CSC/CPE 138

COMPUTER NETWORKING FUNDAMENTALS

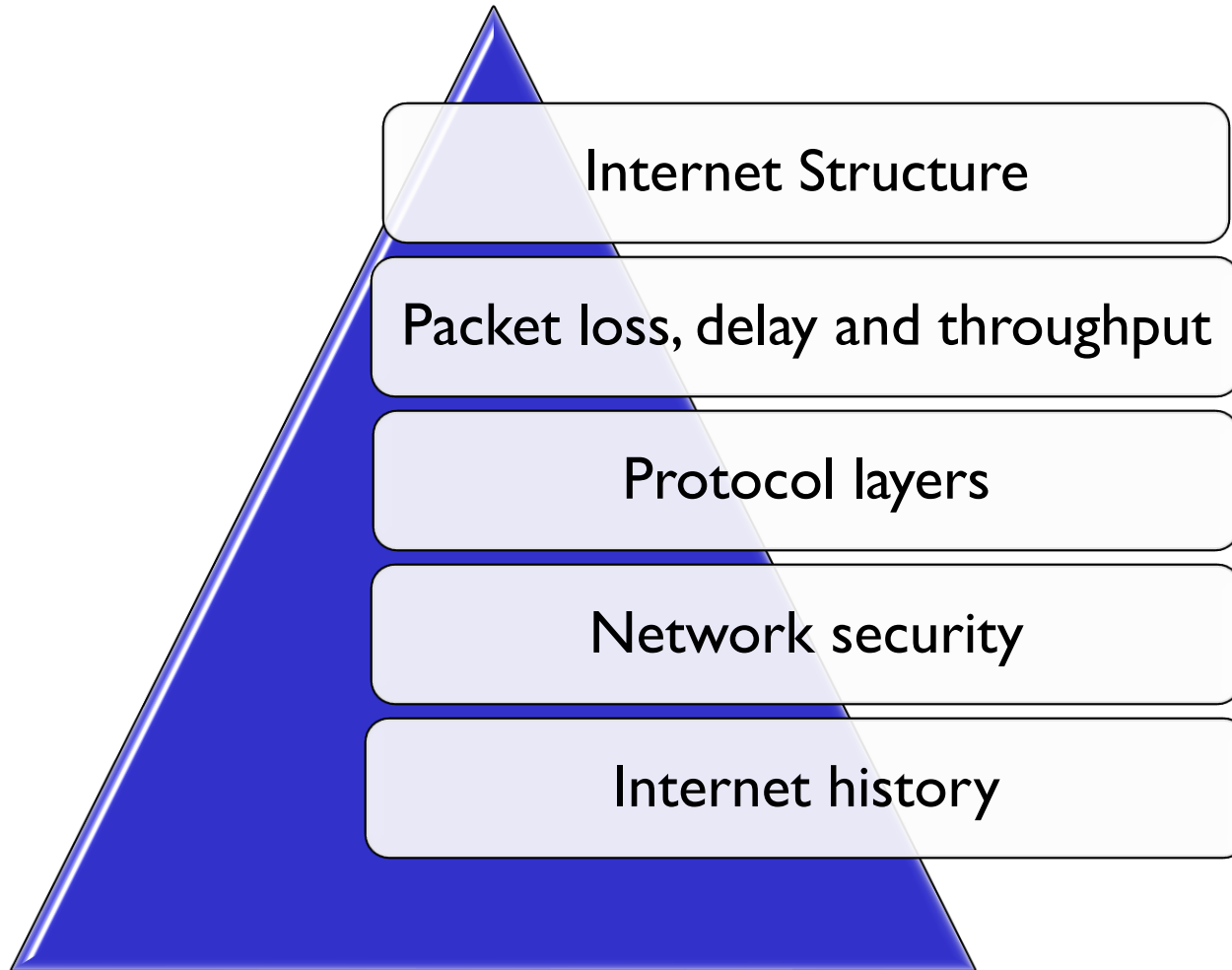Department of Computer Science
Spring 2024
Lecture 1_2
Slides adapted from Computer Networking : A Top-Down
Approach, Kurose Ross, 8th Edition

SACRAMENTO
STATE

What's in this Lecture?

Internet Structure

Packet loss, delay and throughput

Protocol layers

Network security

Internet history

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**

mobile network

global ISP

home network
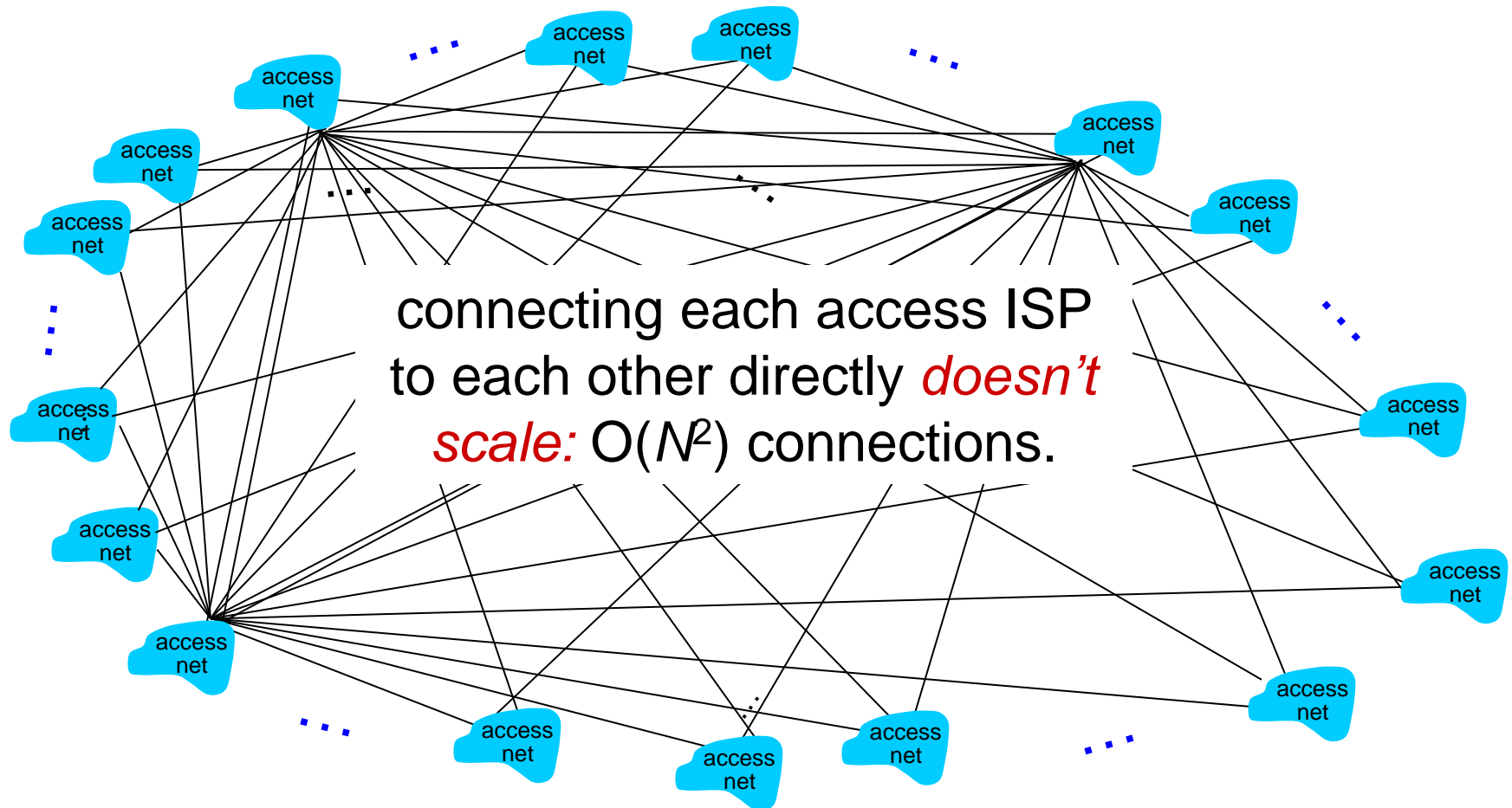
regional ISP

institutional network
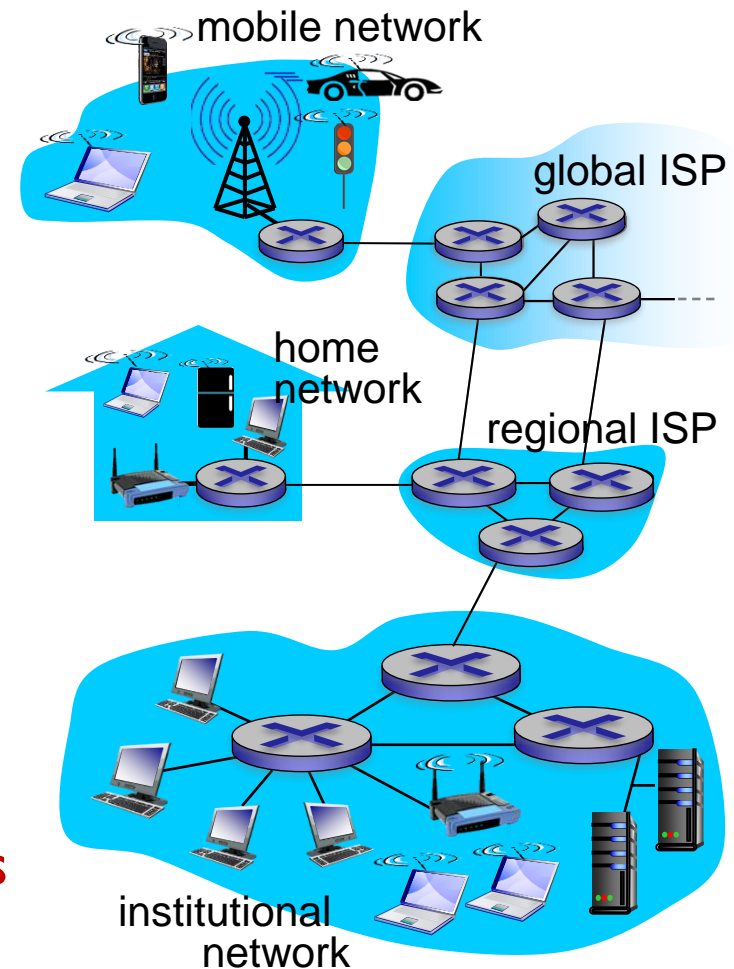
Internet structure: network of networks

