CSC/CPE 138

COMPUTER NETWORK FUNDAMENTALS

Lecture 1_2: Computer Network and the Internet – Part 2

California State University, Sacramento
Fall 2024

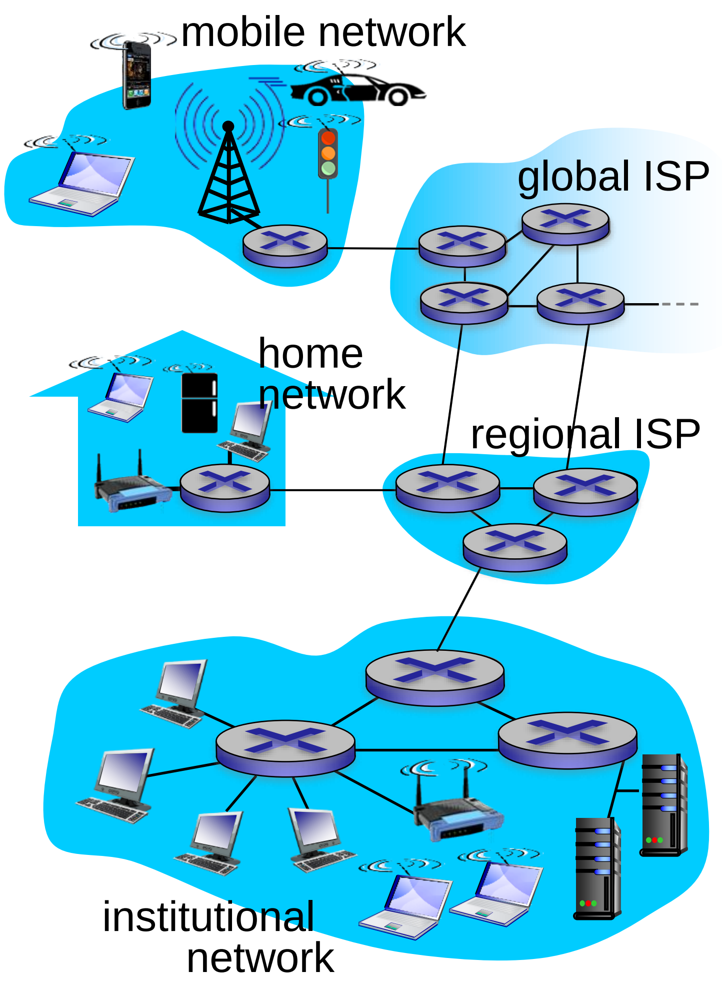
Slide Courtesy: Computer Networking: A Top-Down Approach, Kurose Ross, 8th Edition

What's in this Lecture?

- Internet Structure
- Packet loss, delay and throughput
- Protocol layers
- Network security
- Internet history

