Welcome to

CS 3516:
Computer Networks

Prof. Yanhua Li

Time: 9:00am –9:50am M, T, R, and F
Zoom Lecture
Fall 2020 A-term

Quiz 1

Answers are available in Canvas

Grades are available on Canvas

Quiz 2

9/8 Next Tuesday

Network performances:

Delay, Loss, and Throughput

(These topics will be covered today and next Monday)

Chapter 1: roadmap

1.1 what is the Internet?

"nuts and bolts" view

service view

1.2 network edge

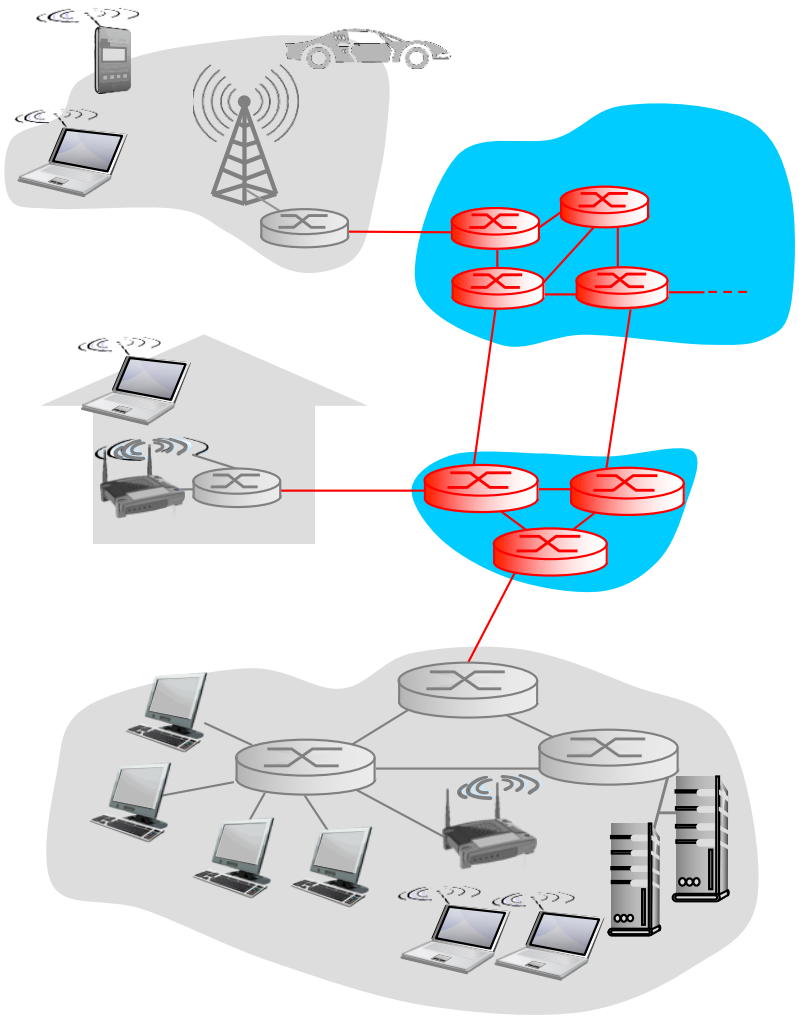
- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

The network core

mesh of interconnected routers with three key aspects in network core



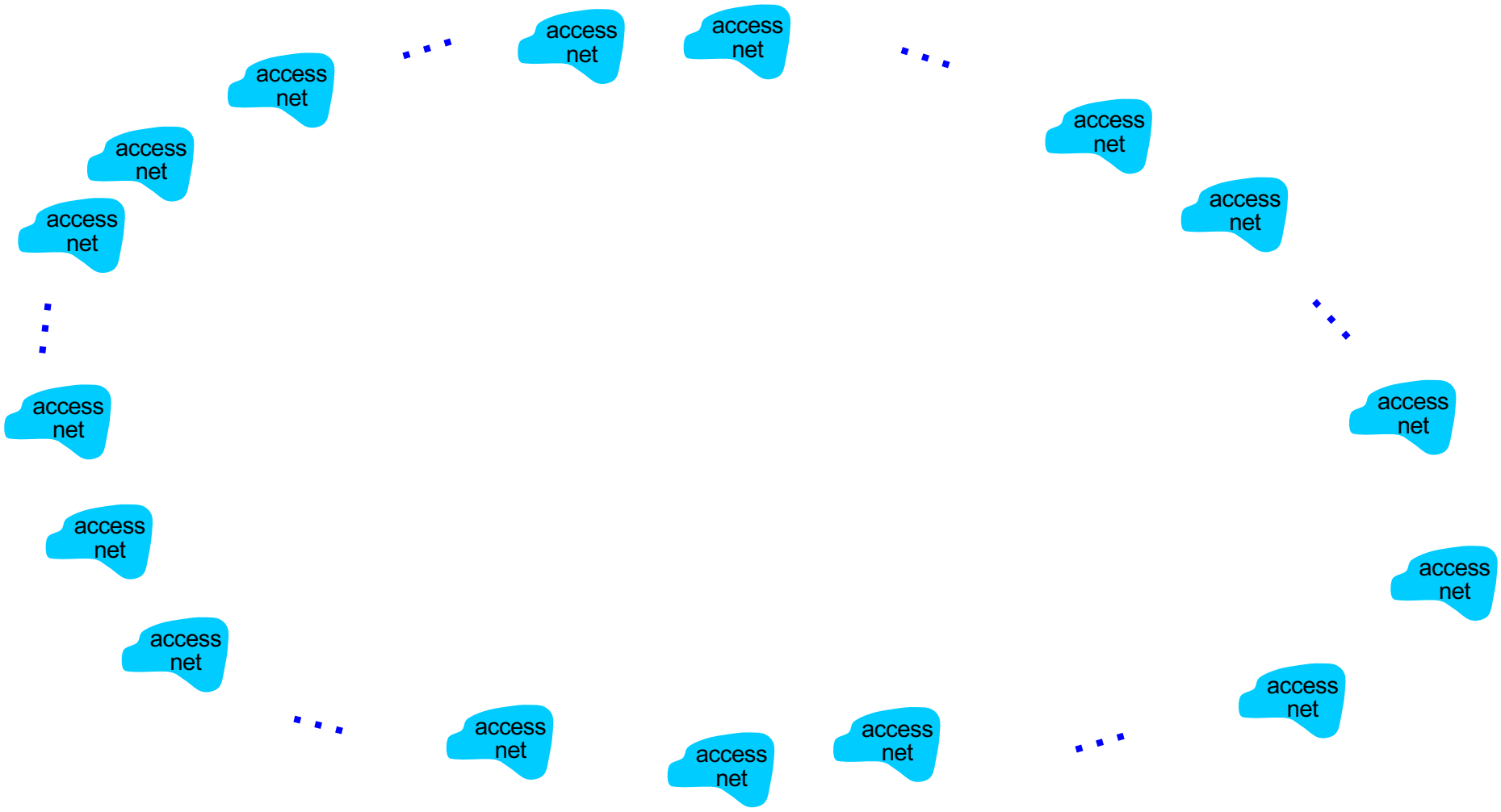
- Link: Switching, Resource allocation (chp 1.3)-- microscope
- Network: Network Core Structure / Management / Coordination (chp 1.3)-- macroscope
- Node: Routing & Forwarding (to be discussed in Network layer chp 4)