Question: given *millions* of access ISPs, how to connect them together?
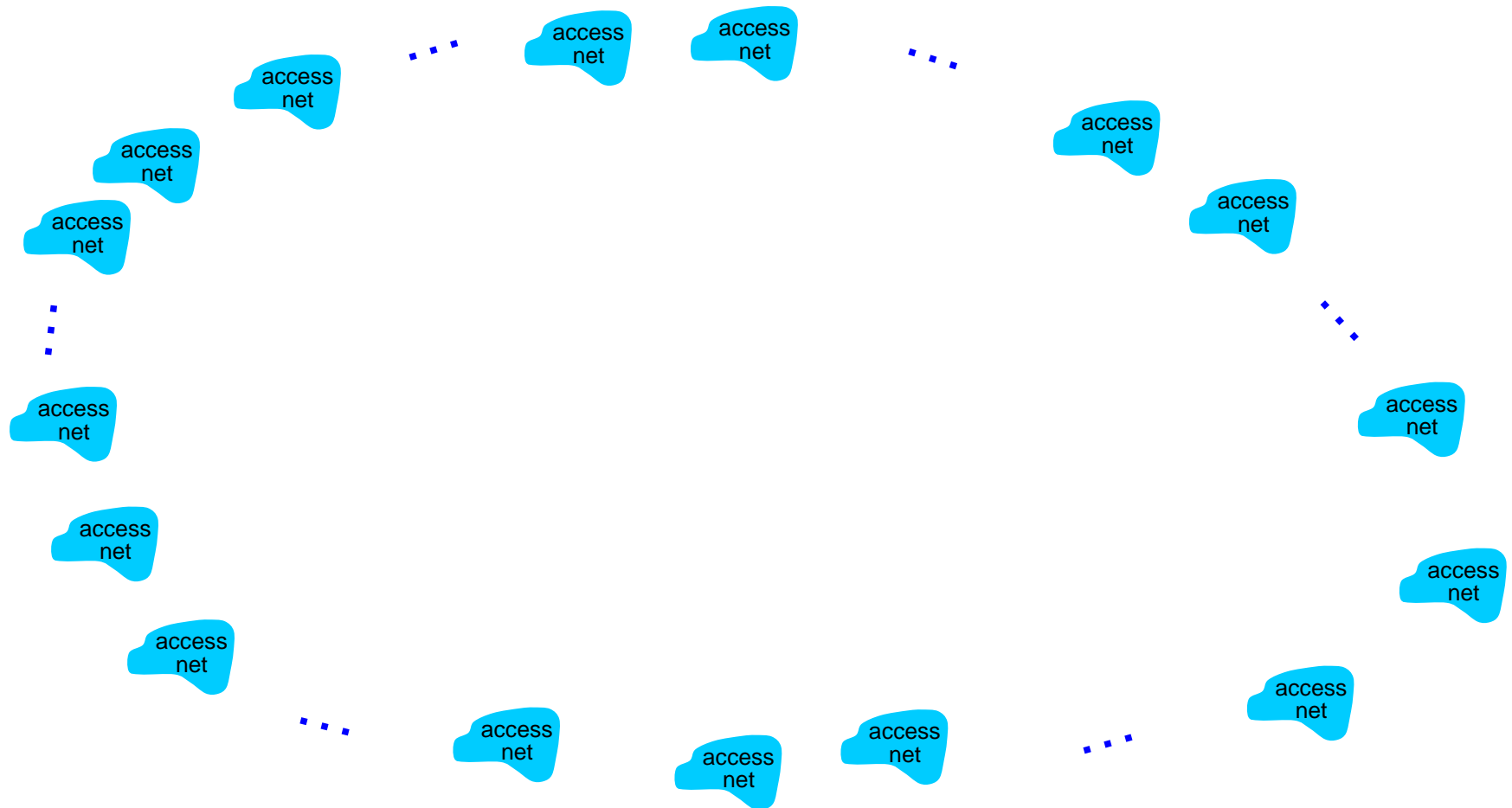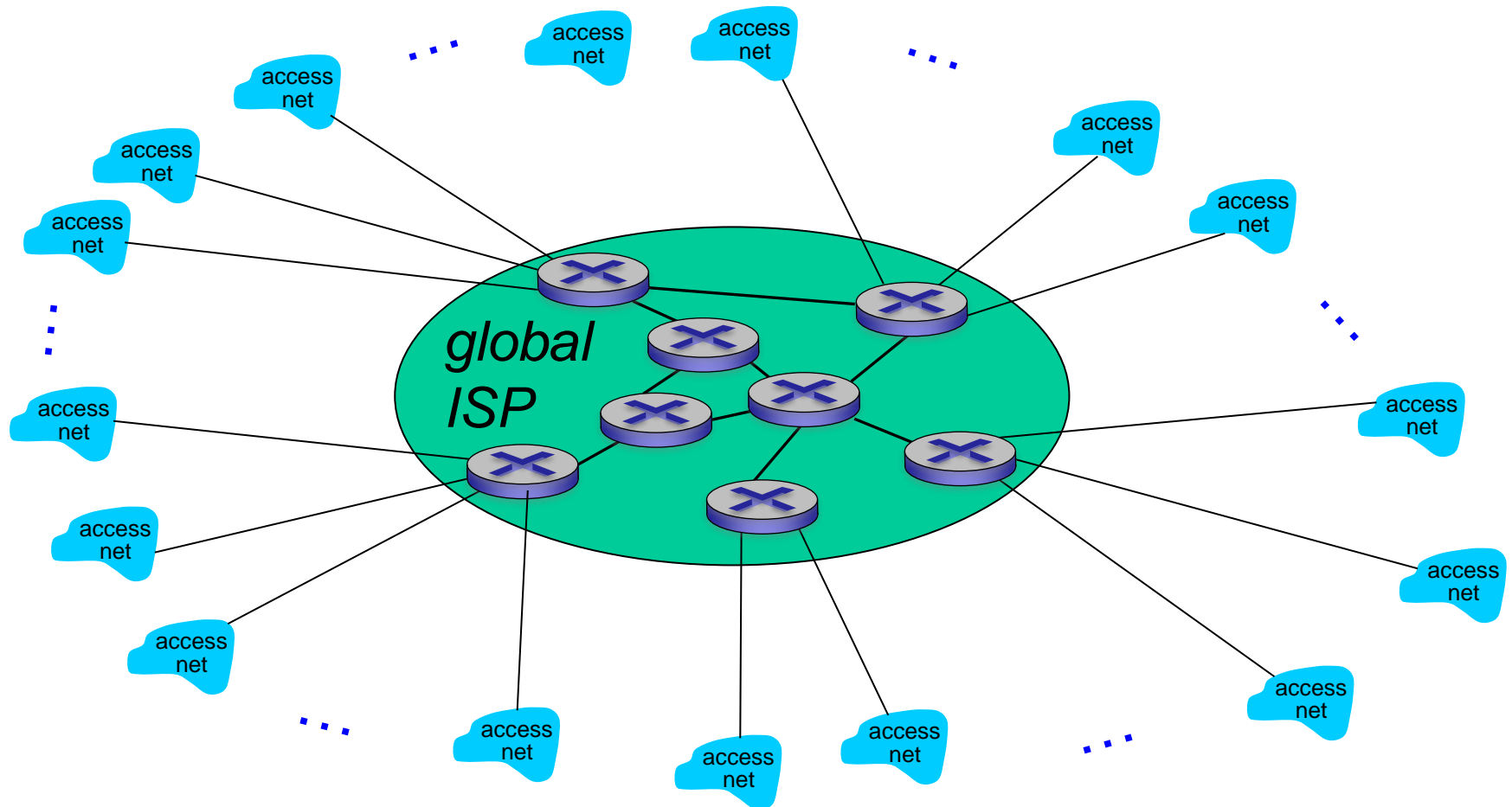
Internet structure: network of networks

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

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

Internet structure : network of networks

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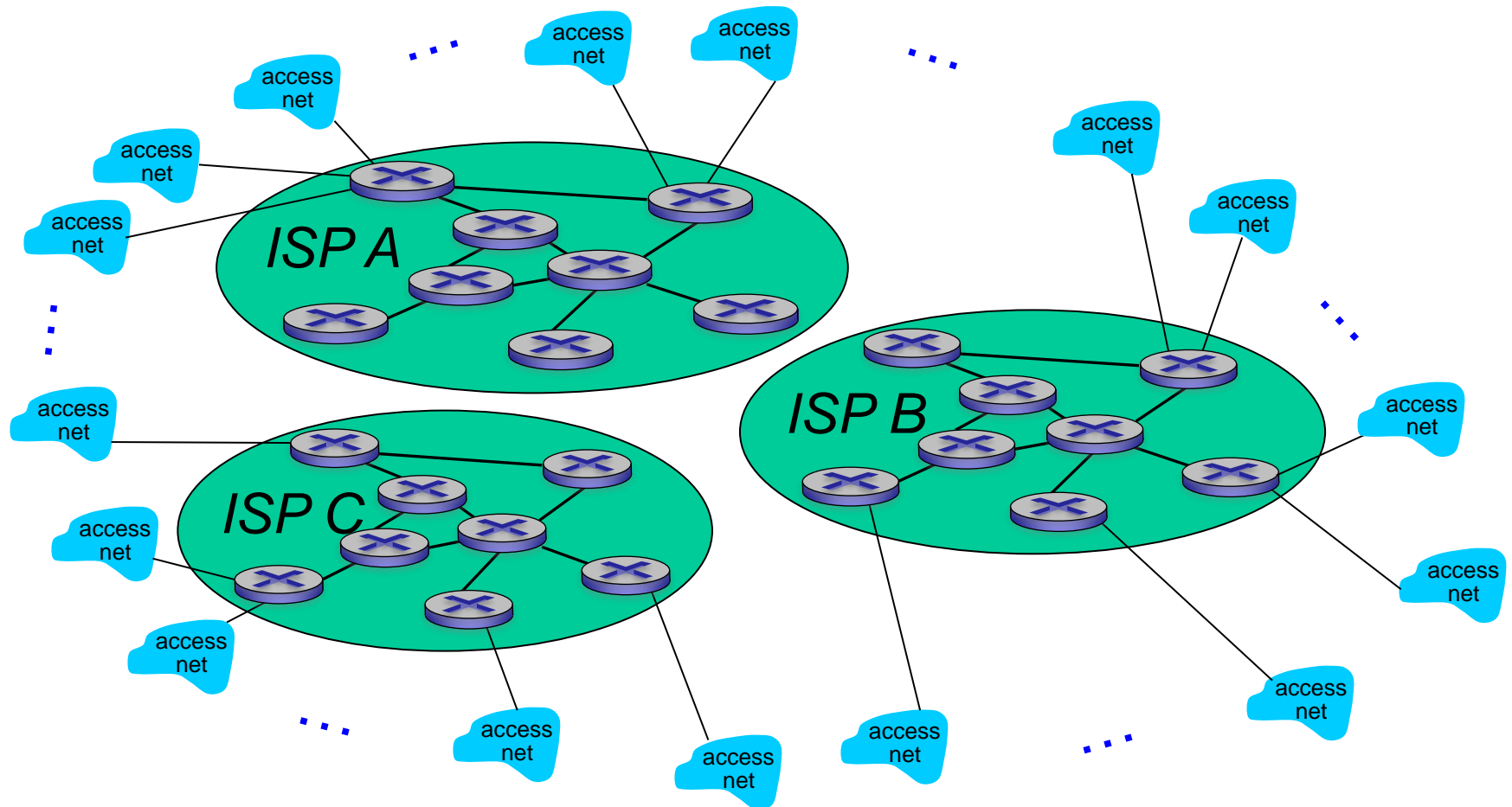*Customer* and *provider* ISPs have economic agreement.