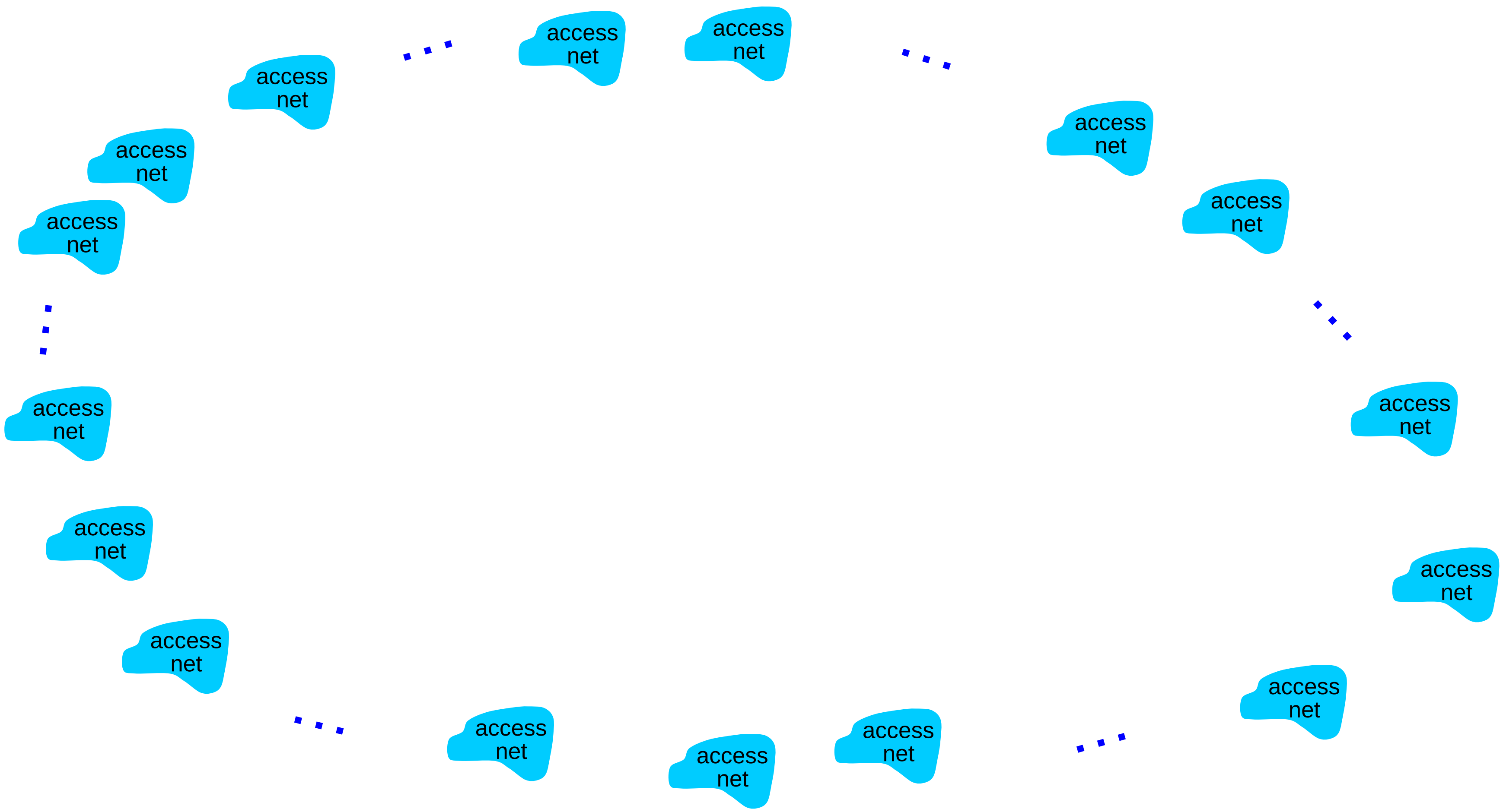
Internet structure: network of networks

- 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



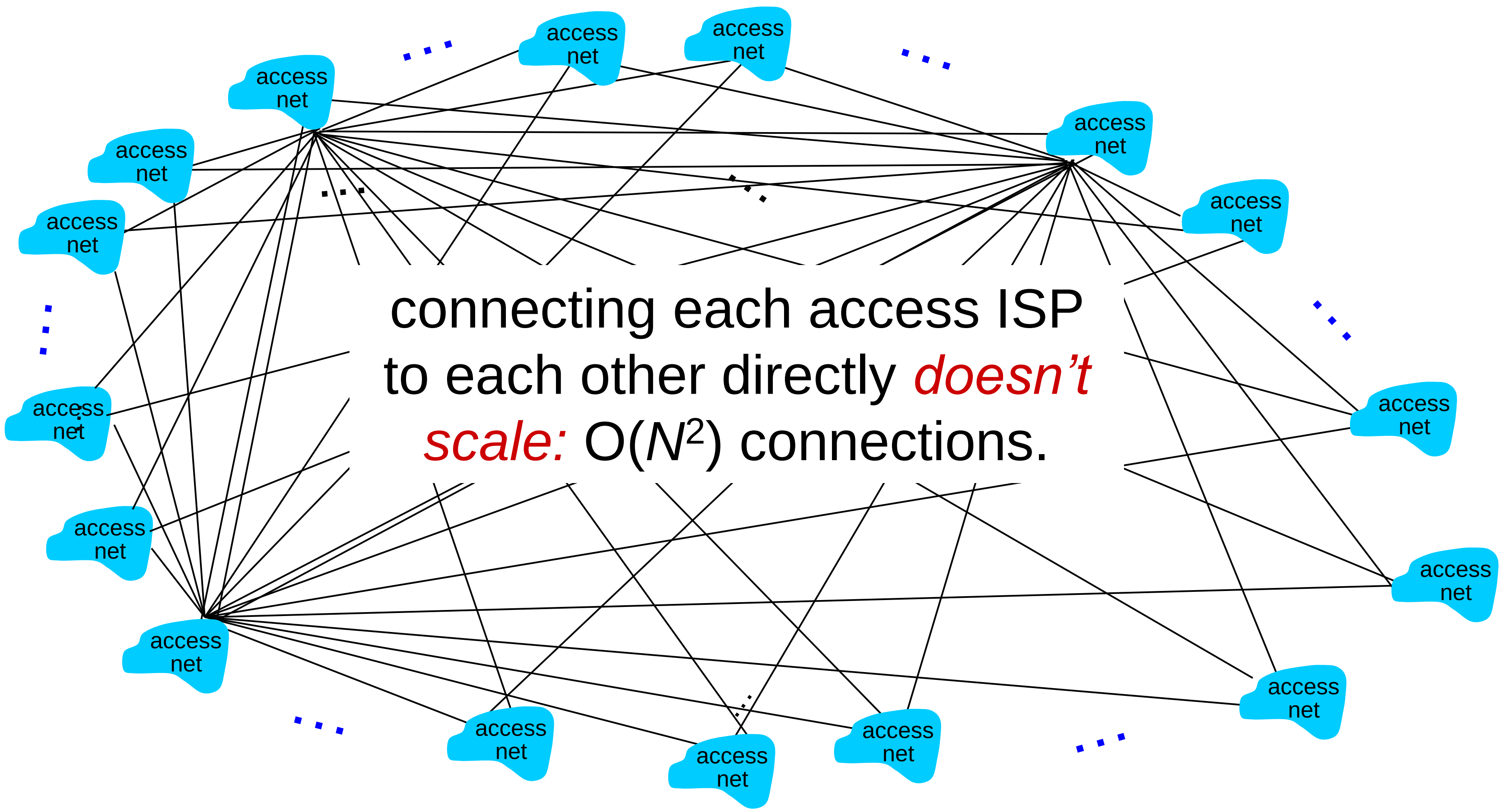
Internet structure: network of networks

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



Internet structure: network of networks

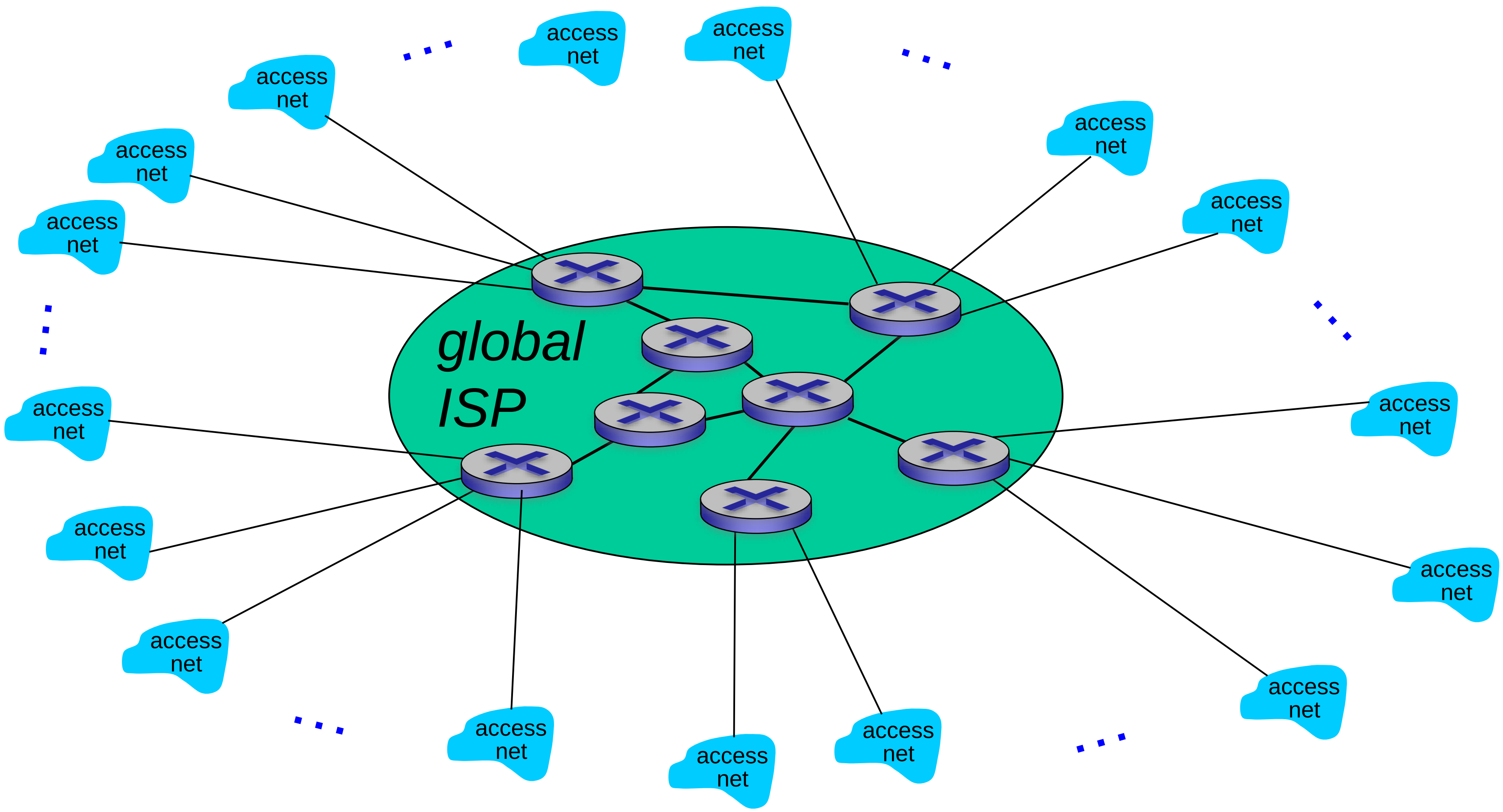
Option: *connect each access ISP to every other access ISP?*



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

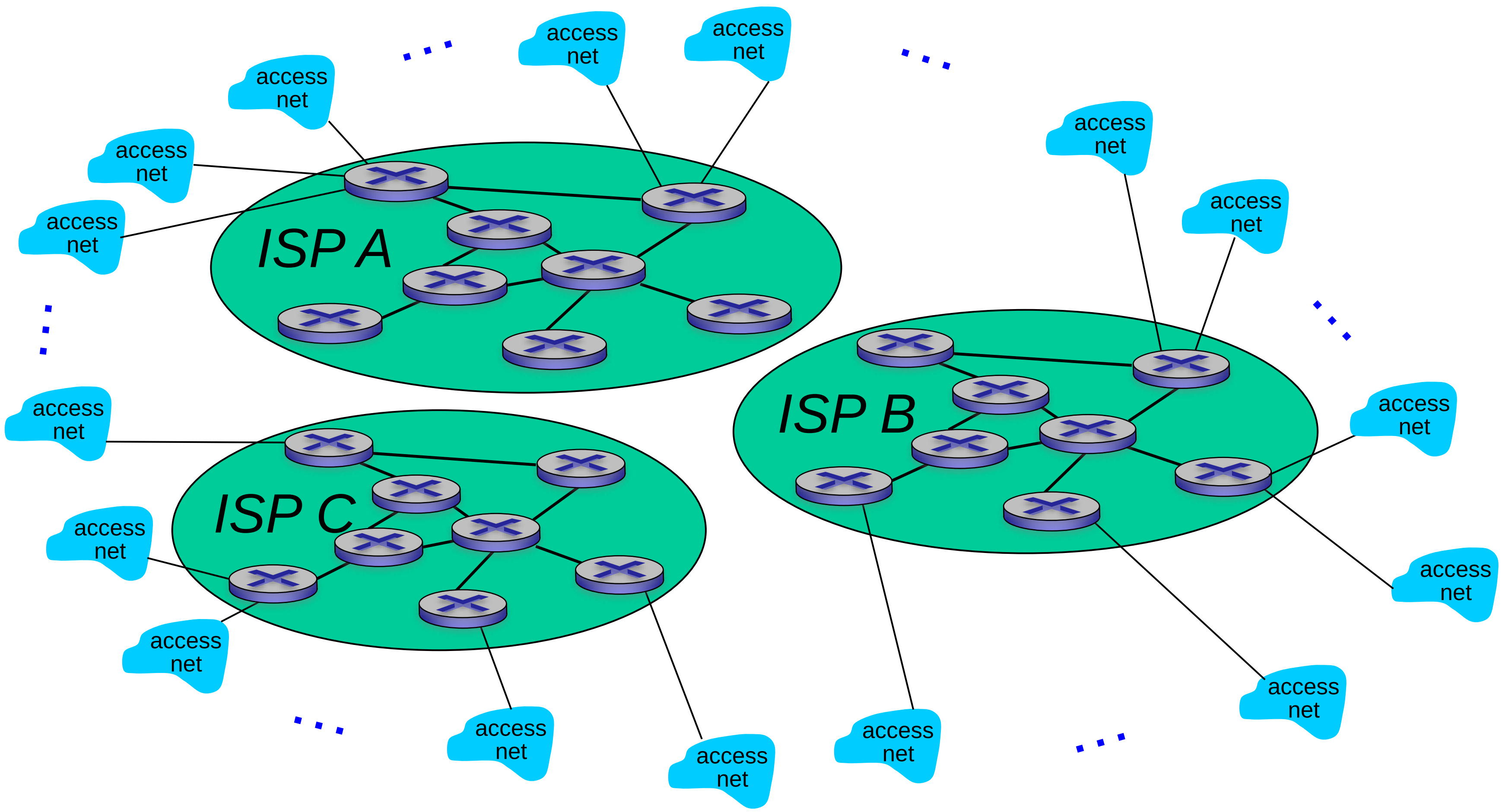
Internet structure : network of networks

