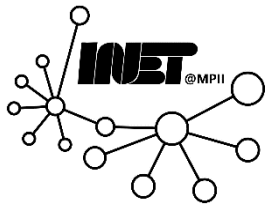
Data Networks

Introduction



Introduction

Goals:

- Get "feel" & terminology
- More depth, detail *later* in course
- Approach:
  - Use Internet as example

Overview:

- What's the Internet?
- What's a protocol?
- Network edge:
  - *End-systems, access net, physical media*
- Network core:
  - *Packet/circuit switching, Network structure*
- Performance: *Delay, loss, throughput*
- Protocol layers, service models
- Networks under attack: Security
- History

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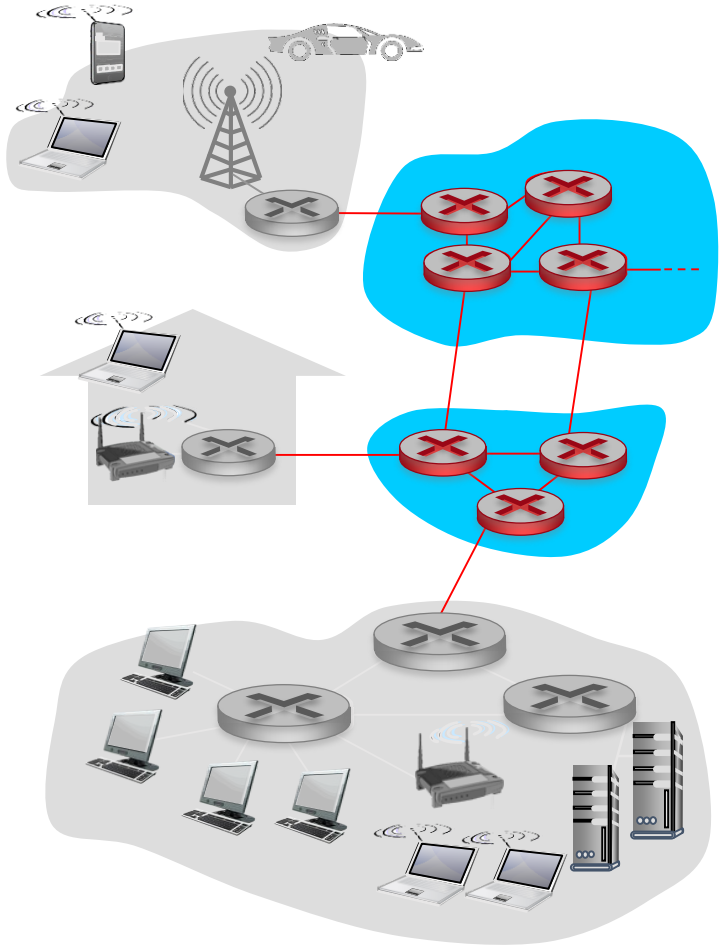
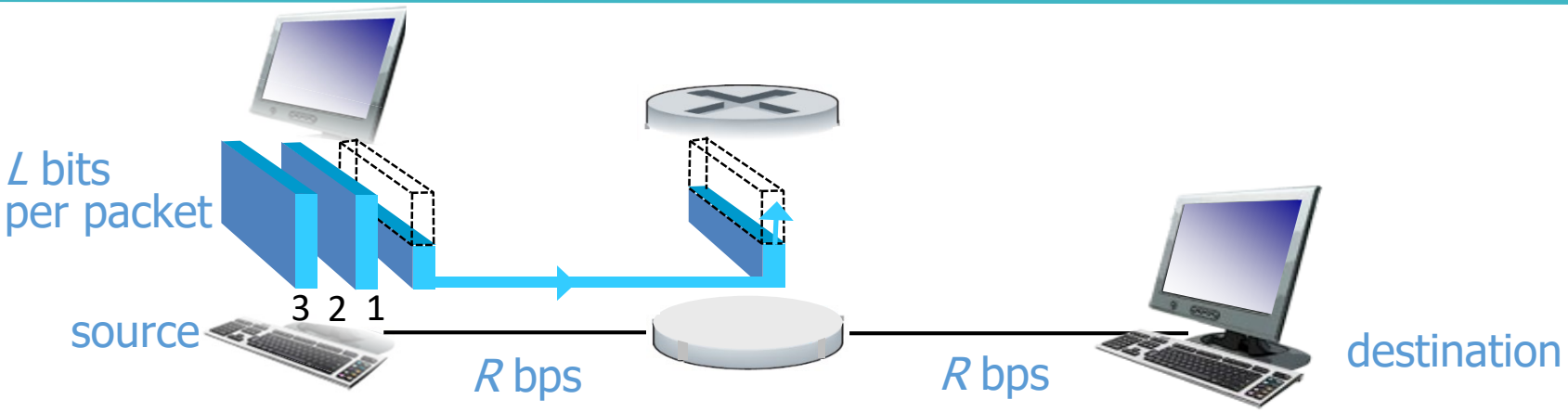
The network core

- 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



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

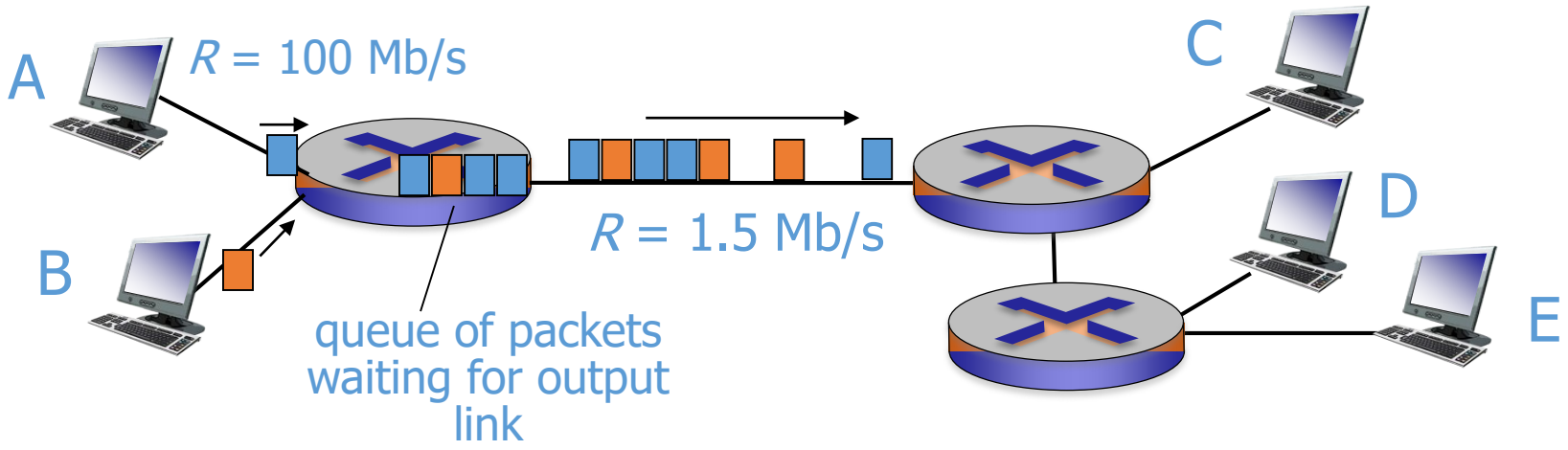
One-hop numerical example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- One-hop transmission delay = 5 s

