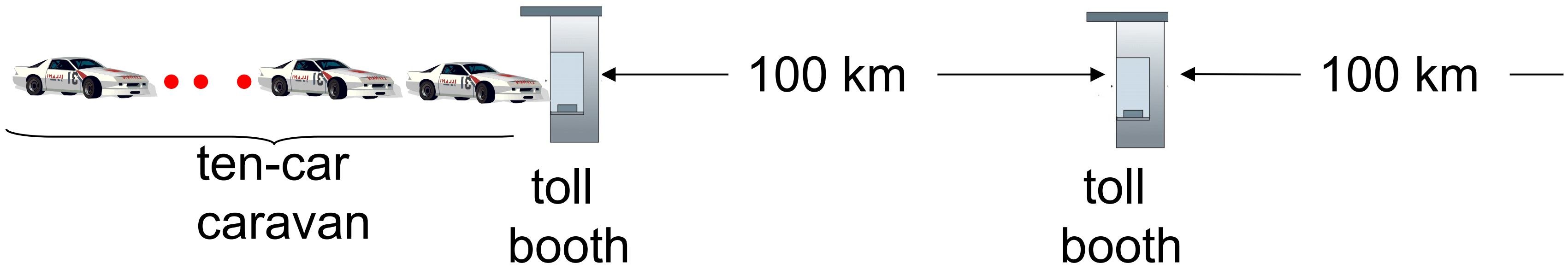
Caravan analogy



- 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: 100km/(100km/hr)= 1 hr
- *A:* 62 minutes

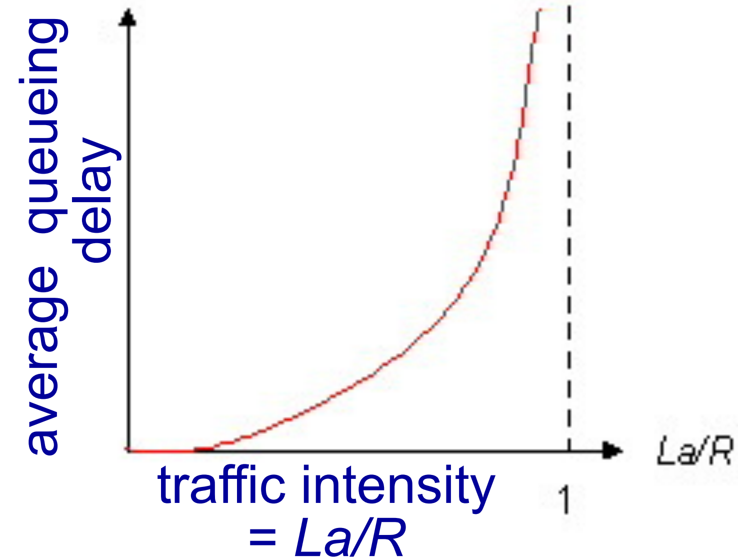
Caravan analogy (more)



- 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* ~ 0: avg. queueing delay small
- *La/R* -> 1: avg. queueing delay large
- *La/R* > 1: more "work" arriving than can be serviced, average delay infinite!