Internet structure : network of networks
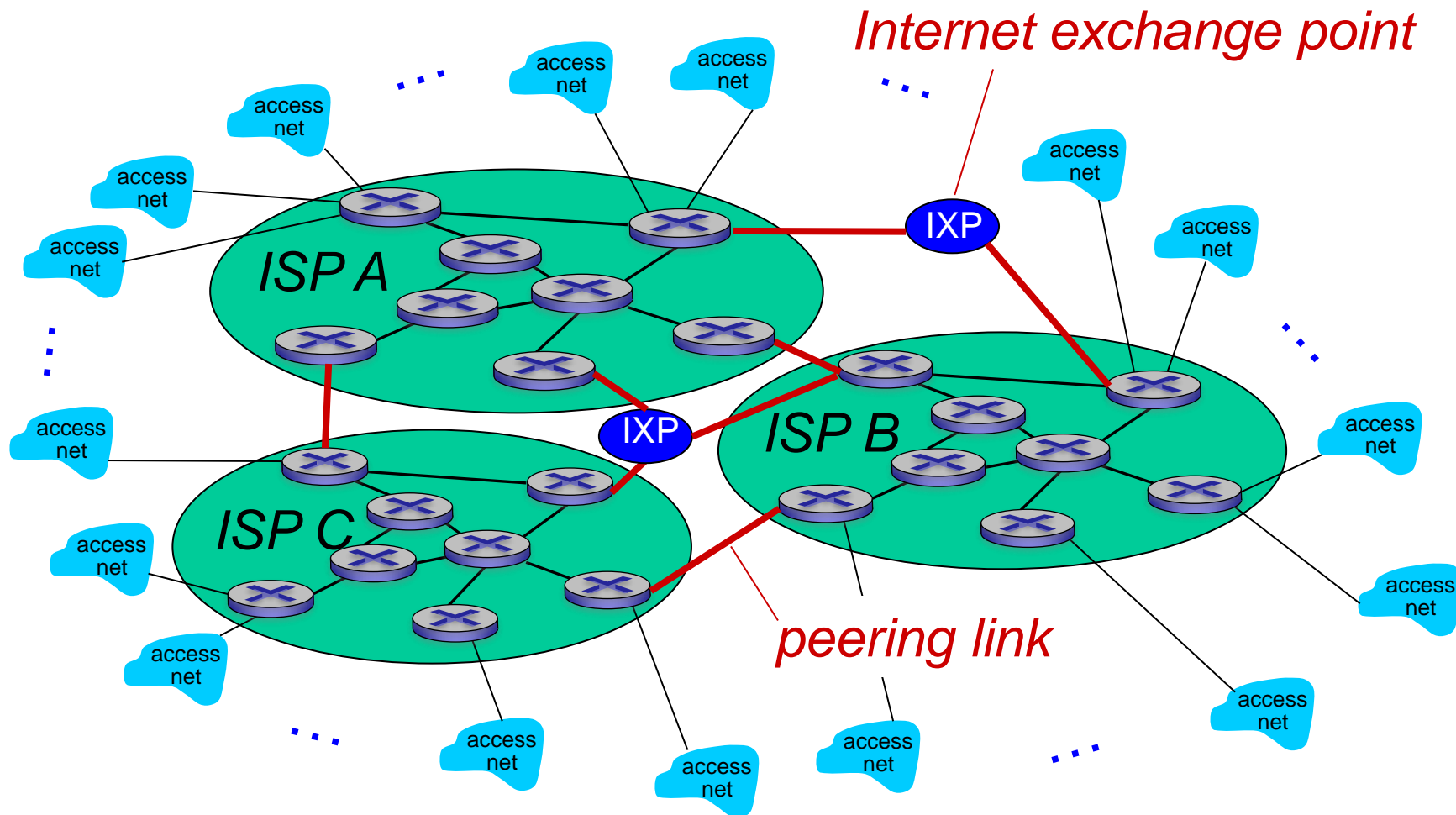
But if one global ISP is viable business, there will be competitors ….

Internet structure: network of networks

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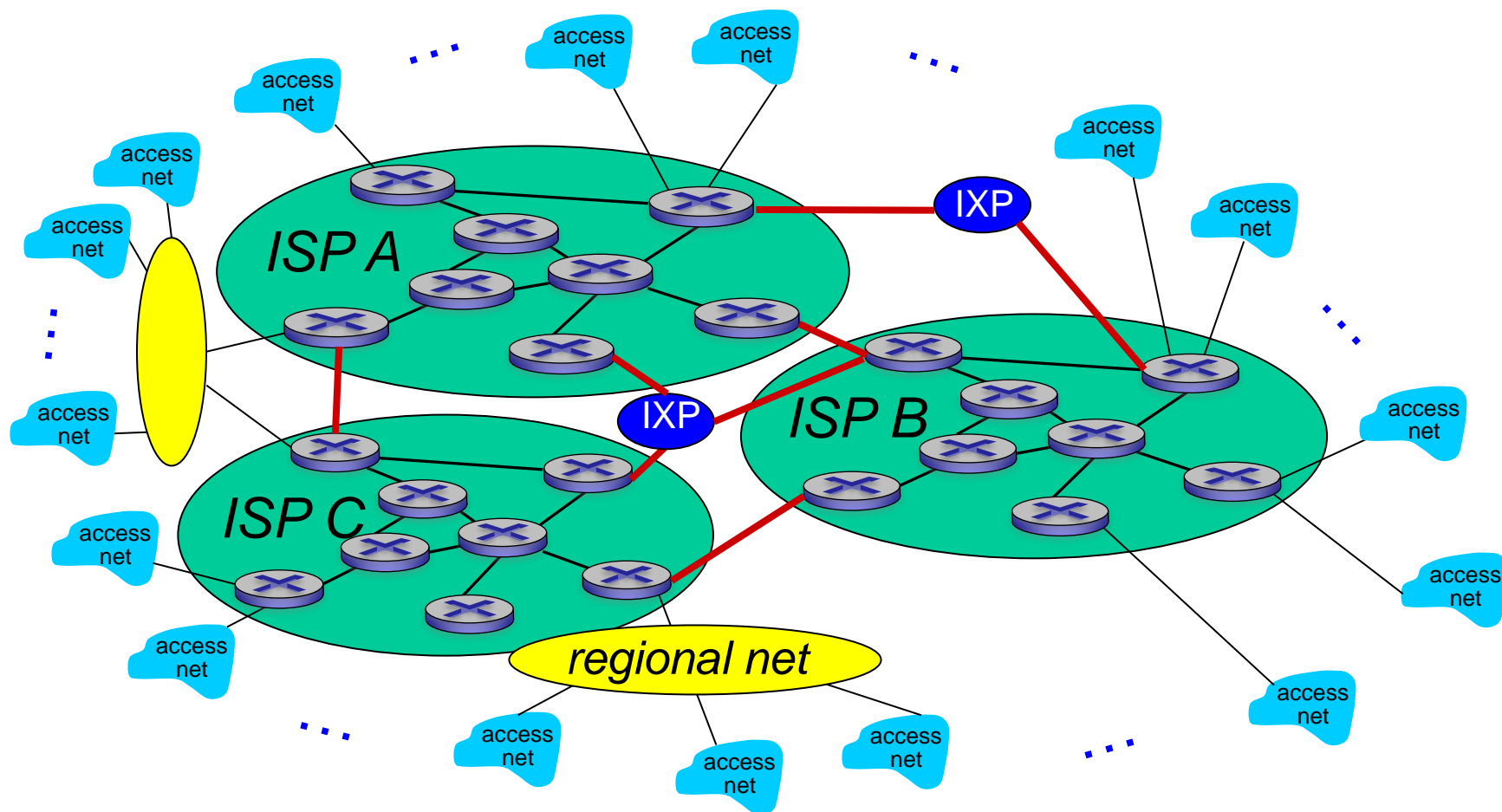

Internet exchange point

peering link

ISP A

ISP B

ISP C

Internet structure : network of networks

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

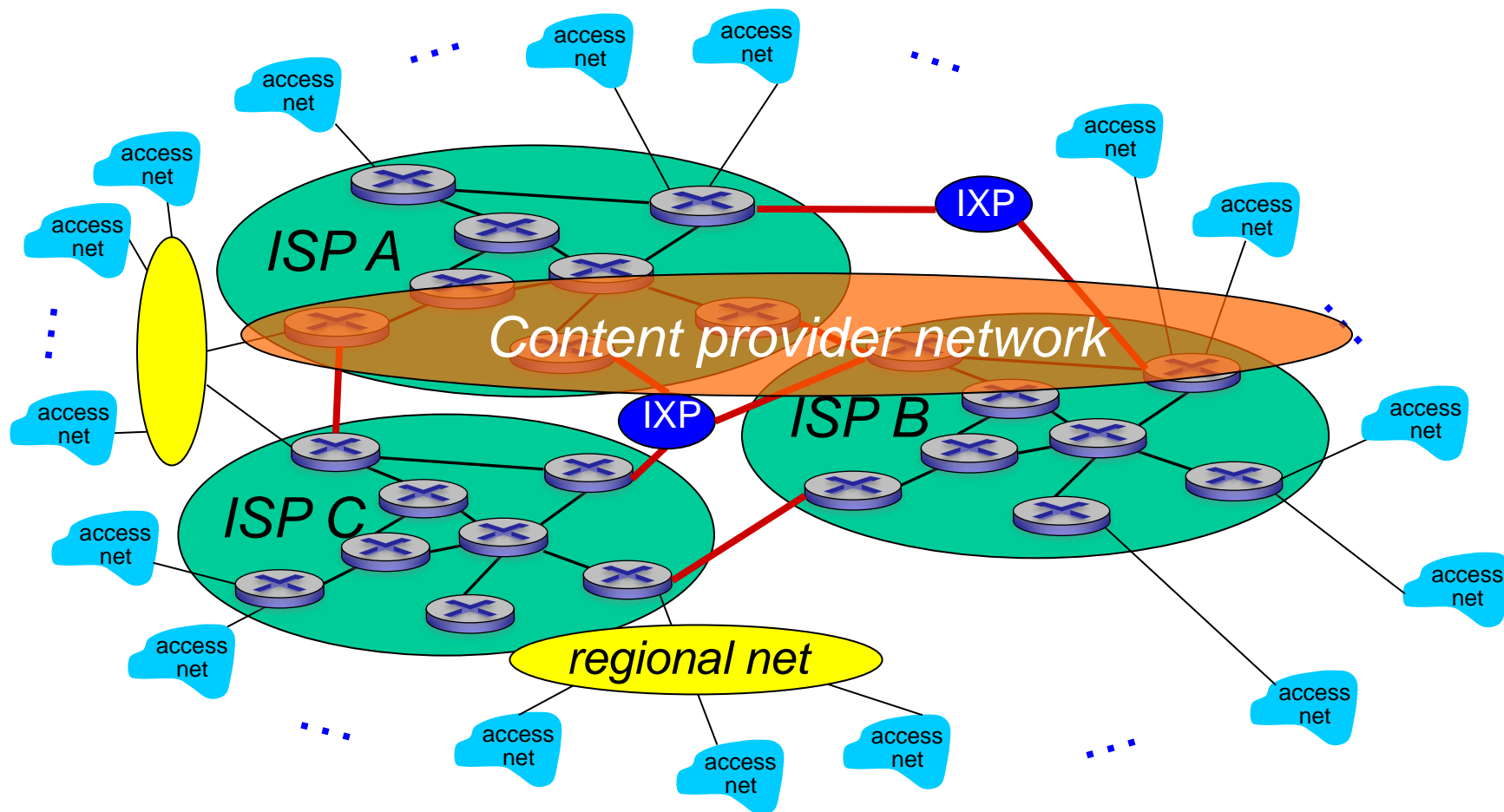# Internet structure: network of networks