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

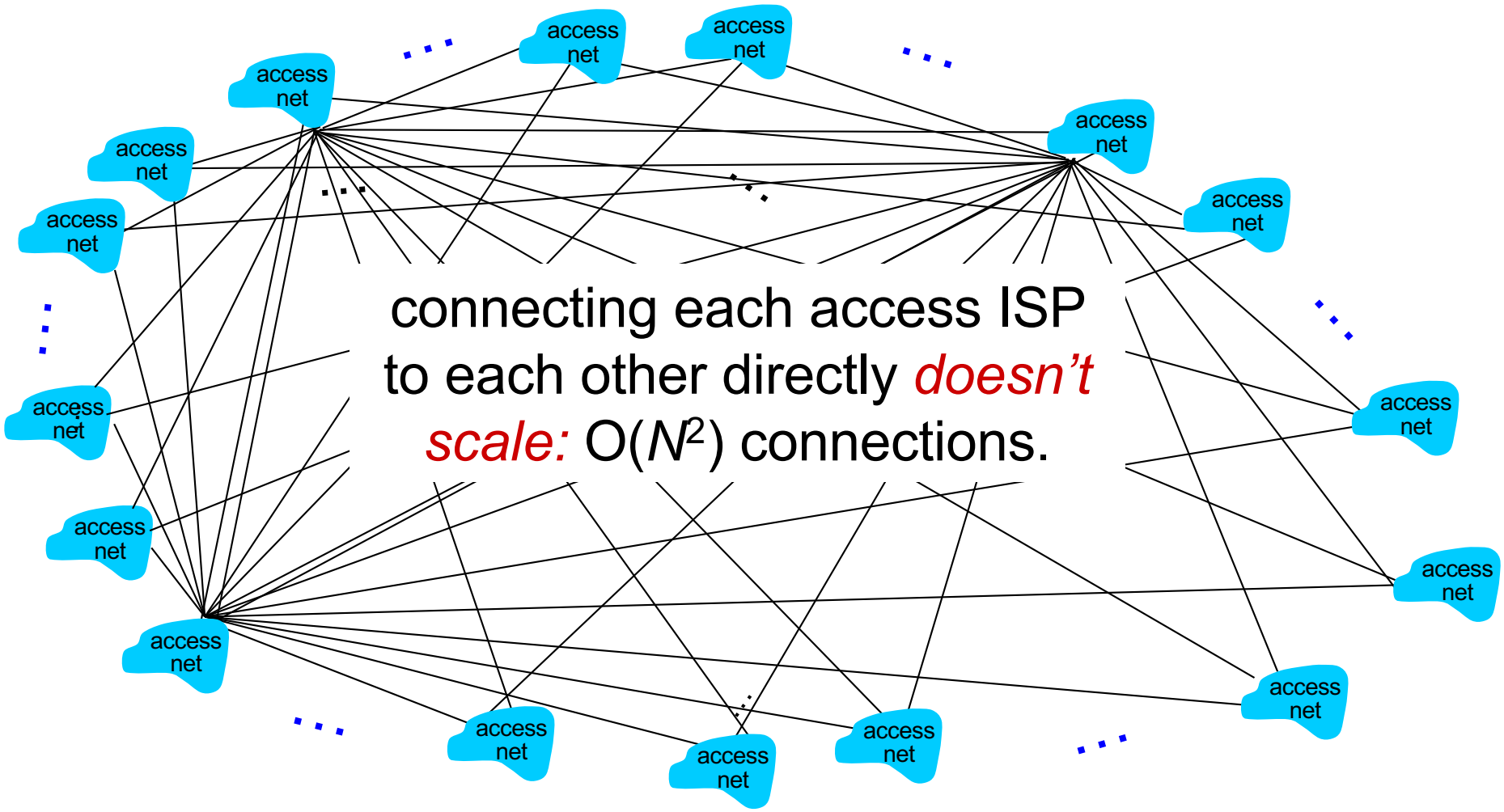
Internet structure: network of networks

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



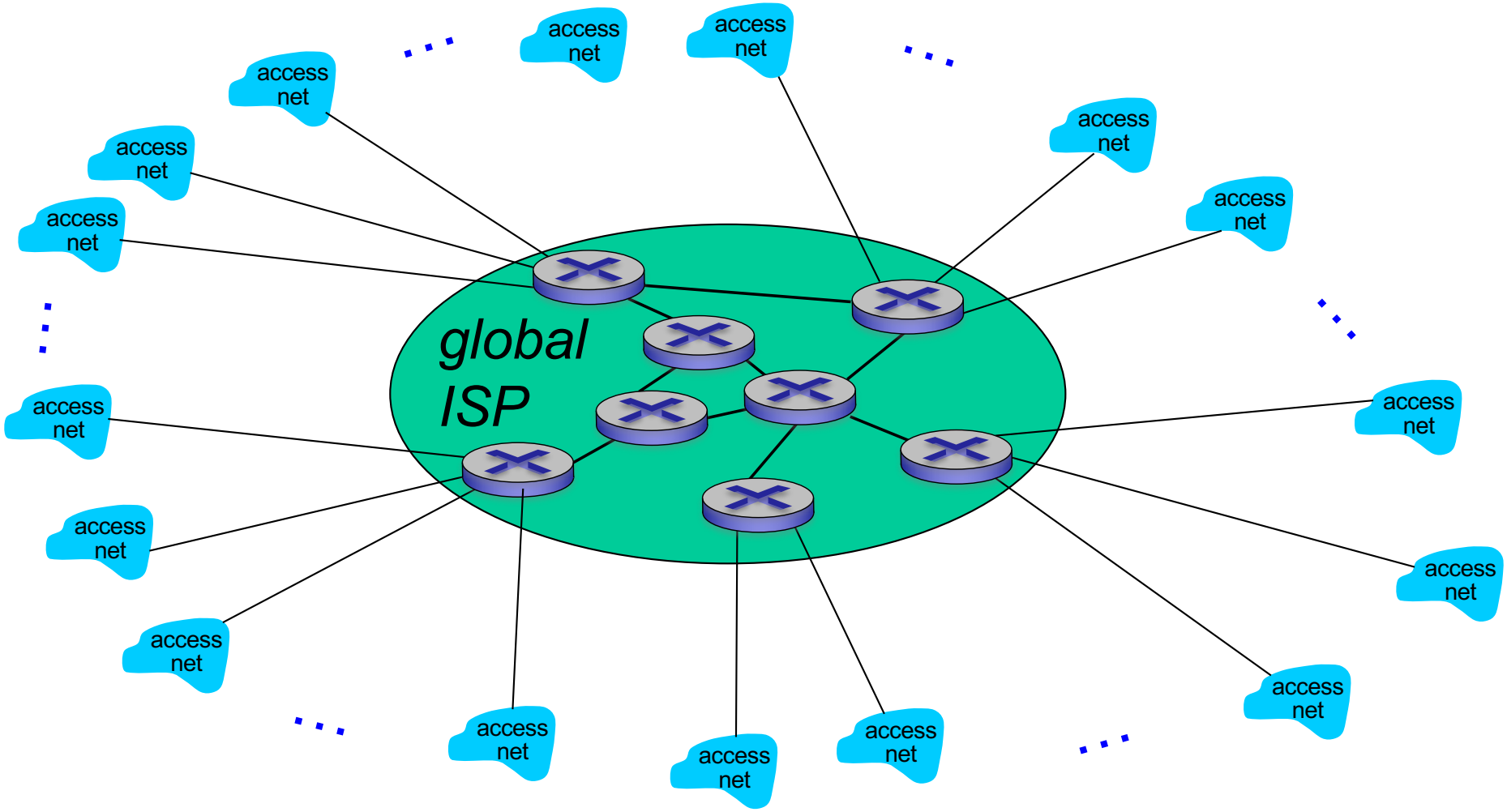
Internet structure: network of networks

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



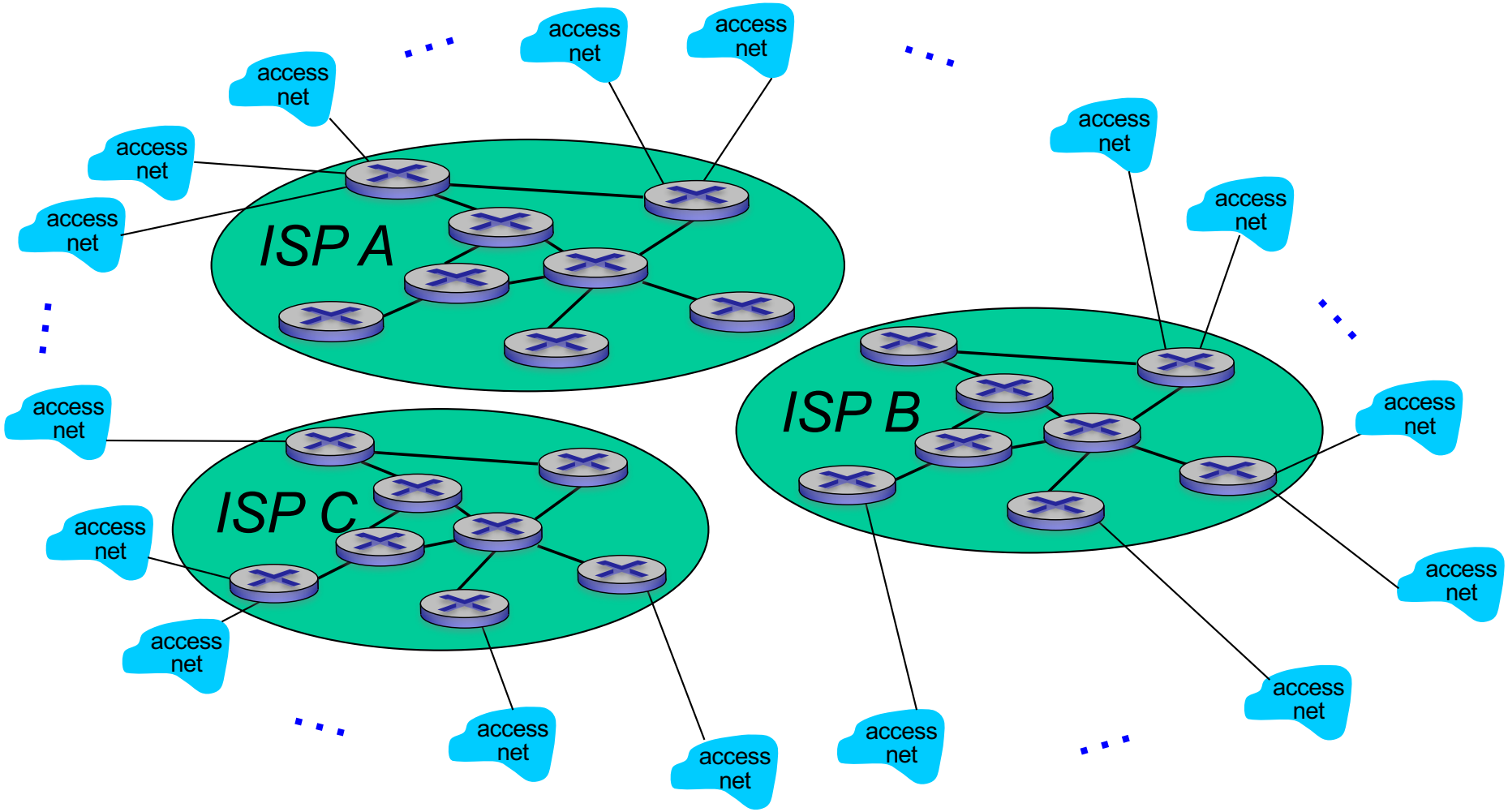
Internet structure: network of networks