*End-end delay = 2*L/R*
(assuming zero propagation delay)

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:

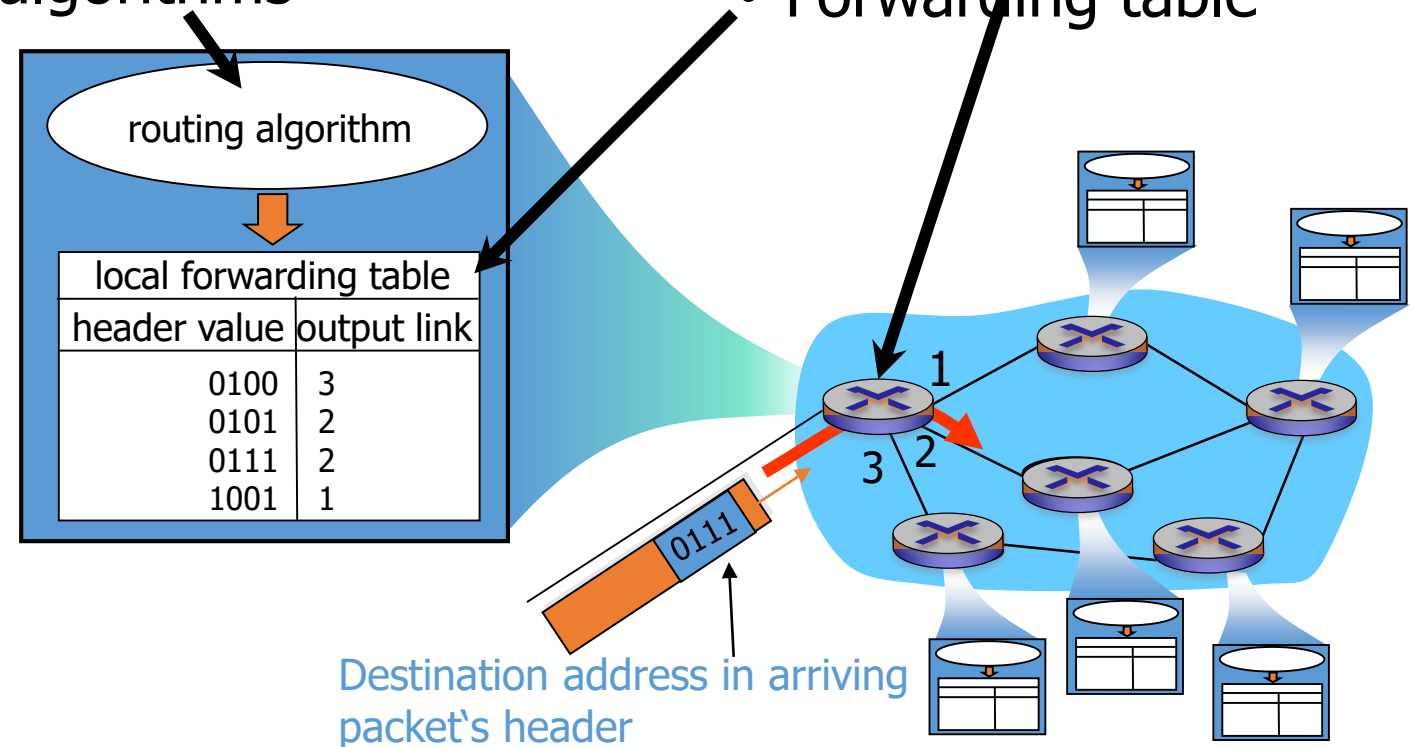
Determines source-destination route taken by packets

- Routing algorithms

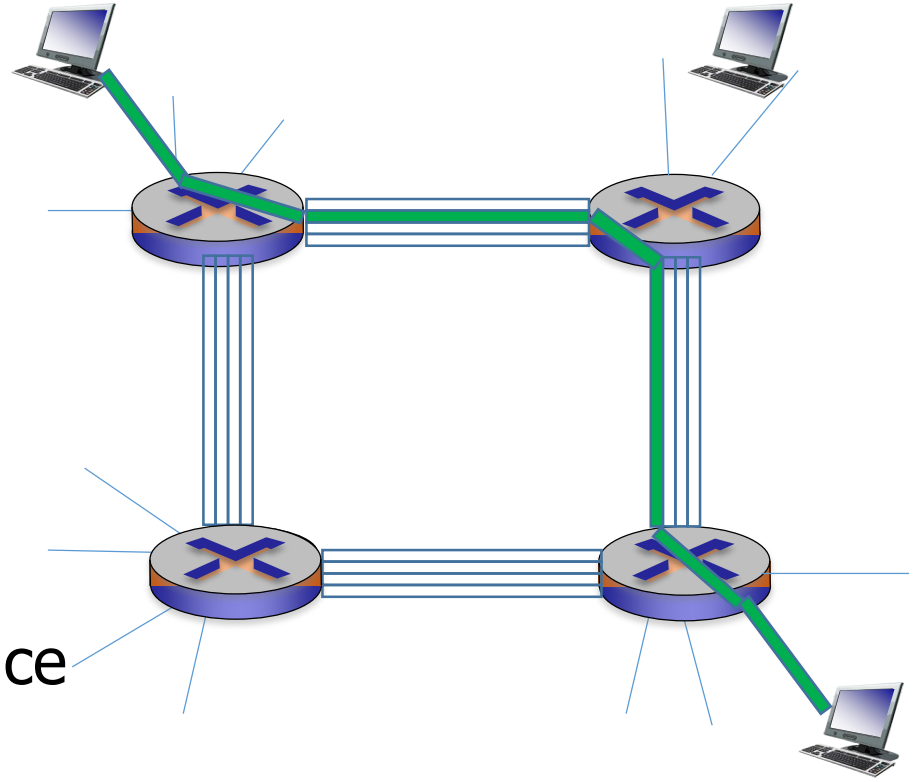
Forwarding:

Move packets from router's input to appropriate router output

- Forwarding table



Alternative core: Circuit switching



End-end resources allocated to, reserved for "call" between source & dest.:

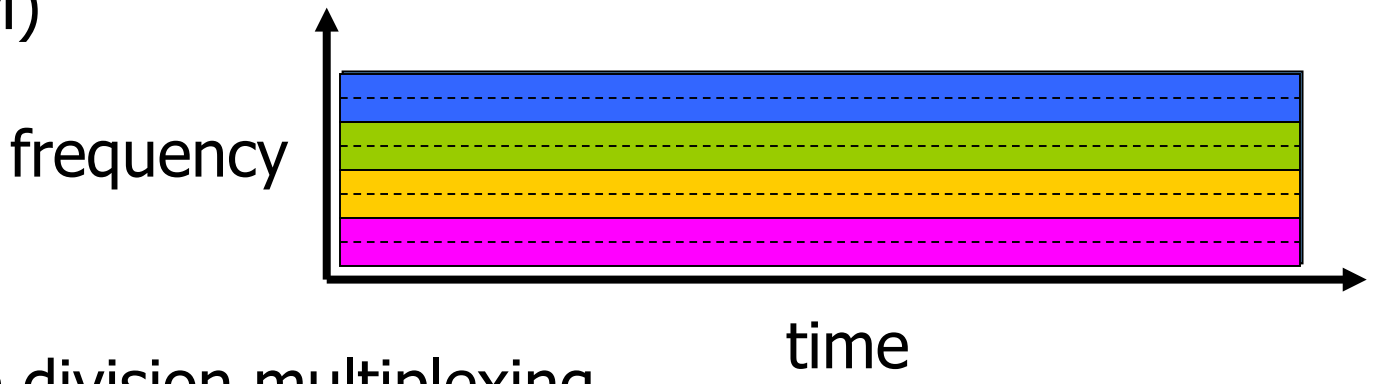
- In diagram, each link has four circuits
  - Call gets 2nd circuit in top link and 1st circuit in right link
- Dedicated resources: no sharing
  - Circuit-like (guaranteed) performance
- Circuit segment idle if not used by call *(no sharing)*
- Commonly used in traditional telephone networks

Circuit switching: FDM versus TDM

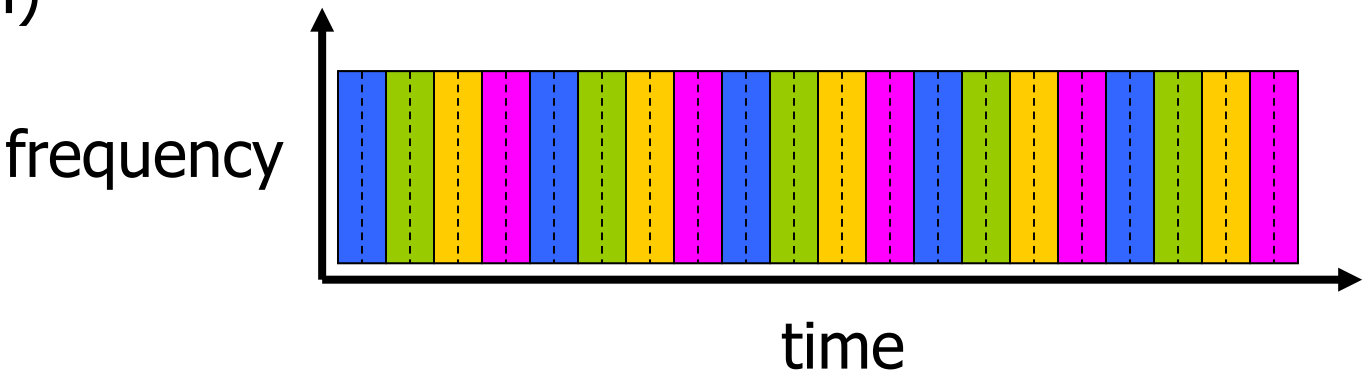
Example:

4 users

Frequency division multiplexing (FDM)



Time division multiplexing (TDM)

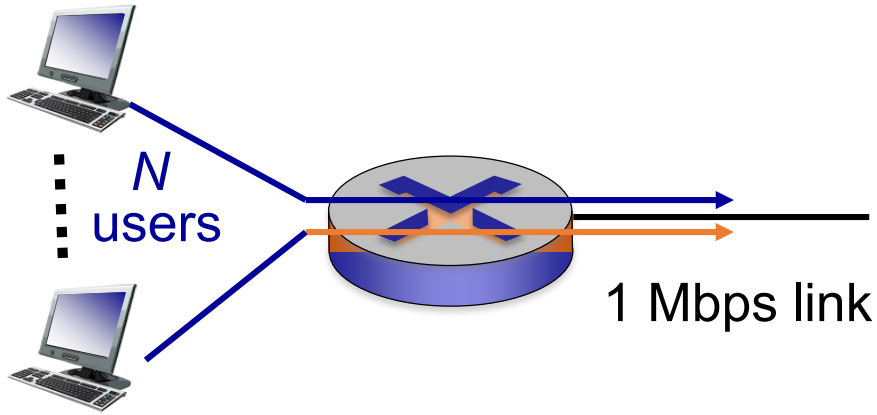


Packet switching versus circuit switching

Packet switching may allow 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 *

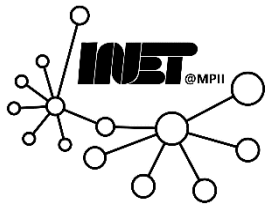
- *Q:* How did we get value 0.0004?
- *Q:* What happens if > 35 users?

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

Packet switching versus circuit switching

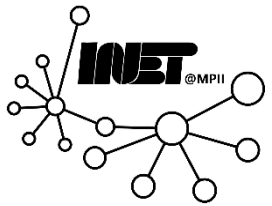
Is packet switching a "slam dunk winner?"