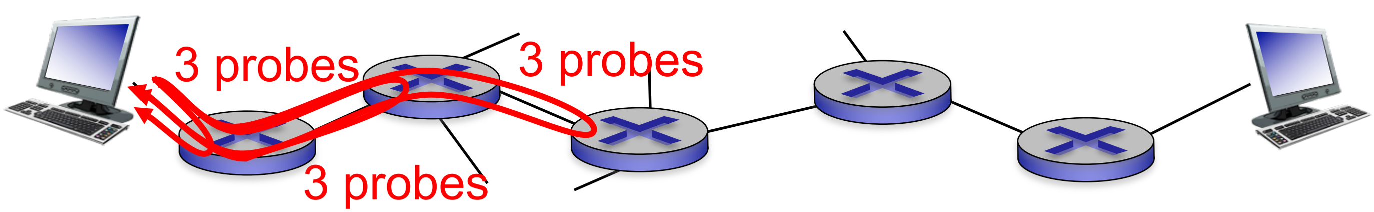
La/R ~ 0

La/R -> 1

* 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

trans-oceanic link

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

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

Demo in Class

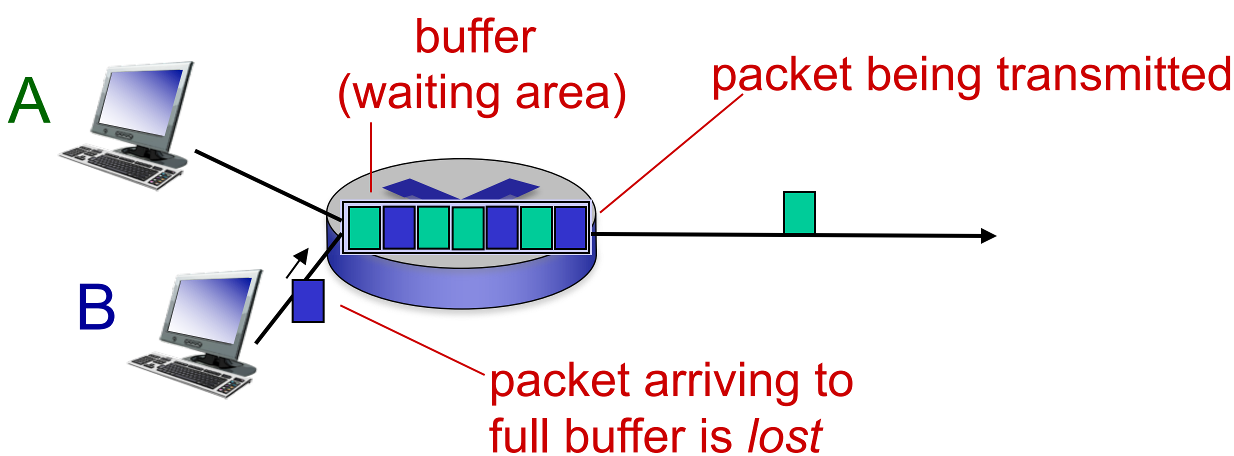
1. traceroute www.google.com

2. traceroute europa.eu

- What are differences you can see?
- Can you see the link across the ocean?
- Why?

Packet loss

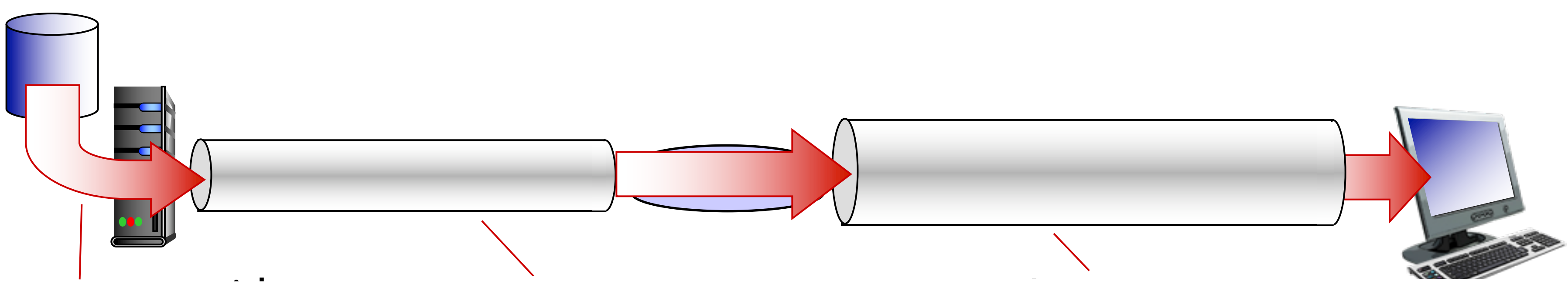
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