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



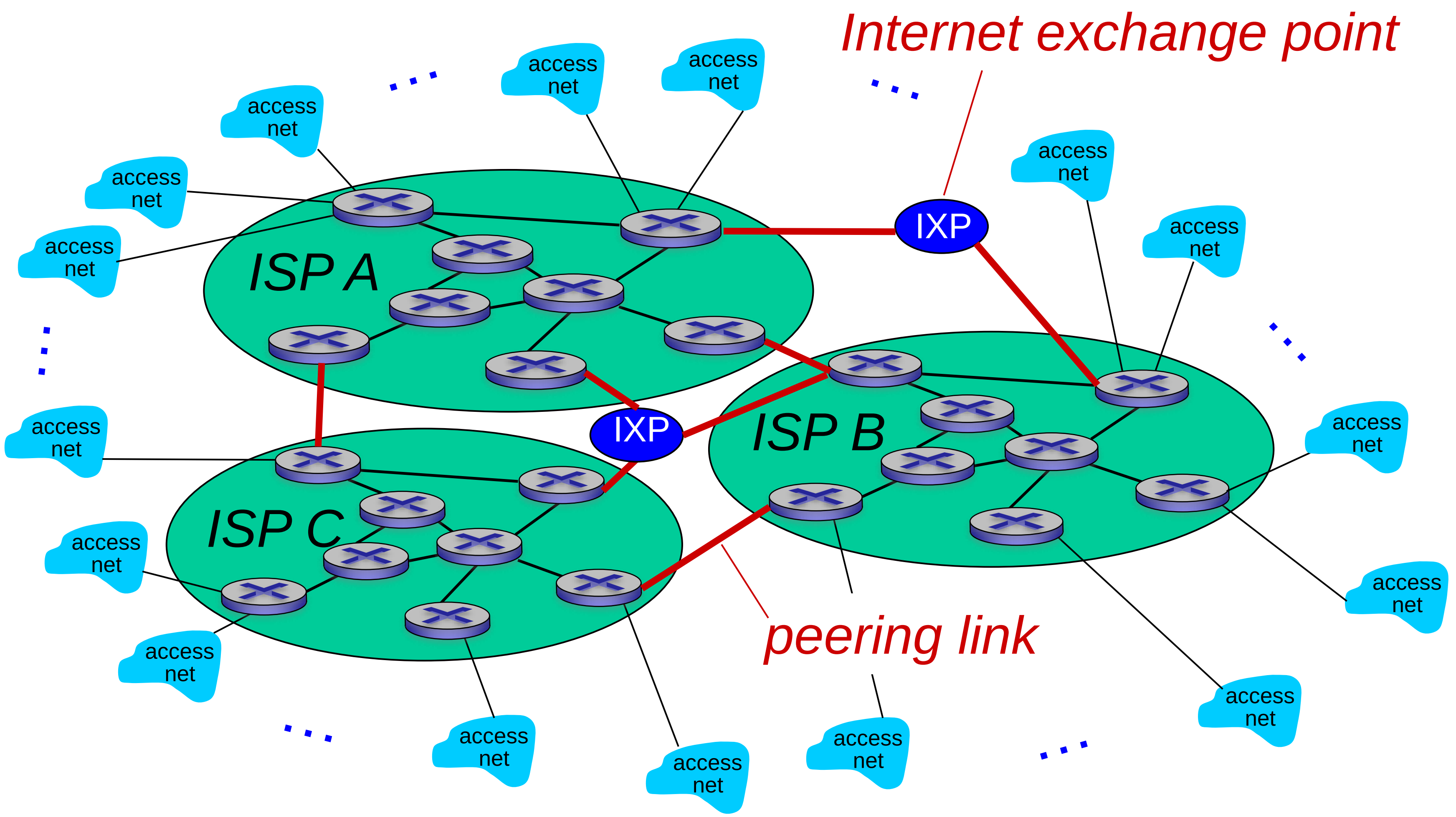
Internet structure : network of networks

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



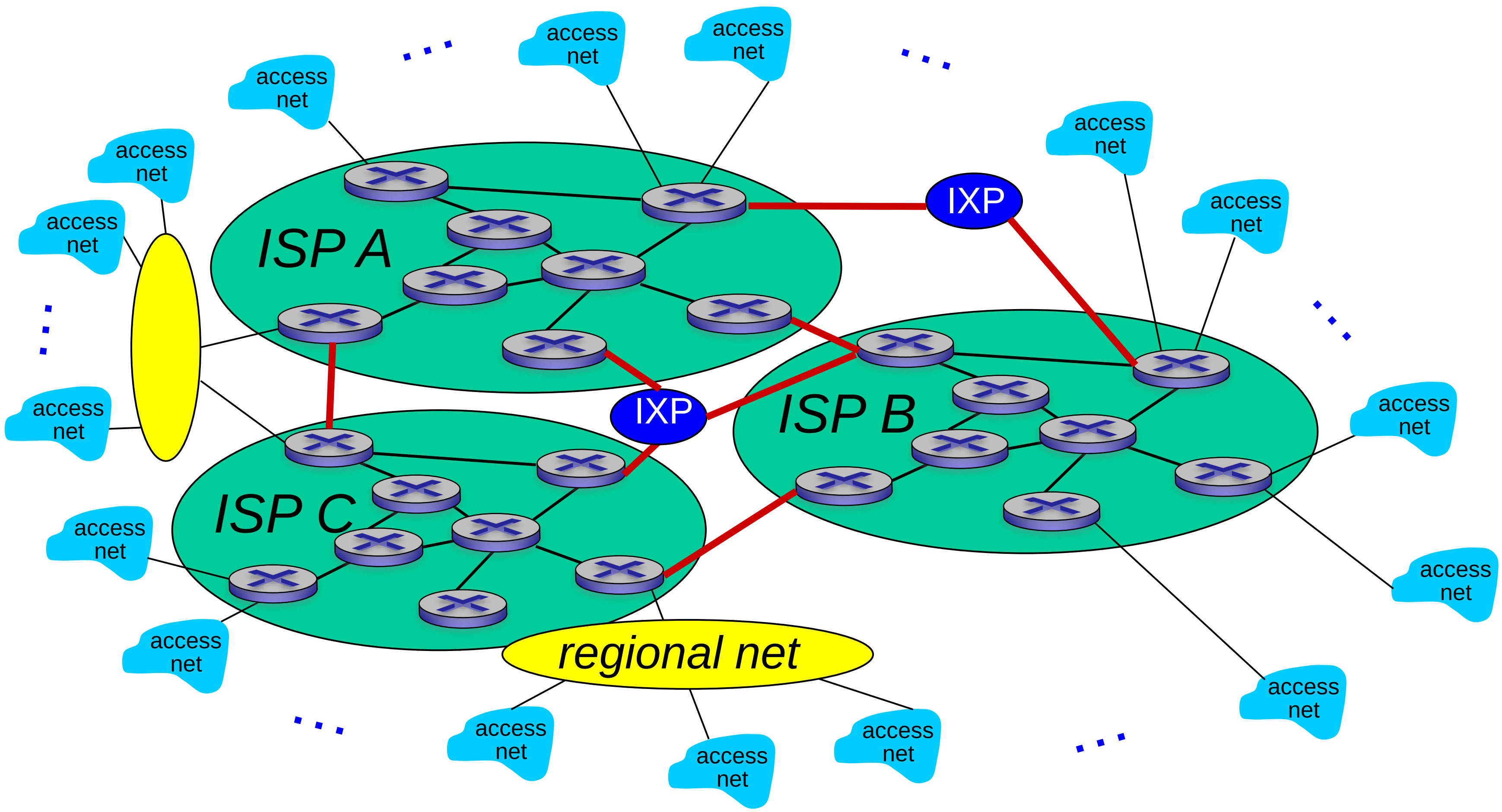
Internet structure: network of networks

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



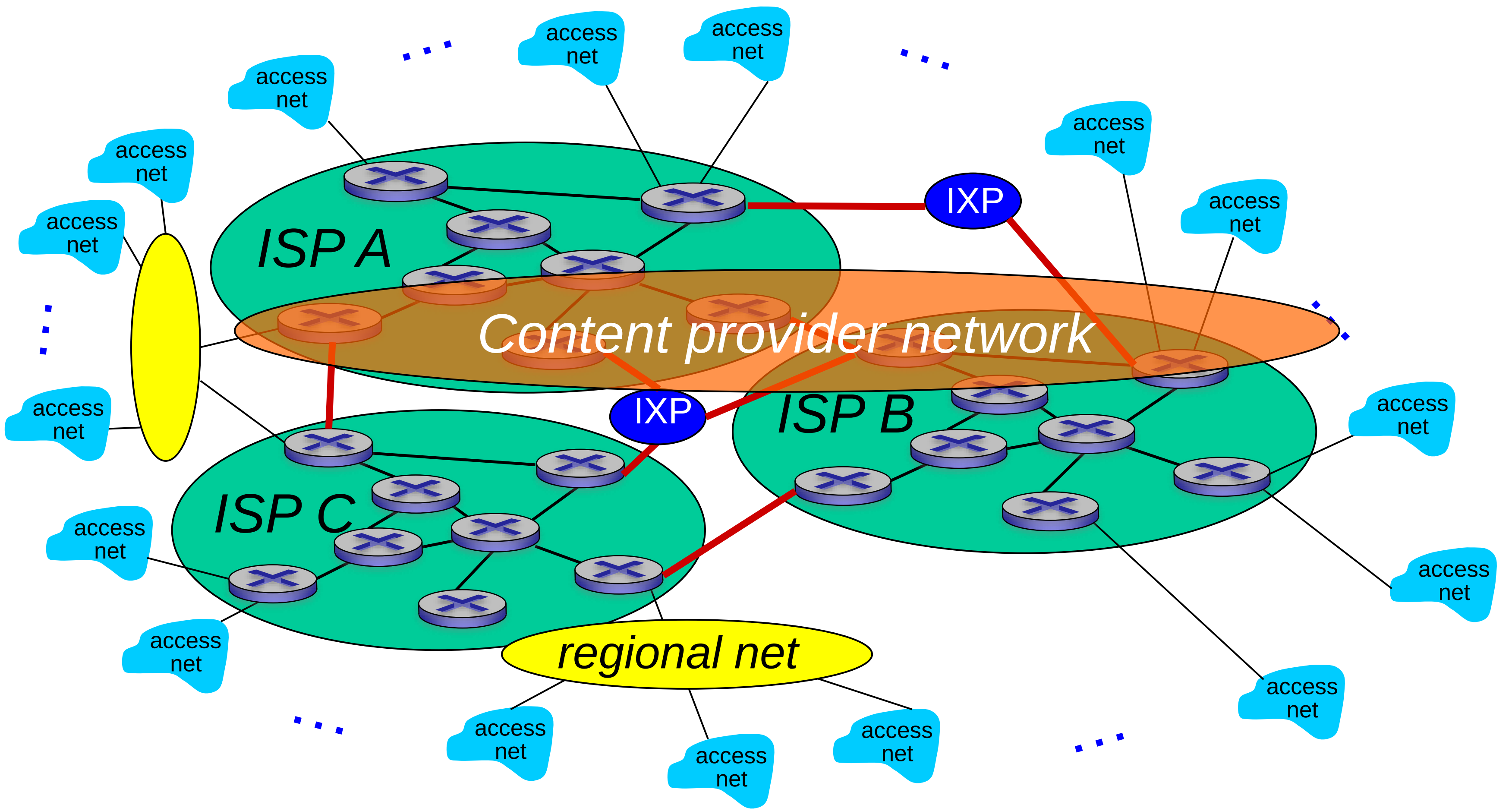
Internet structure : network of networks