- 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 …



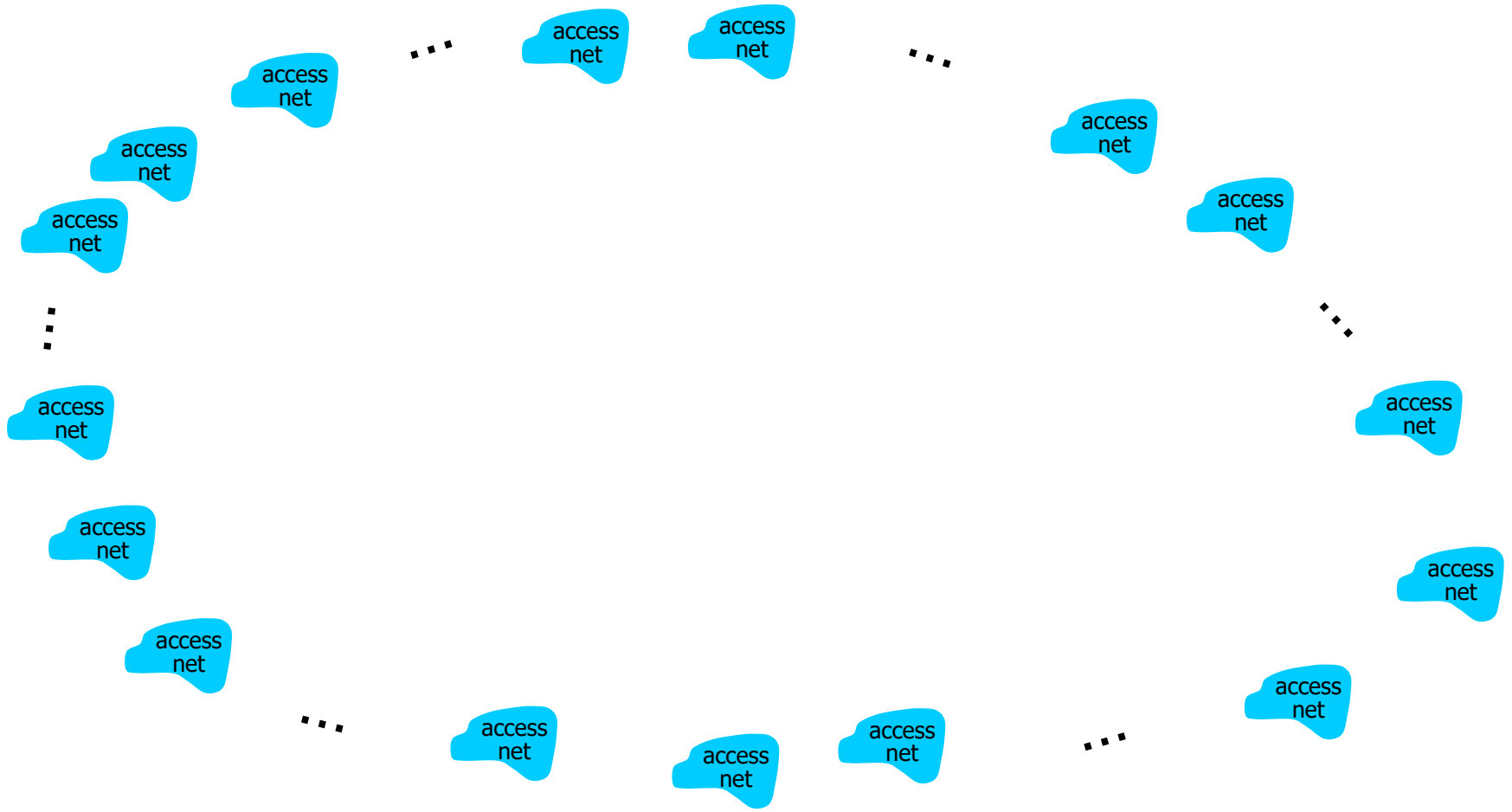
Internet structure: Network of networks

- 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 us 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?



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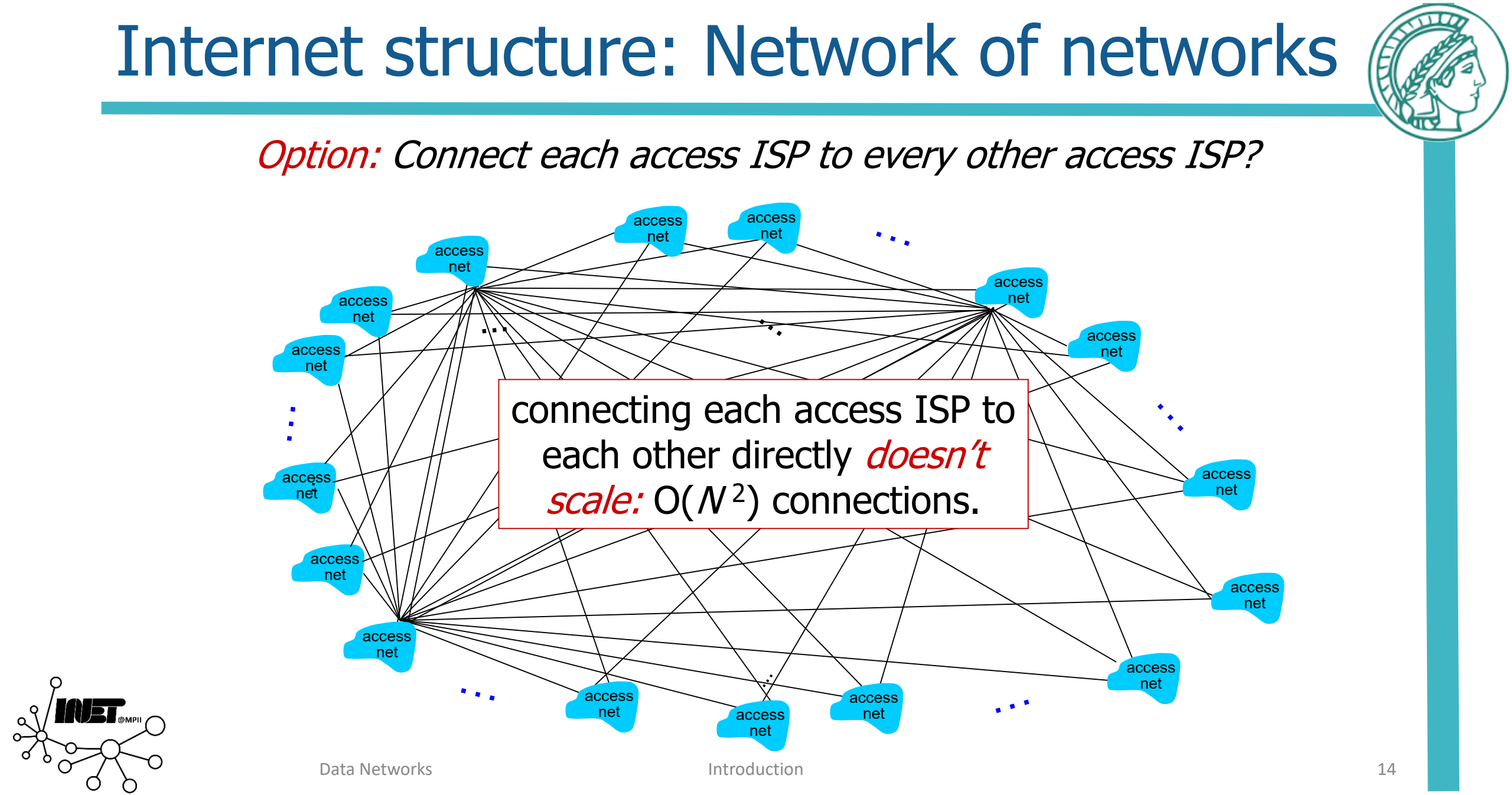
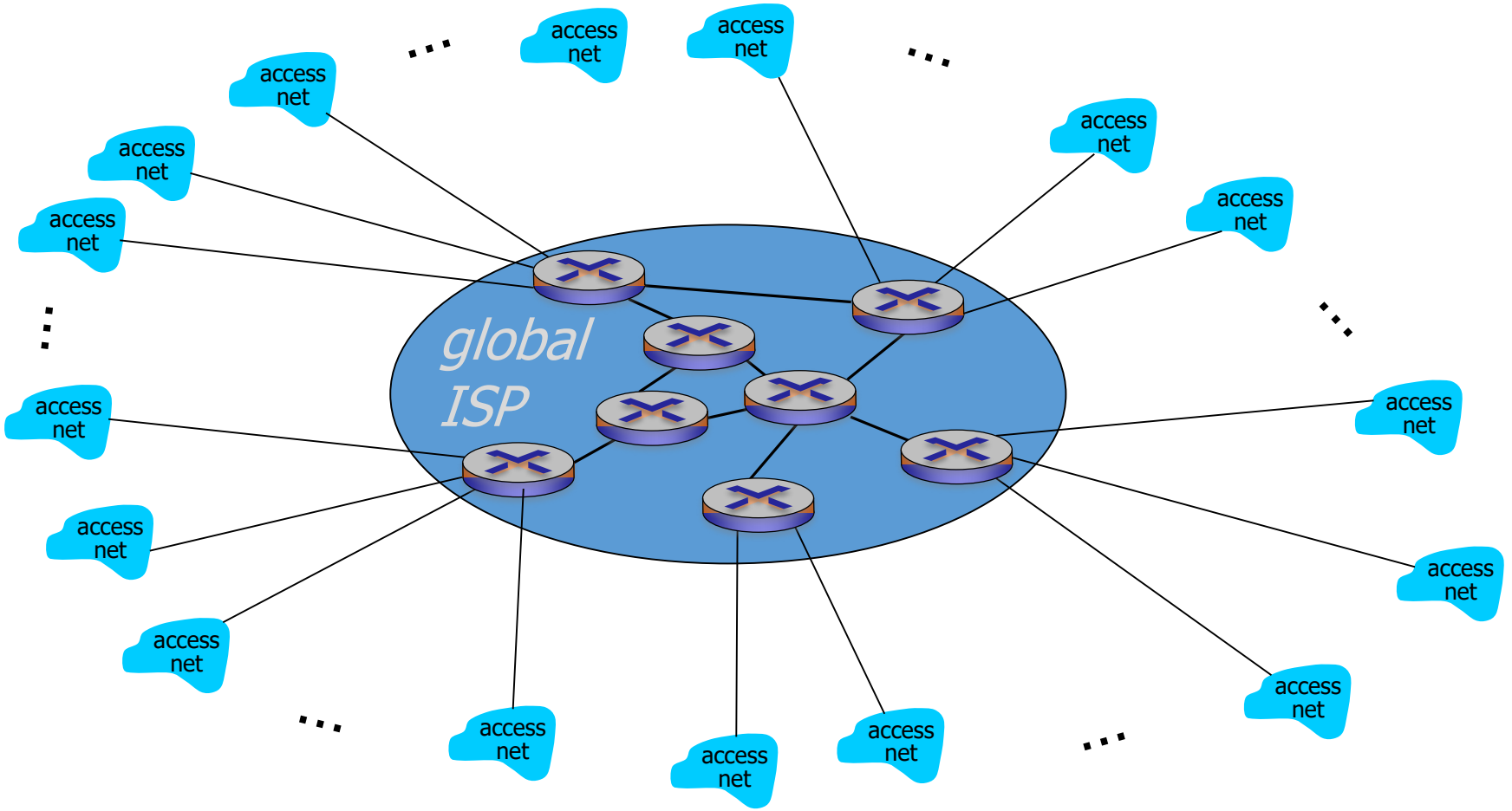