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

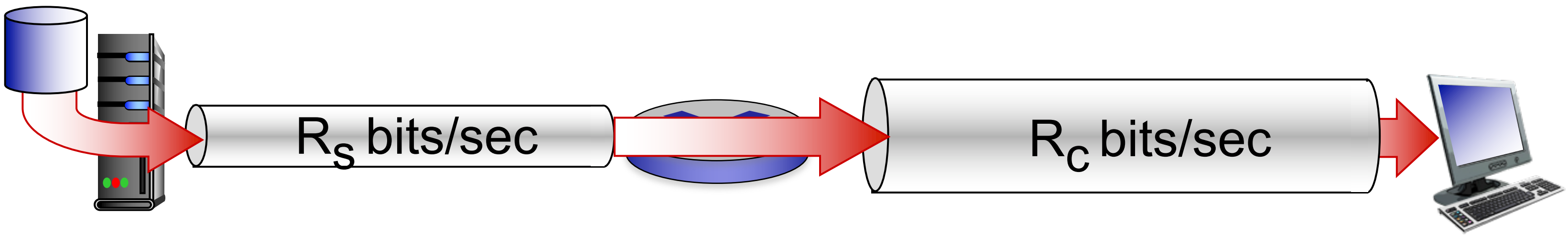
Throughput

- *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

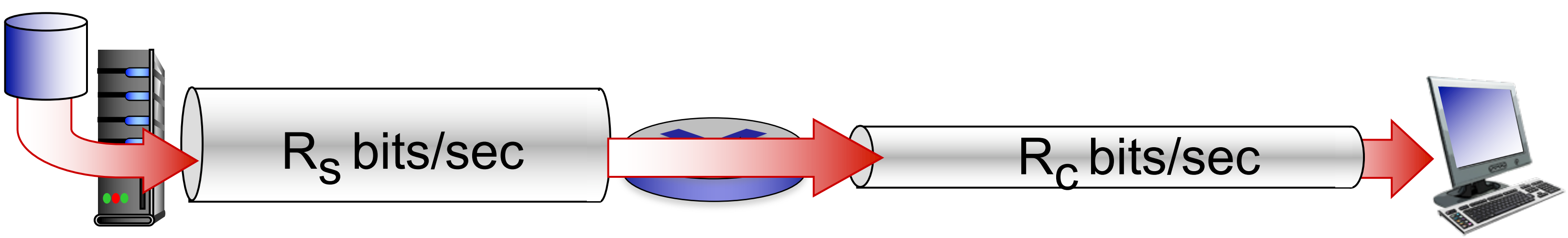


Throughput (more)