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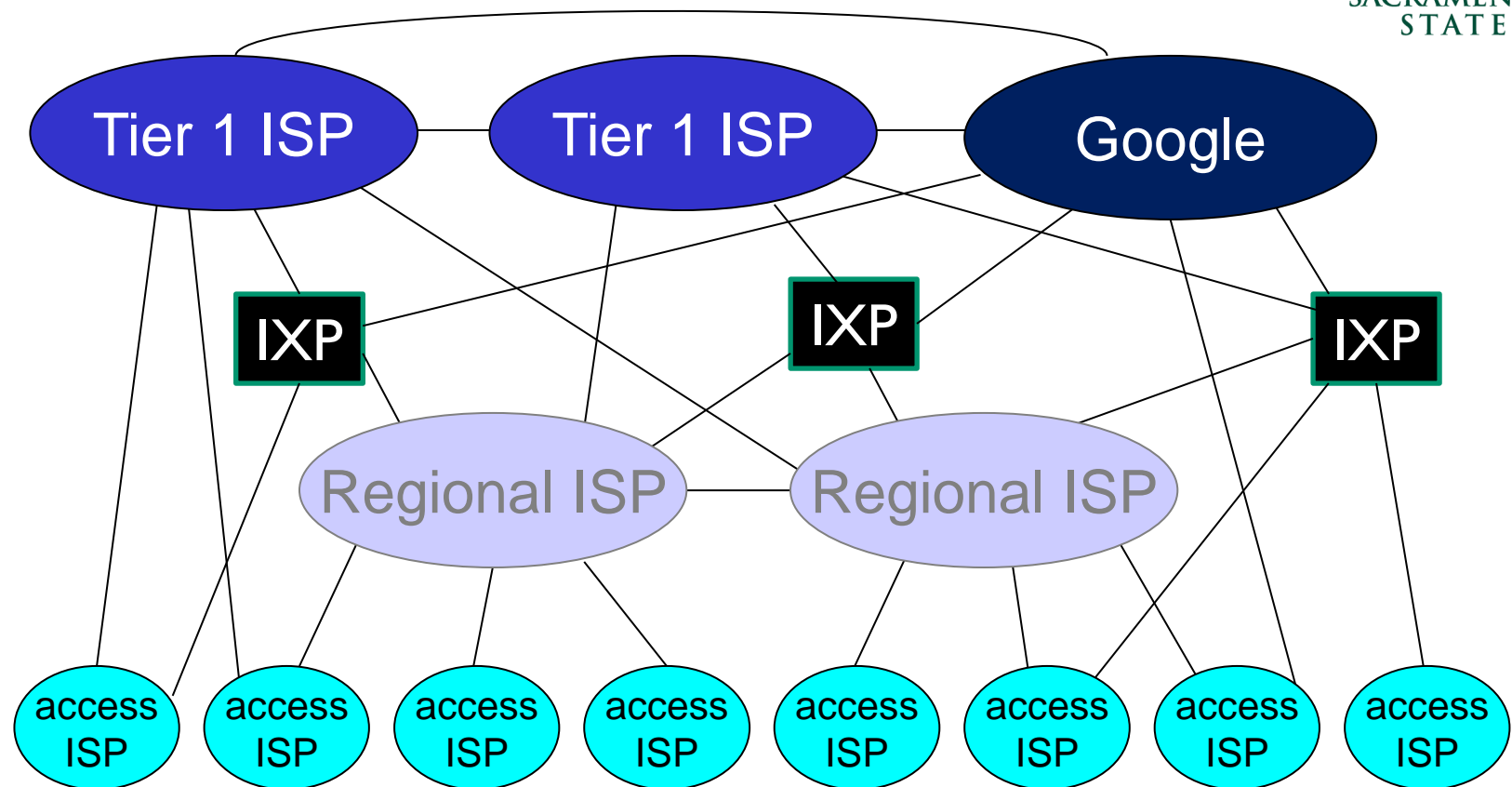
- **at center: small # of well-connected large networks**
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g., Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Tier-1 ISP: e.g., Sprint

POP: point-of-presence

to/from backbone

peering

to/from customers
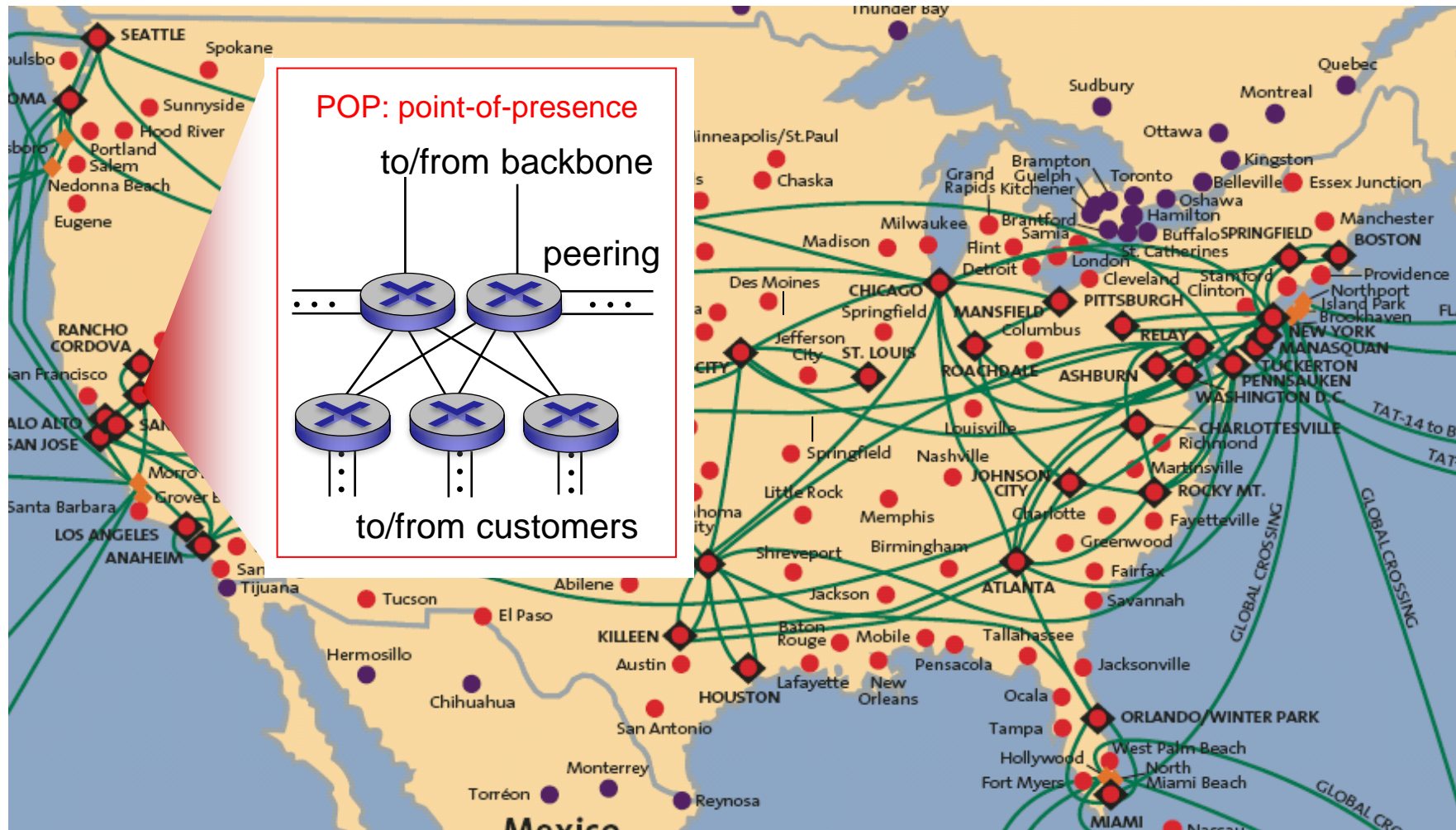
ISP Networks

Concept Check.

WHAAAA?!?!
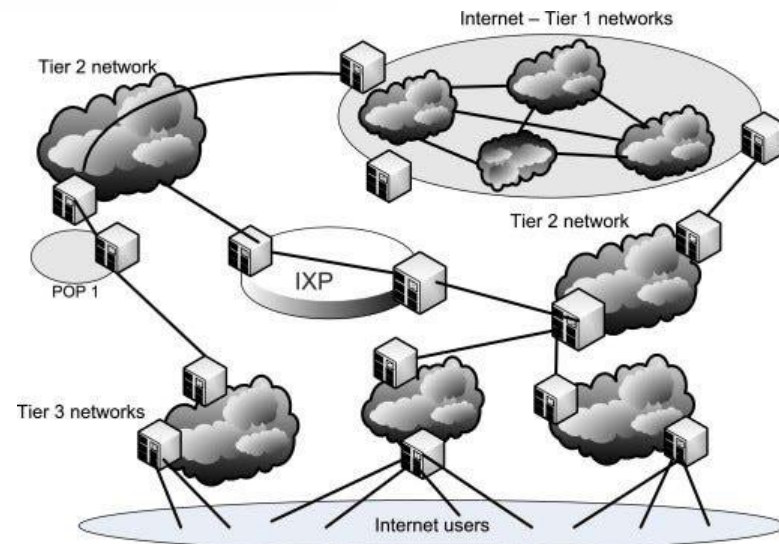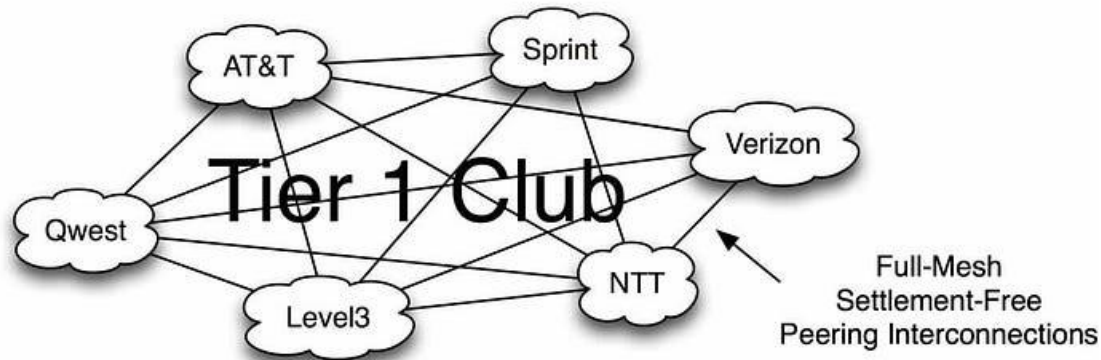
Which ISP will you choose to connect your home to Internet?
Answer: Access ISP

Which type of ISP will you choose to connect your ISP to Another?
Answer: Regional ISP

What is a physical location called through which Internet infrastructure companies such as Internet Service Providers (ISPs) and CDNs connect with each other.
Answer: IXP

What is Network Performance?
Why is it important?