Option: Connect each access ISP to every other access ISP?

Internet structure: Network of networks

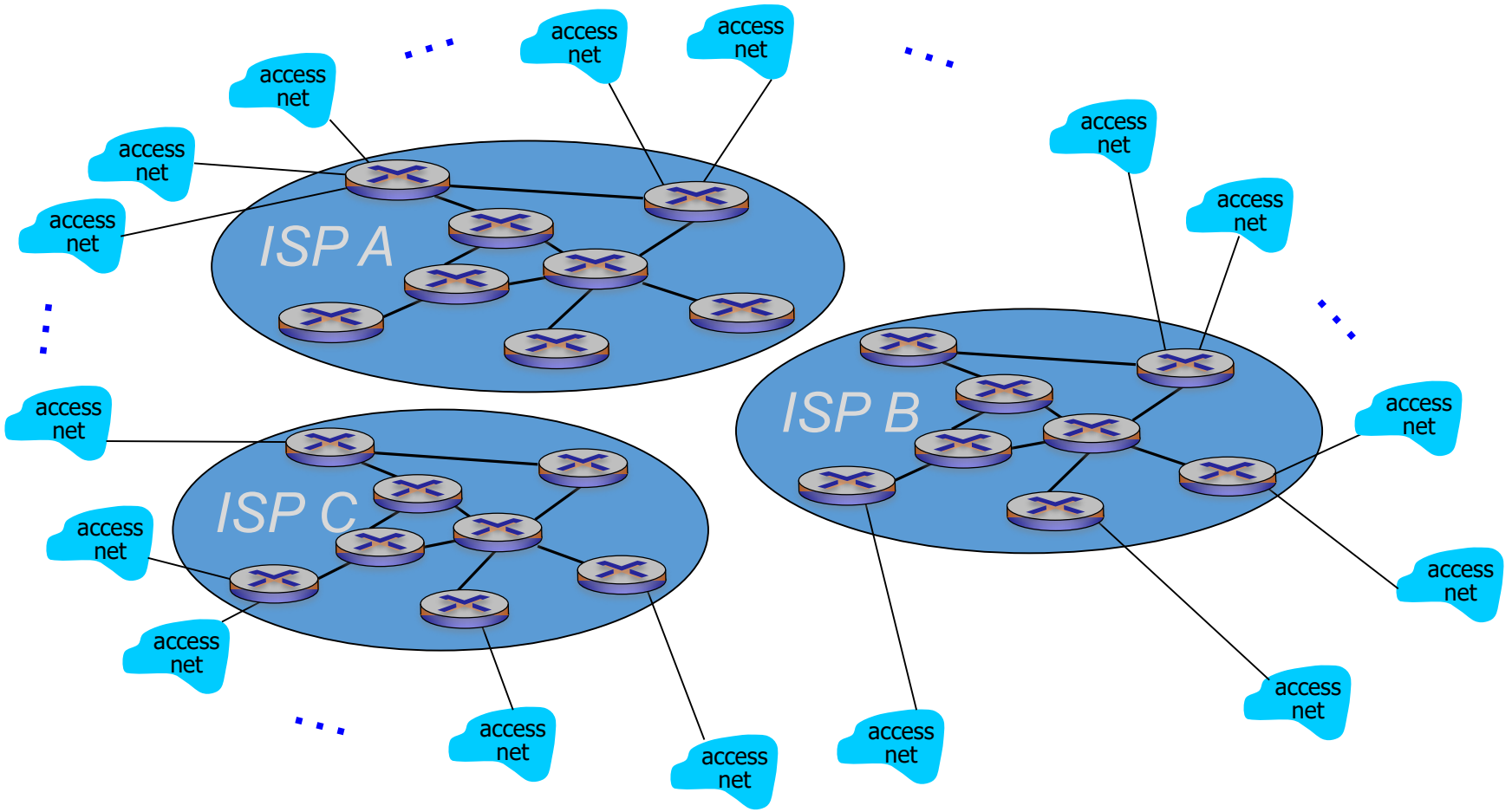
Option: Connect each access ISP to one global transit ISP?

