

Chapter I

Introduction

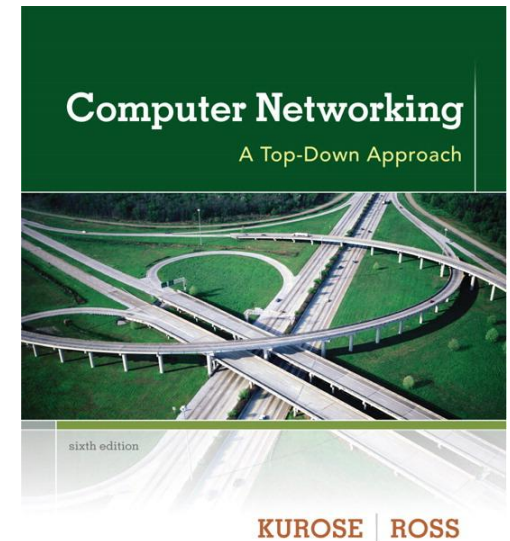
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Computer Networking: A Top Down Approach

6th edition

Jim Kurose, Keith Ross

Addison-Wesley

March 2012

Chapter 1: introduction

our goal:

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

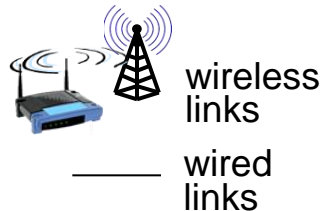
overview:

- ❖ 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

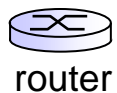
What's the Internet: “nuts and bolts” view



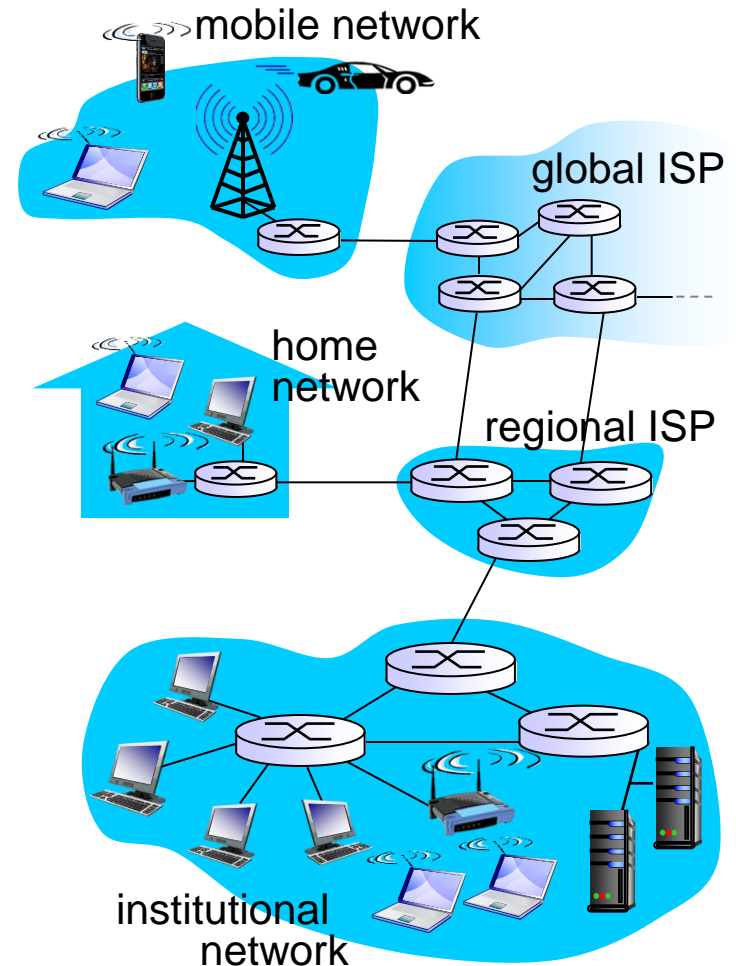
- ❖ millions of connected computing devices:
 - *hosts* = *end systems*
 - running *network apps*



- ❖ *communication links*
 - fiber, copper, radio, satellite
 - transmission rate: *bandwidth*



- ❖ *Packet switches*: forward packets (chunks of data)
 - *routers* and *switches*



“Fun” internet appliances



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



Web-enabled toaster +
weather forecaster



Tweet-a-watt:
monitor energy use



Internet
refrigerator



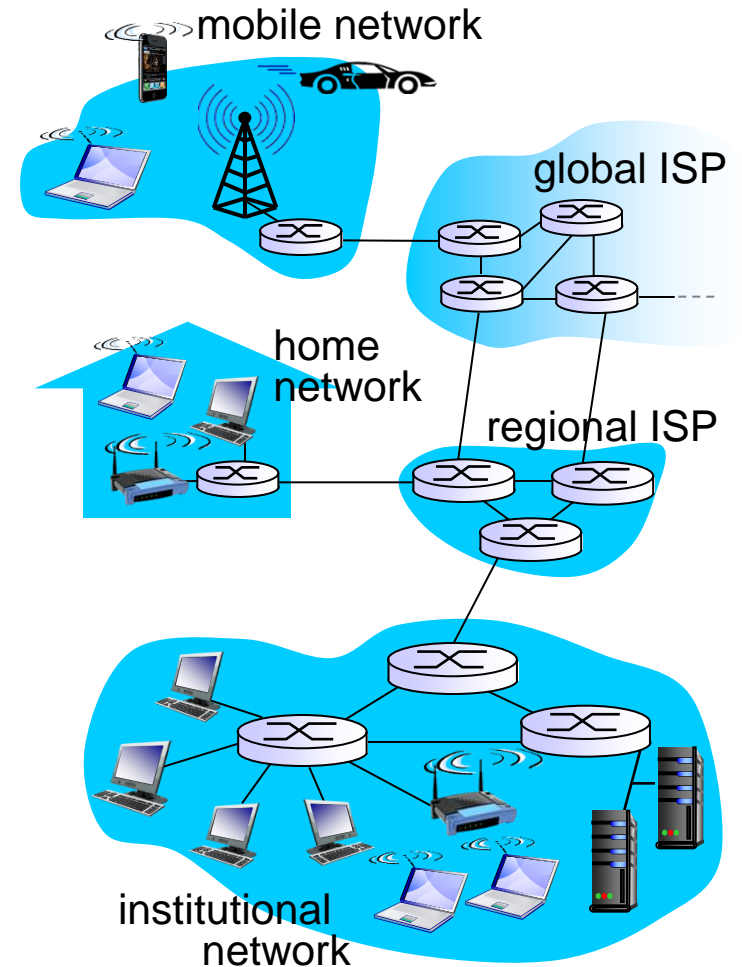
Slingbox: watch,
control cable TV remotely



Internet phones

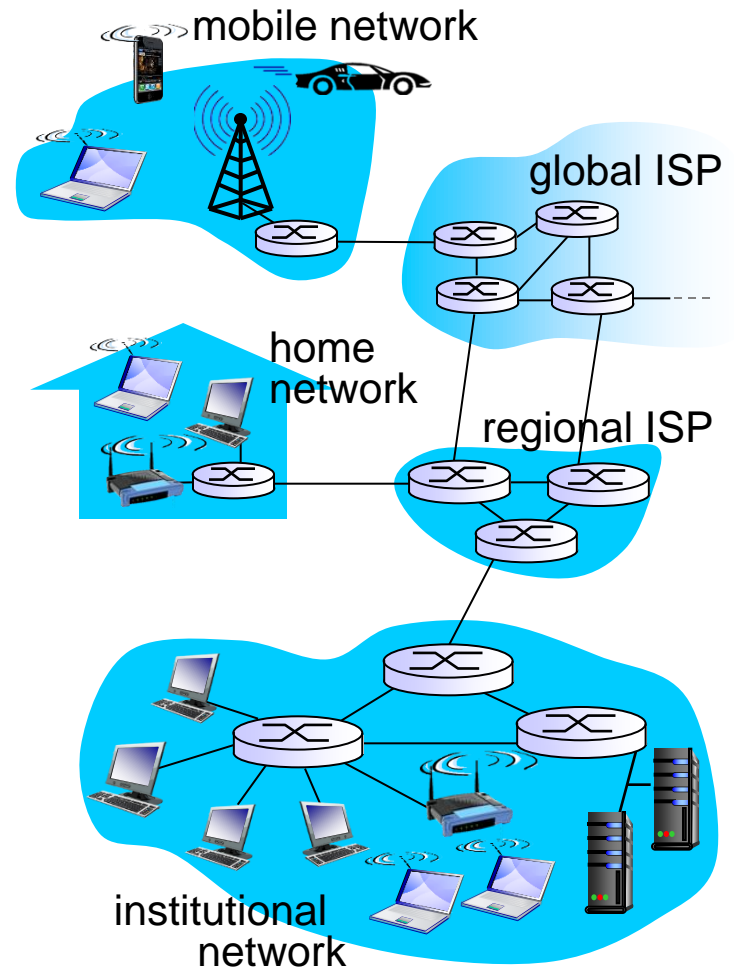
What's the Internet: “nuts and bolts” view

- ❖ *Internet: “network of networks”*
 - Interconnected ISPs
- ❖ *protocols* control sending, receiving of msgs
 - 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 msgs sent
- ... specific actions taken
when msgs received, or
other events

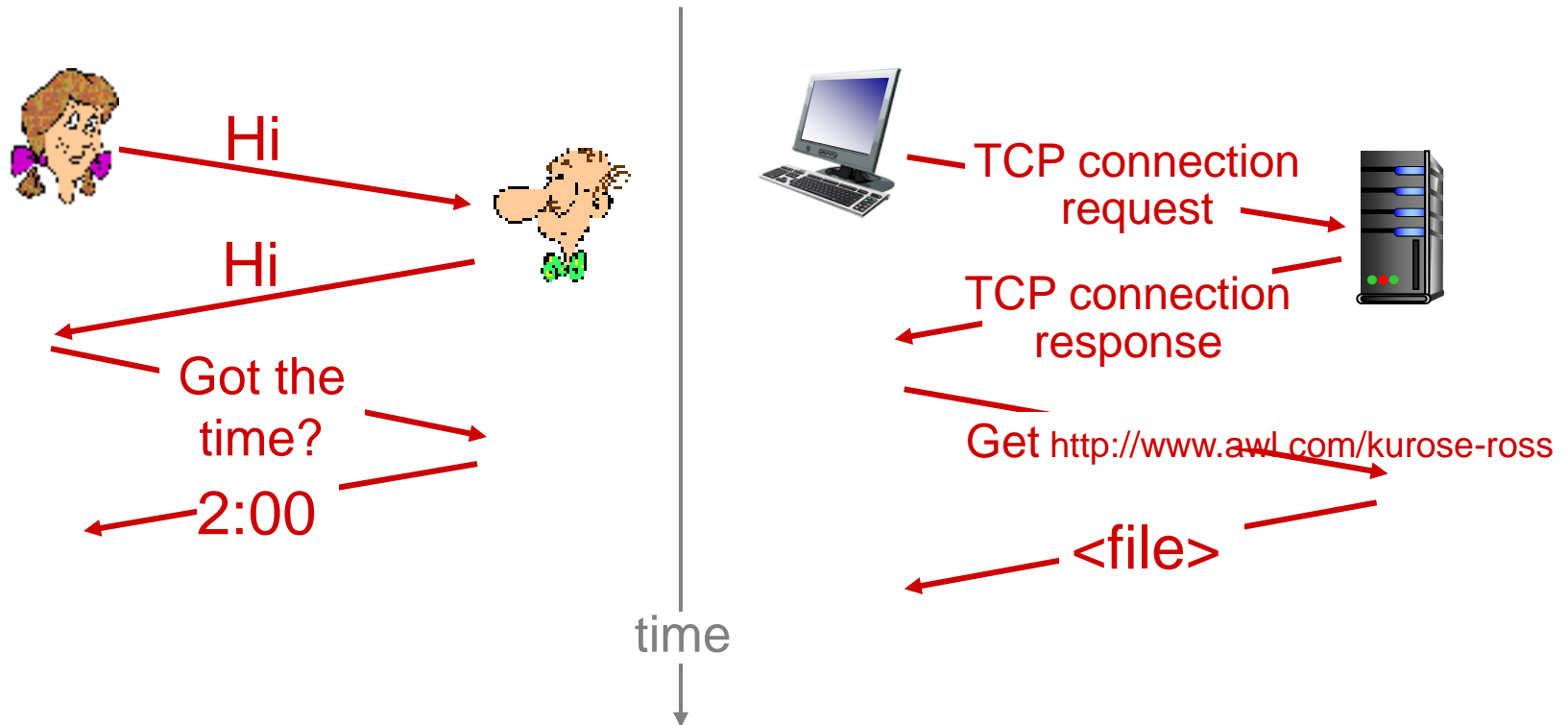
network protocols:

- ❖ 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

What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

A closer look at network structure:

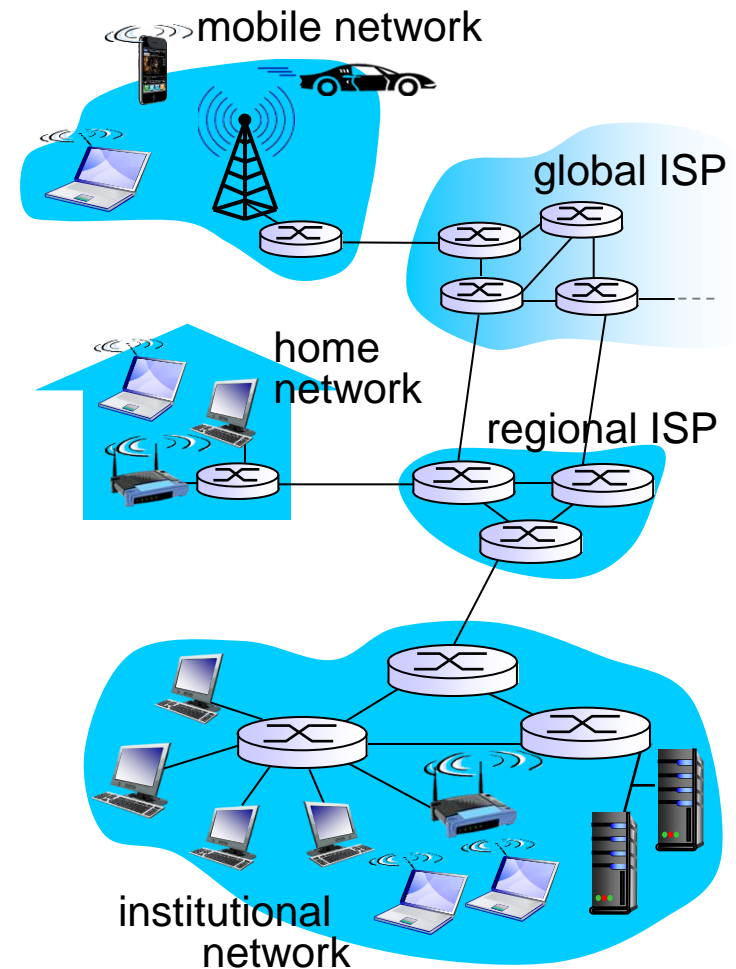
❖ *network edge:*

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

❖ *access networks, physical media:* wired, wireless communication links

❖ *network core:*

- interconnected routers
- network of networks



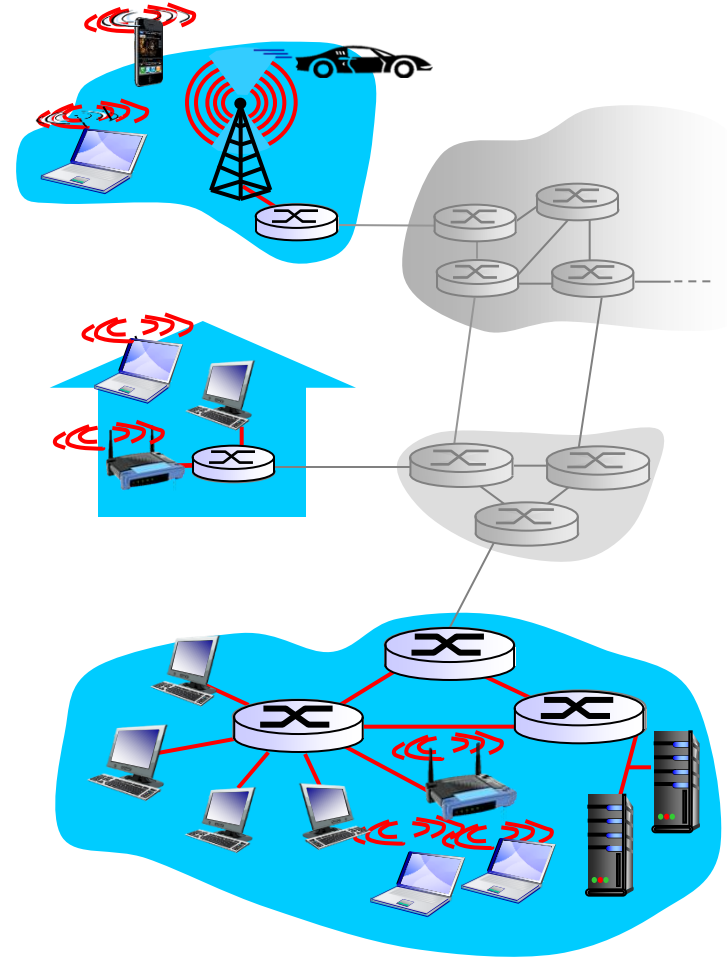
Access networks and physical media

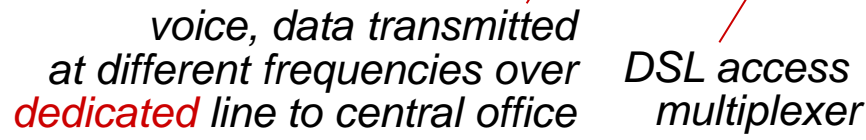
Q: How to connect end systems to edge router?

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

keep in mind:

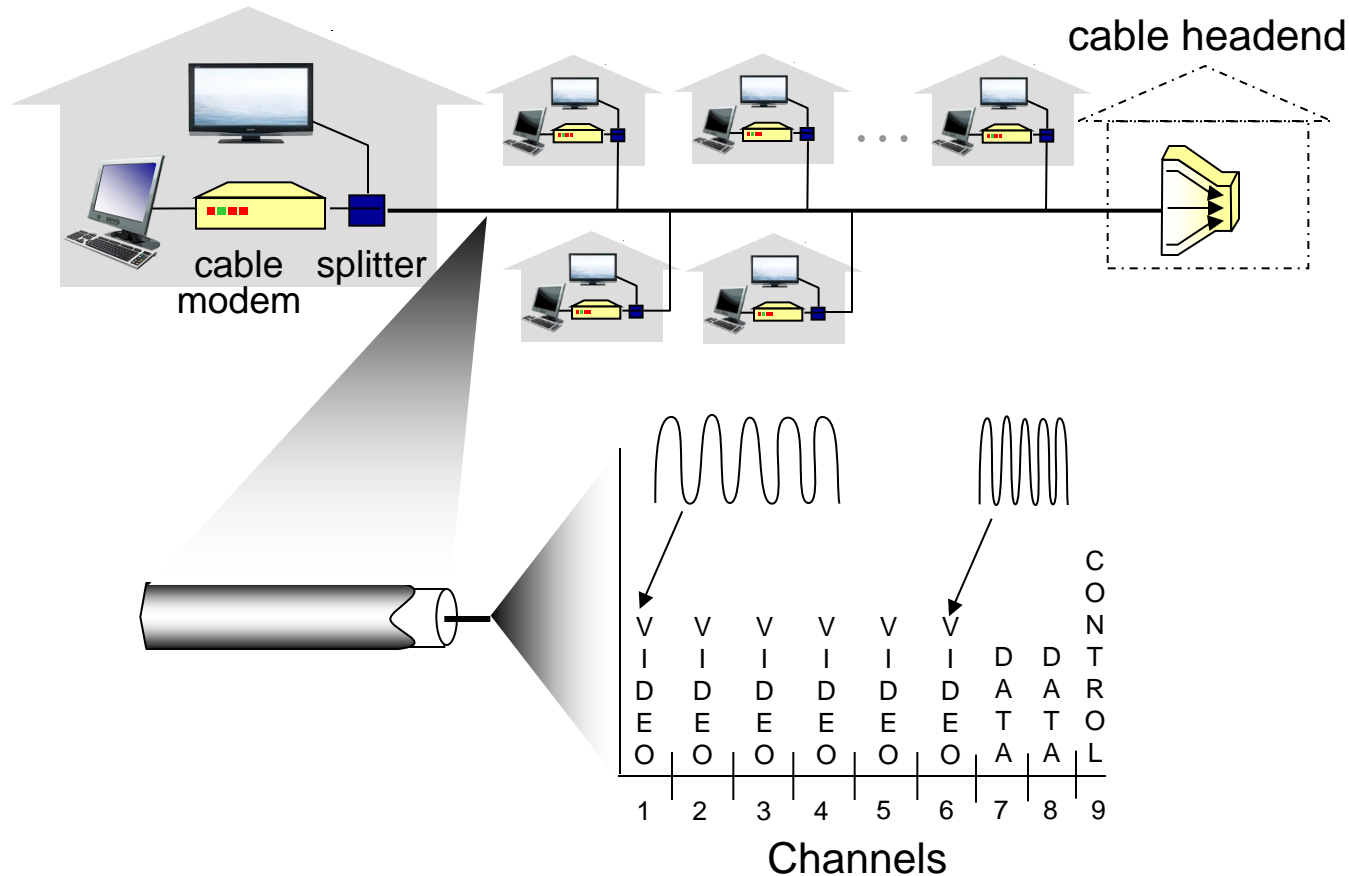
- ❖ bandwidth (bits per second) of access network?
- ❖ shared or dedicated?





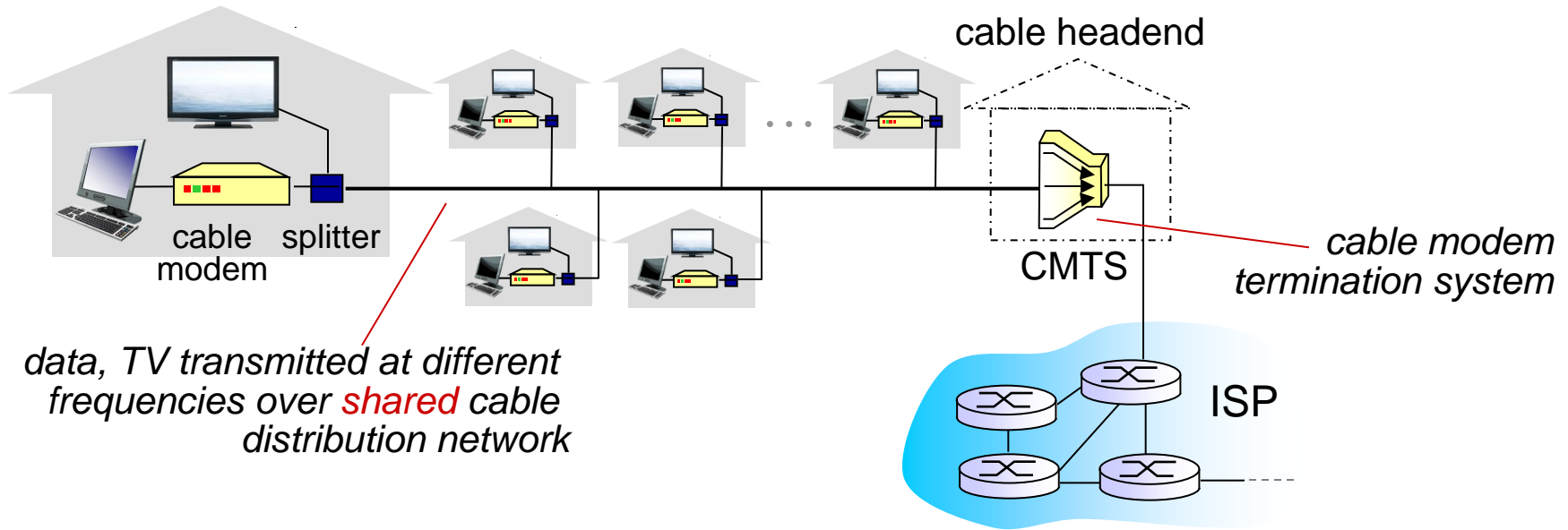
- ❖ use *existing* telephone line to central office DSLAM
 - data over DSL phone line goes to Internet
 - voice over DSL phone line goes to telephone net
- ❖ < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- ❖ < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access net: cable network



frequency division multiplexing: different channels transmitted in different frequency bands