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

packet being transmitted (delay)

packets queueing (delay)

free (available) buffers: arriving packets dropped (loss) if no free buffers
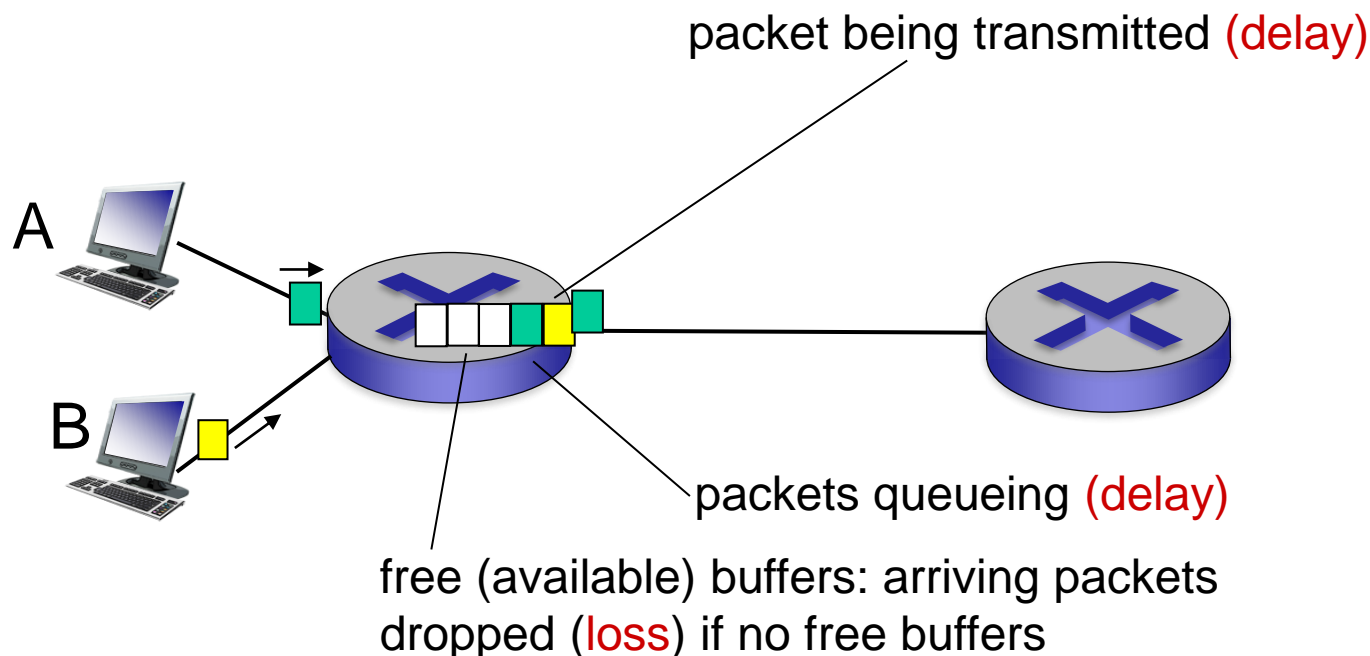
Four sources of packet delay
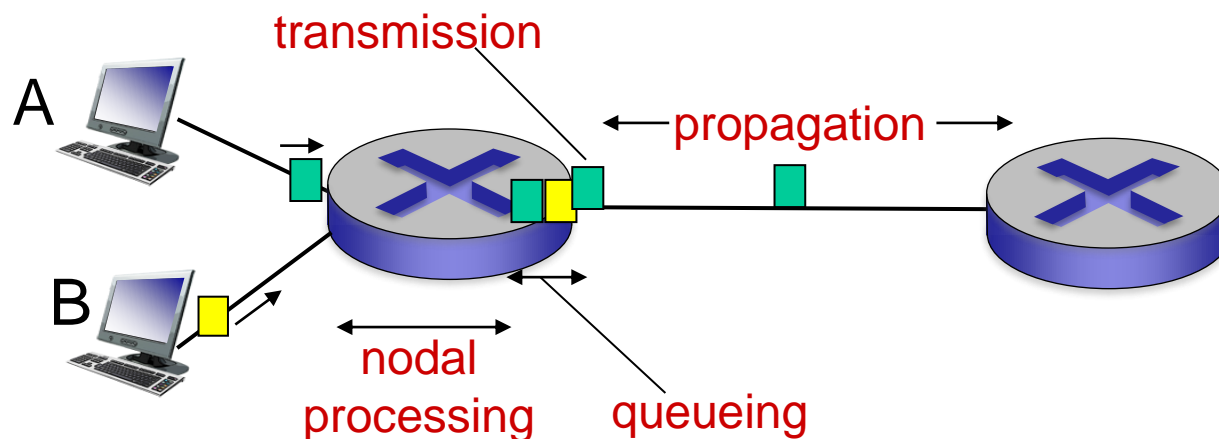
$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

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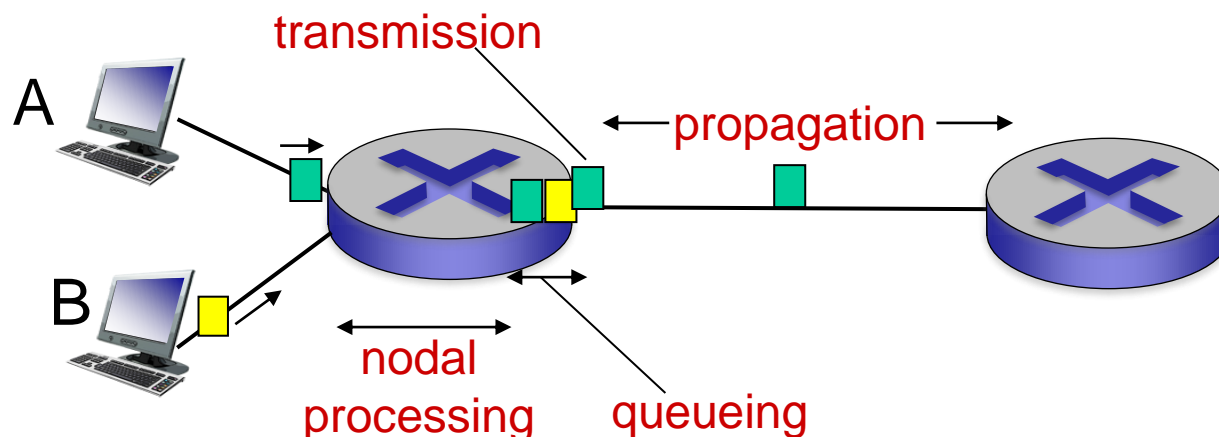
$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

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

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

Caravan analogy

ten-car caravan   toll booth   100 km   toll booth   100 km
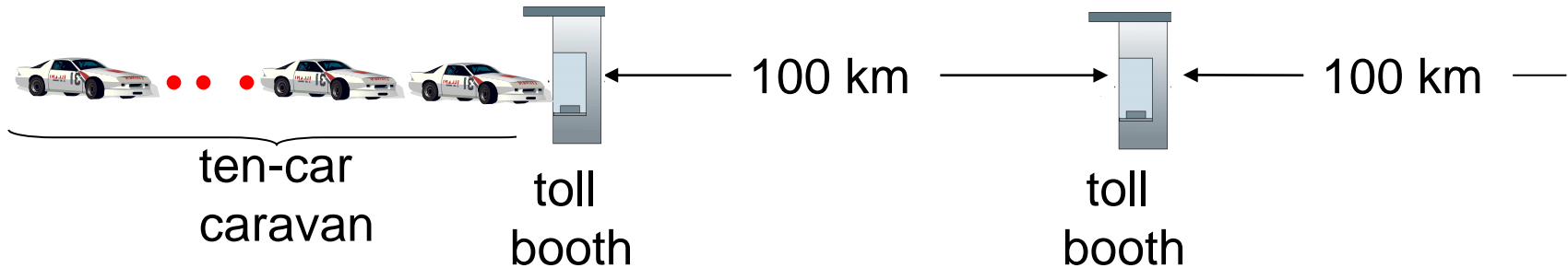
- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (bit transmission time)
- car ~ bit; caravan ~ packet
- *Q: How long until caravan is lined up before 2nd toll booth?*

- 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)

ten-car caravan   toll booth   100 km   toll booth   100 km
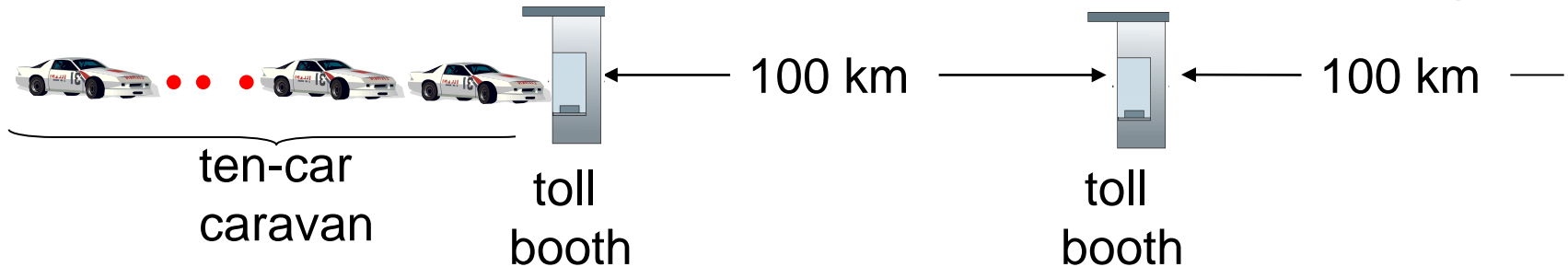
- suppose cars now "propagate" at 1000 km/hr
- and suppose toll booth now takes one min to service a car
- *Q:* Will cars arrive to 2nd booth before all cars serviced at first booth?

  - *A: Yes!* after 7 min, first car arrives at second booth; three cars still at first booth

Example: Computing delays

Question: Suppose Host A wants to send a large file to Host B. The path from Host A to Host B has three links with distances L1 = 2 Kilometer, L2 = 3 Kilometer, and L3 = 4 Kilometer, with transmission rates R1 = 500 Kbps, R2 = 2Mbps, and R3 = 1Mbps respectively.