Customer and provider ISPs have economic agreement.



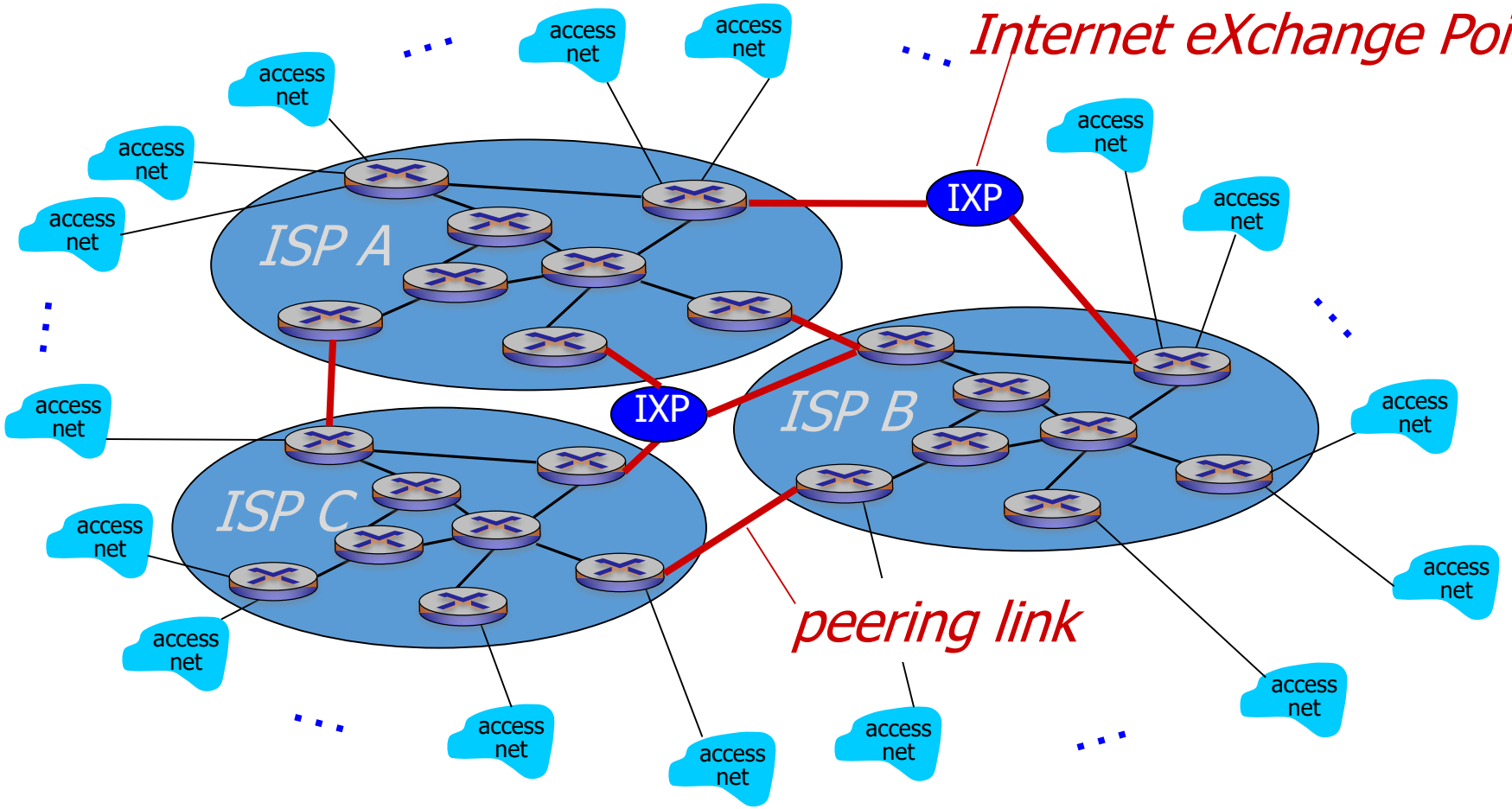
Internet structure: Network of networks

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



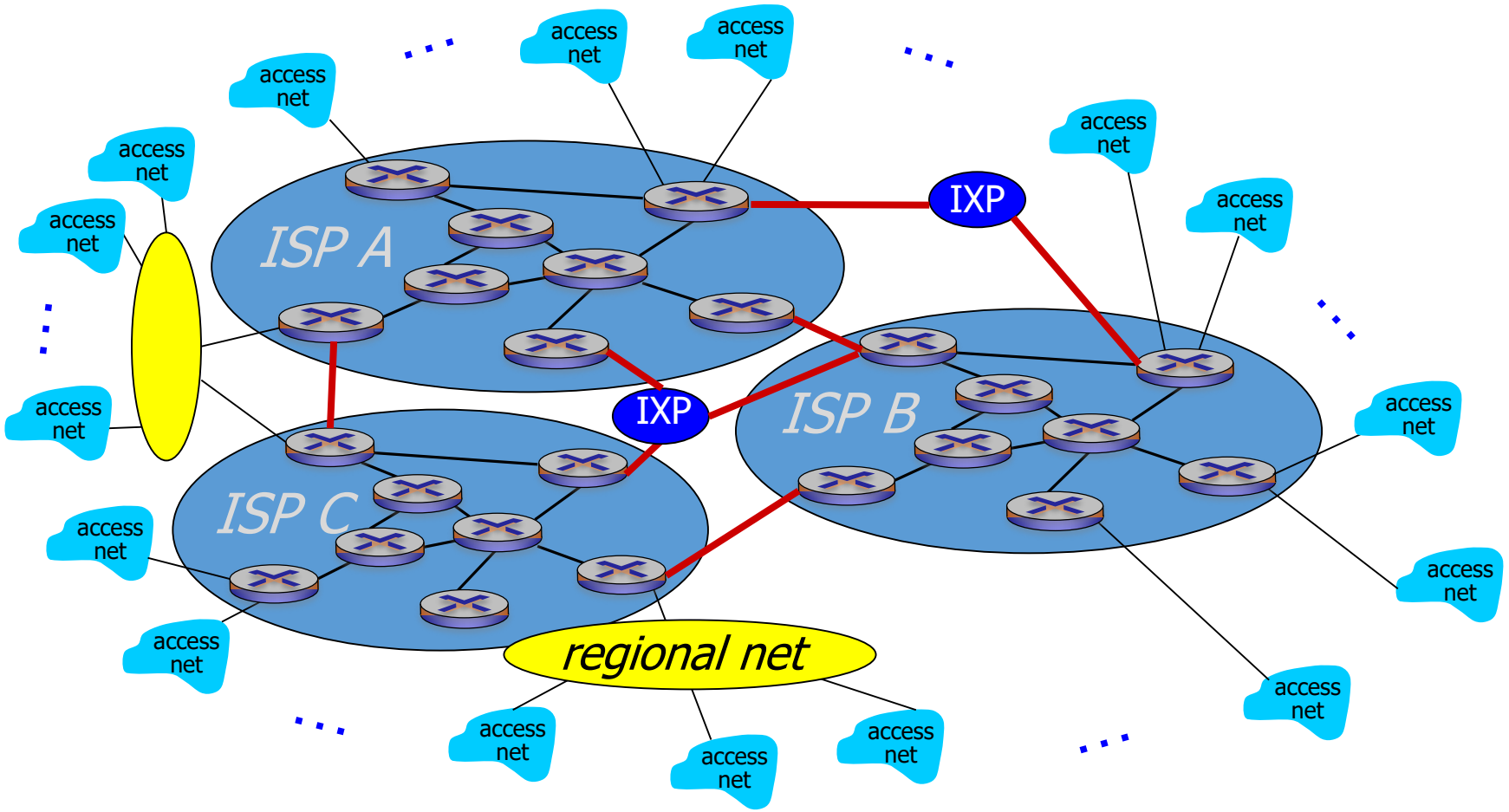
Internet structure: Network of networks