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

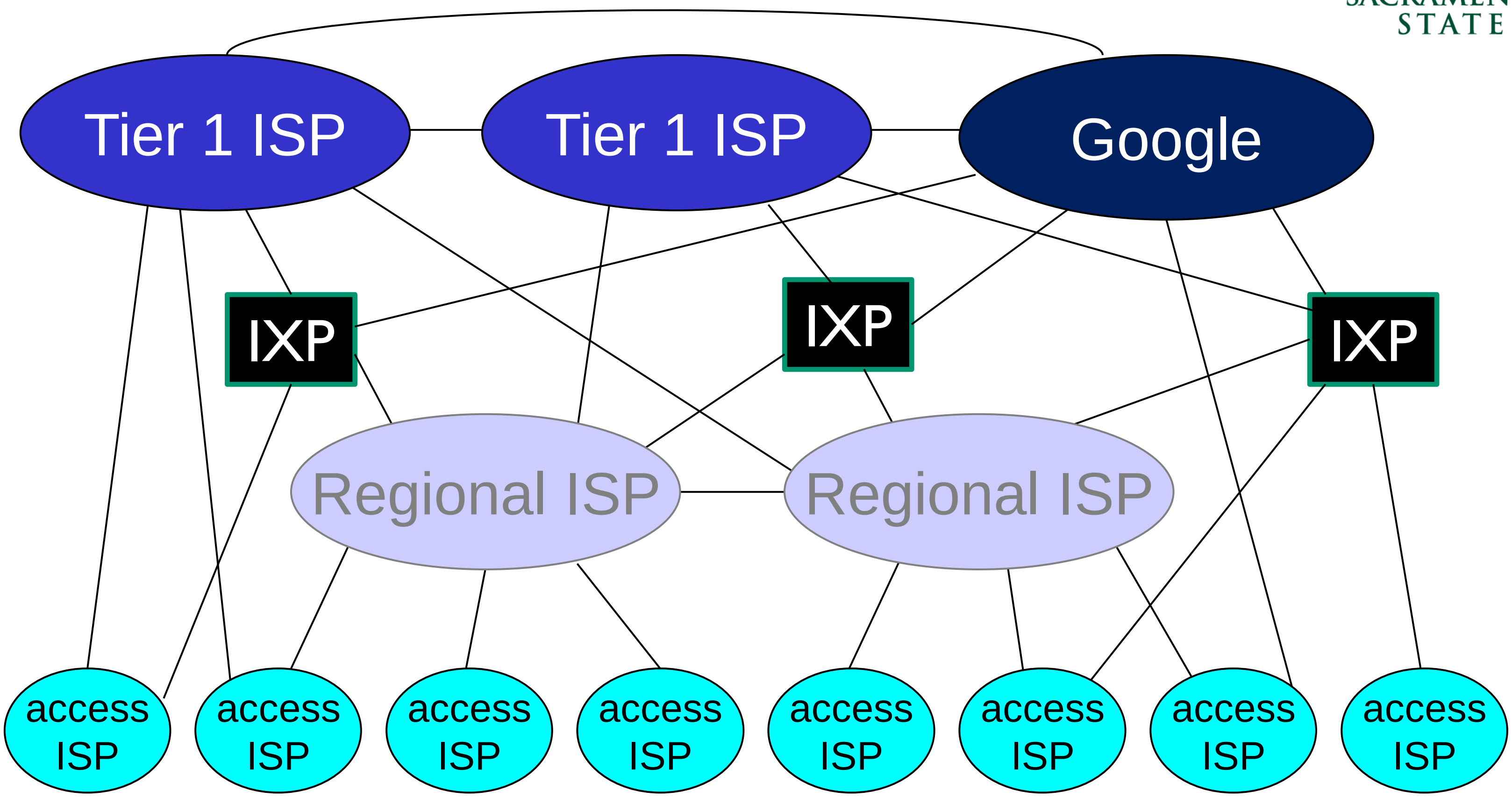


Internet structure: network of networks

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

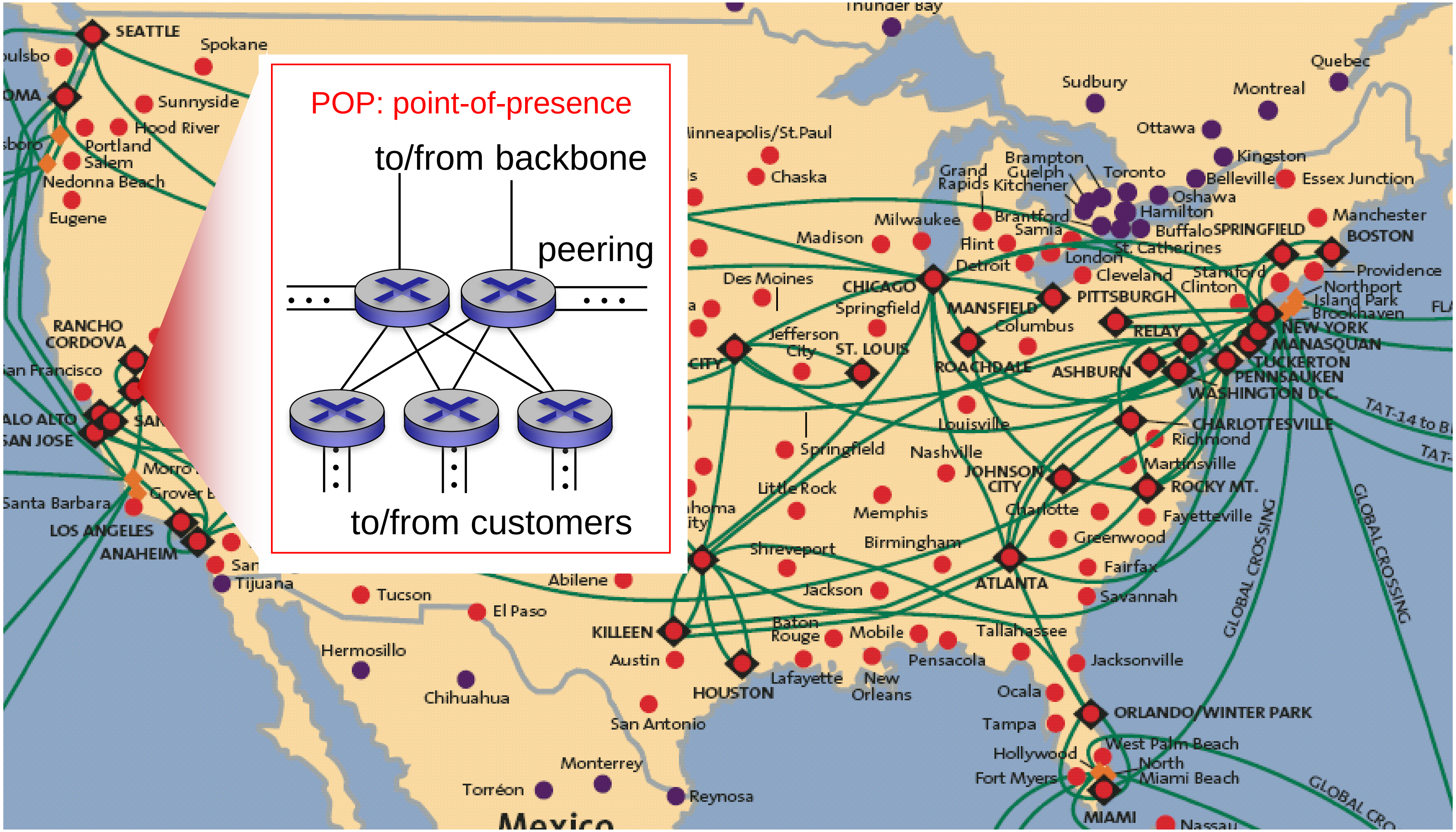


Internet structure: network of networks

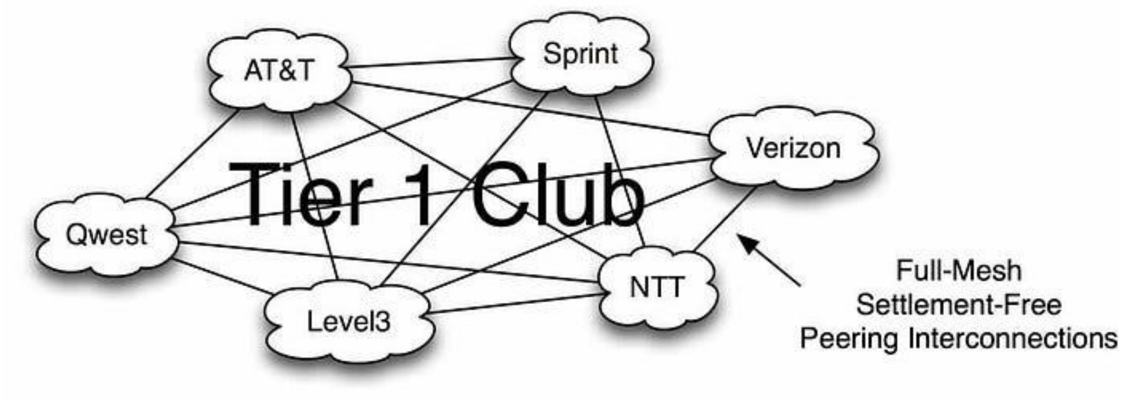


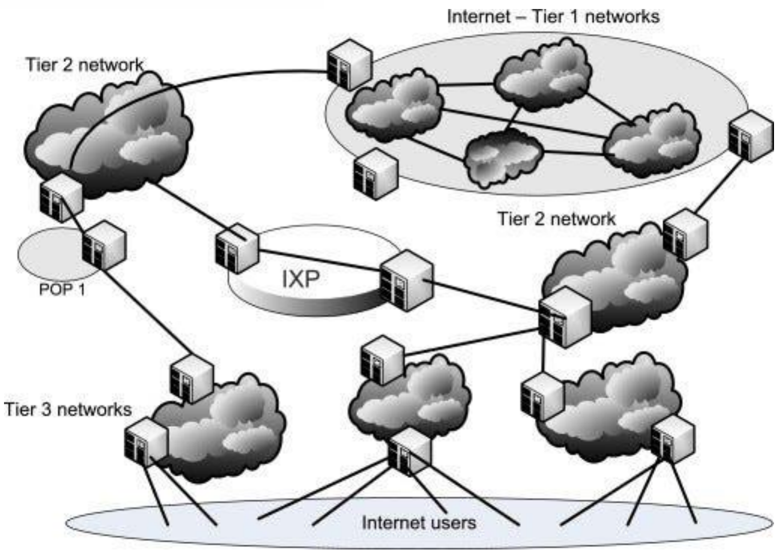
- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g., Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Tier-1 ISP: e.g., Sprint