	L1 = 2Km		L2 = 3Km		L3 = 4Km	
Host A	R1 = 500Kbps	Router	R2 = 2Mbps	Router	R3 = 1Mbps	Host B
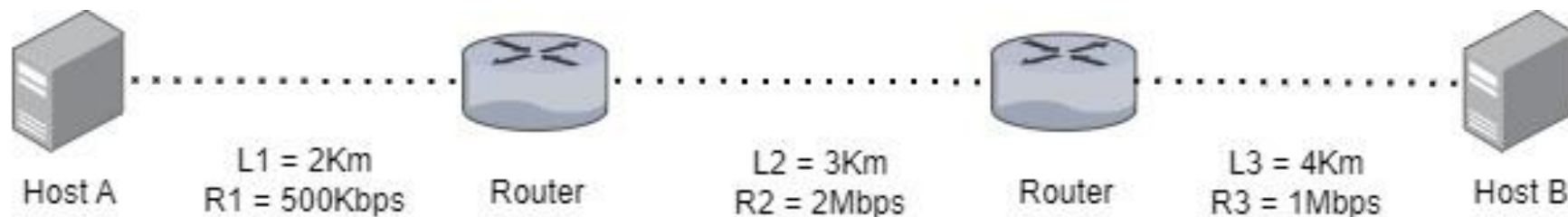
Assume, the file is 4 megabytes and propagation speed is 3×10^8 m/sec, compute transmission delay and propagation delay of each of the three links.

Example: Computing delays

Solutions

Link 1

    Transmission delay: $L/R = 4 * 8 * 1024^2$ bits / 500 Kbps = 65.536

    Propagation delay: $d/s = 2$ km / $3 * 10^8$ m/sec = 0.000006666

Link 2

    Transmission delay: $L/R = 4 * 8 * 1024^2$ bits / 2 Mbps = 16 s

    Propagation delay: $d/s = 3$ km / $3 * 10^8$ m/sec = 0.00001

Link 3

    Transmission delay: $L/R = 4 * 8 * 1024^2$ bits / 1 Mbps = 1s

    Propagation delay: $d/s = 4$km / $3 * 10^8$ m/sec = 0.0000133

DIY: Compute Delay

Question: Suppose Host A wants to send a large file of size 10 megabytes to Host B. The path from Host A to Host B has three links with distances L1 = 10 Kilometer, L2 = 2 Kilometer, and L3 = 5 Kilometer, with transmission rates R1 = 50 Kbps, R2 = 1Gbps, and R3 = 4 Mbps respectively. Compute transmission delay and propagation delay of each of the three links. (Assume propagation speed is $3\text{x}10^8$ m/sec.)

Solution Hint:
File size = $10*10^6 * 8$
L1 -> Transmission delay = L /R
L1 -> Propagation delay = d/s.

Answer :

Link	Transmission Delay	Propagation Delay
LI	1600s	33us
L2	0.08	6us
L3	20	16us

Queueing delay (revisited)

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

average queueing delay

traffic intensity = *La/R*

La/R

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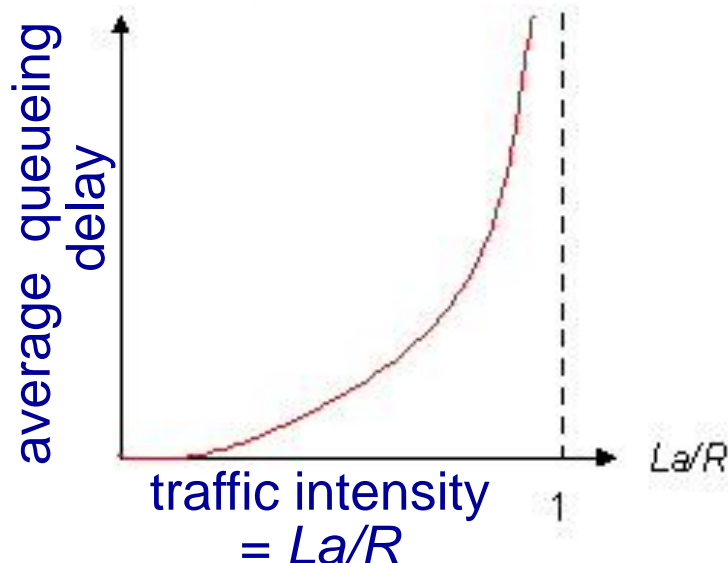
- *La/R ~ 0*: avg. queueing delay small
- *La/R -> 1*: avg. queueing delay large
- *La/R > 1*: more "work" arriving than can be serviced, average delay infinite!

La/R ~ 0

La/R -> 1

Group Activity(4 members)

In a router, we can compute transmission delay, propagation delay and queueing delay.

1. What parameter change increases the propagation delay? How can you balance it?

2. What parameter/variable change decreases transmission delay? How can you balance it?

3. What parameter/variable change increases queueing delay?

Hint: Look at the formula of each delay methods and tweak the numerator or denominator as per the question.

"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.

3 probes   3 probes

3 probes
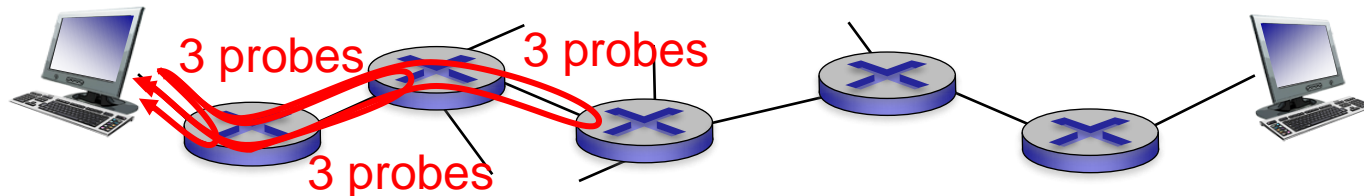
"Real" Internet delays, routes

traceroute: google.com

```
traceroute google.com
traceroute to google.com (142.250.191.46), 64 hops max, 52 byte packets
 1  10.0.0.1 (10.0.0.1)  6.611 ms  6.024 ms  3.485 ms
 2  100.93.195.202 (100.93.195.202)  13.616 ms
    100.93.195.203 (100.93.195.203)  16.049 ms  11.028 ms
 3  po-101-rur101.florin.ca.ccal.comcast.net (96.110.223.193)  16.797 ms
    po-101-rur102.florin.ca.ccal.comcast.net (96.110.223.197)  14.048 ms
    po-101-rur101.florin.ca.ccal.comcast.net (96.110.223.193)  38.173 ms
 4  po-100-xar02.florin.ca.ccal.comcast.net (96.217.68.165)  16.662 ms
    po-100-xar01.florin.ca.ccal.comcast.net (96.217.68.157)  12.783 ms
    po-100-xar02.florin.ca.ccal.comcast.net (96.217.68.165)  15.790 ms
 5  96.217.68.133 (96.217.68.133)  15.697 ms  18.375 ms *
 6  ae-501-ar01.sacramento.ca.ccal.comcast.net (96.216.129.194)  24.707 ms
    ae-501-ar01.fresno.ca.ccal.comcast.net (96.216.129.182)  22.132 ms
    ae-501-ar01.sacramento.ca.ccal.comcast.net (96.216.129.194)  47.125 ms
 7  be-36441-cs04.losangeles.ca.ibone.comcast.net (96.110.45.237)  27.916 ms
    be-36431-cs03.sunnyvale.ca.ibone.comcast.net (96.110.41.105)  20.214 ms
    be-36421-cs02.losangeles.ca.ibone.comcast.net (96.110.45.229)  27.665 ms
 8  be-1312-cr12.sunnyvale.ca.ibone.comcast.net (96.110.46.30)  18.711 ms
    be-2411-pe11.losangeles.ca.ibone.comcast.net (96.110.33.14)  24.469 ms
    be-1312-cr12.sunnyvale.ca.ibone.comcast.net (96.110.46.30)  18.301 ms
```
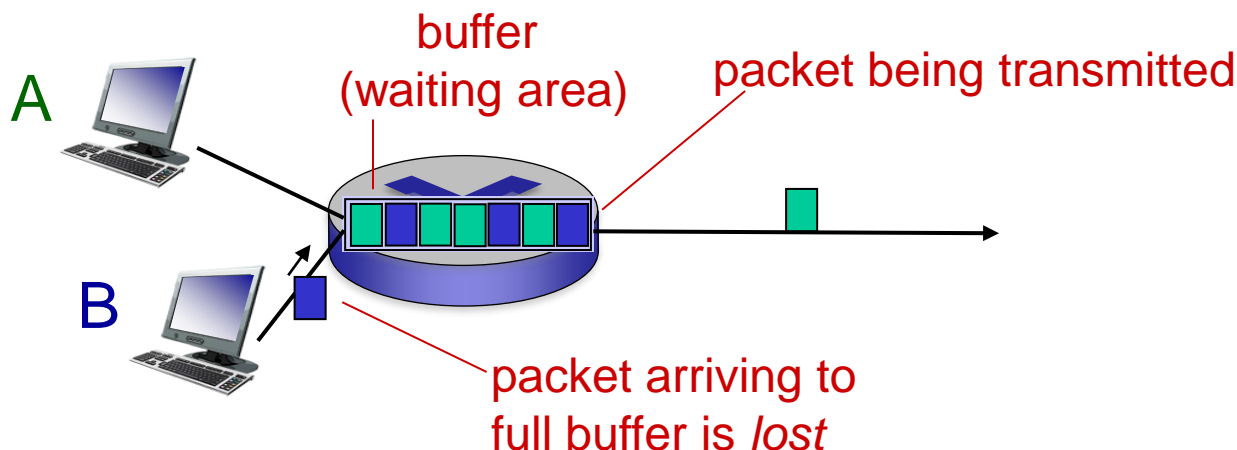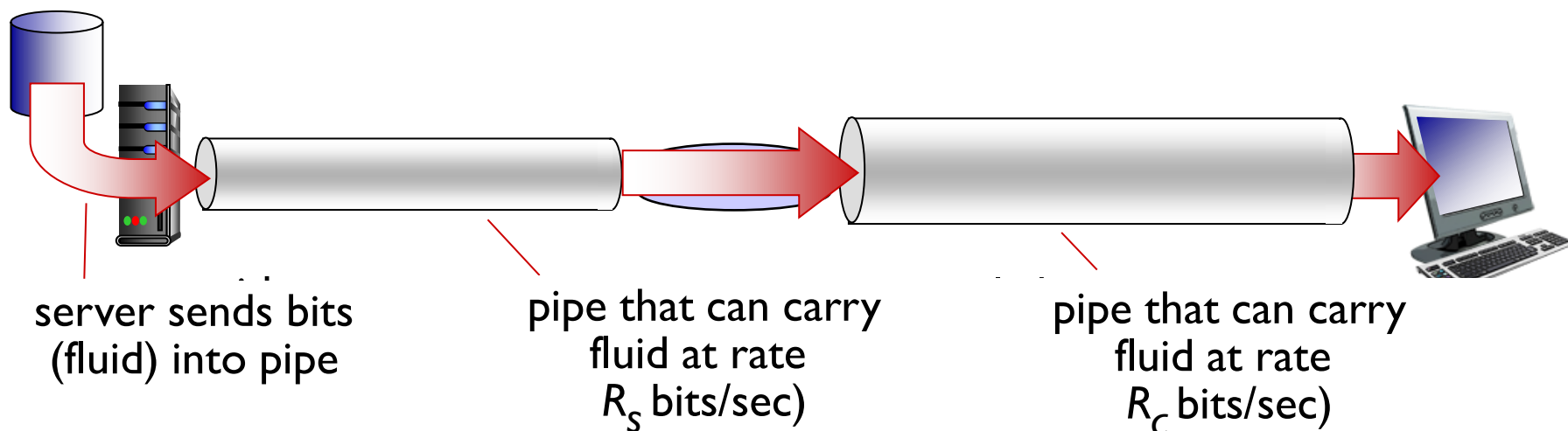
RTT