Access net: cable network



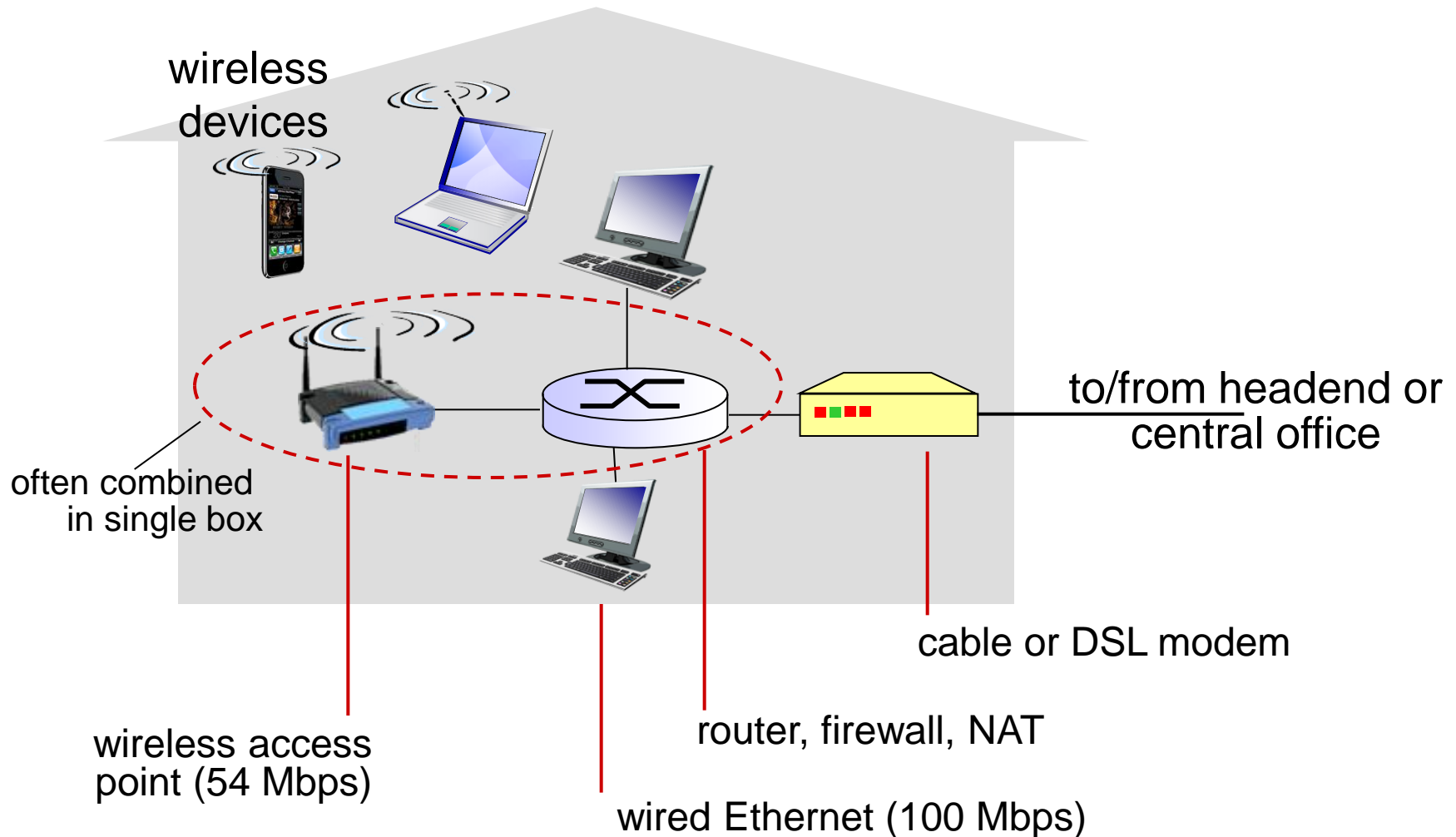
❖ HFC: hybrid fiber coax

- asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate

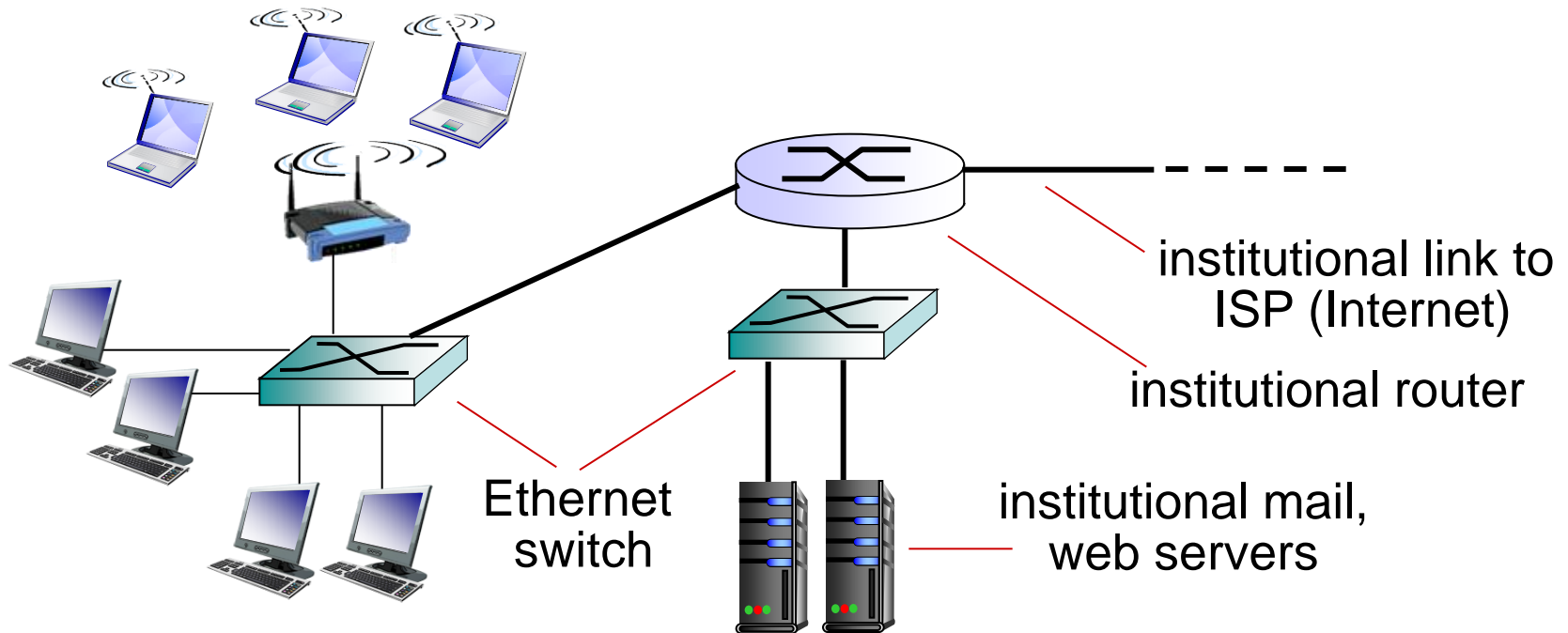
❖ network of cable, fiber attaches homes to ISP router

- homes **share access network** to cable headend
- unlike DSL, which has dedicated access to central office

Access net: home network



Enterprise access networks (Ethernet)



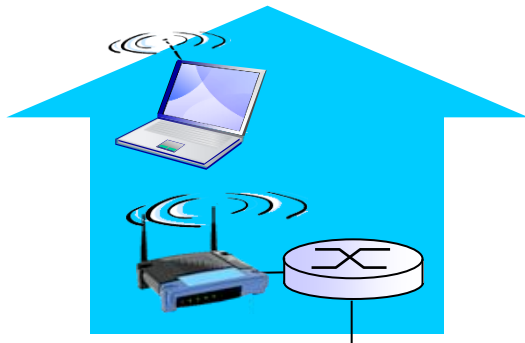
- ❖ typically used in companies, universities, etc
- ❖ 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- ❖ today, end systems typically connect into Ethernet switch

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 (WiFi): 11, 54 Mbps transmission rate



to Internet

wide-area wireless access

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



to Internet

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)

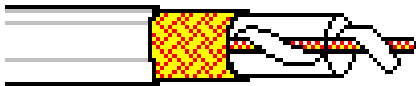
- ❖ two insulated copper wires
 - Category 5: 100 Mbps, 1 Gbps Ethernet
 - Category 6: 10Gbps



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 Gpbs transmission rate)
- ❖ low error rate:
 - repeaters spaced far apart
 - immune to electromagnetic noise



Physical media: radio

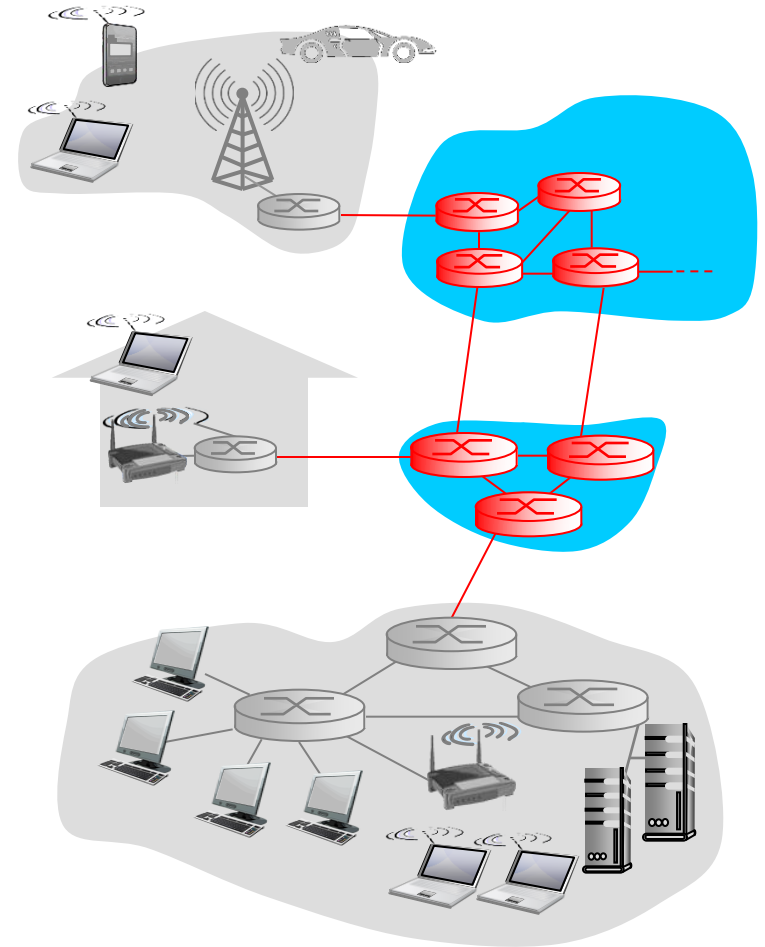
- ❖ signal carried in electromagnetic spectrum
- ❖ no physical “wire”
- ❖ bidirectional
- ❖ propagation environment effects:
 - reflection
 - obstruction by objects
 - interference

radio link types:

- ❖ **terrestrial microwave**
 - e.g. up to 45 Mbps channels
- ❖ **LAN** (e.g., WiFi)
 - 11 Mbps, 54 Mbps
- ❖ **wide-area** (e.g., cellular)
 - 3G cellular: ~ few Mbps
- ❖ **satellite**
 - Kbps to 45Mbps channel (or multiple smaller channels)
 - 270 msec end-end delay
 - geosynchronous versus low altitude

The network core

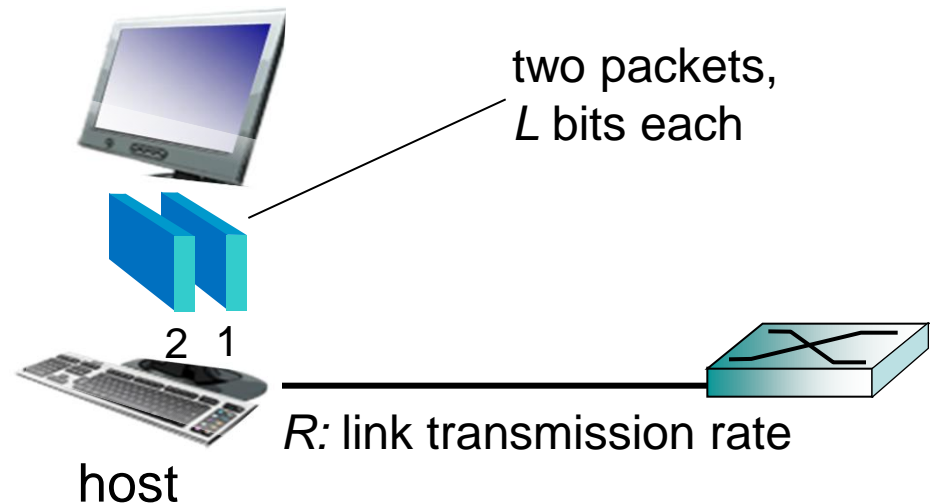
- ❖ mesh of interconnected routers
- ❖ packet-switching: hosts break application-layer messages into *packets*
 - forward packets from one router to the next, across links on path from source to destination
 - each packet transmitted at full link capacity



Host: sends *packets* of data

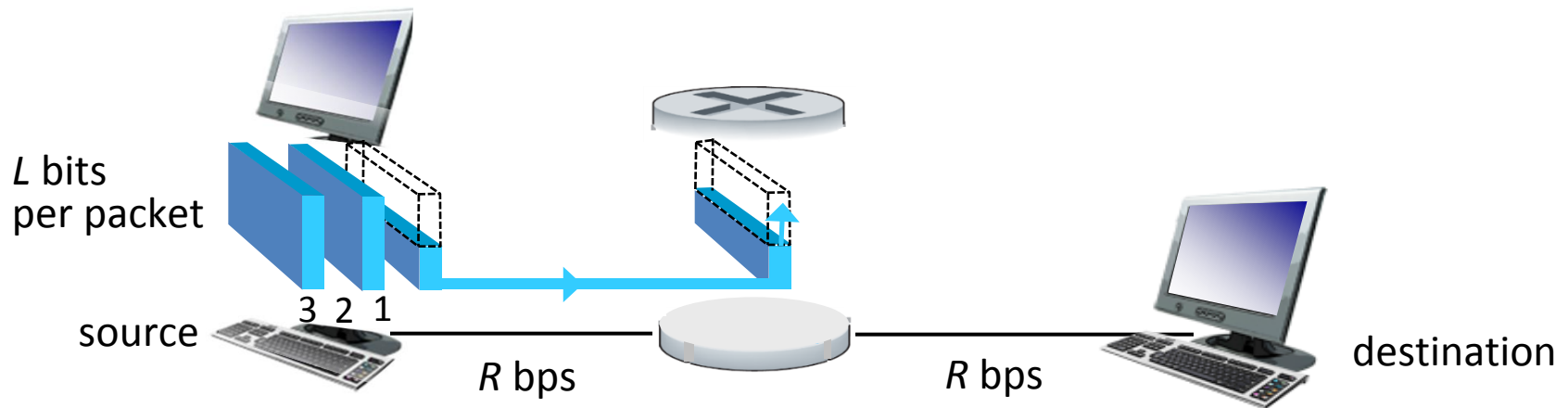
host sending function:

- ❖ 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



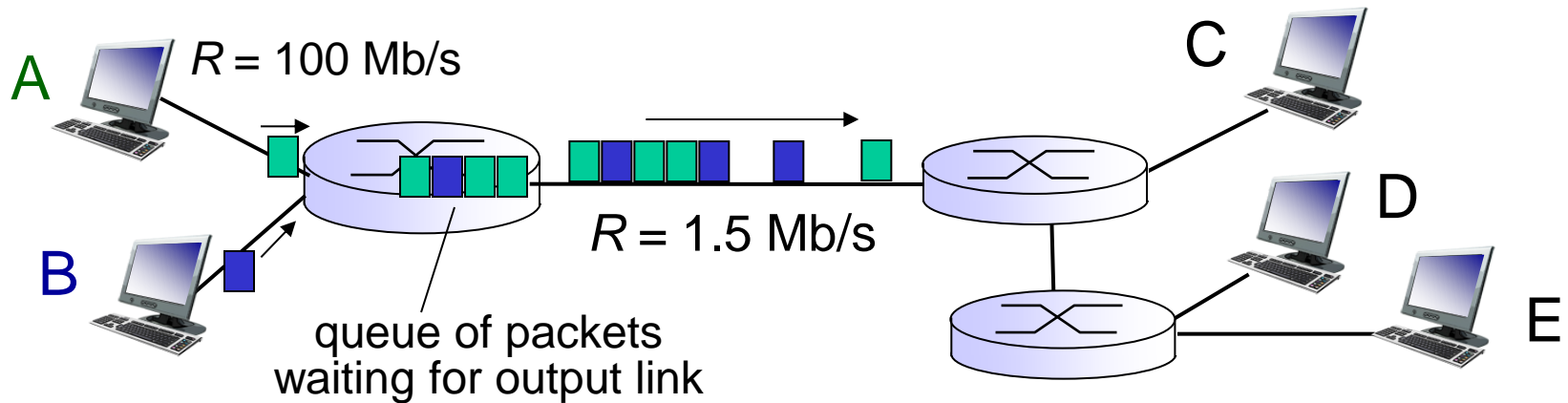
- ❖ takes L/R seconds to transmit (push out) L -bit packet into link at R bps
- ❖ *store and forward*: entire packet must arrive at router before it can be transmitted on next link
- ❖ end-end delay = $2L/R$ (assuming zero propagation delay)

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:

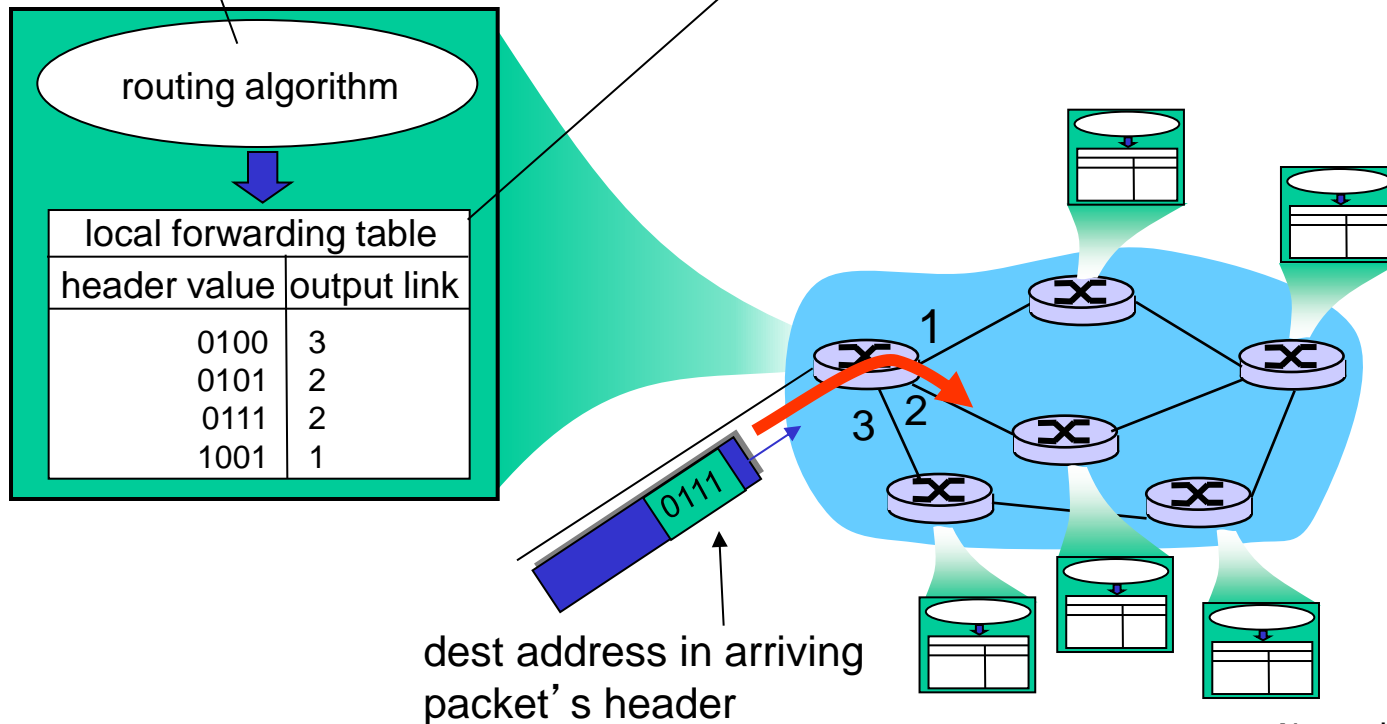
- ❖ If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
 - packets will queue, wait to be transmitted on link
 - packets can be dropped (lost) if memory (buffer) fills up

Two key network-core functions

routing: determines source-destination route taken by packets

- *routing algorithms*

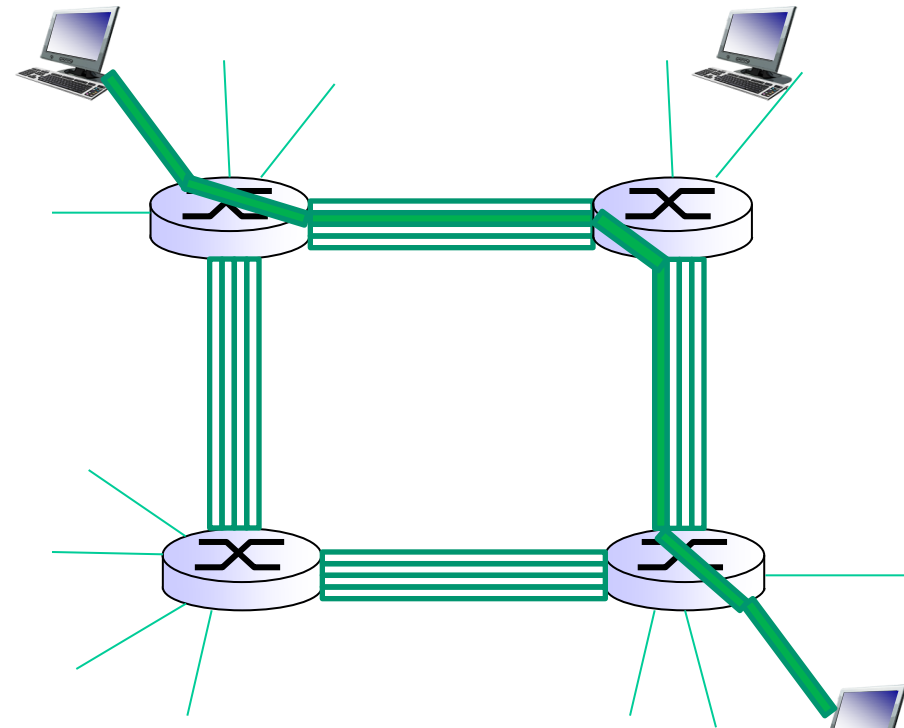
forwarding: move packets from router's input to appropriate router output



Alternative core: circuit switching

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

- ❖ In diagram, each link has four circuits.
 - call gets 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

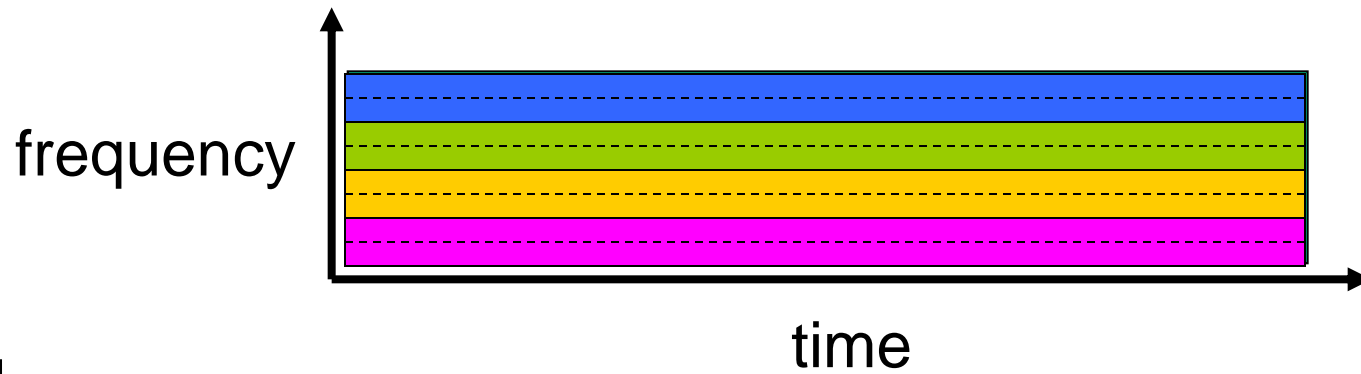


Circuit switching: FDM versus TDM

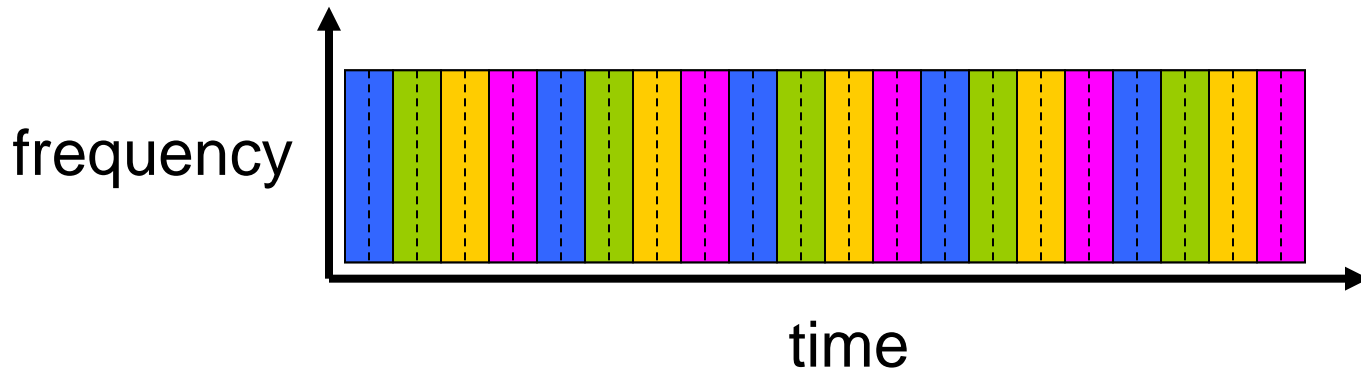
FDM

Example:

4 users



TDM

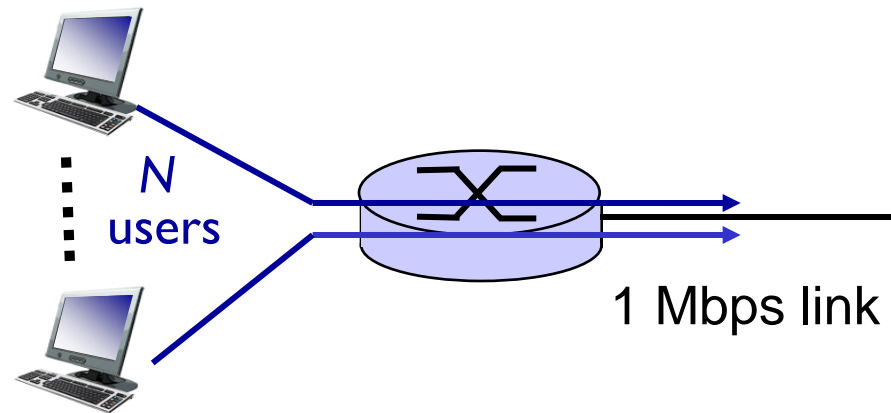


Packet switching versus circuit switching

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 ?

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)

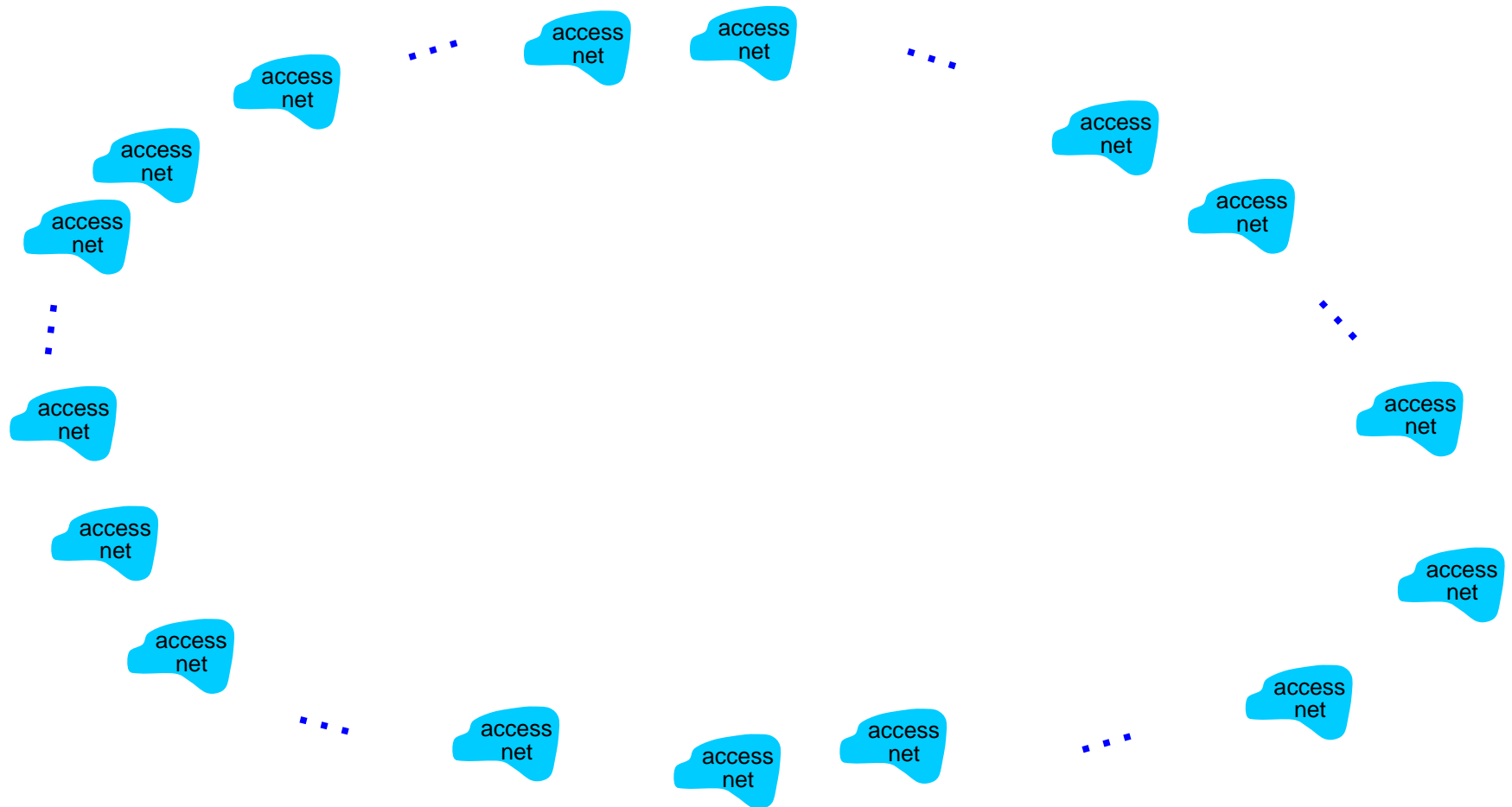
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