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



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

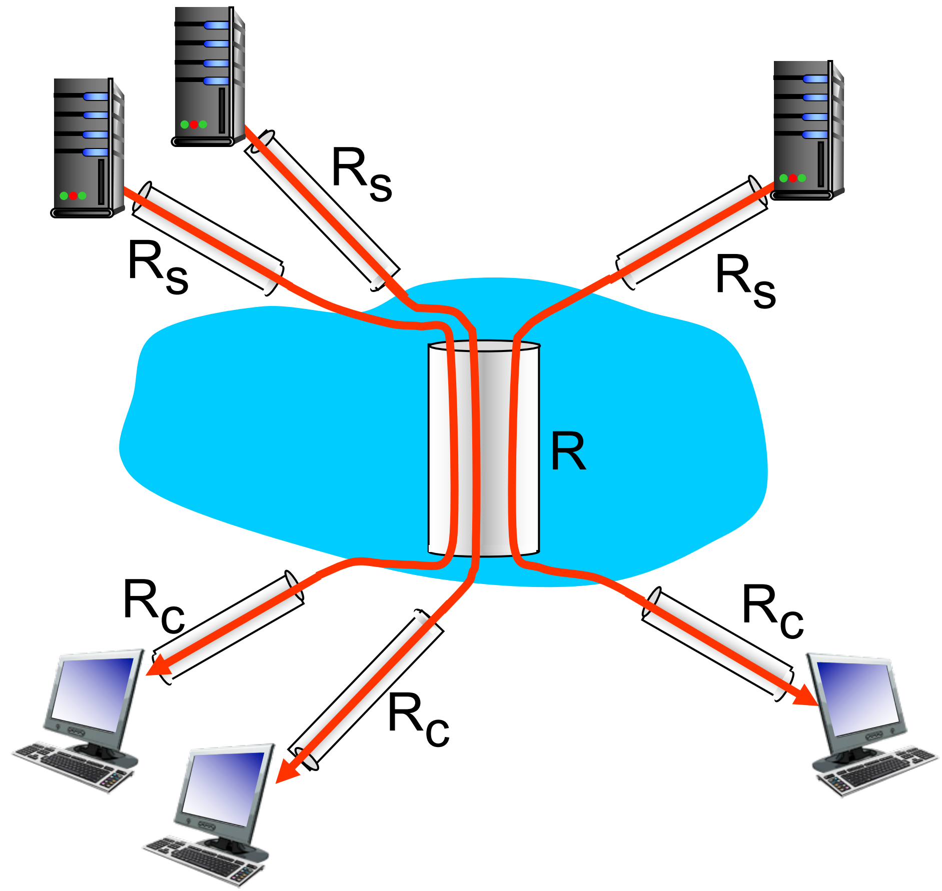


bottleneck link

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/

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

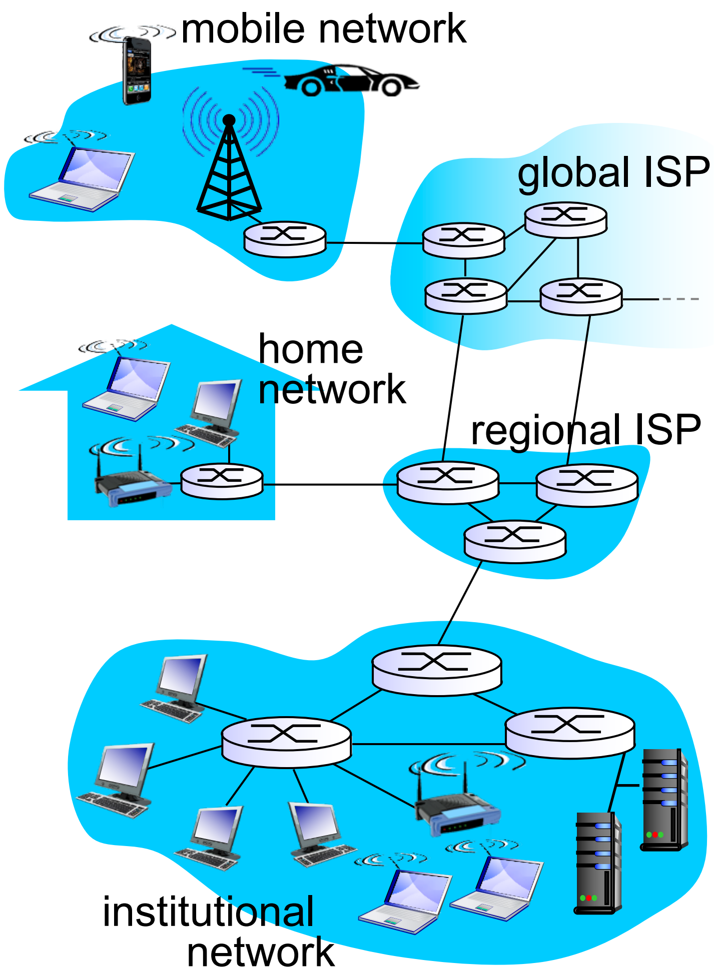
1.5 protocol layers, service models

1.6 ~~networks under attack: security~~

1.7 ~~history~~

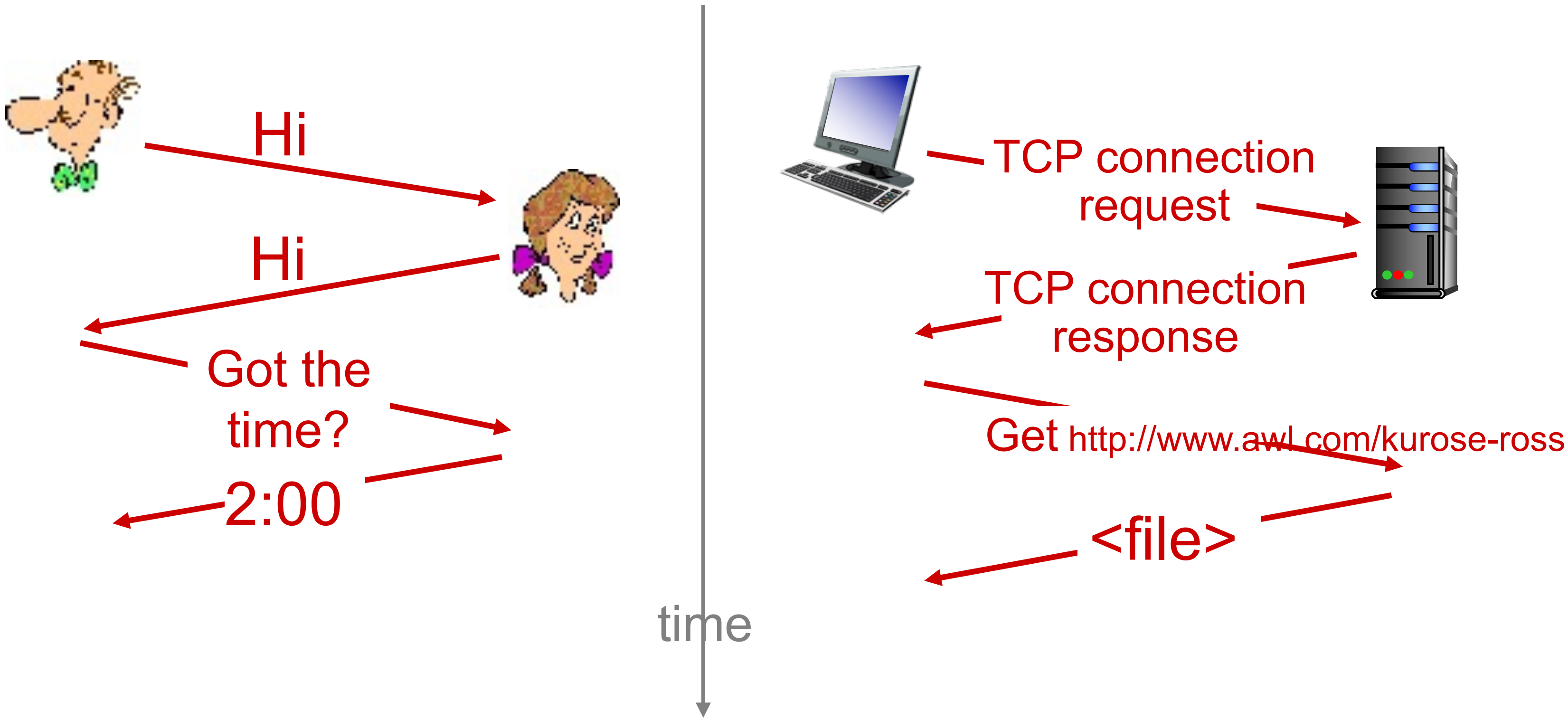
What's the Internet: a software view

- *protocols* control sending, receiving msgs
  - e.g., HTTP, Skype, TCP, IP, 802.11
- *Internet standards: standardize protocol specifications*
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's a protocol?

a human protocol and a computer network protocol:



3 elements: format, order of msgs, and *actions*

What's a protocol?

human protocols:
- "what's the time?"
- "I have a question"
- introductions

… specific msgs sent
… in a specific order
… specific actions taken when msgs received, or other events

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

protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

Protocol "layers"

Networks are complex, with many "pieces":

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

Question:

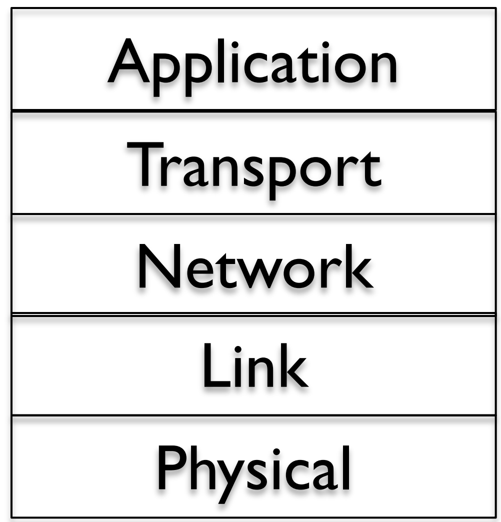
is there any hope of *organizing* structure of network?

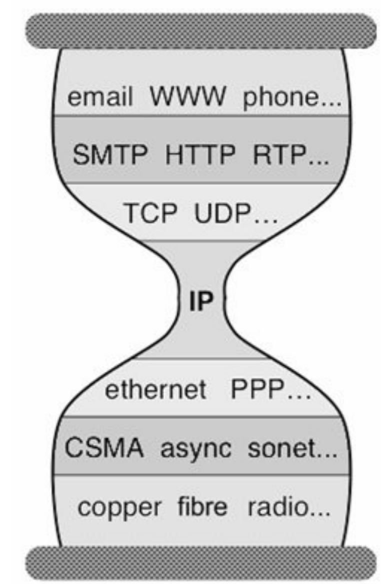
…. or at least our discussion of networks?

Internet Protocol "layers"

Networks are complex, with many "pieces":