Hop / Node / Router

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

buffer
(waiting area)

packet being transmitted

A

B

packet arriving to
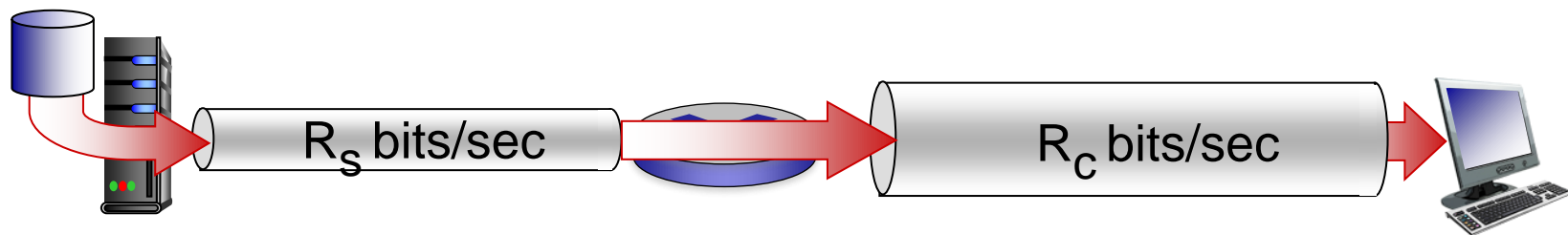full buffer is *lost*

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

server sends bits
(fluid) into pipe

pipe that can carry
fluid at rate
R_s bits/sec)

pipe that can carry
fluid at rate
R_c bits/sec)

Throughput (more)

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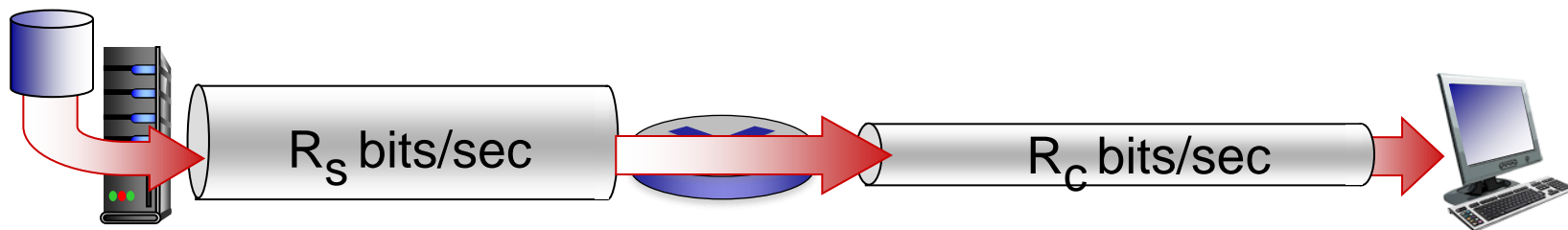

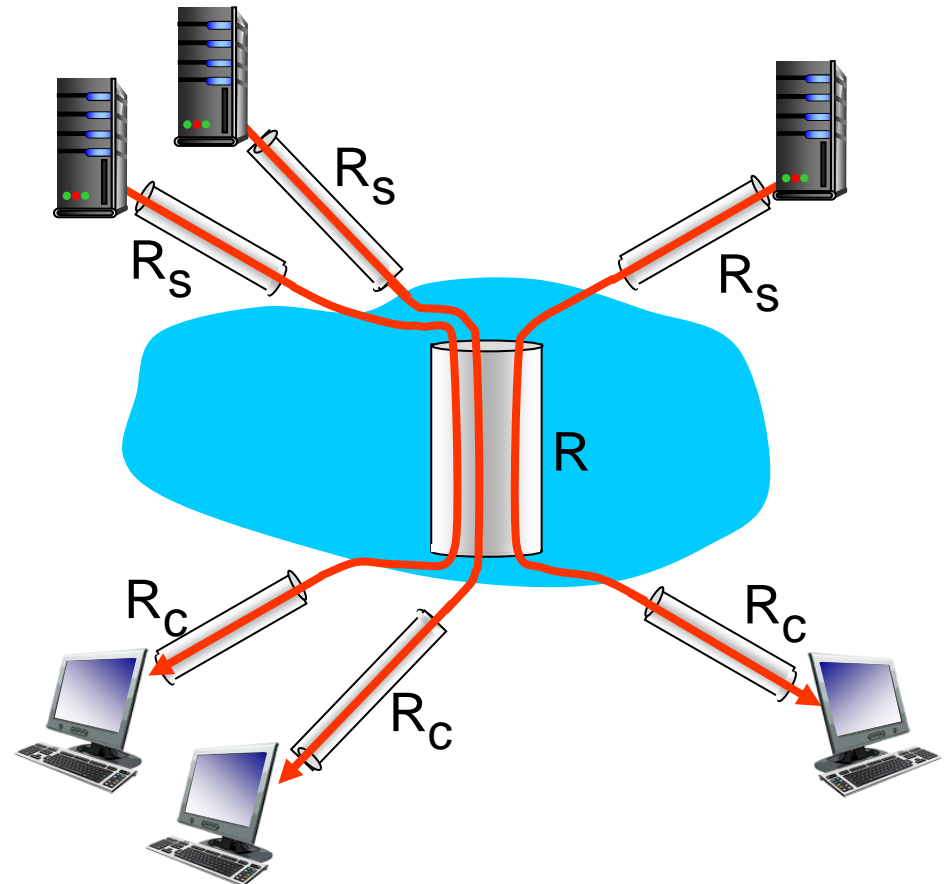- $R_s > R_c$ What is average end-end throughput?

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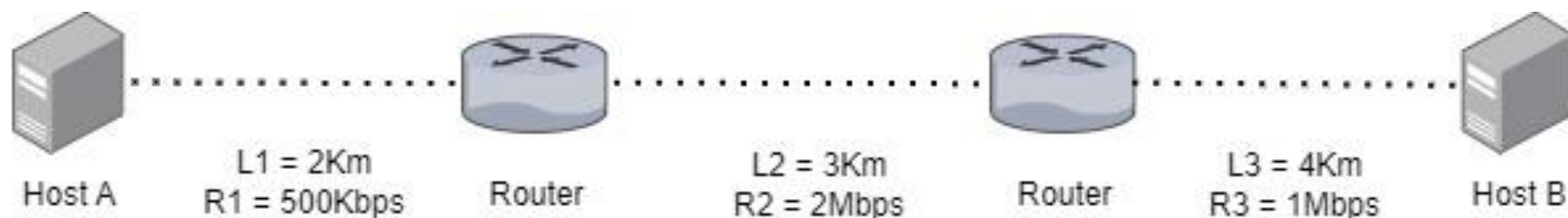link on end-end path that constrains end-end throughput

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

Question: Throughput identification

Suppose Host A wants to send a large file to Host B. The path from Host A to Host B has three links with distances L1 = 2 Kilometer, L2 = 3 Kilometer, and L3 = 4 Kilometer, with transmission rates R1 = 500 Kbps, R2 = 2Mbps, and R3 = 1Mbps respectively.


```
L1 = 2Km              L2 = 3Km              L3 = 4Km
R1 = 500Kbps          R2 = 2Mbps           R3 = 1Mbps
Host A      Router              Router              Host B
```

Suppose the file is 4 megabytes and propagation speed is 3×10^8 m/sec, compute transmission delay and propagation delay of each of the three links.

Assuming no other traffic in the network, what is the throughput for the file transfer?

Answer: 500 Kbps

Protocol "layers"

Networks are complex,
with many "pieces":

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

Question:

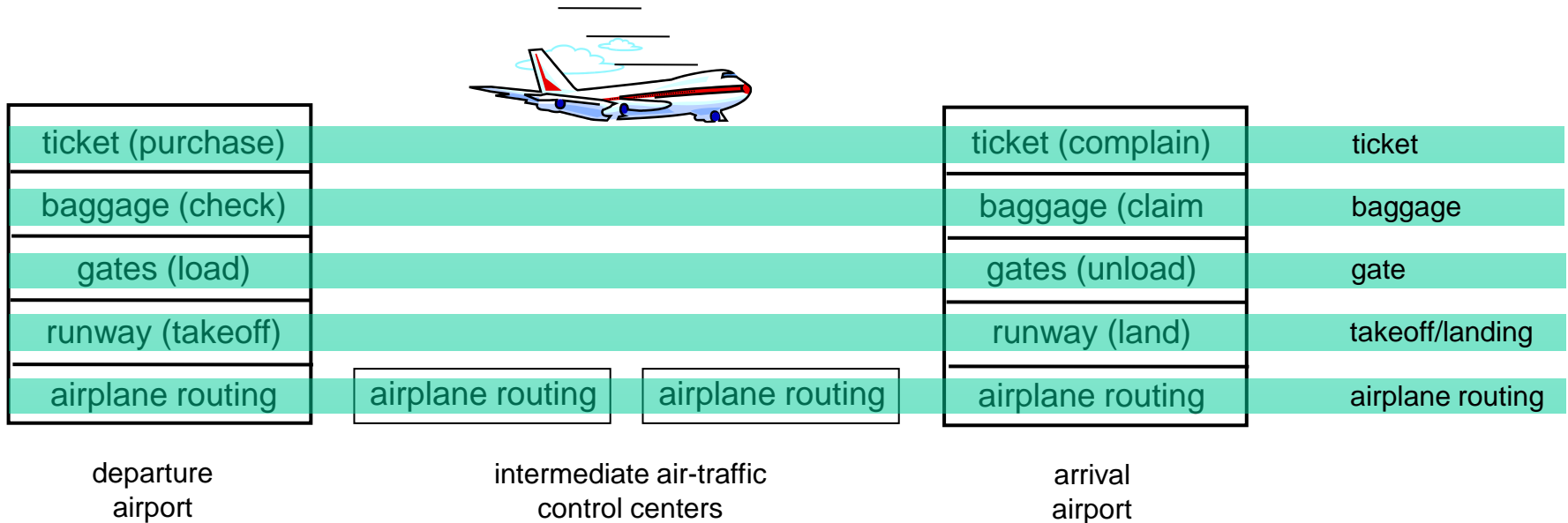is there any hope of *organizing* structure of network?

…. or at least our discussion of networks?

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?