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

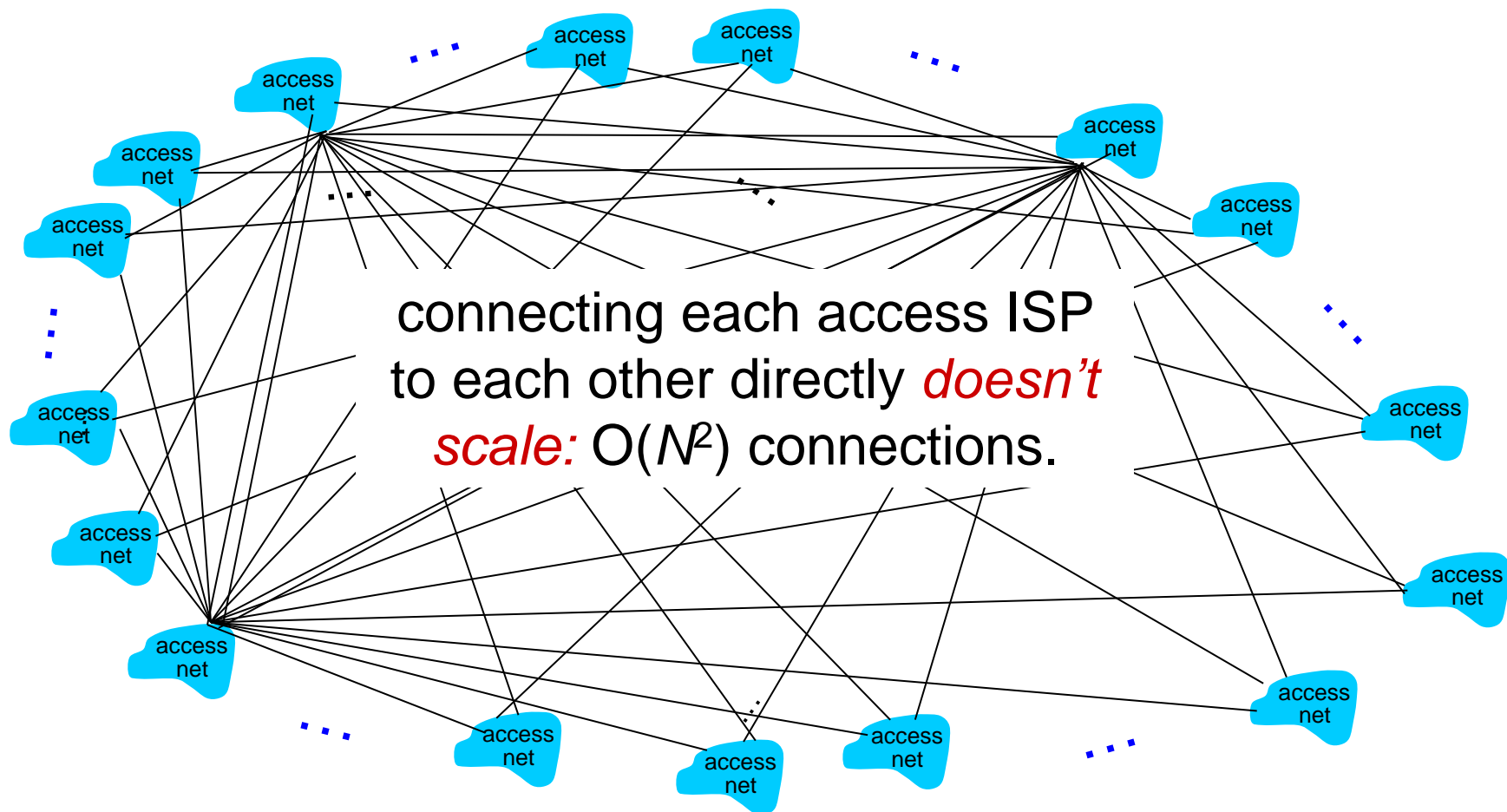
Internet structure: network of networks

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



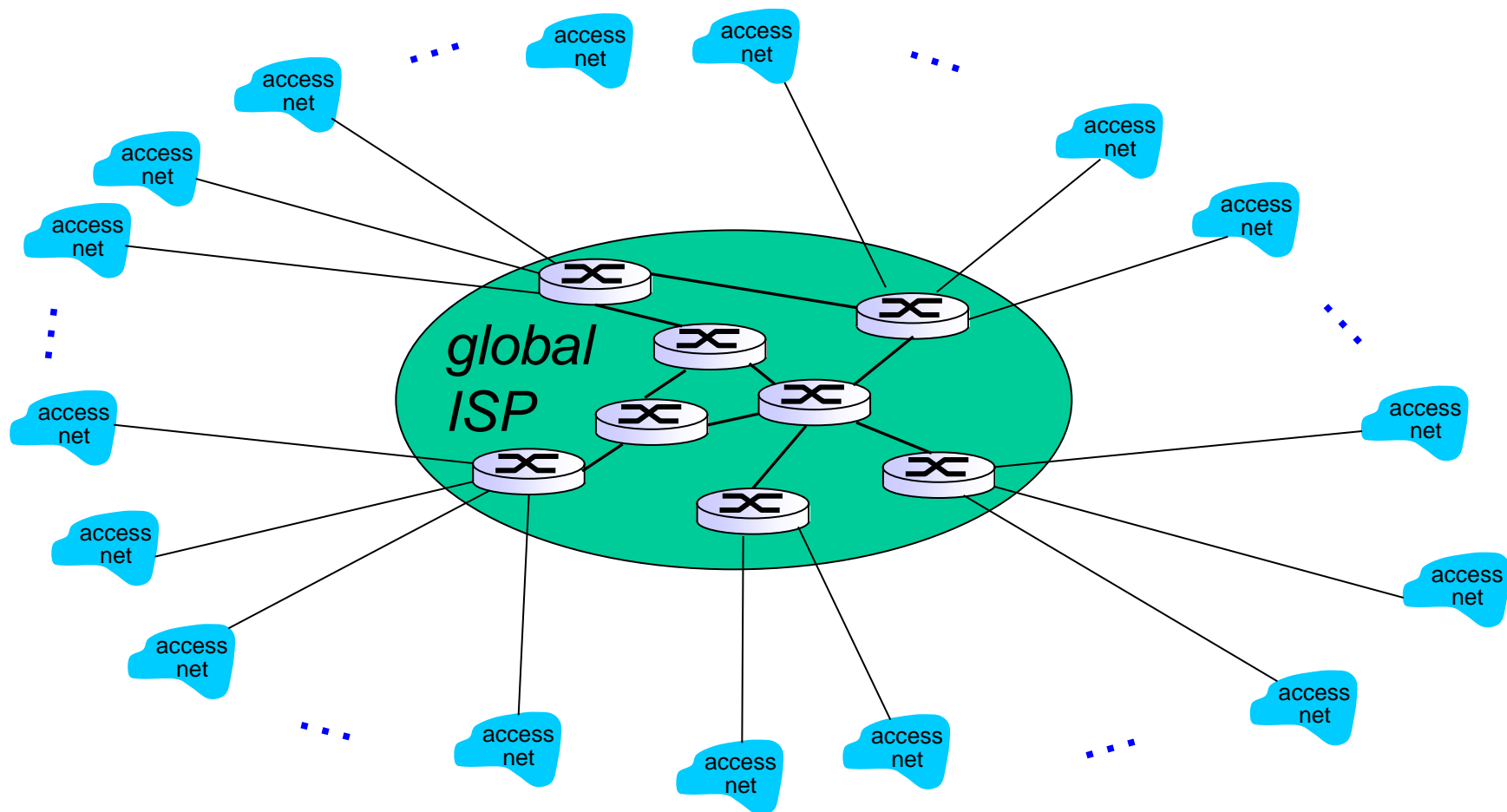
Internet structure: network of networks

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



Internet structure: network of networks

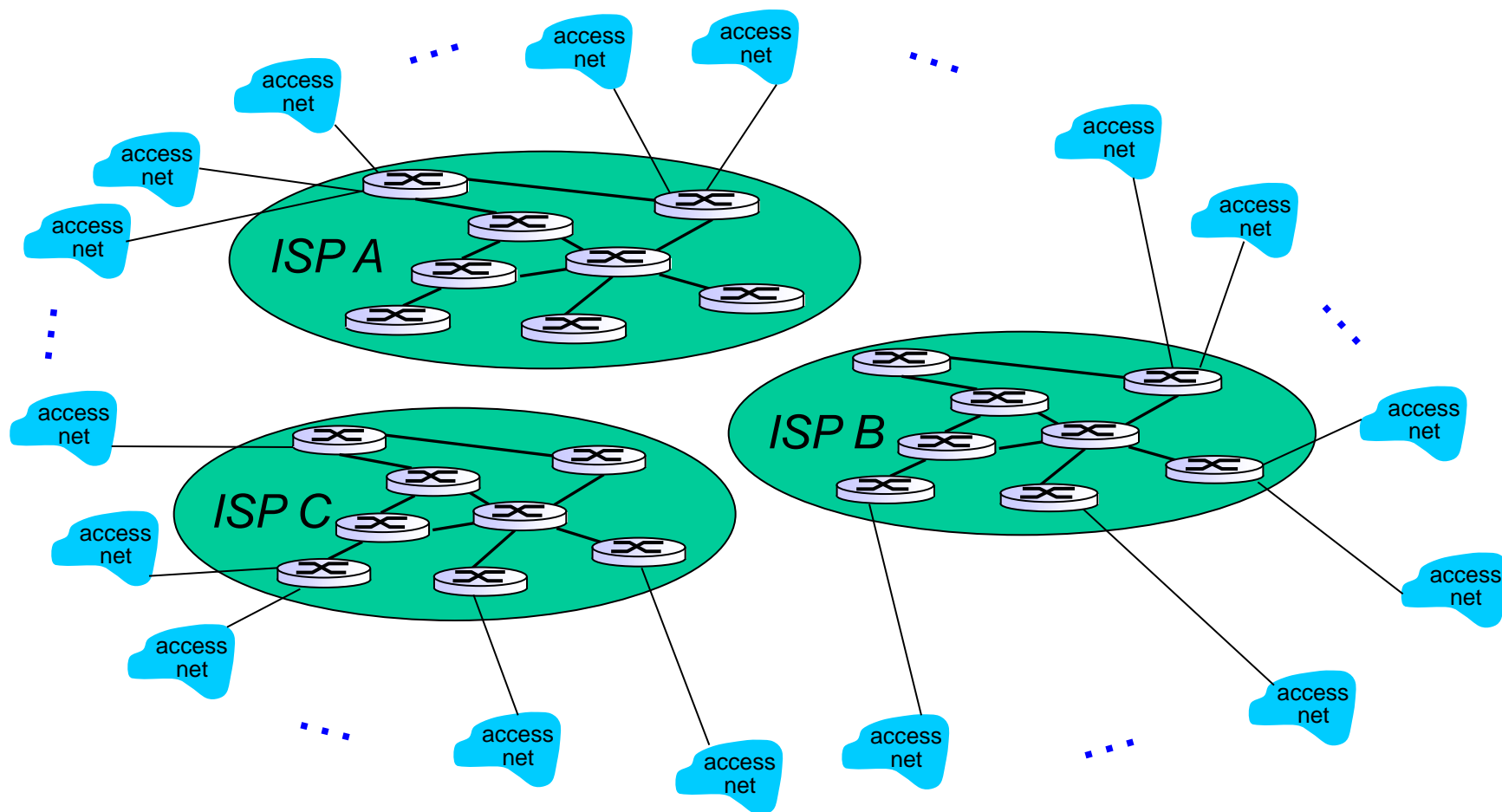
*Option: connect each access ISP to a global transit ISP? **Customer** and **provider** ISPs have economic agreement.*



Internet structure: network of networks

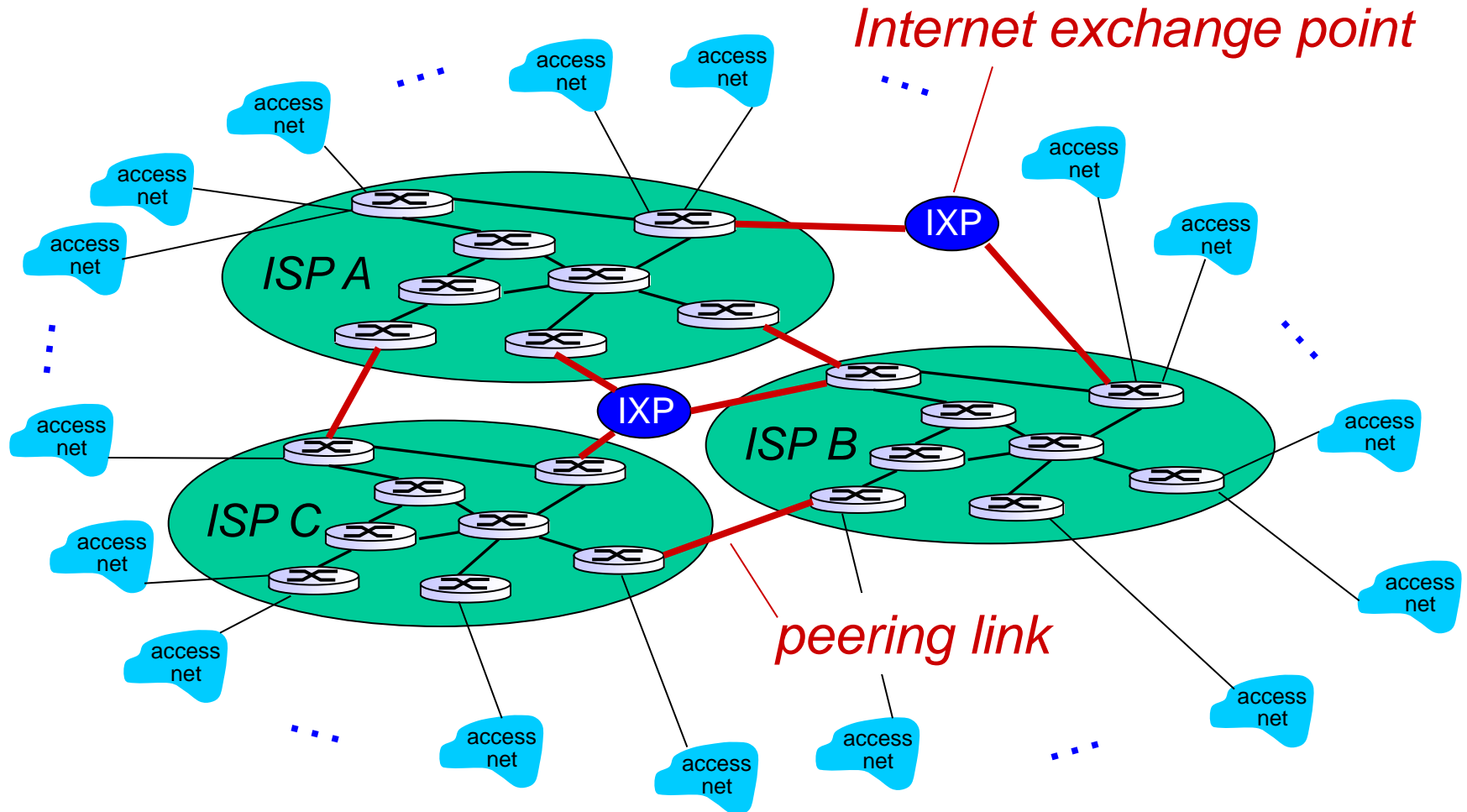
But if one global ISP is viable business, there will be competitors

....