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



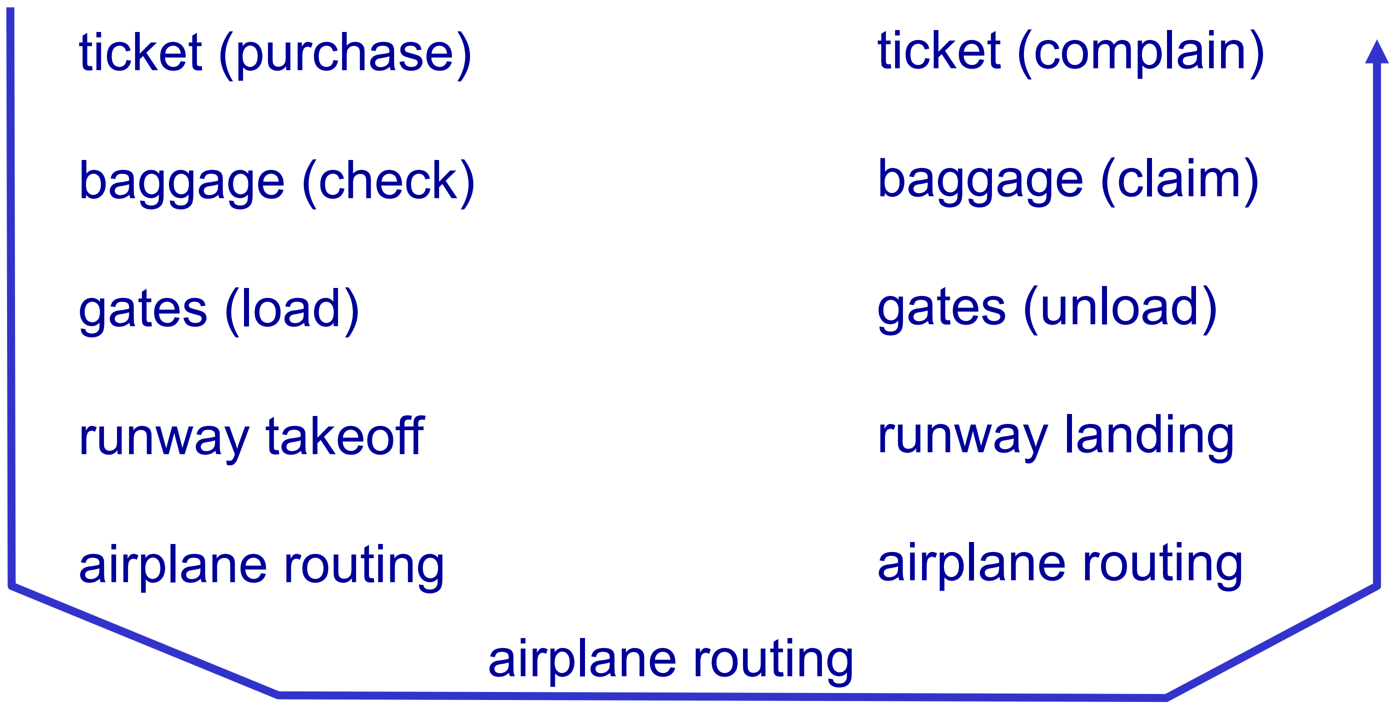


Why Layering?

Decomposed complex delivery into fundamental components

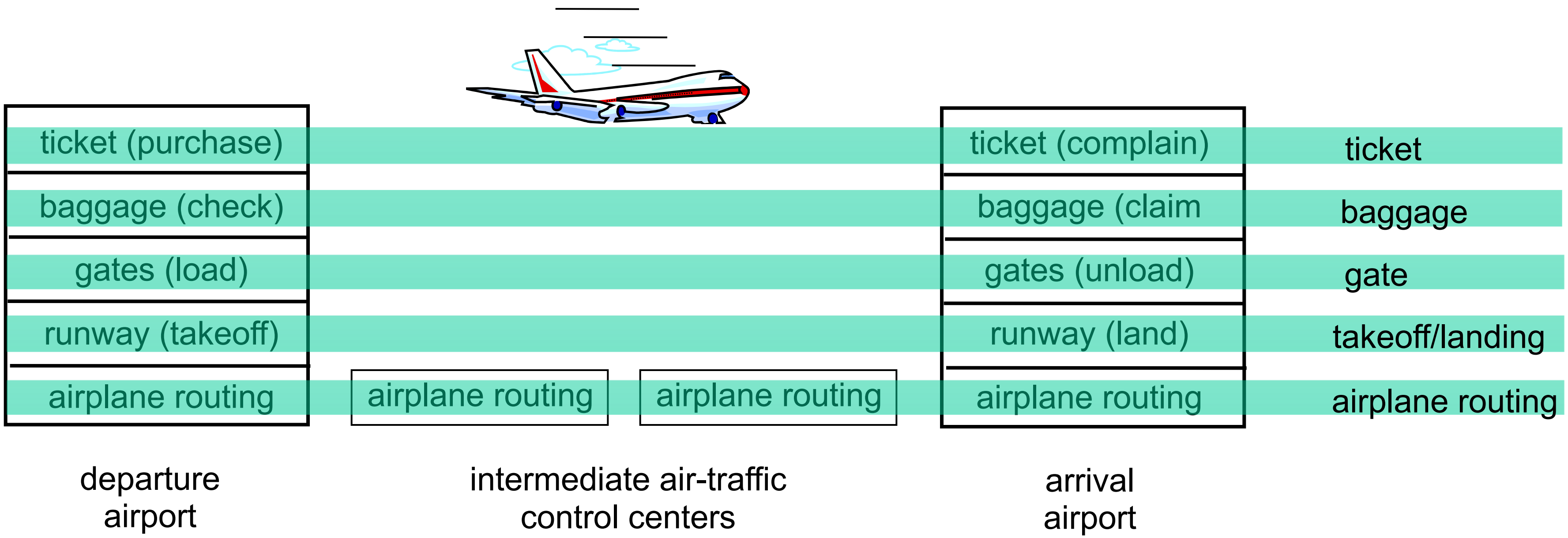
- Explicit structure allows identification, relationship of complex system's pieces
  - layered *reference model* for discussion
- Modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to the rest of system