Layering of airline functionality

departure airport		intermediate air-traffic control centers		arrival airport	
ticket (purchase)				ticket (complain)	ticket
baggage (check)				baggage (claim	baggage
gates (load)				gates (unload)	gate
runway (takeoff)				runway (land)	takeoff/landing
airplane routing	airplane routing	airplane routing		airplane routing	airplane routing

departure airport   intermediate air-traffic control centers   arrival airport

layers: each layer implements a service
- via its own internal-layer actions
- relying on services provided by layer below

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 |
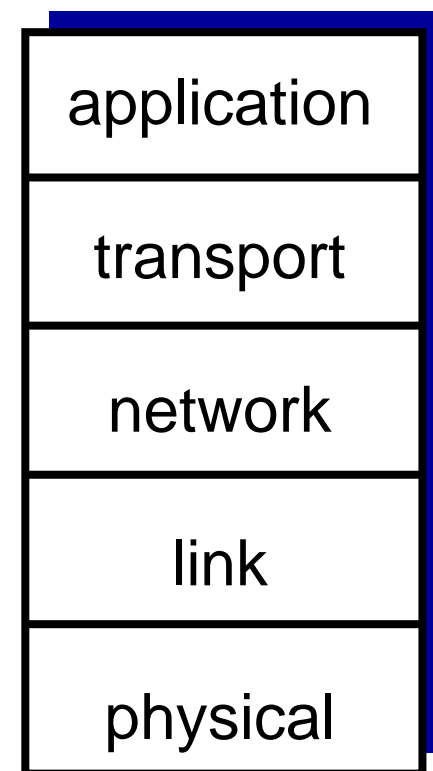
Network security

Can you identify the type of attack?
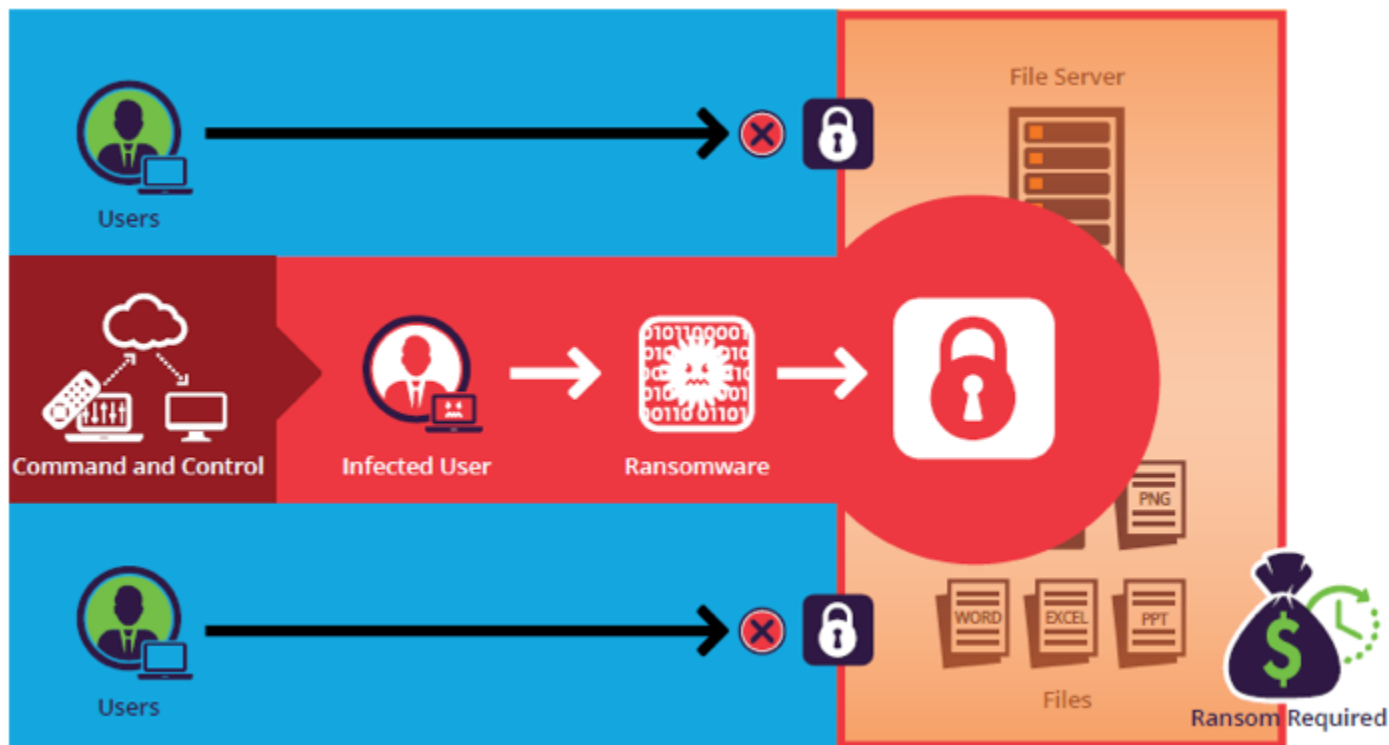
Bad guys: attack server, network infrastructure

Denial of Service (DoS): attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic
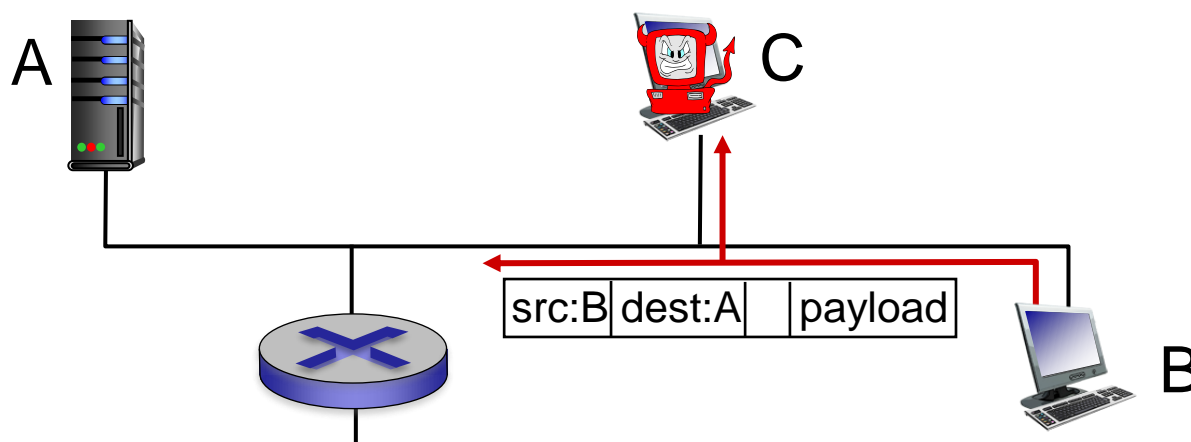
1. select target

2. break into hosts around the network (see botnet)

3. send packets to target from compromised hosts

target
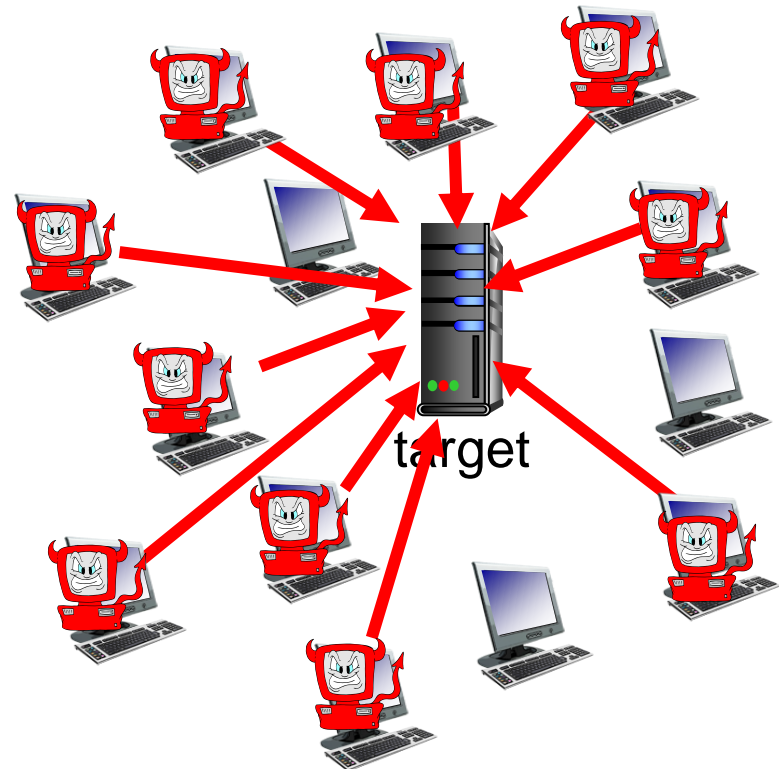
Bad guys can sniff packets

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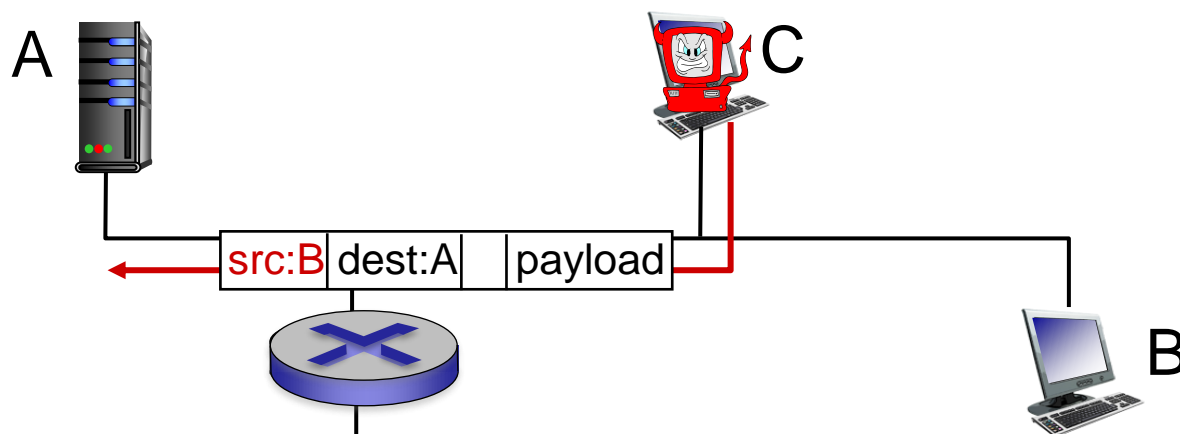
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by

| src:B | dest:A | | payload |

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

Bad guys can use fake addresses

IP spoofing: send packet with false source address

A

C

src:B | dest:A | payload

B

Internet history - Discussion

1961-1972: Early packet-switching principles

1972-1980: Internetworking, new and proprietary nets

1980-1990: new protocols, a proliferation of networks

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

Internet history

2005-present - Discussion

- ~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)

Summarize Concepts Lecture 1

- Internet Structure
- Performance: loss, delay, throughput
- Layering, service models
- Security
- Internet History

End of Lecture 1_2