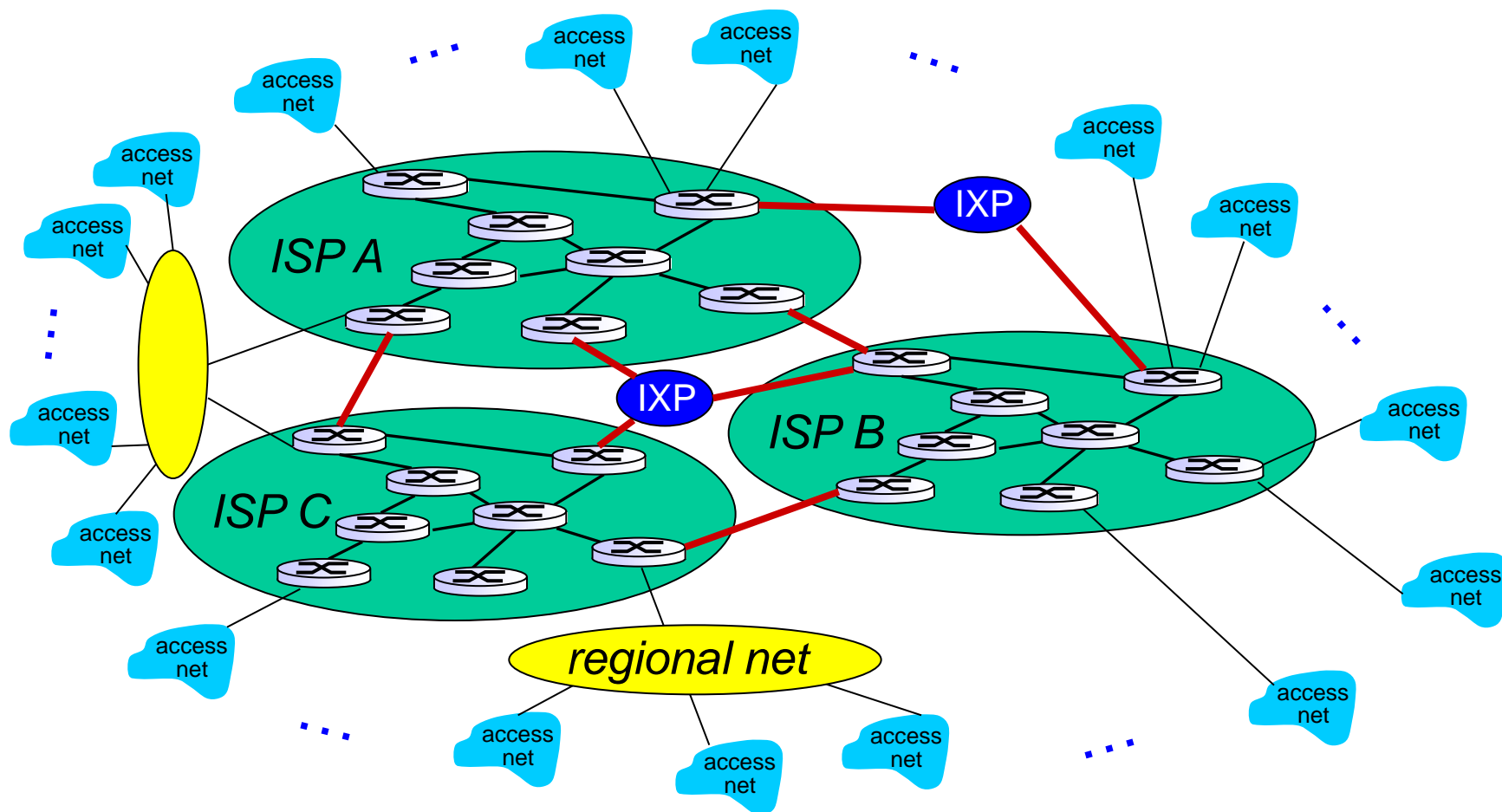
Internet structure: network of networks

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



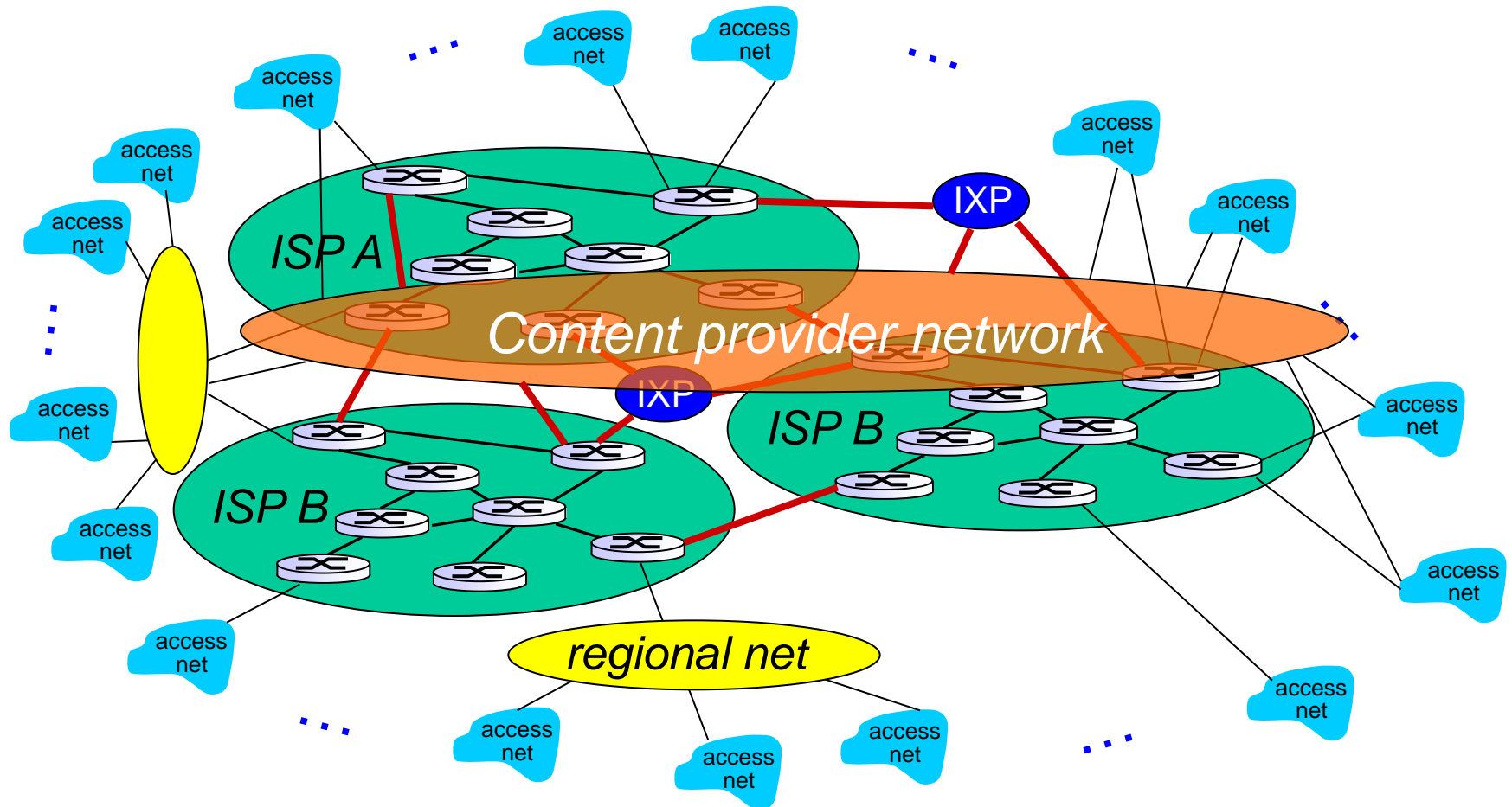
Internet structure: network of networks

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

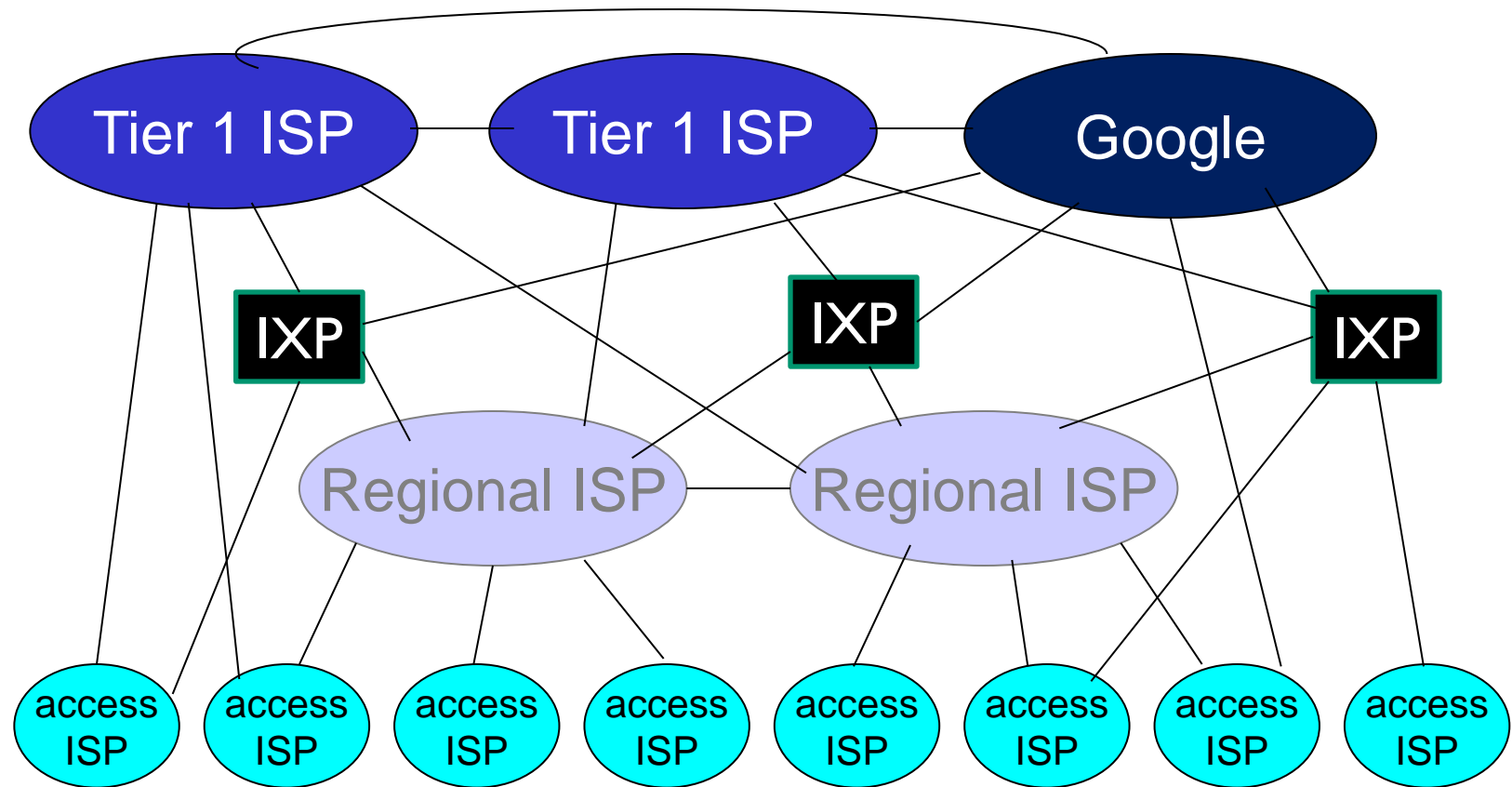


Internet structure: network of networks

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

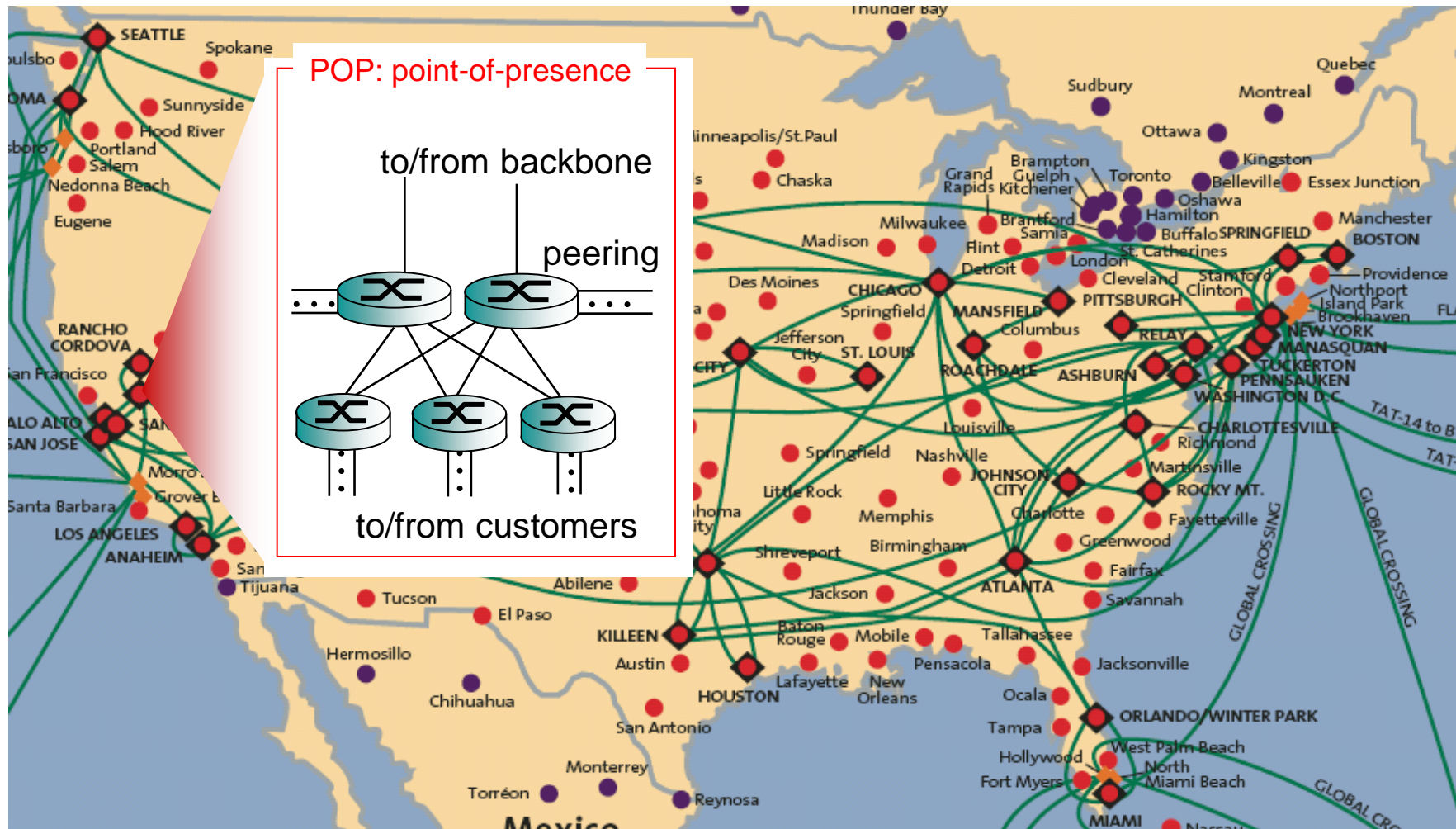


Internet structure: network of networks



- ❖ 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

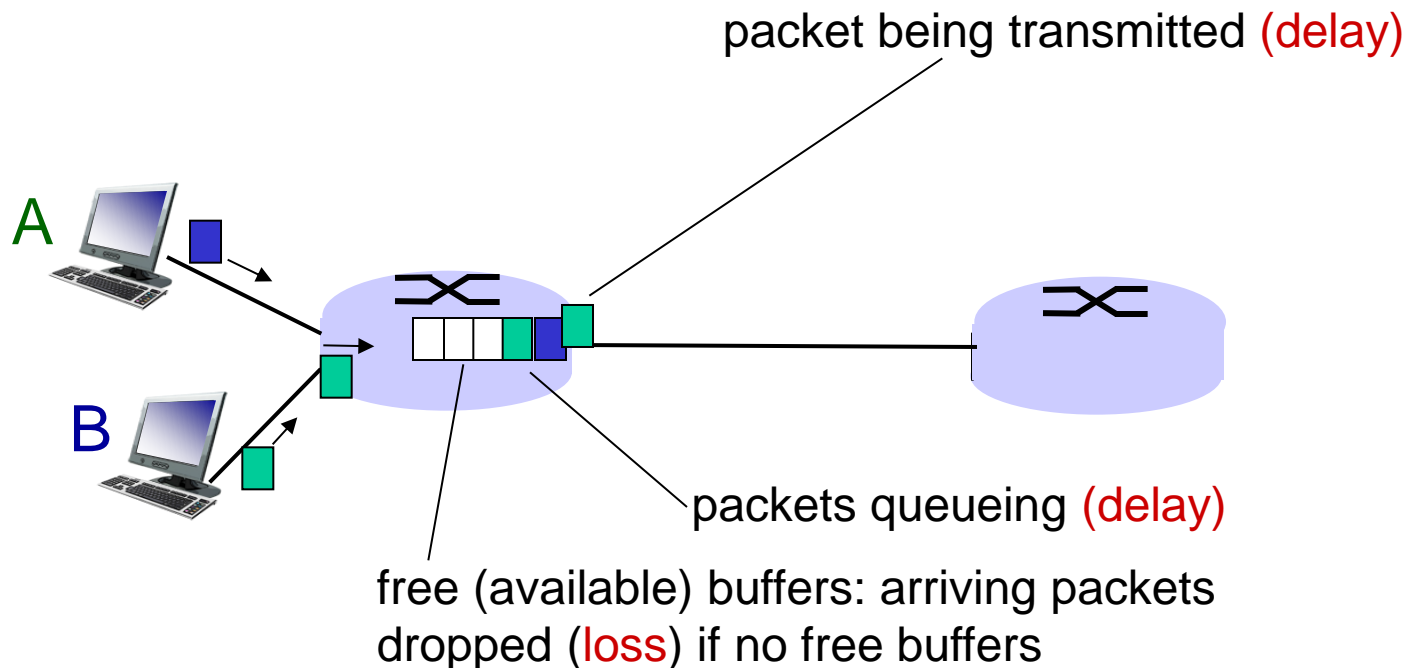
Tier-I ISP: e.g., Sprint



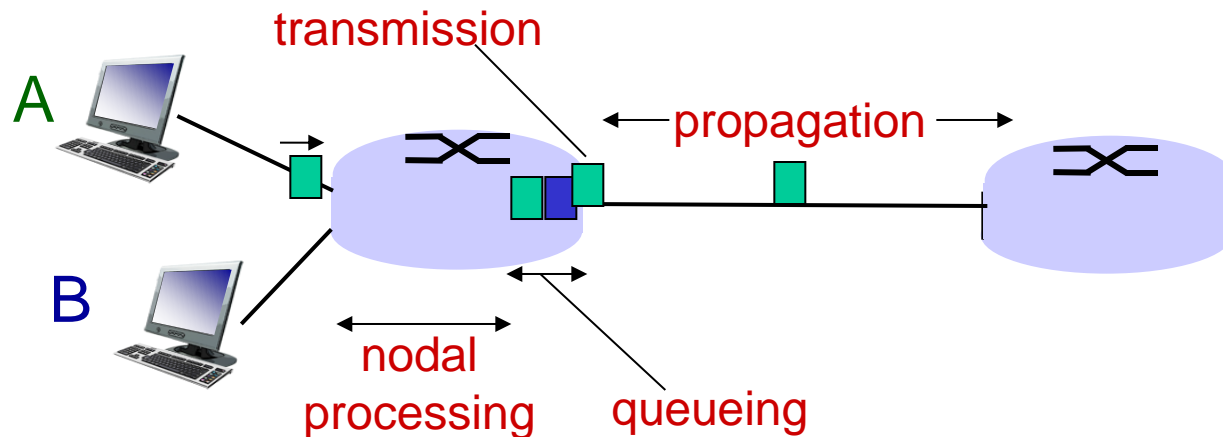
How do loss and delay occur?

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



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

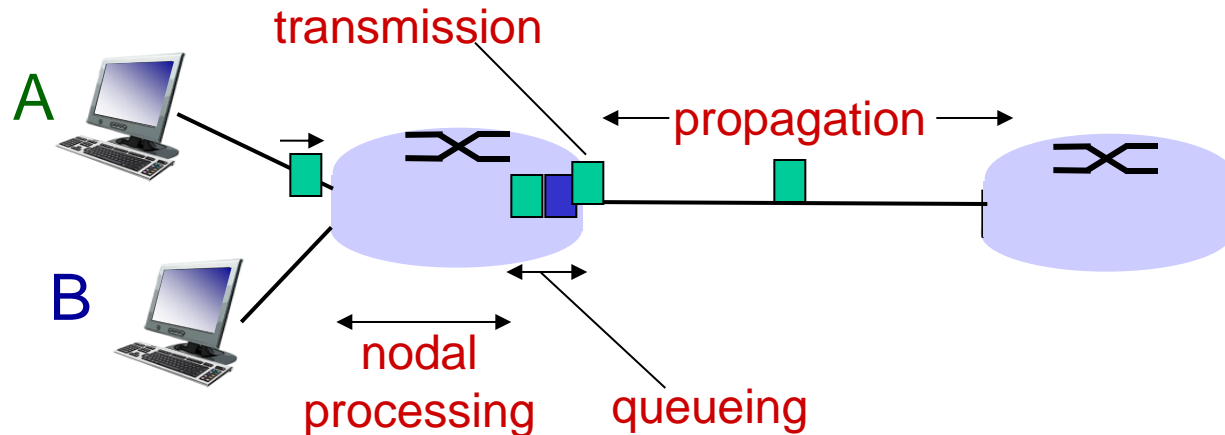
d_{proc} : nodal processing

- 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



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

d_{trans} : transmission delay:

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

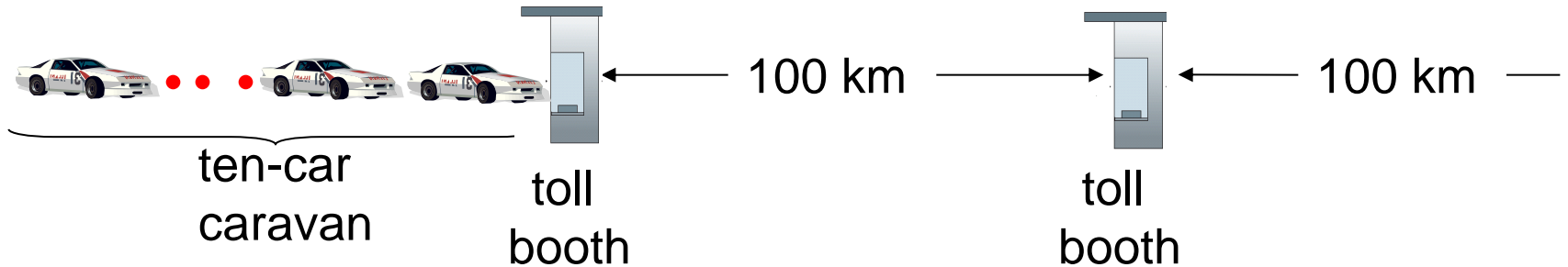
d_{prop} : propagation delay:

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

d_{trans} and d_{prop}
very different

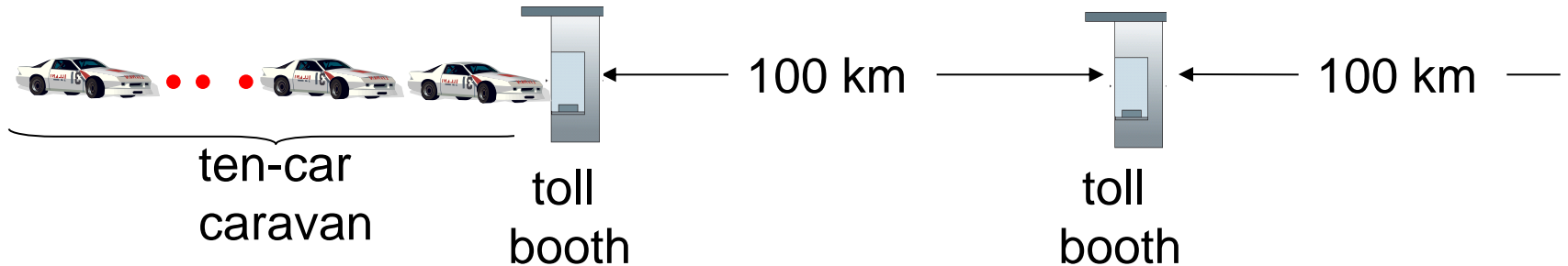
* Check out the Java applet for an interactive animation on trans vs. prop delay

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 booth:
 $100\text{km} / (100\text{km/hr}) = 1$ hr
 - **A: 62 minutes**

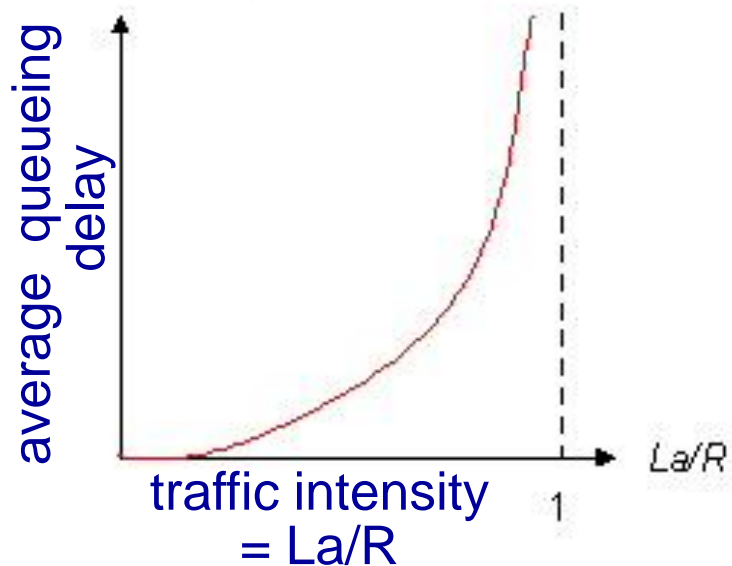
Caravan analogy (more)



- ❖ 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, 1st car arrives at second booth; three cars still at 1st 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!



$La/R \sim 0$

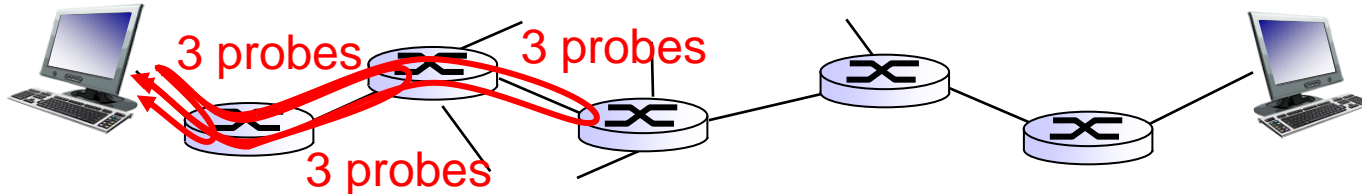


$La/R \rightarrow 1$

* Check out the Java applet for an interactive animation on queueing 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

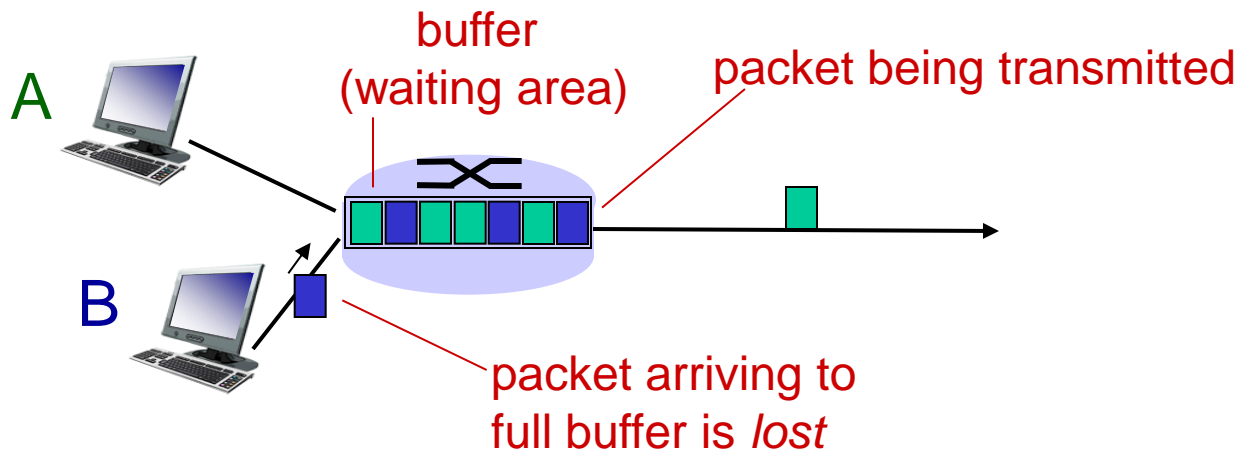


* means no response (probe lost, router not replying)