Analog: 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

Layering in Internet protocol stack

Applications

… built on …

Reliable (or unreliable) transport

… built on …

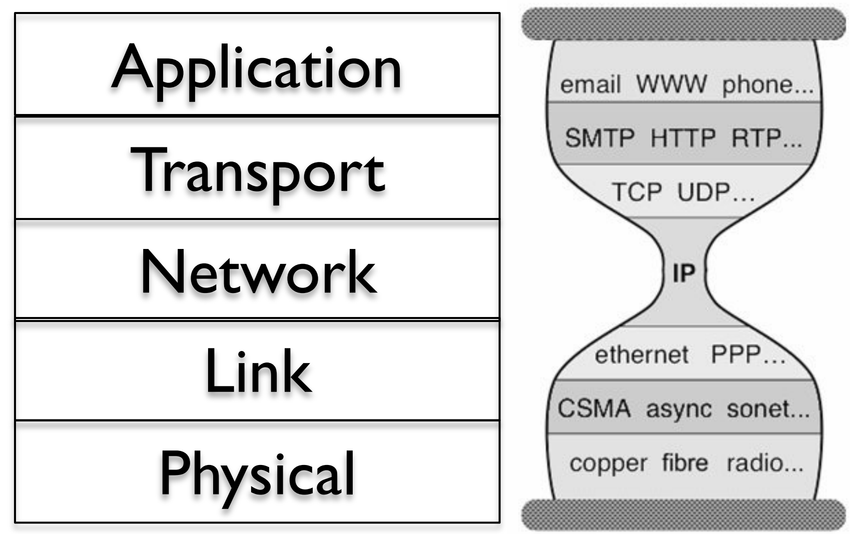
Best-effort global packet delivery

… built on …

Best-effort local packet delivery

… built on …

Physical transfer of bits



Modified based on Source: Dr. Scott Shenker (UCB): Slide 7 at The Future of Networking and the Past of Protocols

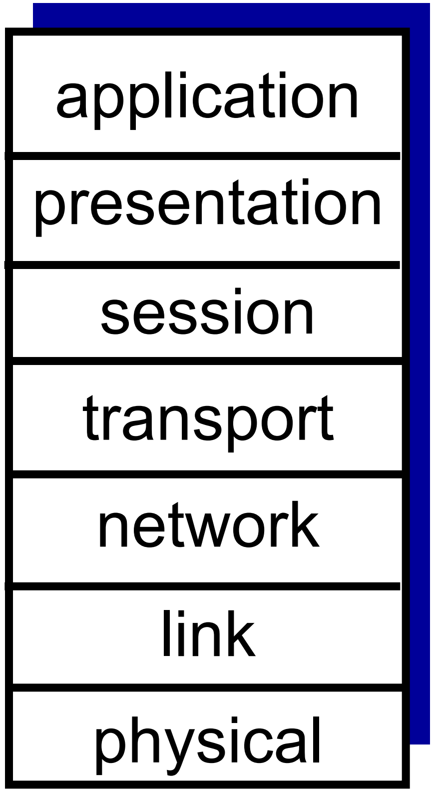
Layering in Internet protocol stack

- *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"