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



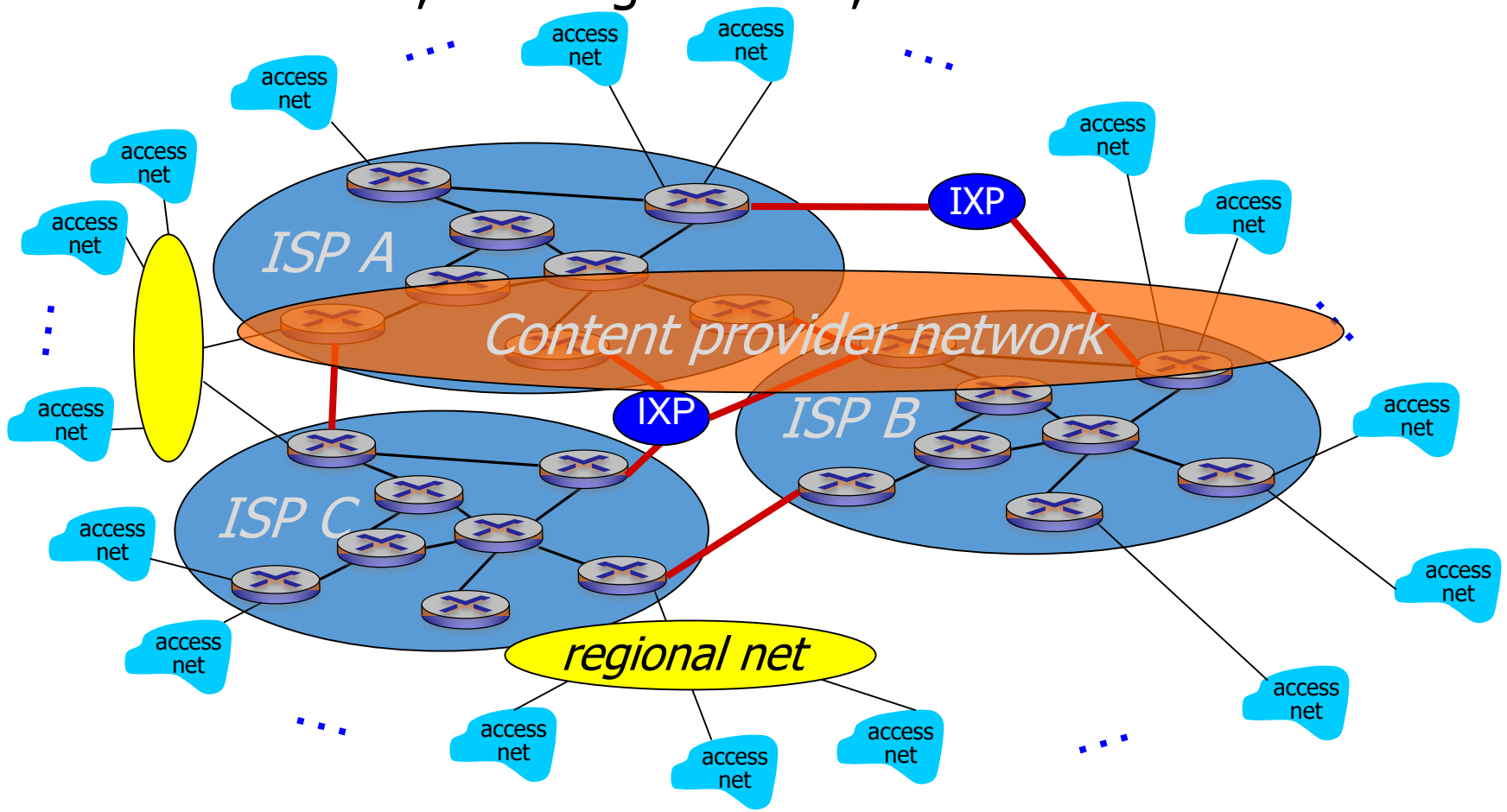
Internet structure: Network of networks

… 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



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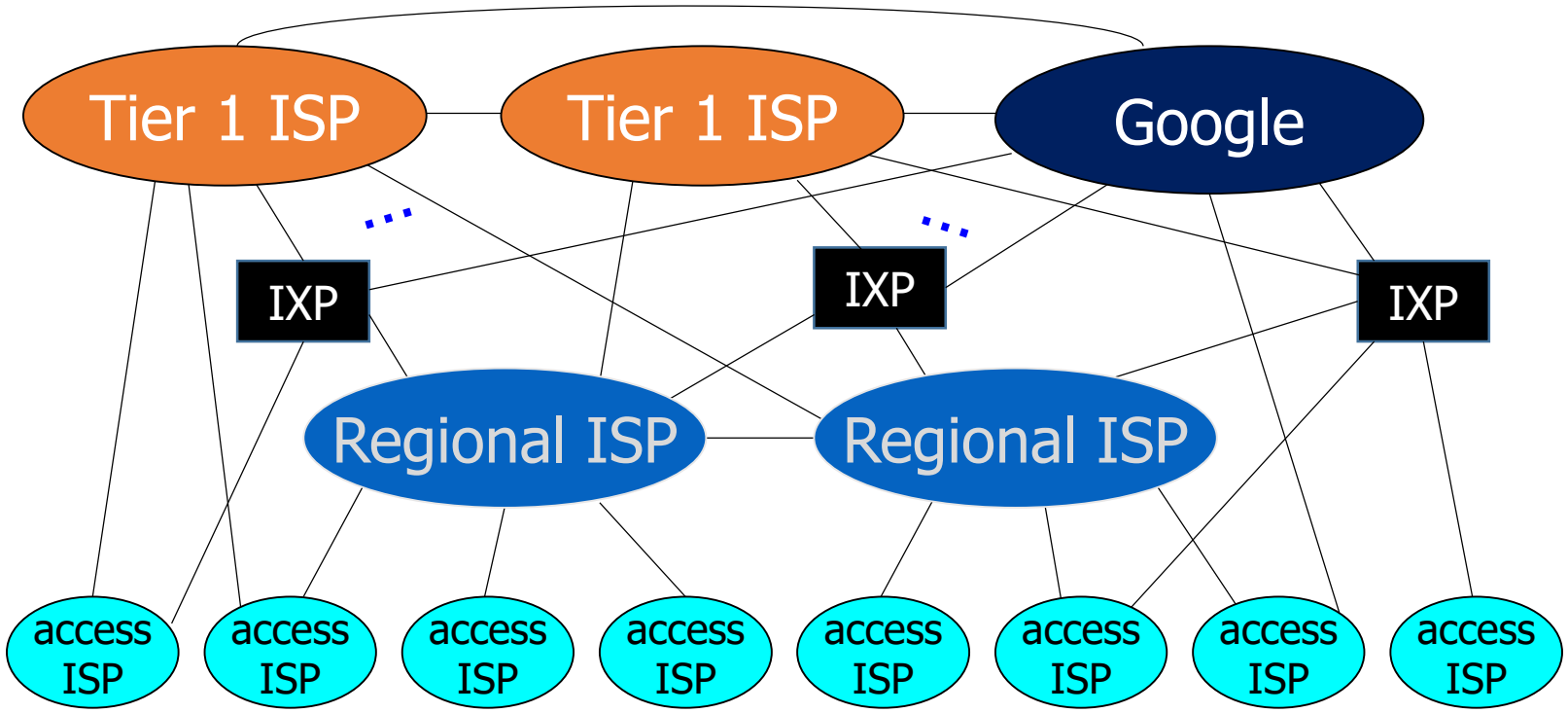