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



Internet structure: network of networks

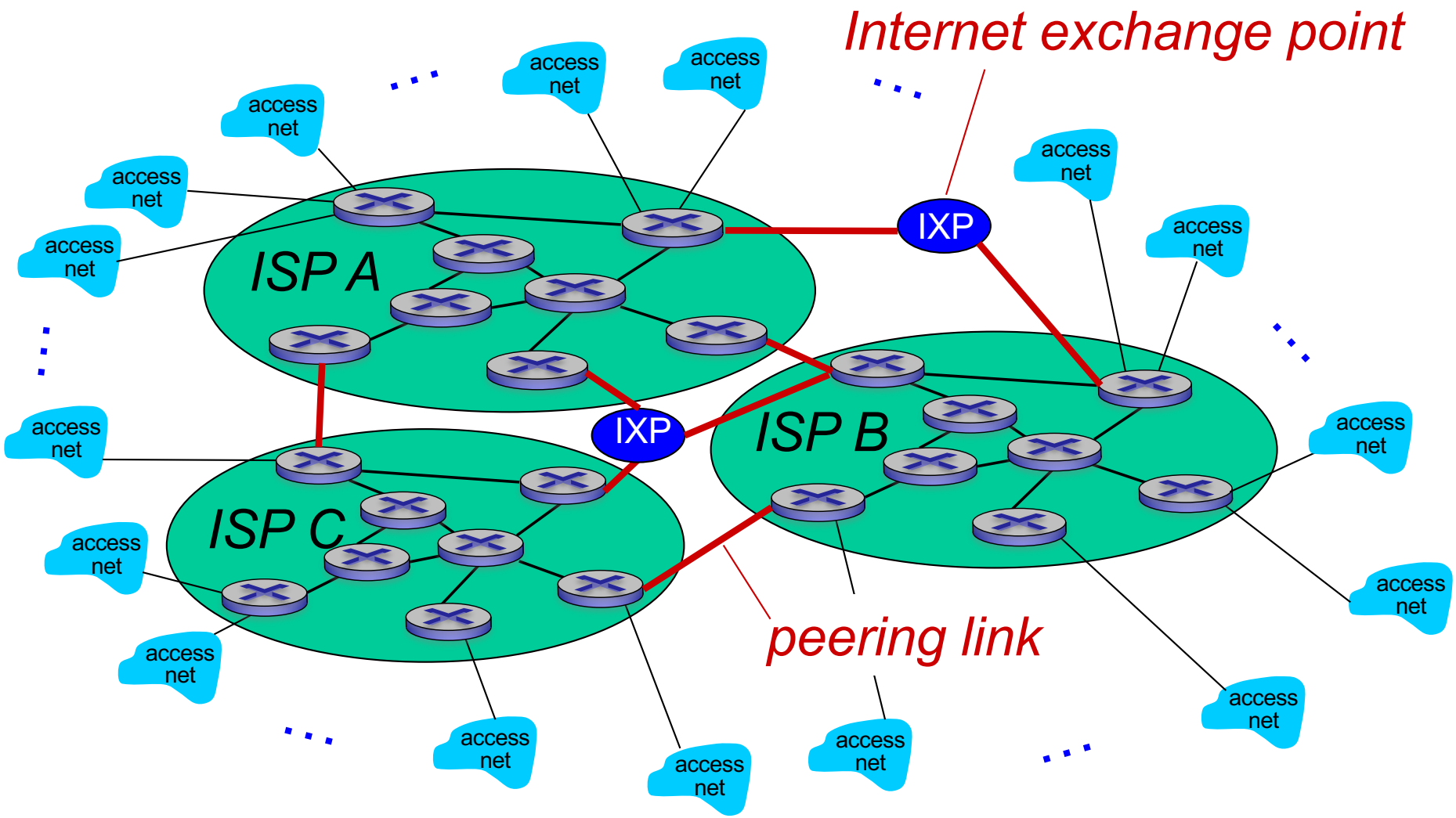
But if one global ISP is viable business, there will be competitors ….



Tier 1 ISPs: Level 3, AT&T, Sprint, NTT

Internet structure: network of networks

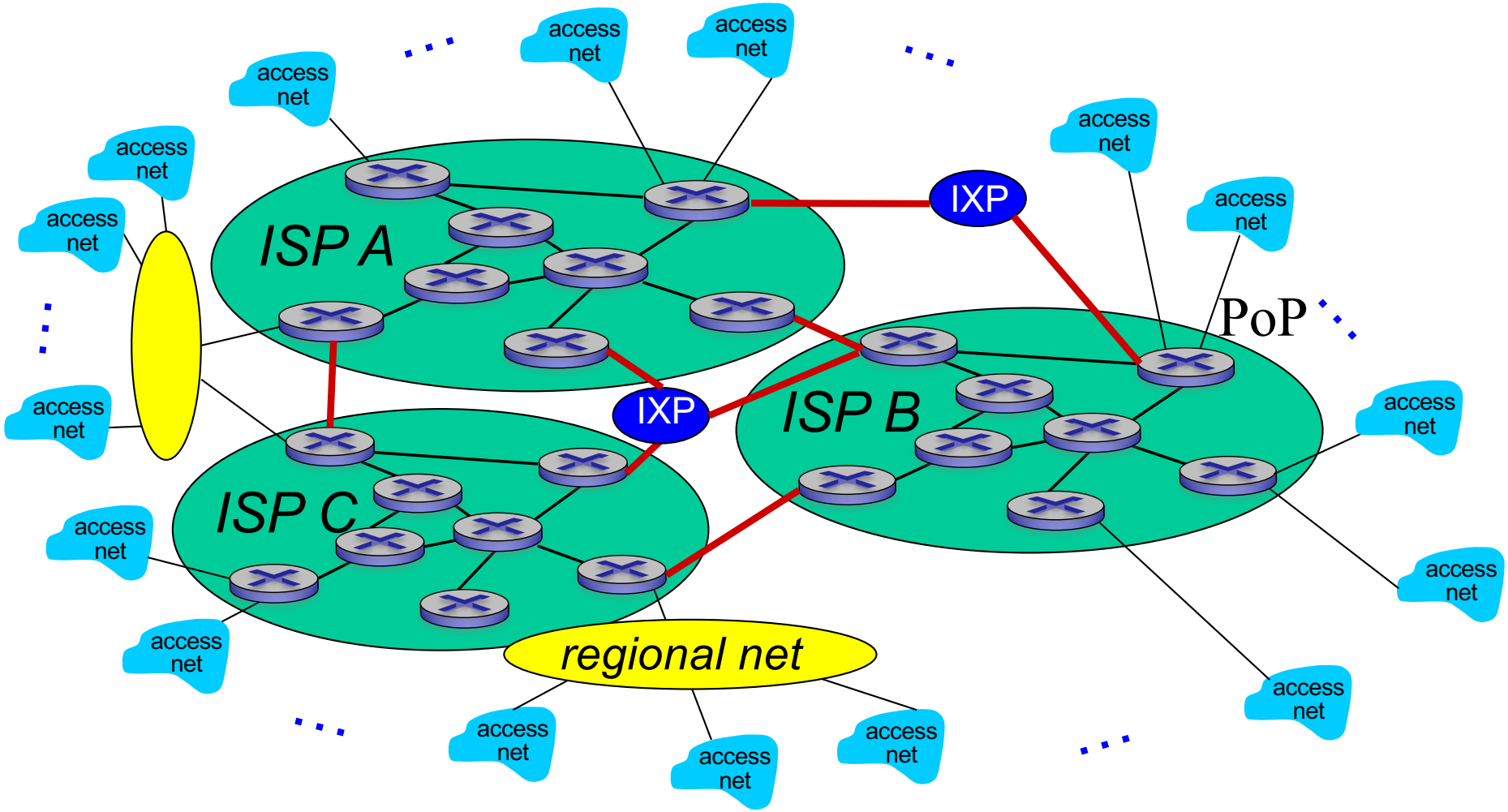
But if one global ISP is viable business, there will be competitors …. which must be interconnected