ISP Networks





Source: https://medium.com/@freegwifi/making-networking-simpler-who-owns-the-internet-20fb73866399

Concept Check.

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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

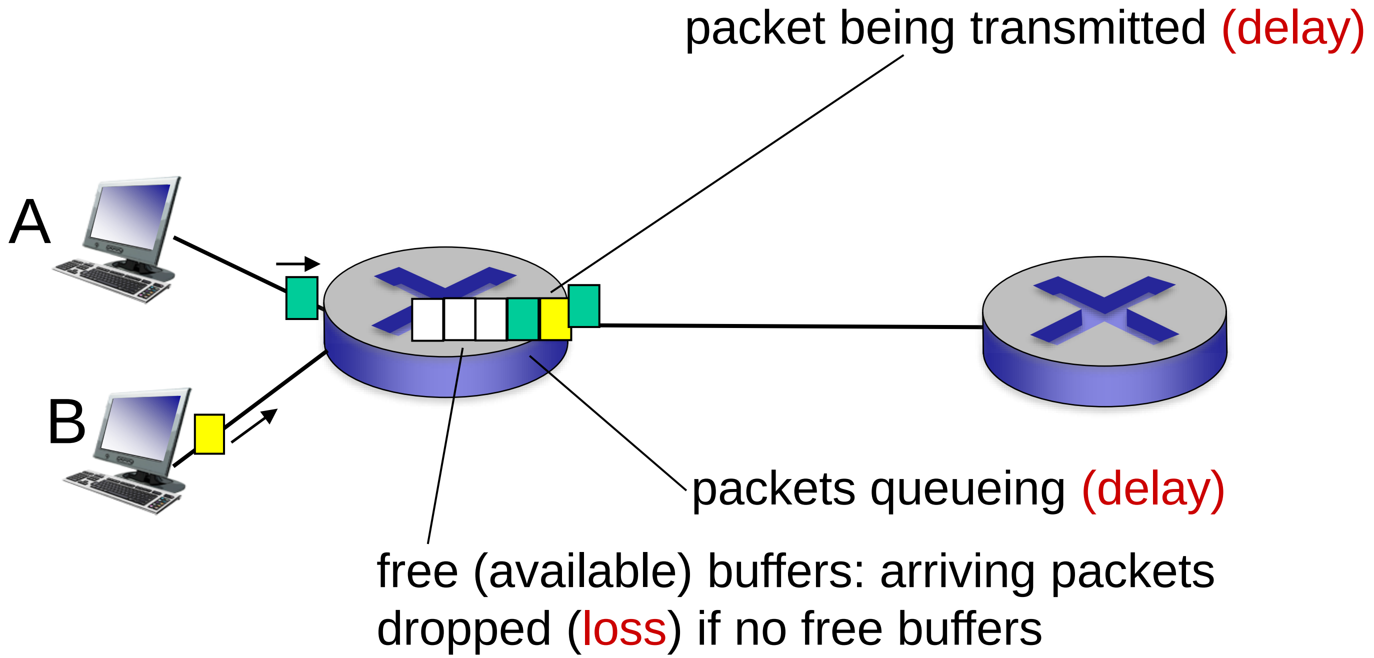
What is a physical location called through which Internet infrastructure companies such as Internet Service Providers (ISPs) and CDNs connect with each other.
Answer: IXP

What is Network Performance?
Why is it important?

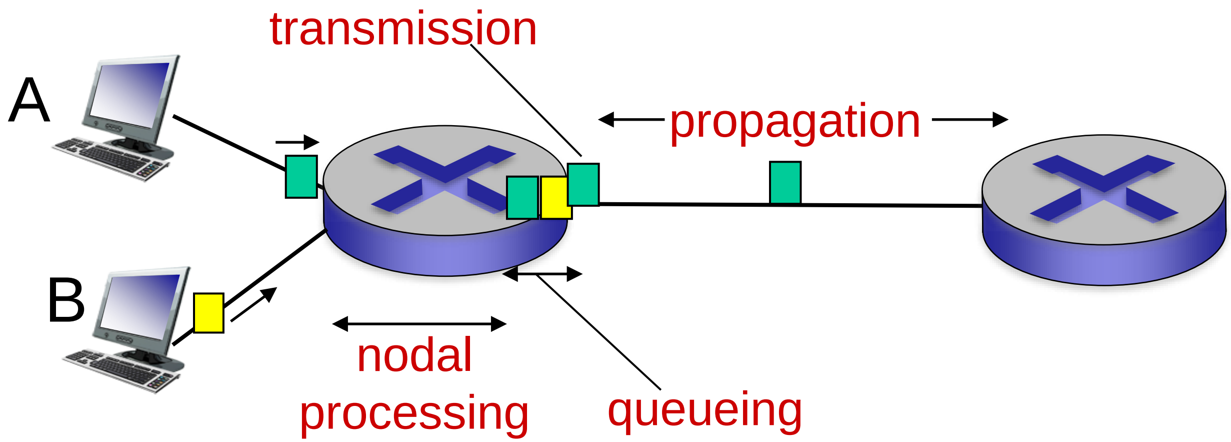
How do loss and delay occur?

packets *queue* in router buffers

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



Four sources of packet delay



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

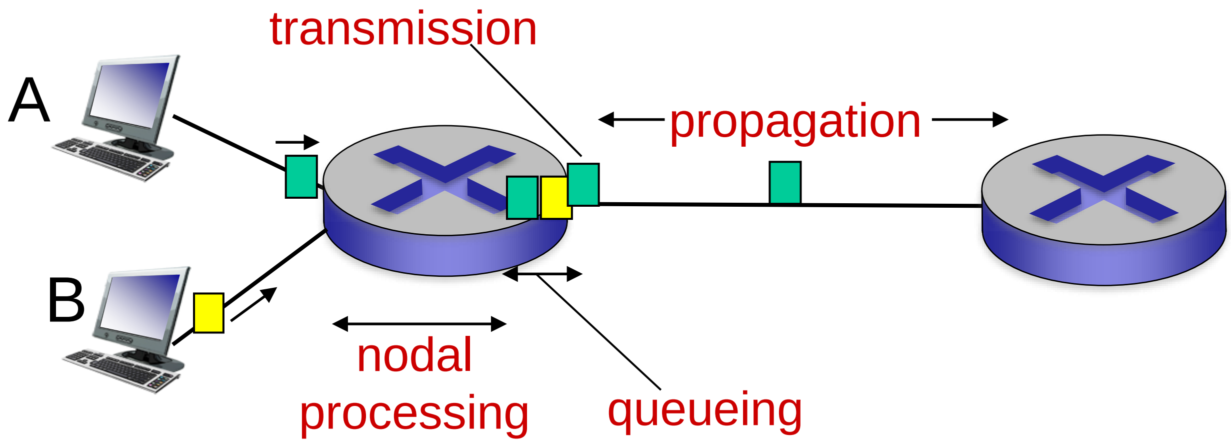
d_{proc}: nodal processing

- 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:

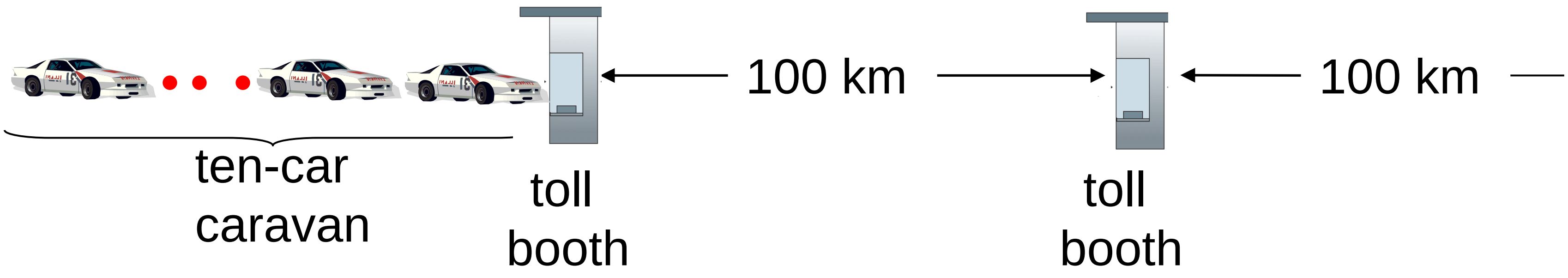
- *L*: packet length (bits)
- *R*: link *bandwidth (bps)*
- $d_{trans} = L/R$

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

d_{prop}: propagation delay:

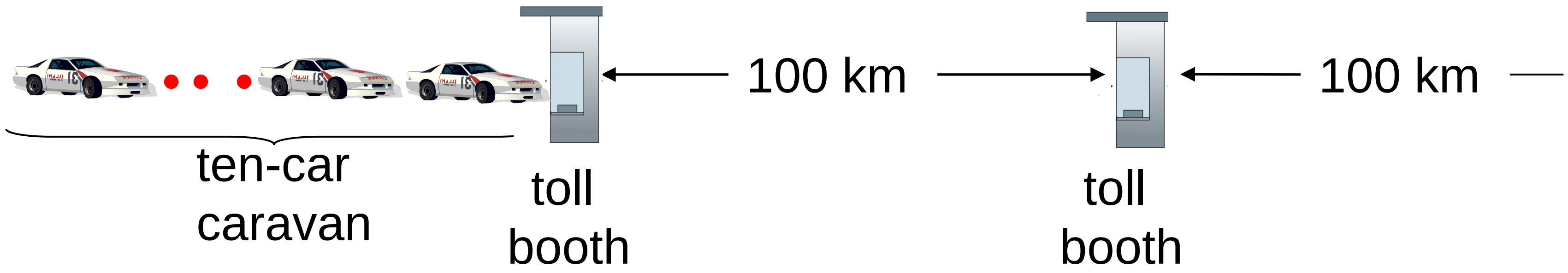
- *d*: length of physical link
- *s*: propagation speed (~3x10^8 m/sec)
- $d_{prop} = d/s$

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*

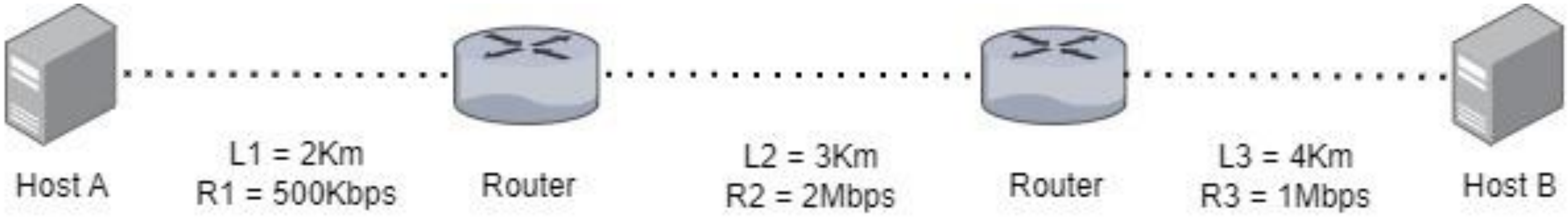
Caravan analogy (more)



- 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

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.



Assume, the file is 4 megabytes and propagation speed is $3x10^8$ 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 s

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

Link 2

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

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

Link 3

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

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

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 $3x10^8$ m/sec.)

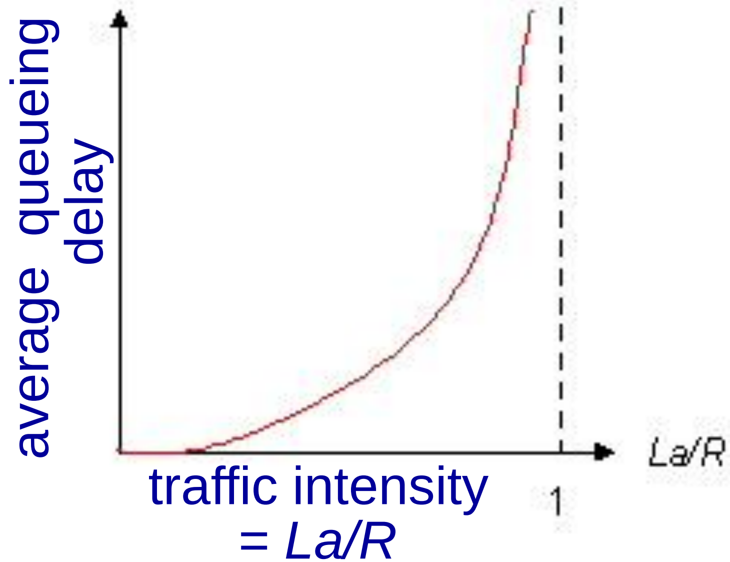
Solution Hint:
File size = $10*10^6 * 8$
L1 -> Transmission delay = L /R
L1 -> Propagation delay = d/s.

Answer :

Link	Transmission Delay	Propagation Delay
L1	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



- *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

Activity(4 members)

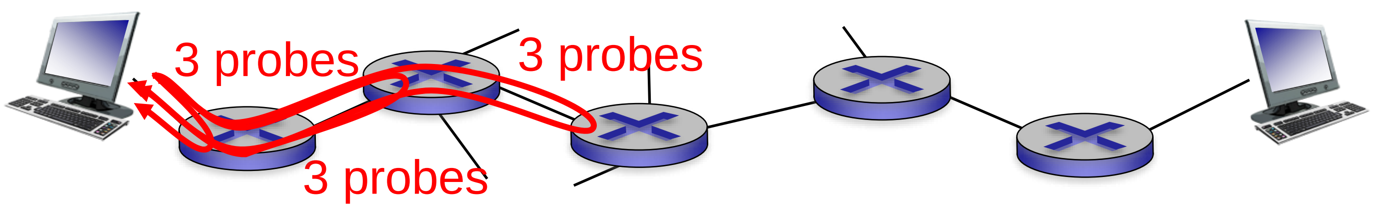
In a router, we can compute transmission delay, propagation delay, and traffic intensity.

- What parameter change increases the propagation delay?
- What parameter/variable change decreases transmission delay?
- What parameter/variable change increases traffic intensity?

Hint: Look at the formula of each delay method 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.