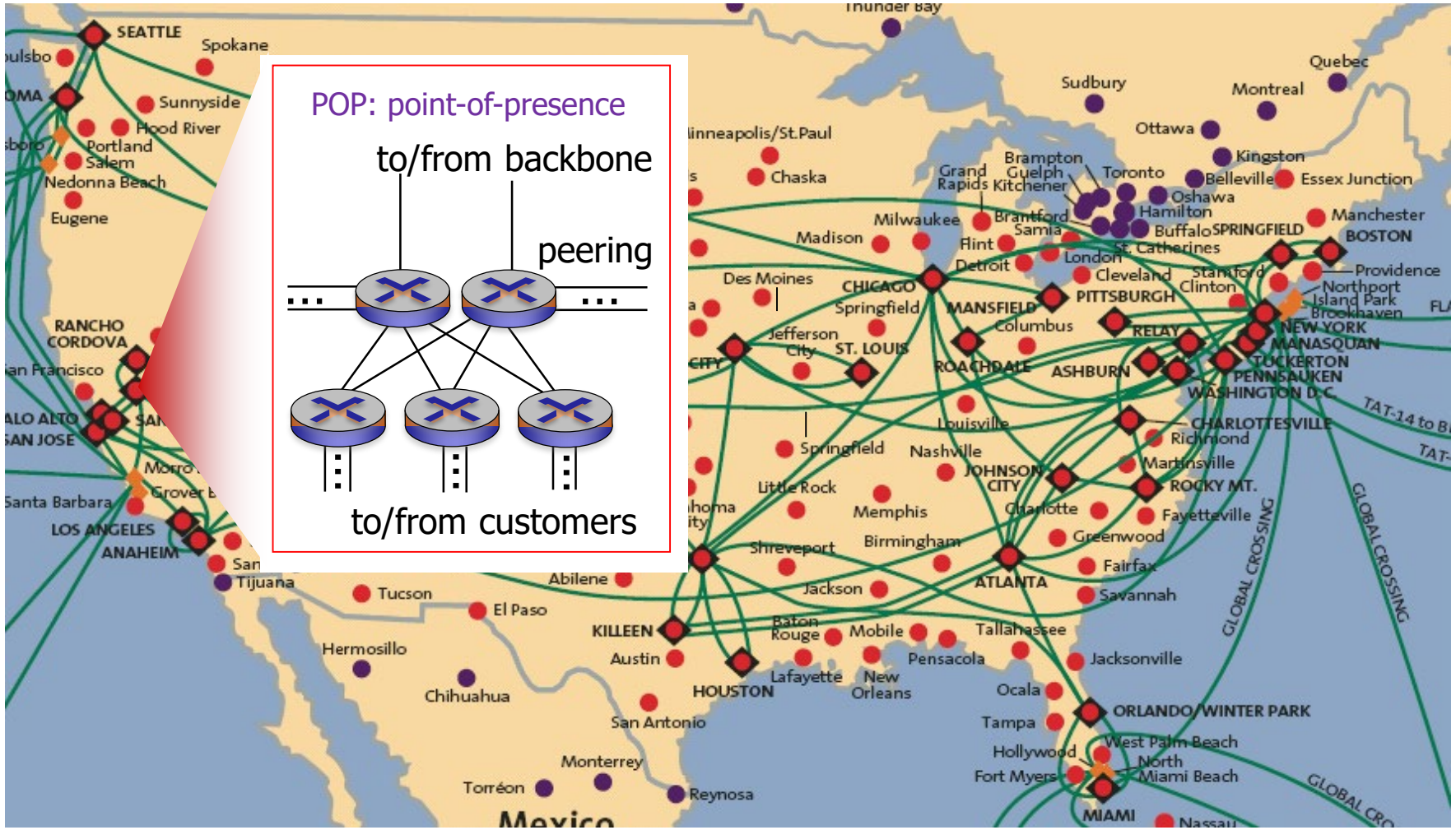


At center: Small # of well-connected large networks

- "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 its data centers to Internet, often bypassing tier-1, regional ISPs

Tier-1 ISP: E.g., Sprint



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