Density?

Internet structure: network of networks

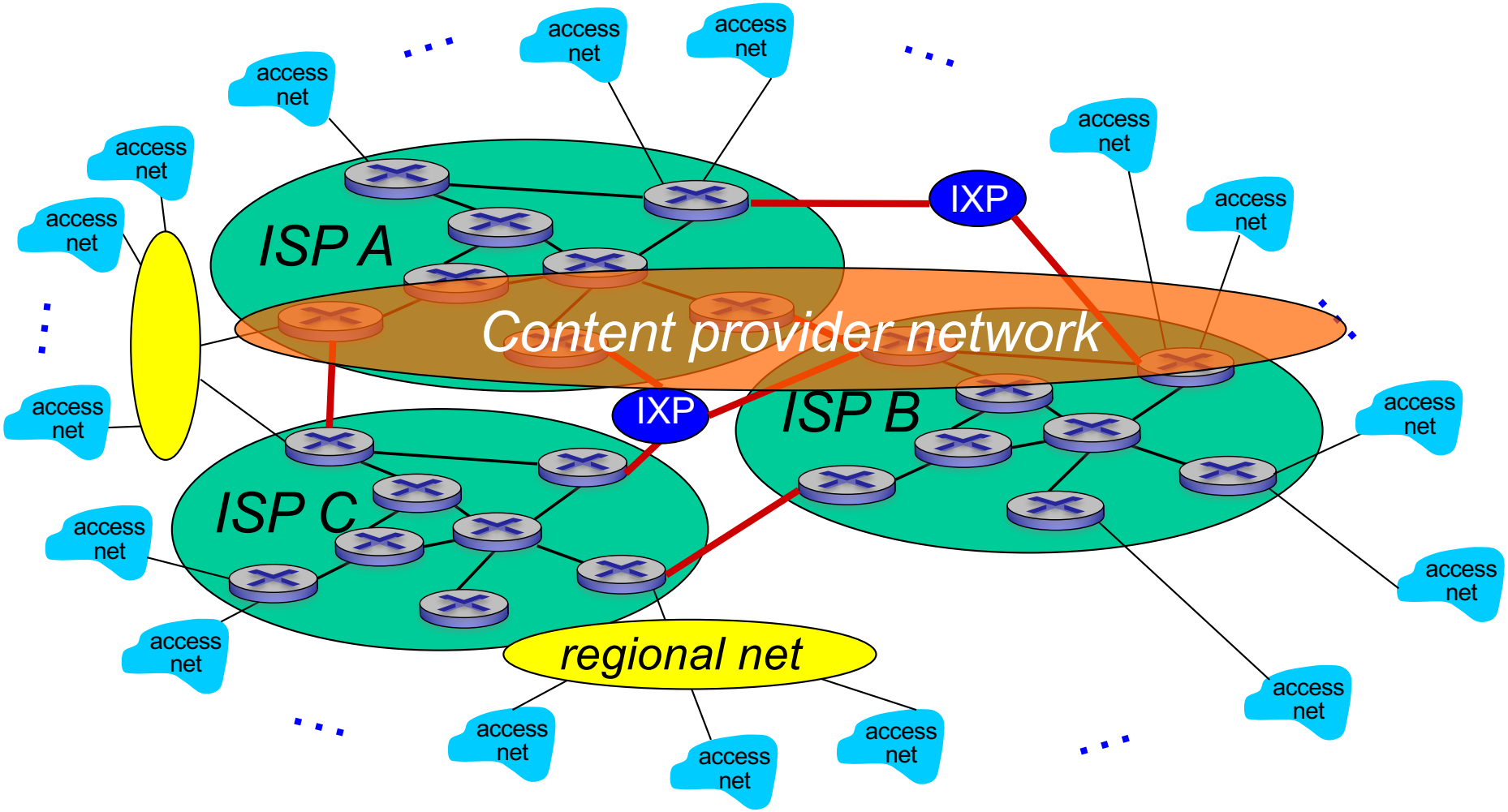
… and regional networks may arise to connect access nets to ISPs