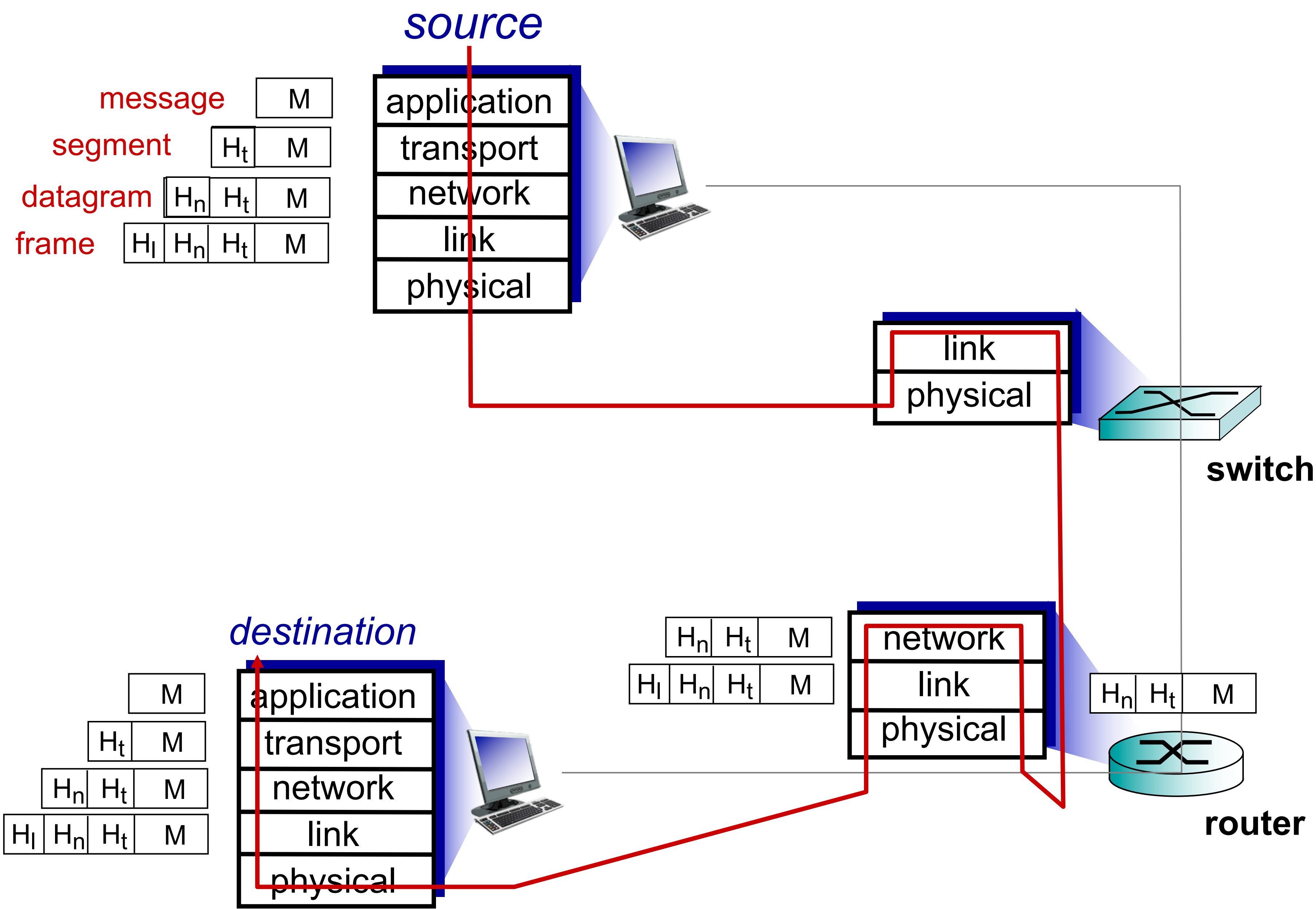
Application
Transport
Network
Link
Physical

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
  - Q: are they needed?



Encapsulation & Decapsulation



Advanced topics (optional)

If you are interested, you can download and study the following Internet tools:

- Packet sniffer and analyzer
  - tcpdump (command)
    - > tcpdump –i en0
    - > tcpdump -i en0 -c 10 -w test.cap
    - > tcpdump –r test.cap
    - *More usage via Google* " tcpdump"
  - wireshark (UI)

Chapter 1: Summary

- what's the Internet?
- network edge
  - hosts, access network
- network core
  - Packet switching versus. circuit switching
- performance: loss, delay, throughput
- what's a protocol?
  - protocol layers, service models

You now have overview, "feel" of the Internet

- more depth, detail *to follow!*