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

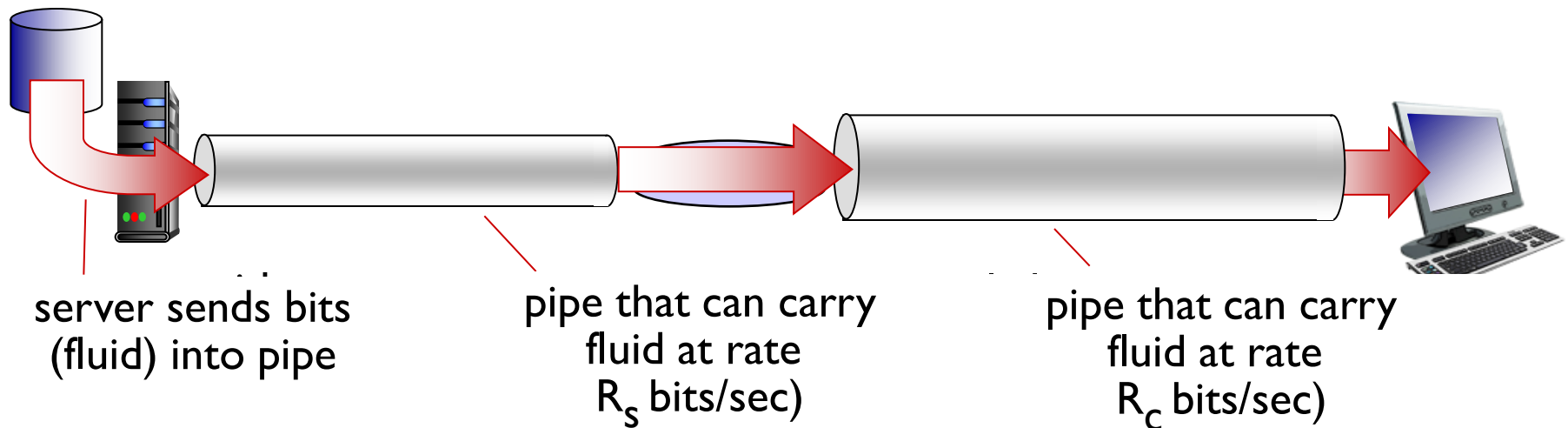
Packet loss

- ❖ 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



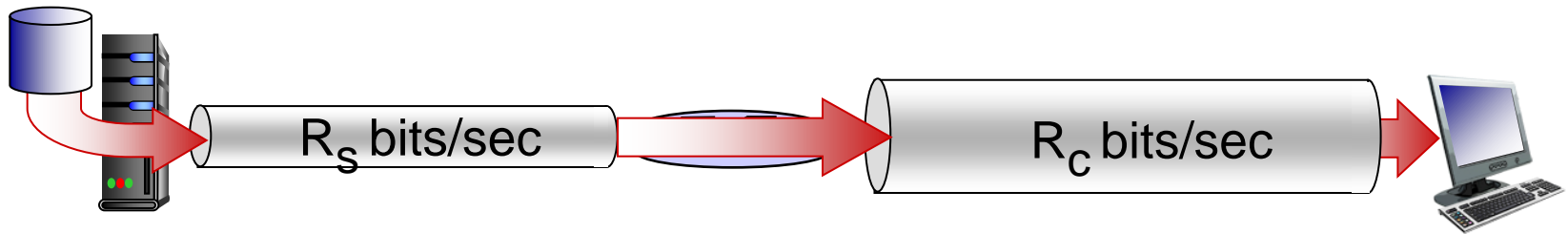
Throughput

- ❖ *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

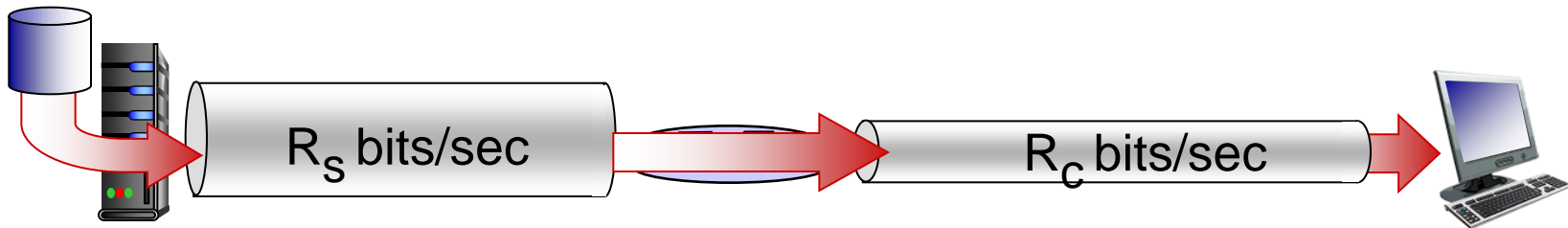


Throughput (more)

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



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

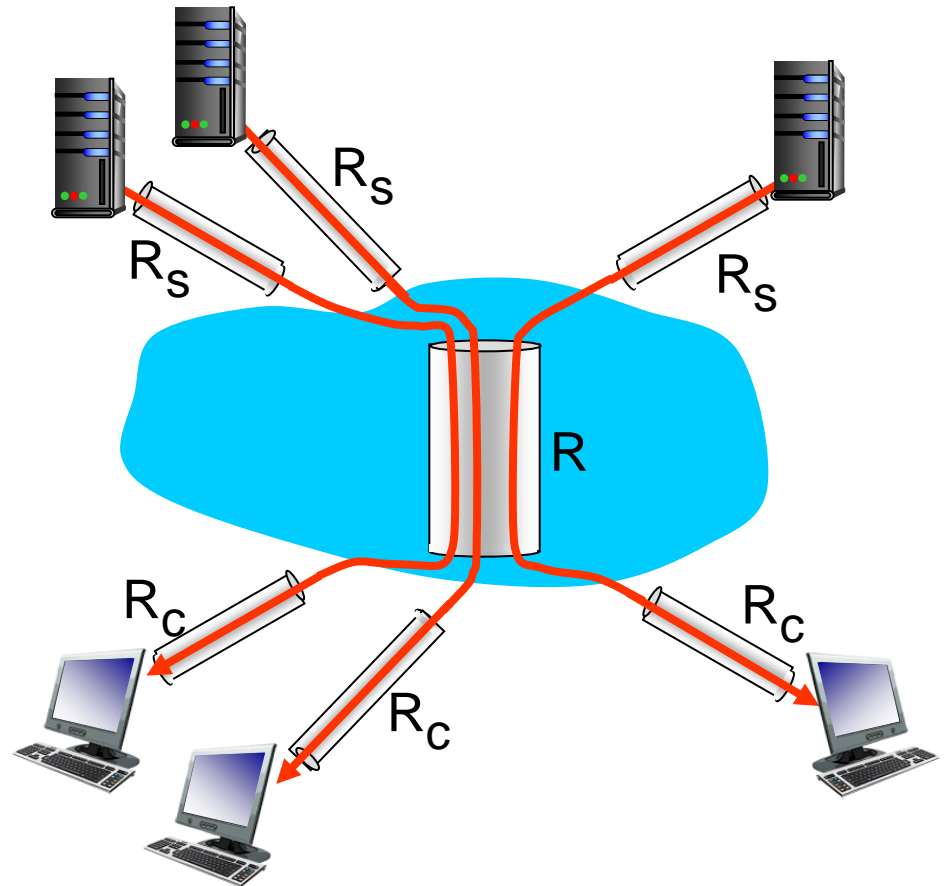


bottleneck link

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

Protocol “layers”

*Networks are complex,
with many “pieces”:*

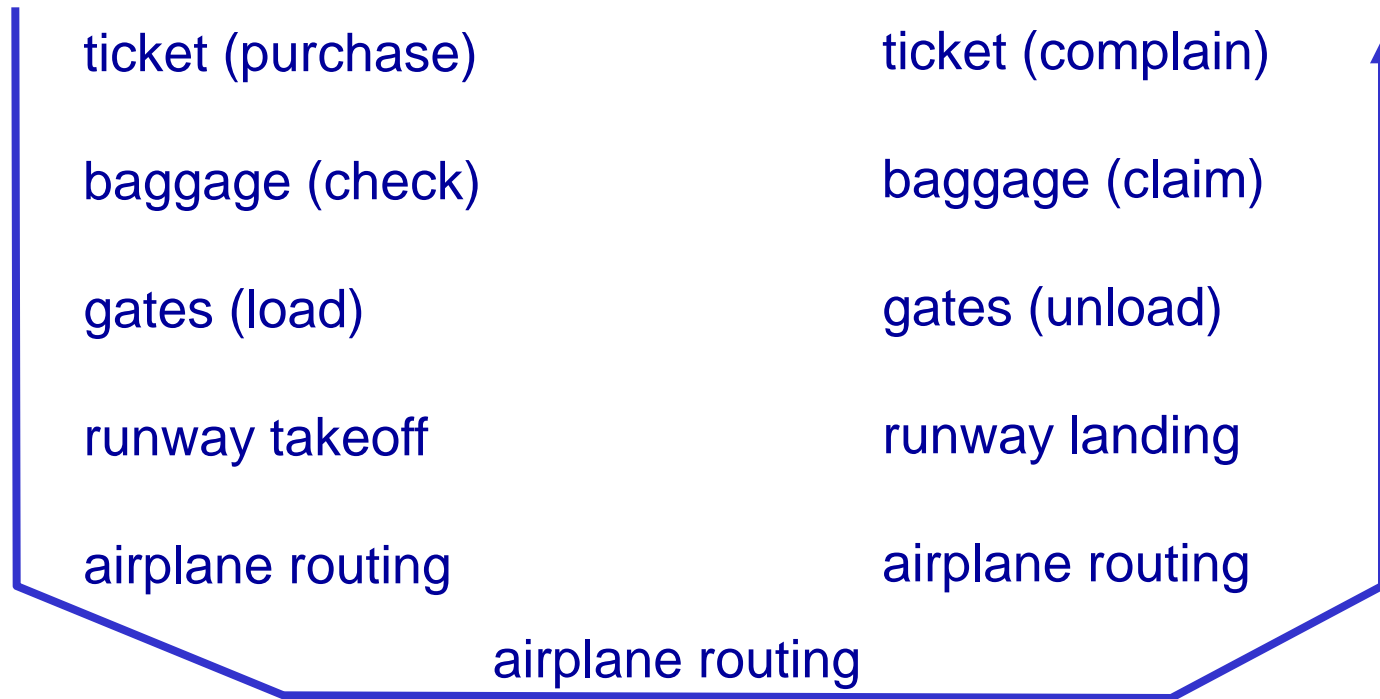
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

is there any hope of
organizing structure of
network?

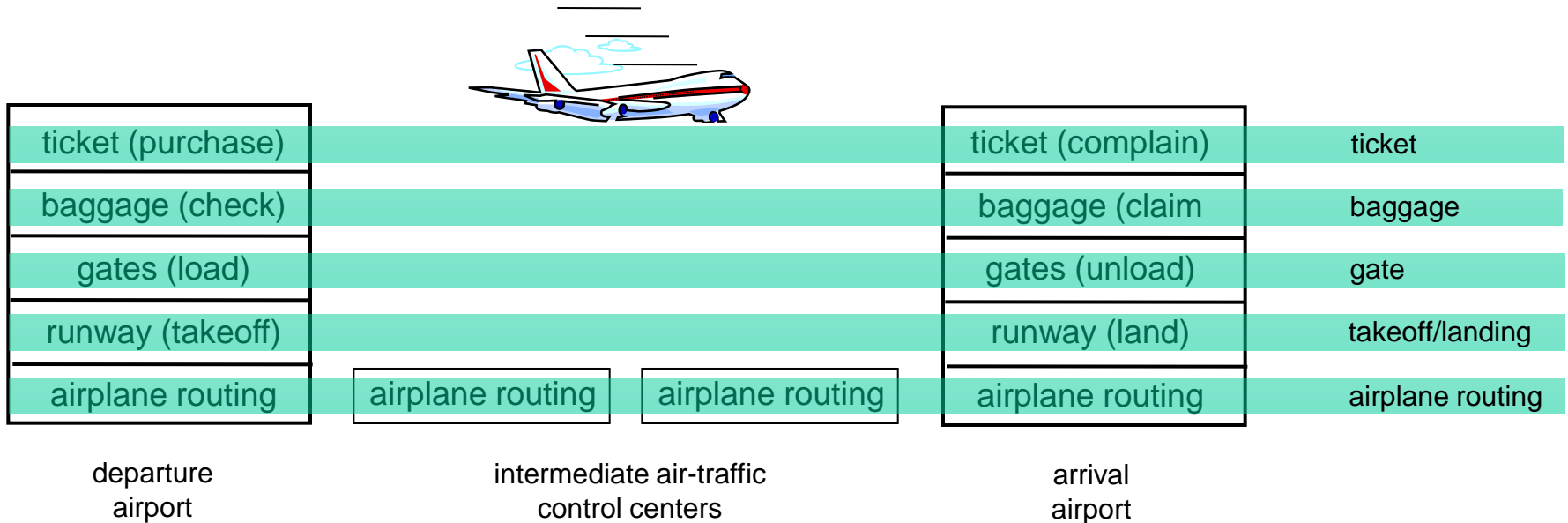
.... or at least our
discussion of networks?

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

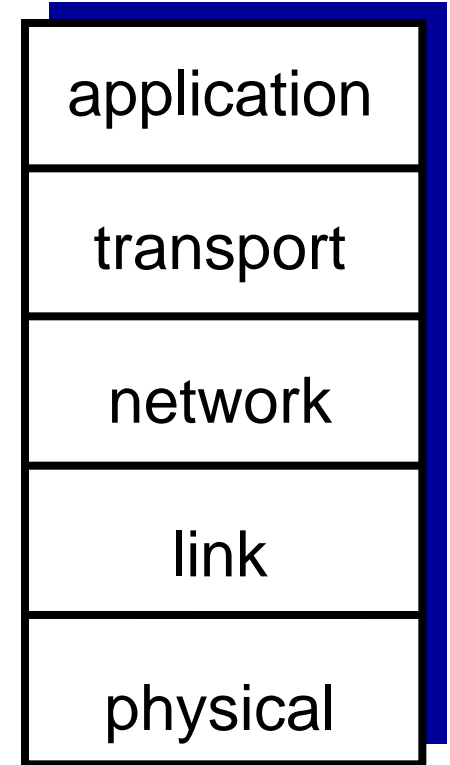
Why layering?

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?

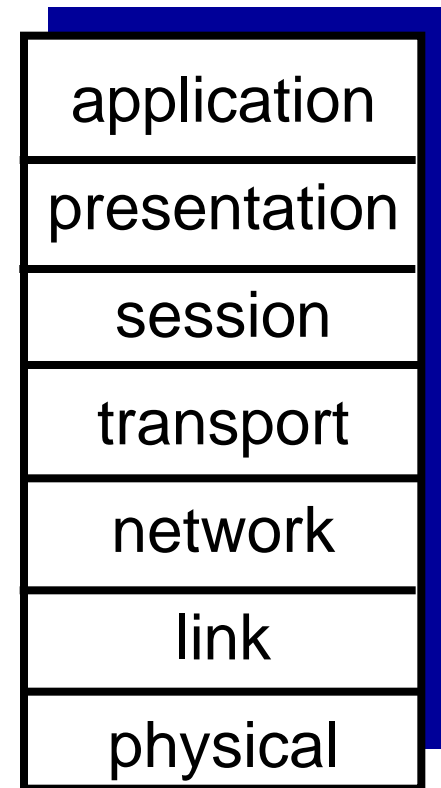
Internet protocol stack

- ❖ *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