Multi-homing

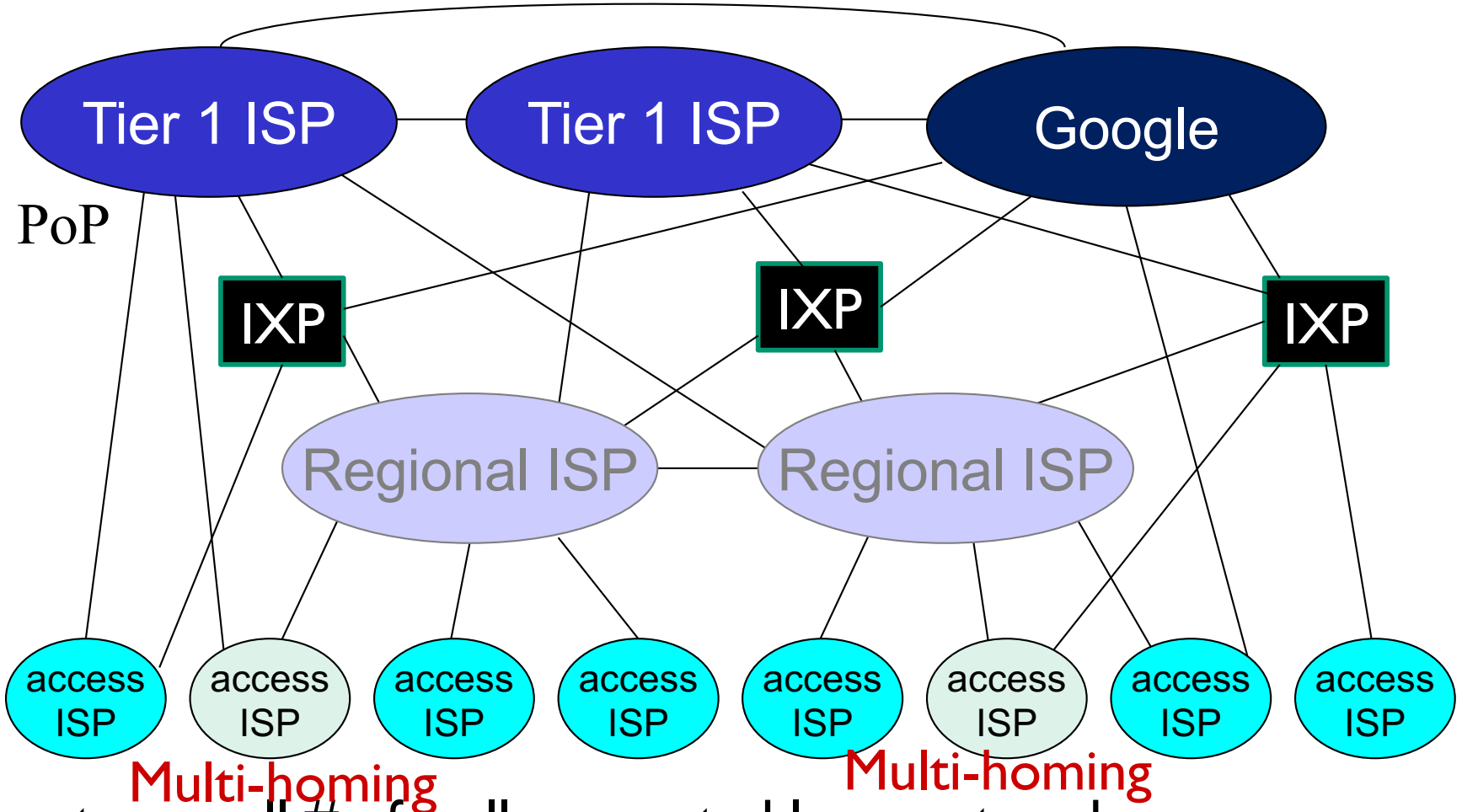
Internet structure: network of networks

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

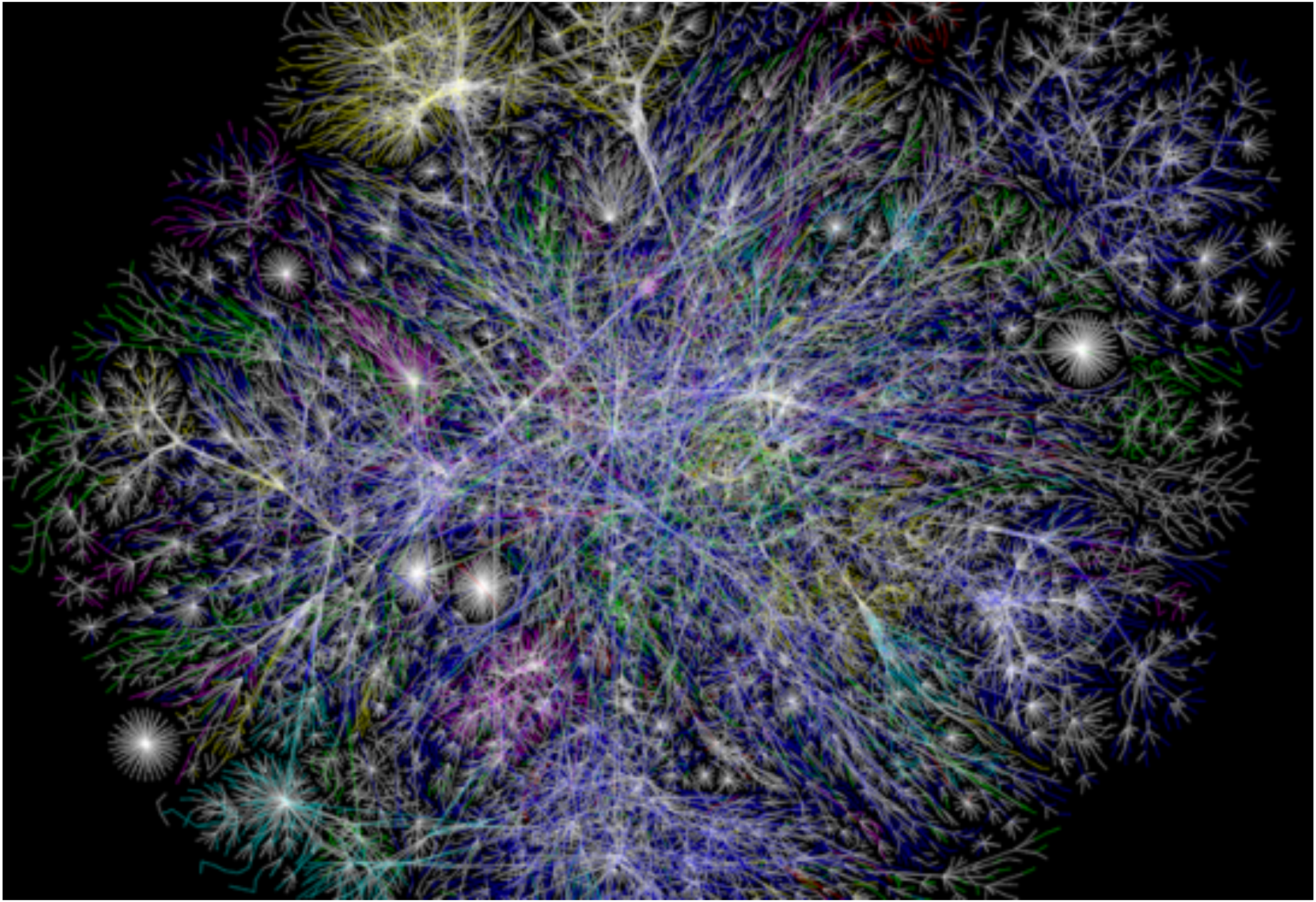


Why CPN? Network Edge or Core?

Internet structure: network of networks

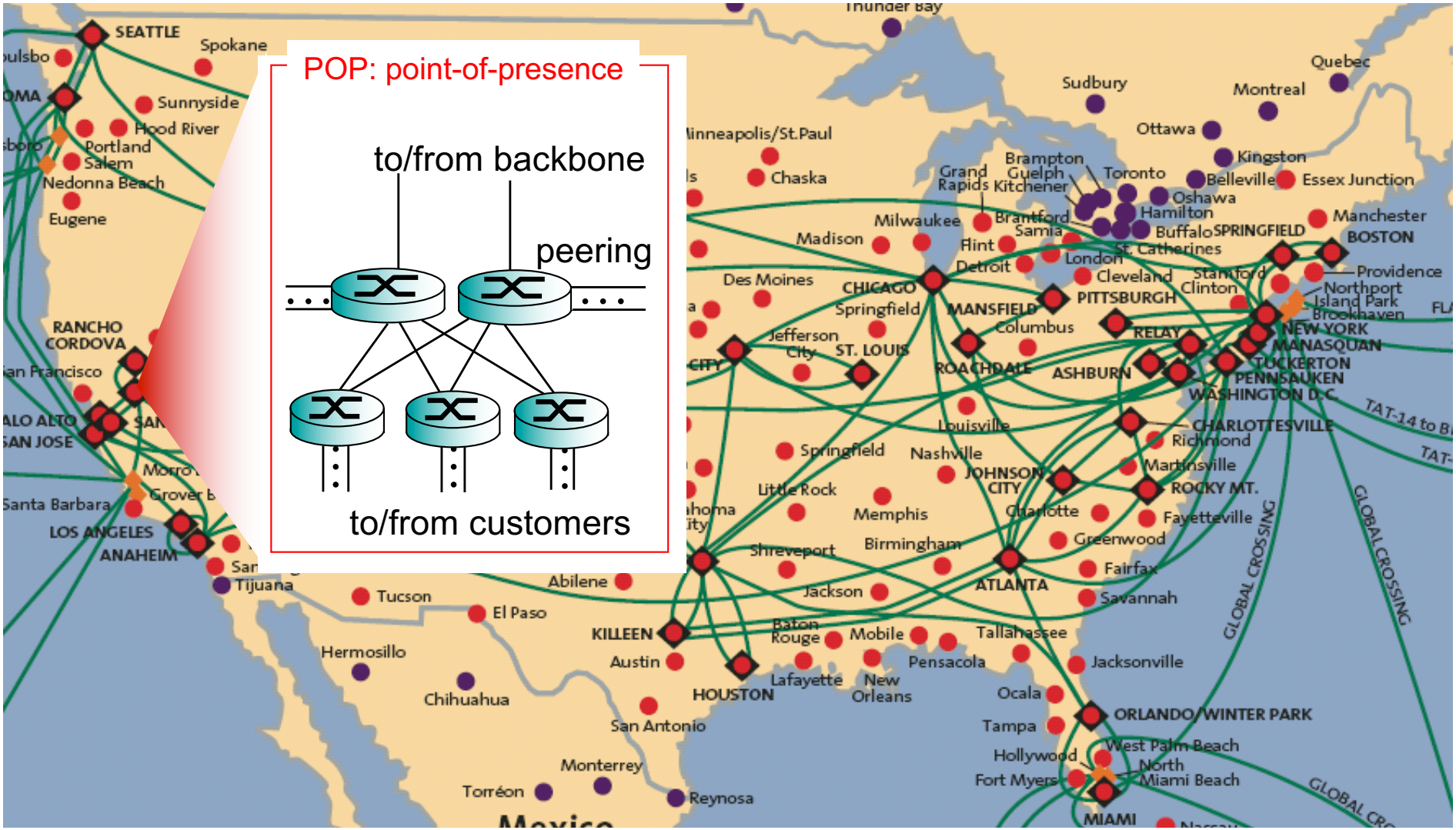


- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g., Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs



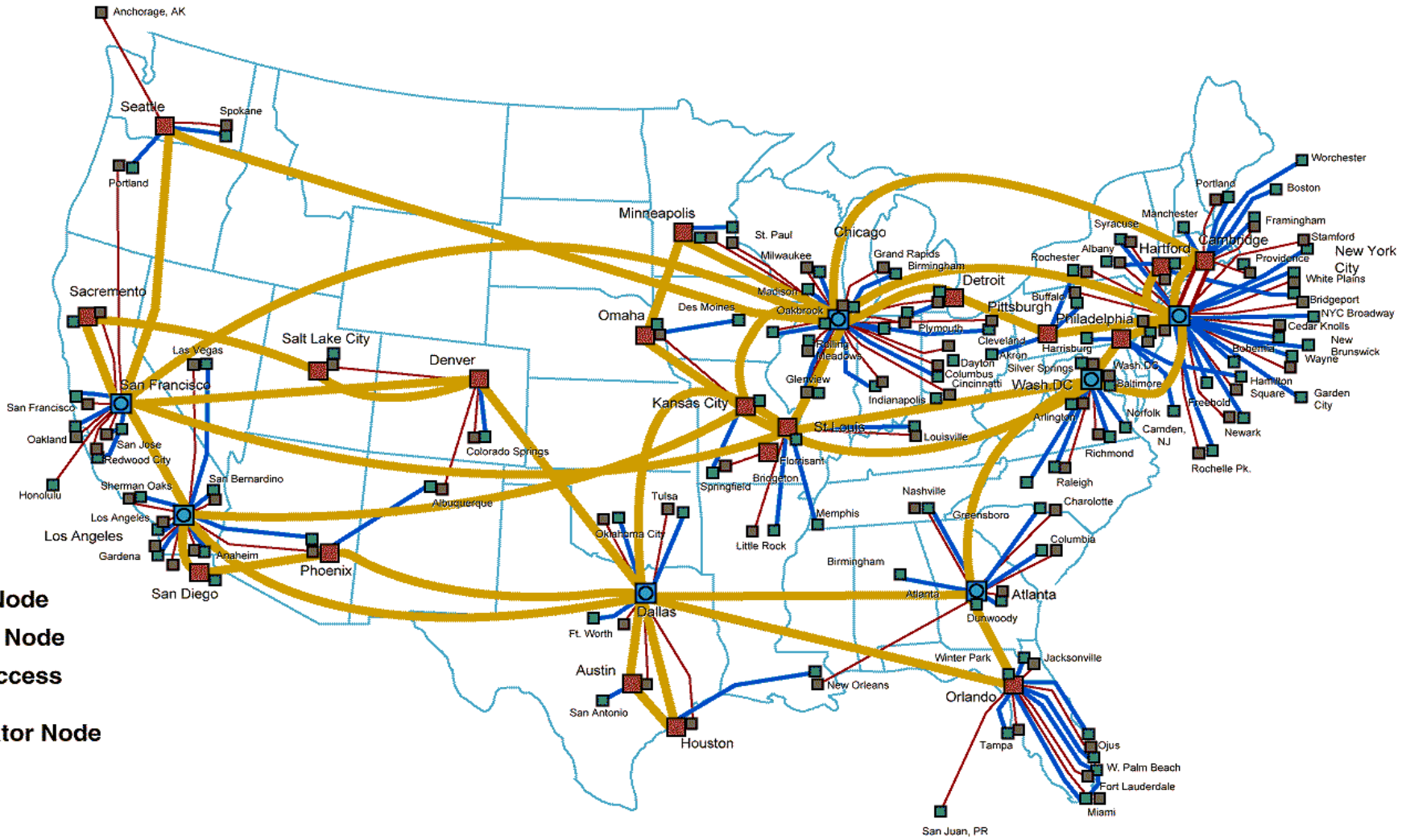
Partial map of the Internet based on the January 15, 2005 data found on opte.org. (from http://atheistuniverse.net/group/internet)

Tier-1 ISP: e.g., Sprint



AT&T IP BACKBONE NETWORK

2Q2000

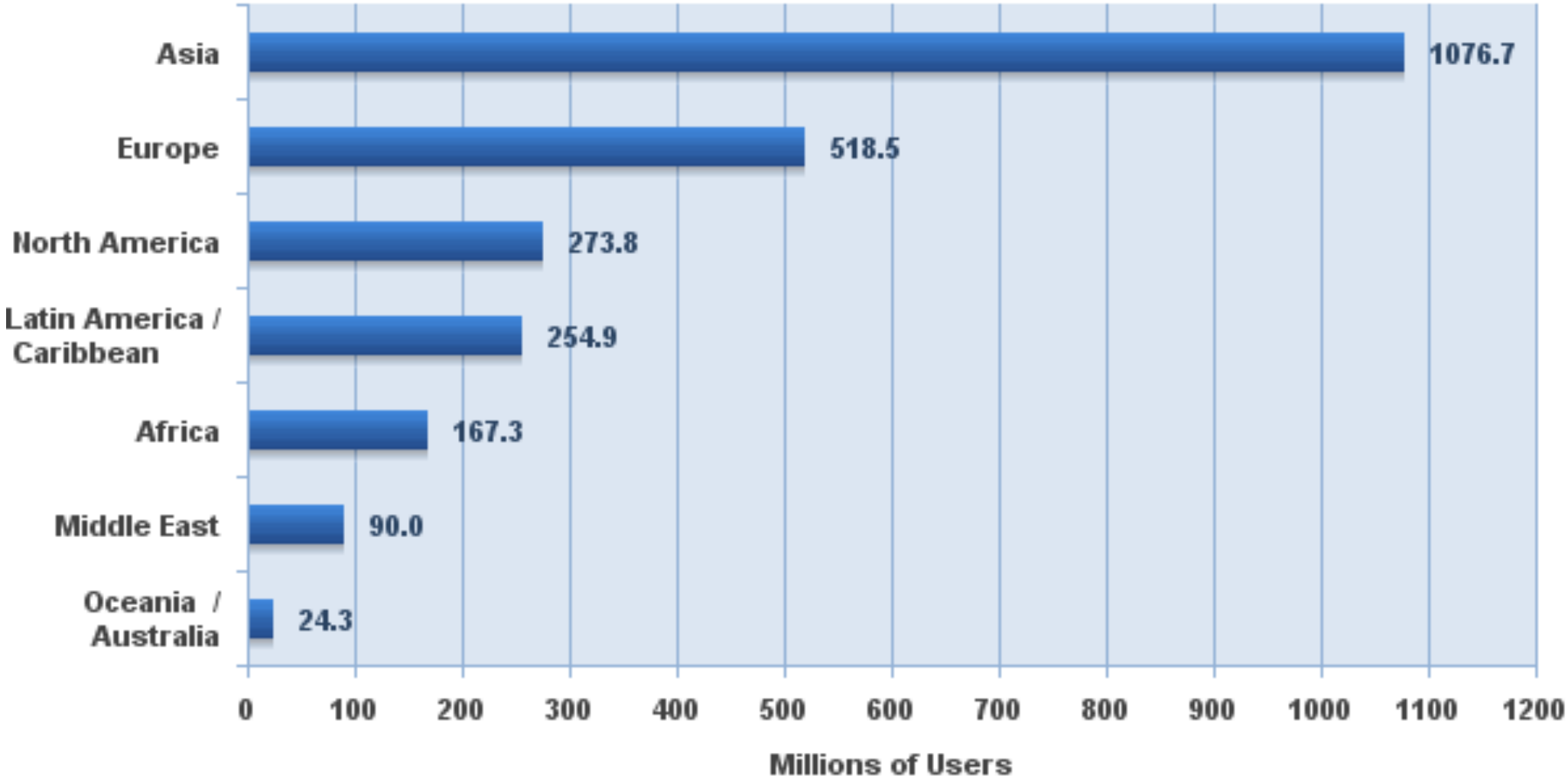


- Gateway Node
- Backbone Node
- Remote Access Router
- Concentrator Node (C9000)
- N X DS3
- N X OC3
- N OC48
- N X OC192

Note: map is not to scale.