“Real” Internet delays, routes

traceroute: google.com

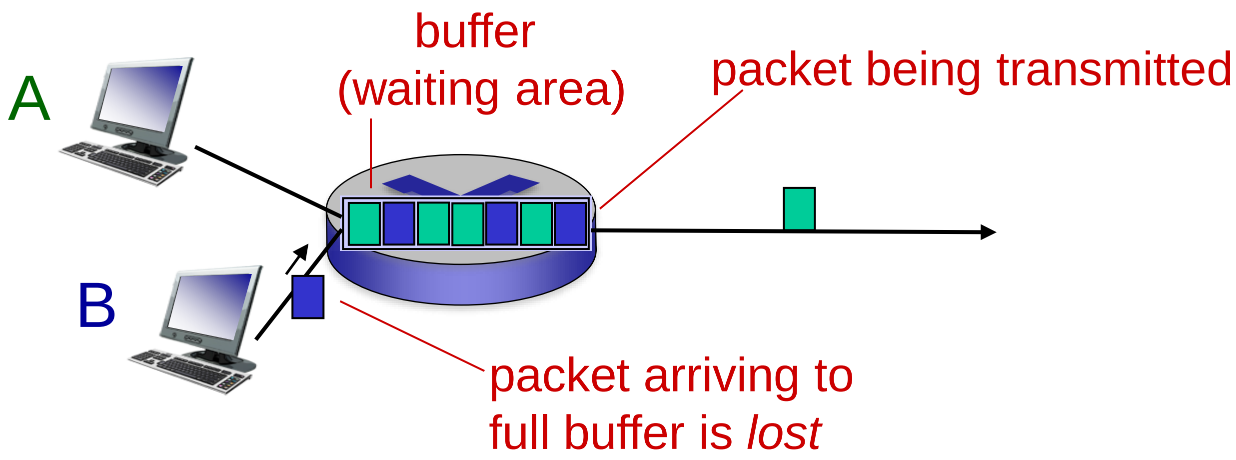
```
traceroute google.com
traceroute to google.com (142.250.191.46), 64 hops max, 52 byte packets
 1  10.0.0.1 (10.0.0.1)  6.611 ms  6.024 ms  3.485 ms
 2  100.93.195.202 (100.93.195.202)  13.616 ms
   100.93.195.203 (100.93.195.203)  16.049 ms  11.028 ms
 3  po-101-rur101.florin.ca.ccal.comcast.net (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

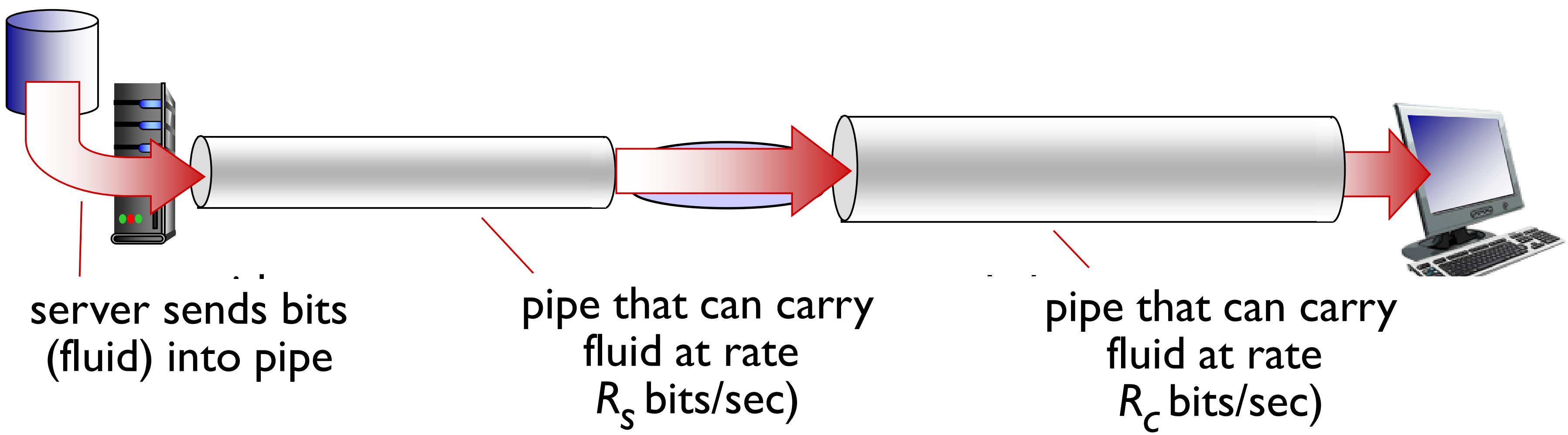
Packet loss

- 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



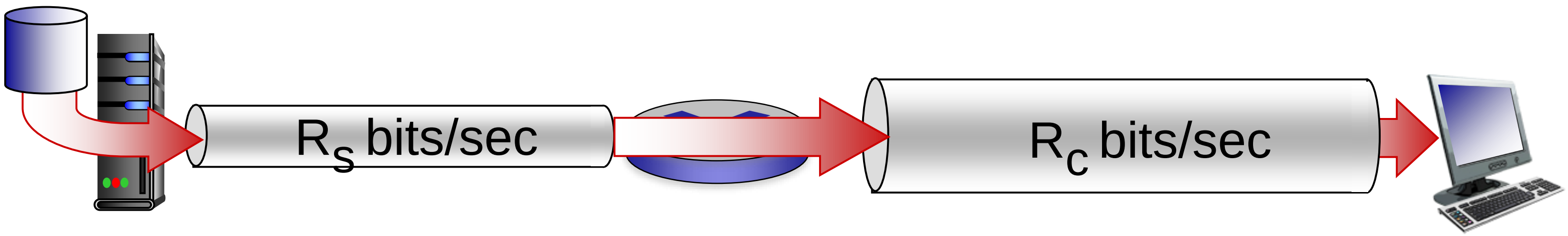
Throughput

- *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

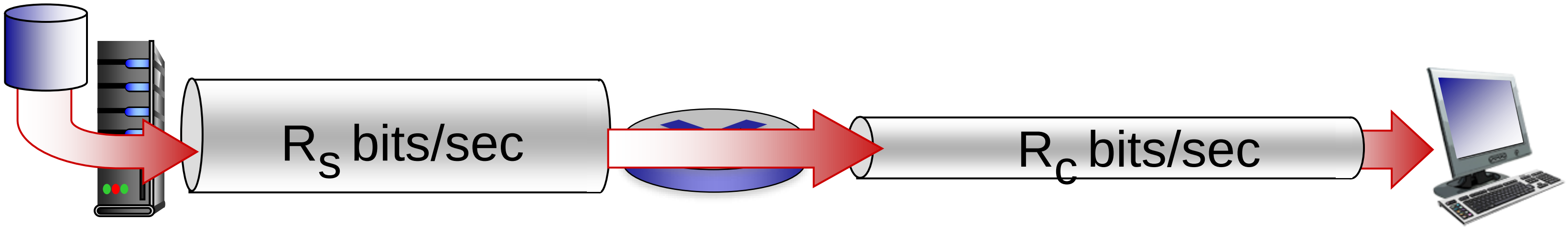


Throughput (more)

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



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

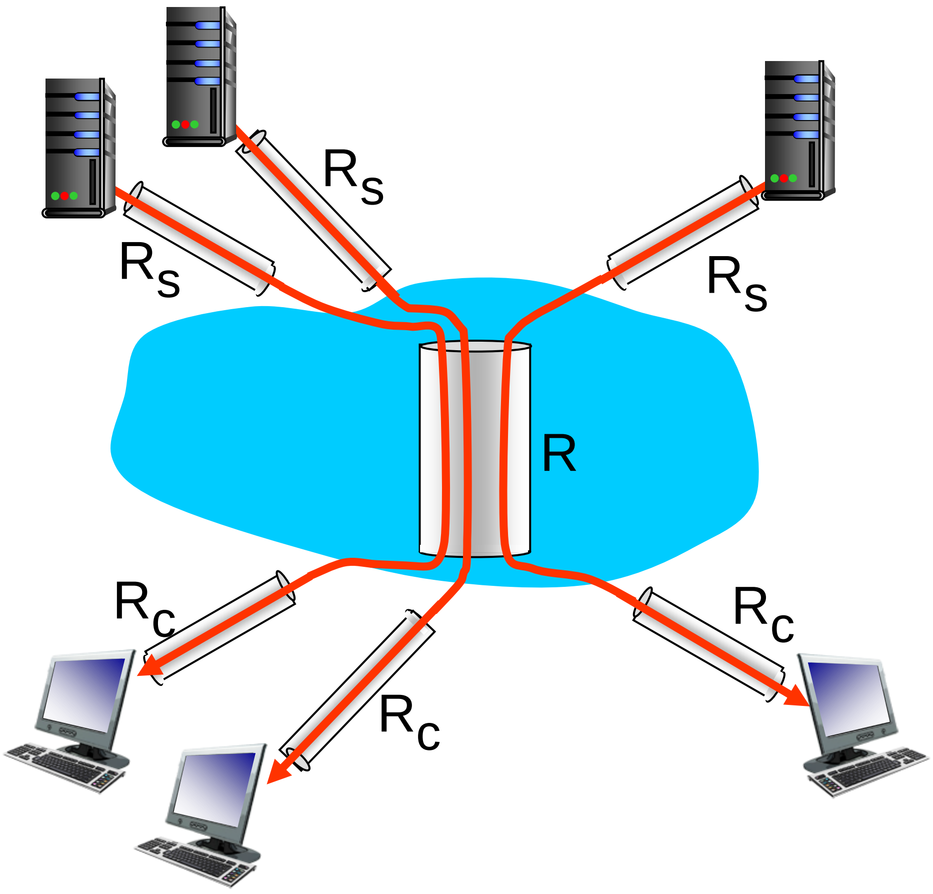


bottleneck link

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

Throughput: Internet scenario

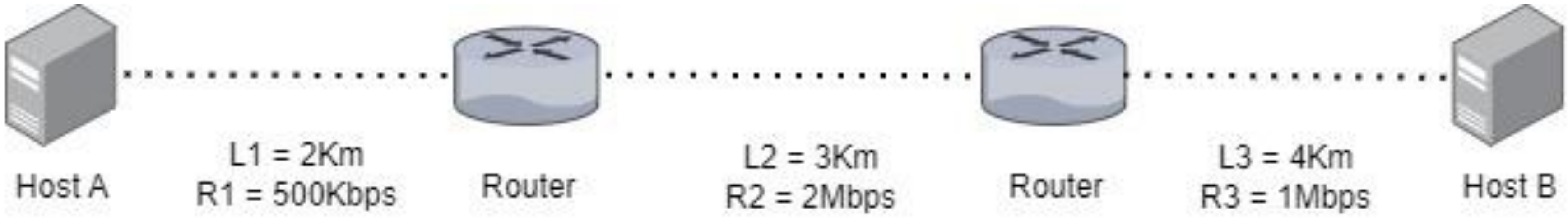
- per-connection end-end throughput: $min(R_c,R_s,R/10)$
- in practice: R_c or R_s is often bottleneck



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

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.



Suppose the file is 4 megabytes and propagation speed is $3x10^8$ 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?

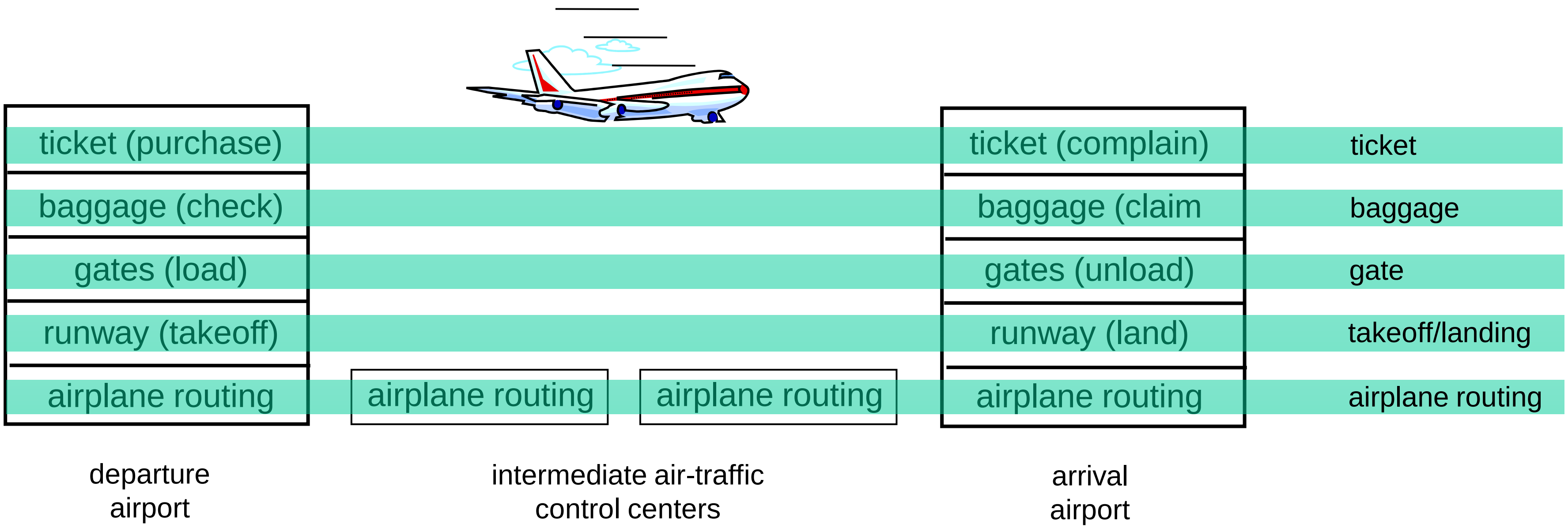
…. or at least our discussion of networks?

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

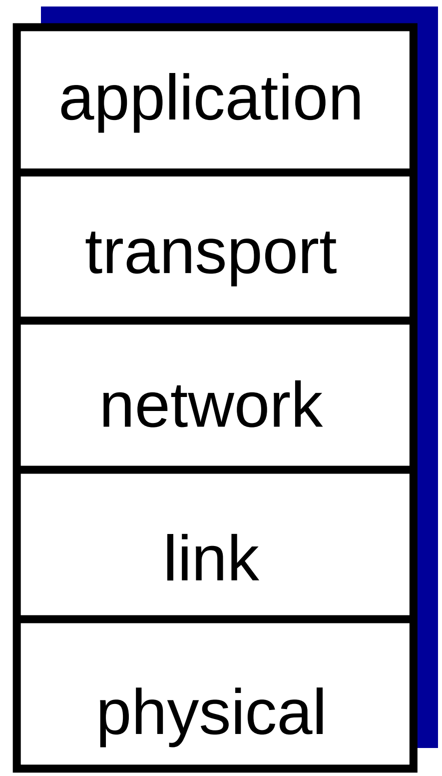


layers: each layer implements a service

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

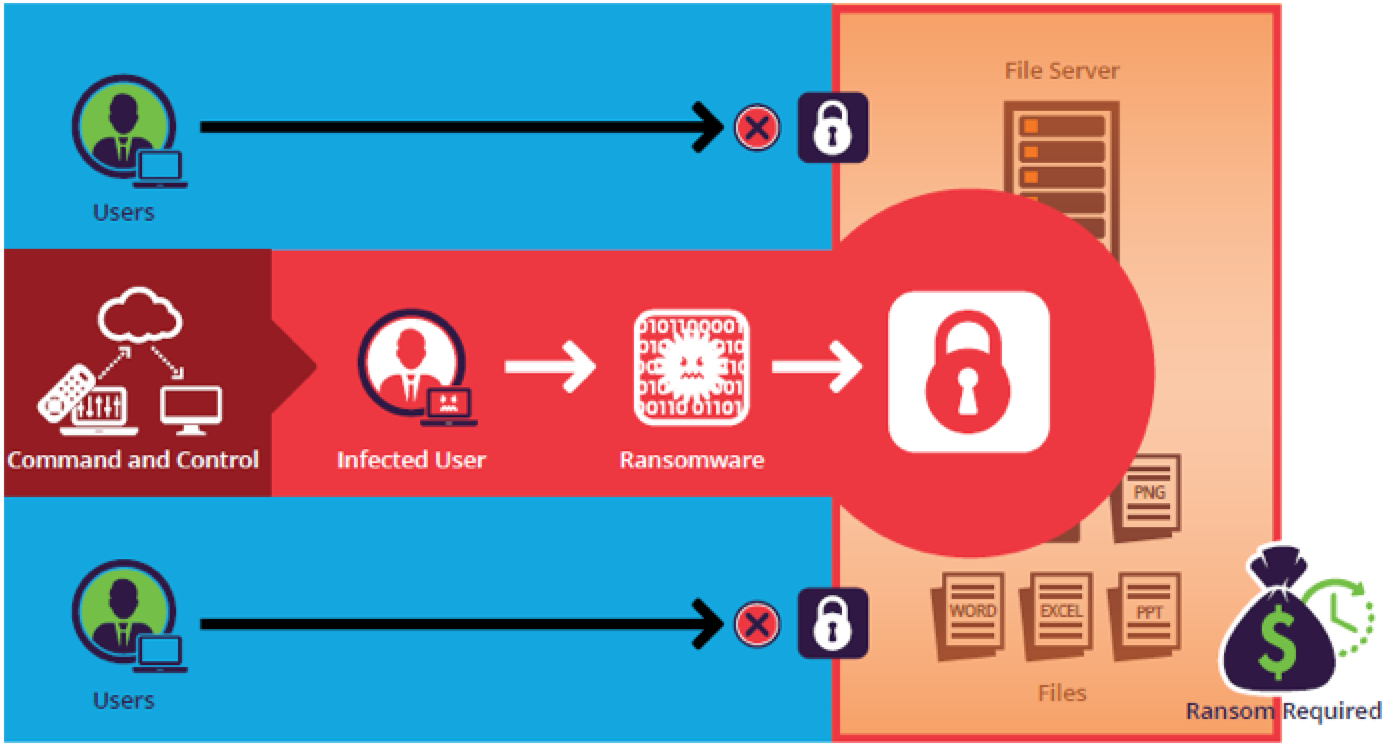
Internet protocol stack

- *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"



Network security

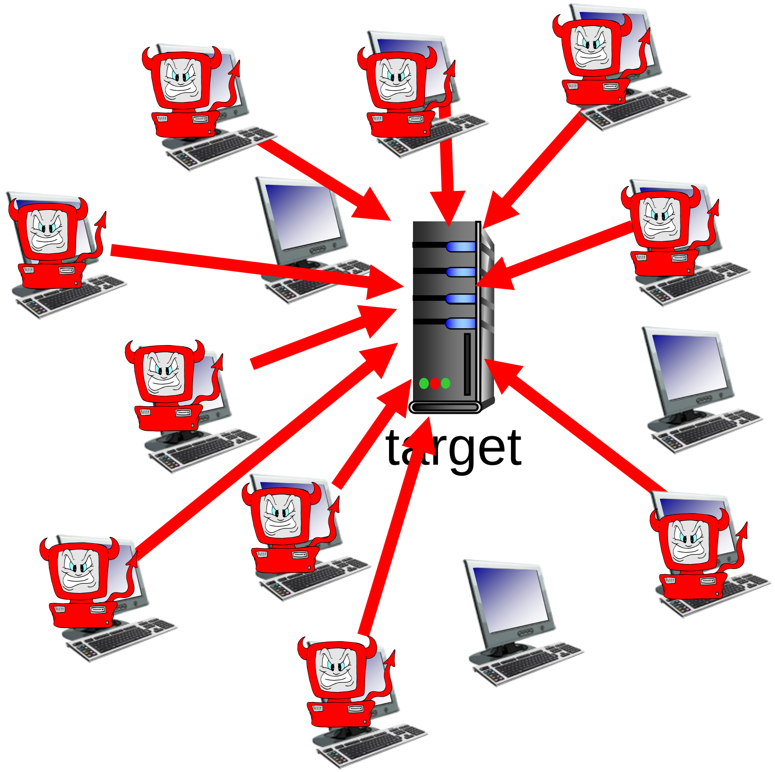
Can you identify the type of attack?



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

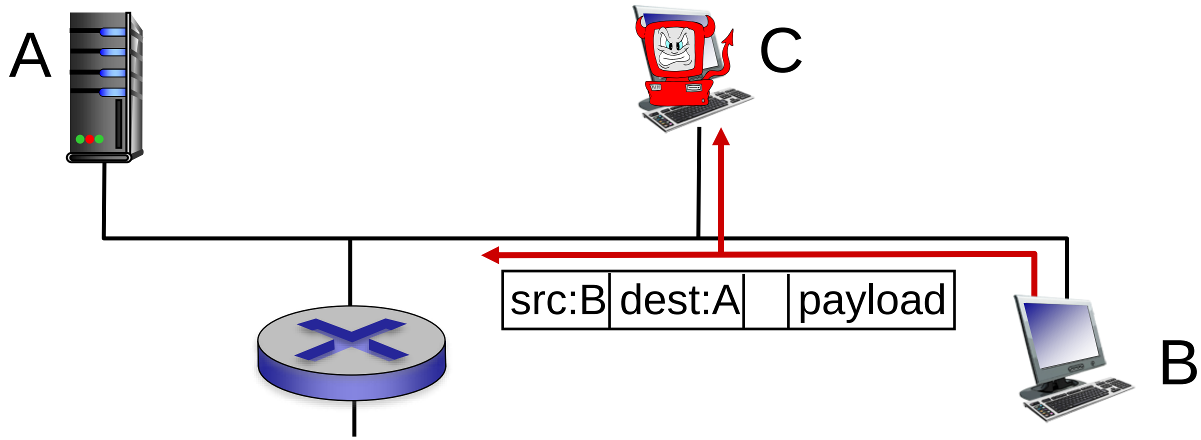
1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts



Bad guys can sniff packets

packet "sniffing":

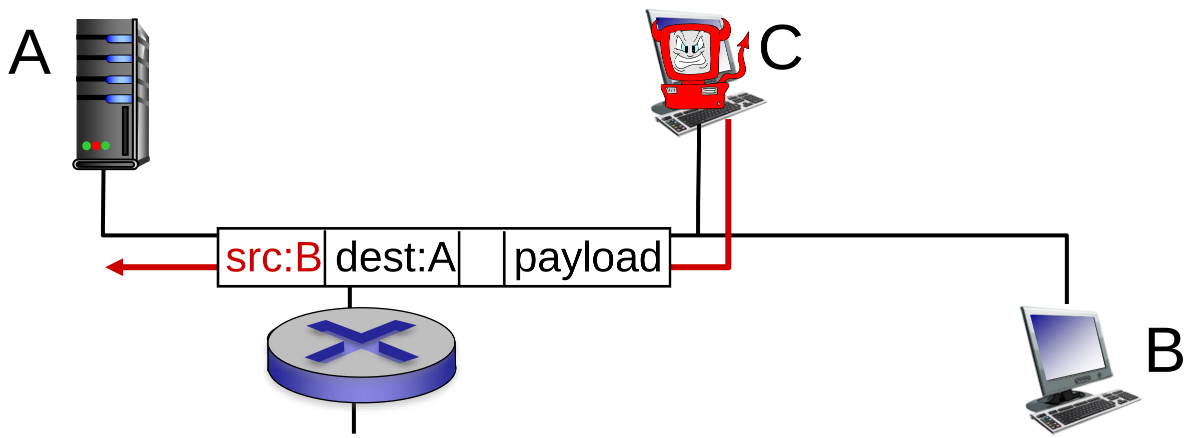
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



- 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



Internet history - Discussion

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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)

Summary

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

End of Lecture 1_2