OC1 (45 Mbps), OC2 (155 Mbps), …, OC192 (10 Gbps)

Internet Users in the World by Geographic Regions - 2012 Q2



Source: Internet World Stats - www.internetworldstats.com/stats.htm
2,405,518,376 Internet users estimated for June 30, 2012

So far…

covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
  - Internet structure
- performance: loss, delay, throughput
- layering, service models

you now have:

- context, overview, "feel" of networking
- more depth, detail *to follow!*

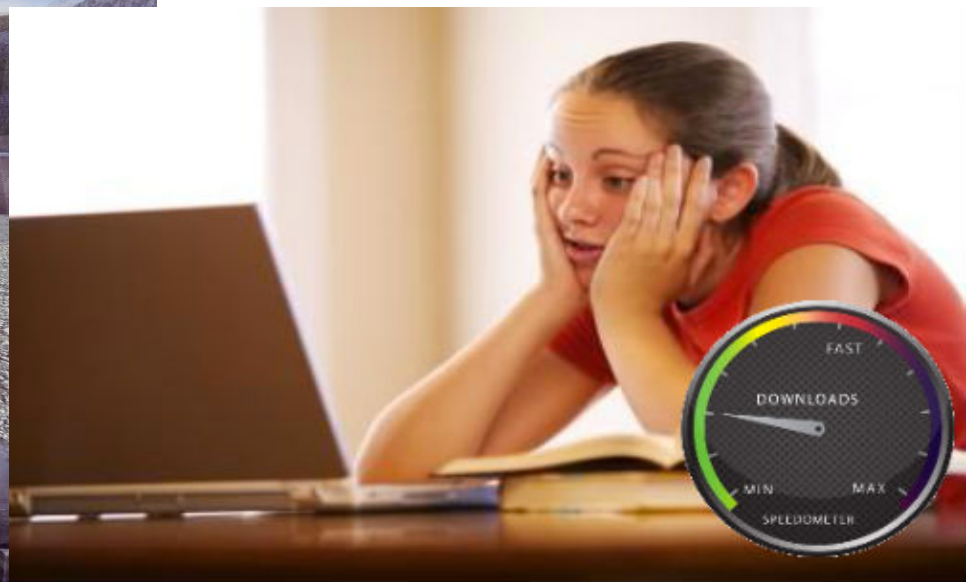
Review and Motivations:

Packet Switching

Pros: Easy to implement, Better resource sharing

Cons: loss, delay, traffic congestion.

Questions: How to quantify the network performance?



Chapter 1: roadmap

1.4 network performance in packet-switched networks

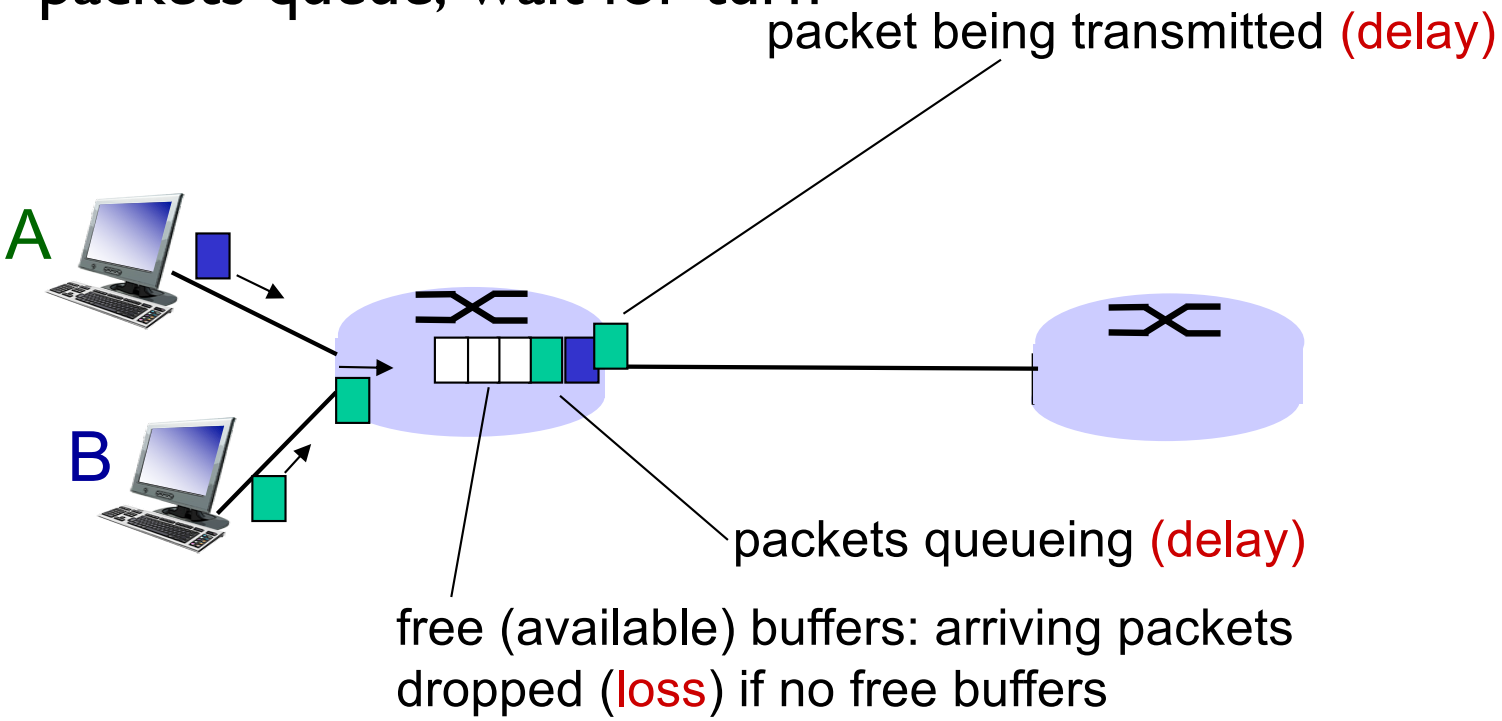
- delay
- loss
- throughput

1.5 protocol layers, service models

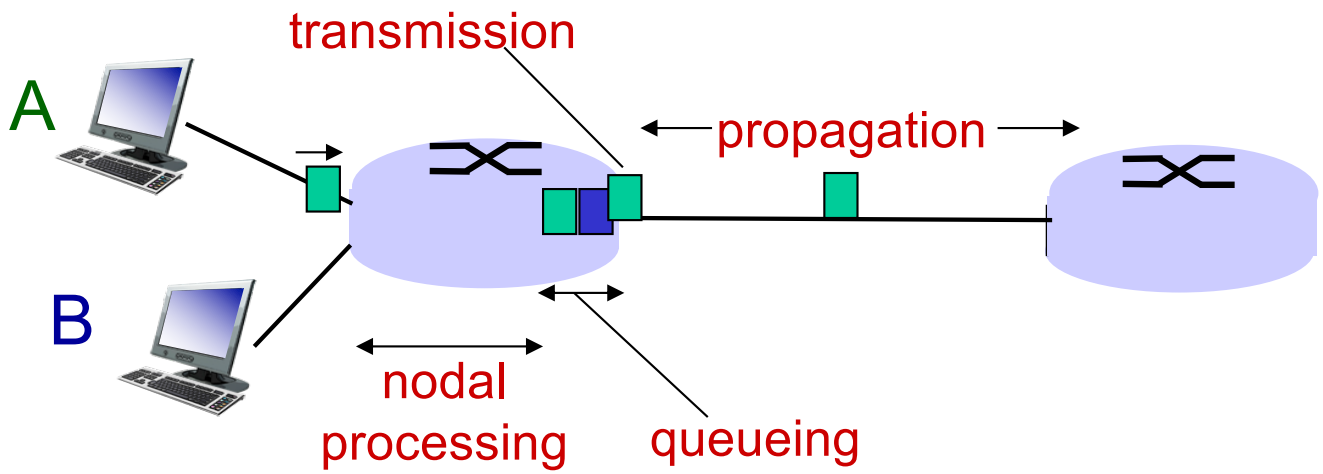
How do loss and delay occur?

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



Nodal delay: $d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$

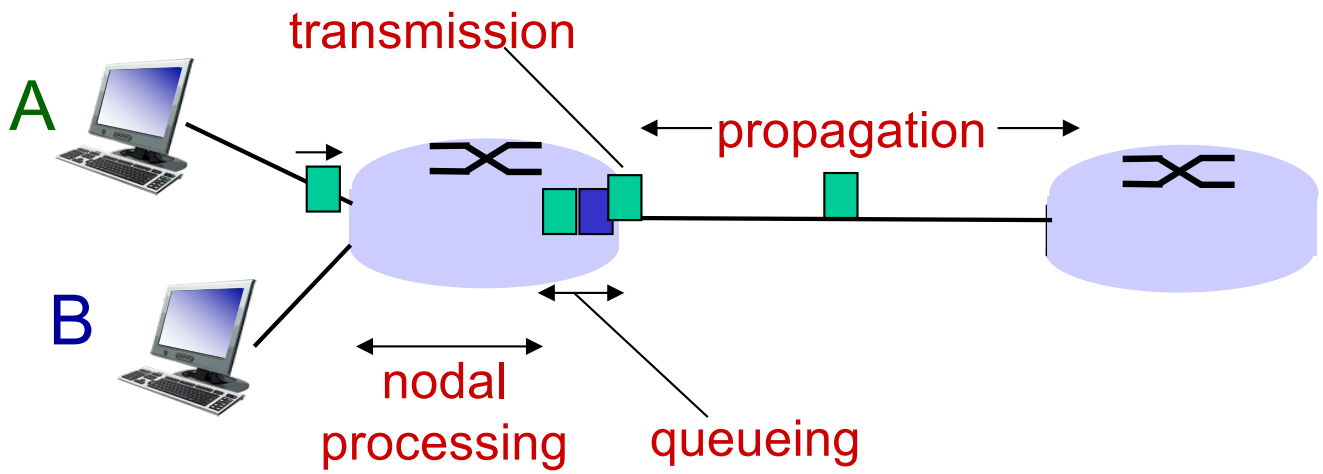
d_{proc}: nodal processing

- check bit errors
- determine output link
- typically < micro-sec

d_{queue}: queueing delay

- time waiting at output link for transmission
- depends on congestion level of router
- micro-sec to milli-sec

Four sources of packet delay



Nodal 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 in medium (~2×10^8 m/sec)
- $d_{prop} = d/s$

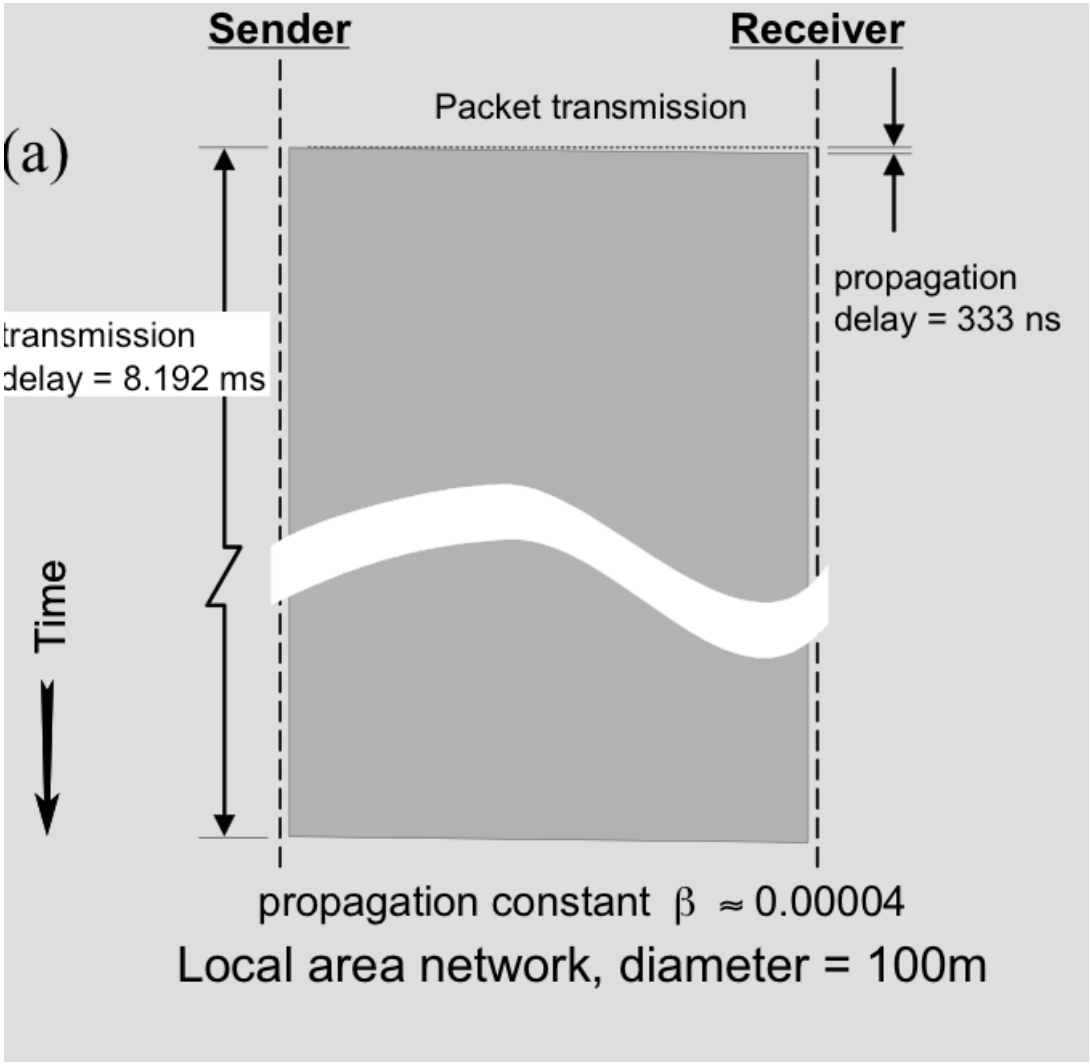
When a packet can be transmitted on a link?

- 1) no other pkt transmitted on the link (in practice)
- 2) no other pkt preceding it in the queue

Source: Slides of Prof Ivan Marsic with Rutgers University

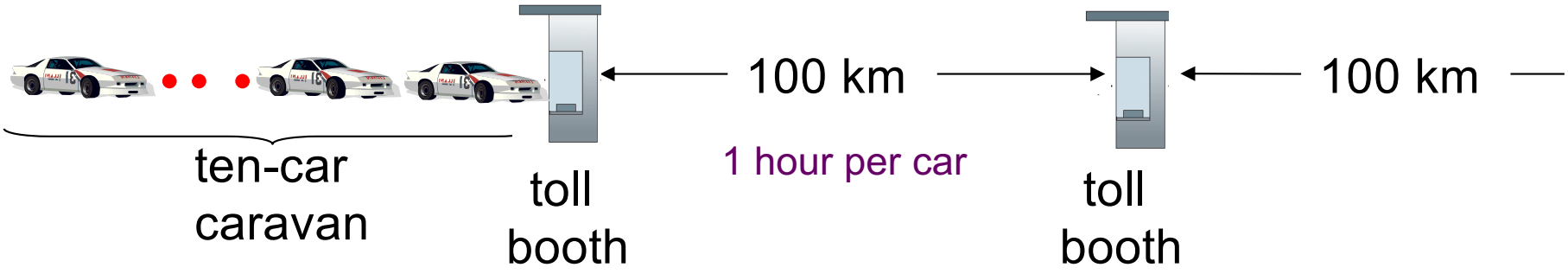
Propagation constant β

Ratio of propagation delay vs. packet transmission time



Wireless LAN 0.00004. Ethernet: 0.01

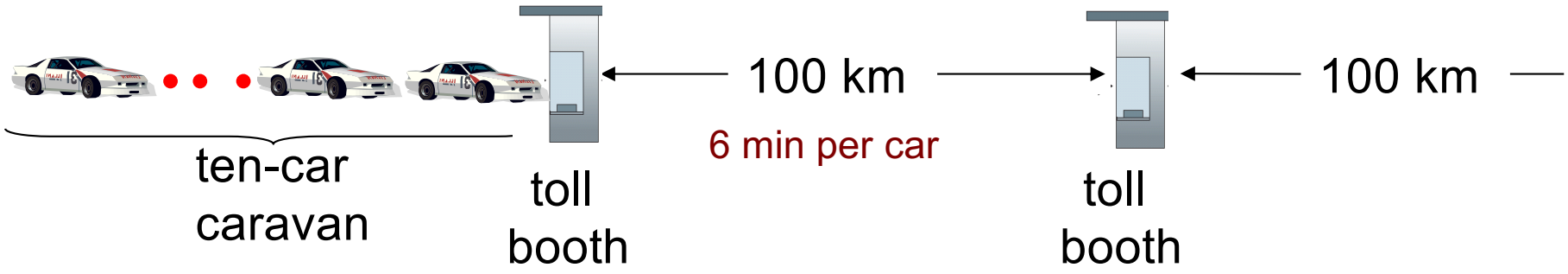
Caravan analogy (trans. & propagation)



- 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 are serviced at first booth?
  - *A: Yes!* after 7 min, 1st car arrives at second booth; three cars still at 1st booth.